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ORIGINAL RESEARCH

Health Care Expenditures Associated With Pollution: Exploratory Methods and Findings

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Abstract

BACKGROUND The research done for this paper is part of the background analysis undertaken to support the work of the Global Commission on Pollution, Health and Development, an initiative of The Lancet, the Global Alliance on Health and Pollution, and the Icahn School of Medicine at Mount Sinai. The paper expands on areas where the current literature has gaps in knowledge related to the health care cost of pollution. Objectives. This study aims to generate an initial estimate of total tangible health care expenditure attributable to man-made pollution affecting air, soil and water.

METHODS We use two methodologies to establish an upper and lower bounds for pollution related health expenditure. Key data points in both models include (a) burden-of-disease (BoD) at the national level in different countries attributable to pollution; and (b) the total cost of health care at the national level in different countries using standard national health accounts expenditure data.

FINDINGS Depending on which determinist model we apply, annual expenditures range from US$630 billion (upper bound) to US$240 billion (lower bound) or approximately three to nine percent of global spending on health care in 2013 (the reference year for the analysis). Although only 14 percent of global total for pollution related health care spending is in lower- and middle-income countries (LMICs) in our primary (lower bound) model, the relative share of spending for pollution related illness is substantial, especially in very low-income countries. Cancer, chronic respiratory and cardio/cerebrovascular illnesses account for the largest health care spending items linked to pollution even in LMICs.

CONCLUSIONS These conditions have historically received less attention by national governments, international public health organizations and development/financial agencies than infectious disease and maternal/child health sectors. Other studies posit that intangible costs associated with environmental pollution include lower productivity and reduced income — components which our models do not attempt to capture. The financial and health impacts are substantial even when we exclude intangible costs, yet it is likely that in many LMICs poor households simply forgo medical treatment and lose household income as a result of man-made environmental degradation.

RECOMMENDATIONS When evaluating the value of public health or environmental programs which prevent or limit pollution-related illness, policy makers should consider the health benefits, the tangible cost offsets (estimated in our models) and the opportunity costs.

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KEY WORDS pollution, diseases burden, cost of healthcare, health expenditure, global estimate

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INTRODUCTION

A detailed review of the cost of pollution is currently being undertaking by the Global Commission on Pollution, Health and Development, an initiative of *The Lancet*, the *Global Alliance on Health and Pollution*, and the *Icahn School of Medicine at Mount Sinai*.[1] The results of this work, which will be published in the *Lancet* in 2017, indicate that pollution results in 9 million deaths each year, or 15% of all deaths worldwide. More than 90% of these deaths occur in low- to middle-income countries (LMICs).[*] The research done for this paper is part of the background analysis undertaken to support the work of the commission in areas where the current literature has gaps in knowledge related to the health care cost of pollution.

For decades, environment and policy experts have focused on social and economic issues related to man-made pollution.[2,3] More recently, increased attention has also been given to health impacts related to pollution.[4-7] Strong scientific evidence now exists on the health problems linked to smoke; other ambient air threats such as ambient particulate matter; contaminated water; and soil with pollutants such as mercury, lead, and other heavy metals or chemicals.[8]

The health care costs associated with pollution are less well known.[9] The Organization for Economic Cooperation and Development (OECD) has estimated the pollution-related health care expenditures for a limited number of its member countries, but its dataset is incomplete and no previous attempts have been made to estimate the global cost of health care related to pollution.[10-12]

Industrialization, urbanization, enhancements in agricultural production methods, food processing, and use of cars are some of the key contributors to the recent increase in health-related pollution. Pollutants from these sources are now known to have a damaging effect on almost all vital organs of living organisms, including the brain, lungs, heart, liver, kidneys, soft tissue, and bone.[13]

Although pollution-related health problems are now well known, they were not a focus of the international development community[14-16] or national health strategies until recently.[17] The 2015 Millennium Development Goals did not incorporate pollution-related health. The World Bank, the International Finance Corporation, and regional development banks do have environmental safeguard policies and attempts have been made to address threats from water, soil, and airborne pollutants. However, other than medical waste disposal projects, none of these environment projects were specifically designed to address pollution-related health problems.

Recently, attempts have been made to add up health-related problems by estimating the global burden of disease (BoD) linked to pollution and its potential impact on development. Notably, such attempts have been made by the World Health Organization (WHO), the Institute for Health Metrics and Evaluation, and Pure Earth.

This study aims to estimate the total annual, global, tangible health care expenditures attributed to pollution (HEAP). Recognizing that significant data constraints exist, including limited health care expenditure data at the global level for specific diseases and premature deaths, we seek to generate an order of magnitude for plausible lower and upper bounds for the tangible health care costs associated with pollution using 2 deterministic models, each with different assumptions and methods.

METHODS

Definitions and Scope of Study. To calculate the global tangible health care costs related to pollution, this paper adopts the same definition of pollution as that used by the *Lancet* Commission study. These include air, water, and soil pollution and specific pollutant types, including ambient particulate matter pollution (APMP), household air pollution (HAP), water pollution, sanitation, and lead pollution. We also use the same pollution-related disease from the *Lancet* Commission study. These include the following:

[*]The *Lancet Commission* defines pollution-related disease as diseases and premature deaths "caused by exposures to all forms of pollution—ambient air pollution; household air pollution; unsafe drinking water and inadequate sanitation; toxic chemicals at industrial, mining and hazardous waste sites; lead; and occupational pollutants."

Table 1. Health Expenditure by Type of Pollution Risk Factor and Region (in billion USD, 2013)

Income Region	Pollution Risk Factor					
	APMP	HAP	Lead	Water	Sanitation	Total
HIC	99	0.08	12	0.69	0.03	112
UMIC	44	28.00	13	6.97	2.42	94
LMIC	7	8.37	1	8.01	4.57	29
LIC	1	1.30	0	1.50	1.11	5
World	**150**	**37.74**	**26**	**17.17**	**8.12**	**239**

APMP, ambient particulate matter pollution; HAP, household air pollution; HIC, high-income countries; LIC, low-income countries; LMIC, lower-middle income countries; UMIC, upper-middle income countries.

Table 2. Health Expenditure Shares by Pollution Risk Factor for Each Income Group

Income Region	Pollution Risk Factor					
	APMP	HAP	Lead	Water	Sanitation	Total
HIC	**89%**	0%	11%	1%	0%	100%
UMIC	47%	30%	13%	7%	3%	100%
LMIC	24%	29%	4%	28%	16%	100%
LIC	13%	27%	**5%**	32%	23%	100%
World	**63%**	**16%**	**11%**	**7%**	**3%**	**100%**

Abbreviations as in Table 1.

- Lower respiratory infections
- Upper respiratory infections and otitis
- Perinatal conditions
- Congenital anomalies
- Malnutrition
- Childhood-cluster diseases
- Cancers
- Cardiovascular diseases
- Chronic obstructive pulmonary disease
- Asthma

Like the *Lancet* Commission, the present paper does not include environmental conditions that lead to premature deaths (eg, stagnant water) and other manmade environment causes that may lead to illnesses and deaths from conditions like malaria but are not directly related to pollution. We also omit some pollution caused by heavy metals other than lead and mercury because the total BoD is small and poorly quantified at the global level.

Main Methodological Challenge. The main methodological challenge in estimating the global expenditure of health care related to pollution stems from limitations in matching existing data on pollution, health outcomes, and disease-level health expenditure.[18,19]

Significant work has already been completed in the past to quantify the following:

- Different types of pollutants that have a negative impact on health and premature deaths
- Morbidity, mortality, and BoD from different health conditions caused by pollution
- The pollution-attributable fraction of many specific health conditions and the overall BoD from these pollutants
- Health expenditure at the national and subnational level and in some cases by specific disease groups in countries that use disease-specific costing or reimbursement mechanisms.[†]

The health care costs related to specific diseases or by BoD groups in countries that do not use disease-specific costing or reimbursement mechanisms (most countries in the world) are not well researched or documented.[20,21] Even in the case of the few countries, like the United States, that use diagnosis-related groups for reimbursement of some hospital care, a significant part of both ambulatory and inpatient care does not apply this costing method. Furthermore, public health activities, medical education, research and development, and a range of nonclinical services like management and insurance loading cost are not captured in the diagnosis-related groups.[22,23]

Previous Theoretical Approaches. In the past a common approach to estimating costs when real data are missing (especially in the environmental, agricultural, transport, and insurance sectors) is to include health utility measures such as disability-adjusted life-years (DALYs) or monetary measures such as willingness to pay (WTP) and willingness to accept.[24]

The global burden of disease established the concept of using the DALYs as the basic metric unit to

[†]Health-*related* expenditure can be divided into 2 categories: tangible costs and intangible costs. There are two types of tangible costs: (a) direct medical costs related to spending on public health and prevention, cure (hospital, physician, and medication costs in persons made ill by pollution), and long-term rehabilitation/home care; and (b) indirect costs related to nonclinical services such as management, support services, health education, research and development, and health insurance loading. Intangible costs are not directly measurable. The four types of intangible costs include (a) the cost of inaction; (b) the shadow cost of forgone treatment; (c) the loss of income as a result of illness; and (d) the cost to economic growth of a sick and less productive workforce. This paper only looks at tangible costs that are captured in standard national health accounts and does not make any attempt to estimate intangible costs, although the latter may be substantial.

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Table 3. Health Expenditure Shares by Income Group for Each Pollution Risk Factor

Income Region	Pollution Risk Factor					
	APMP	HAP	Lead	Water	Sanitation	Total
HIC	66%	0%	46%	4%	0%	47%
UMIC	29%	74%	48%	41%	30%	39%
LMIC	5%	22%	5%	47%	56%	12%
LIC	0%	3%	1%	9%	14%	2%
World	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Abbreviations as in Table 1.

quantify deaths (years of life lost [YLL]) and disability (years of healthy life lost). The value of 1 DALY can be estimated by 2 approaches: the human capital approach and the value per statistical life (VSL).[25]

The human capital approach calculates the indirect cost of productivity loss through the value of an individual's future earnings.[26] In this case, 1 DALY corresponds to 1 person's average contribution to production, namely gross domestic product per capita. This is considered to be the lower bound for the loss on 1 DALY.

The economic approach to valuing risks to life focuses on risk–money tradeoffs for very small risks of death, or the VSL. The VSL measures the WTP of an individual in order to avoid death. In other words, it refers to a tradeoff between wealth and health risk or wealth and death.[27]

The VSL is calculated as follows:

$$\text{VSL} = (\text{WTP}/\text{Reduced Risk of Death})$$

Through this measure, the value of 1 DALY corresponds to VSL/number discounted average YLL. This method provides an upper bound for the loss of 1 DALY.

In the case of VSL calculations, rather than using objective empirical data on expenditure, the estimates are based on the revealed preferences of individuals in terms of their WTP (defined as the amount of money an individual is willing to give to decrease a life-threatening risk).[28]

There are many limitations to this approach. Two notable shortcomings are (1) the lack of data in most developing countries on WTP to avert illness or death caused by pollution or WTP for health care; and (2) ethical issues related to assigning a fixed value on life and making policy decisions on that basis.[29,30]

Approach Used for This Study. We used 2 methodologies to establish upper and lower bounds for pollution-related health expenditure. Key data points in both models included (1) BoD attributable to pollution at the national level in different countries; and (2) the total cost of health care at the national level in different countries, using standard national health accounts expenditure data.[31] BoD was measured in DALYs = sum of YLL (a proxy for mortality) and years of healthy life lost (a proxy for morbidity). Total health expenditure (THE) is measured using national health accounts and reflects public and private sector spending on health care across the entire population. THE has different components, from infrastructure and capital spending to all cost of treatment and associated consumed variable resources.

HEAP1 Methodology. HEAP1 assumes a proportional relationship between THE and BoD share for each pollution risk factor (APMP, HAP, water, sanitation, and lead). Specifically, we estimate global HEAP in 2013 for our first method using the following formulas:

Table 4. Health Expenditure Attributed to Pollution by Selected Diseases (in billions USD)

Income Regions	Cancers	Asthma	Cardiovascular Diseases	Chronic Obstructive Pulmonary Disease	Malnutrition	Lower Respiratory Infections	Upper Respiratory Infections and Otitis	Perinatal Conditions	Childhood-Cluster Diseases	Congenital Anomalies	Total
HIC	170.45	167.80	64.71	30.74	26.00	16.18	9.71	6.59	5.55	5.20	502.92
UMIC	38.51	37.91	14.62	17.50	5.88	3.66	2.19	1.49	1.25	1.18	124.19
LMIC	2.85	1.50	1.12	3.41	4.13	6.73	3.85	1.66	2.56	0.25	28.05
LIC	0.32	0.17	0.12	0.40	0.46	0.75	0.43	0.18	0.28	0.03	3.13
World	**212.13**	**207.37**	**80.58**	**52.04**	**36.46**	**27.31**	**16.17**	**9.91**	**9.65**	**6.66**	**658.29**

Abbreviations as in Table 1.

Table 5. Health Expenditures Attributed to Pollution Broken Down by Selected Diseases (in %)

Income Regions	Cancers	Asthma	Cardiovascular Diseases	Chronic Obstructive Pulmonary Disease	Malnutrition	Lower Respiratory Infections	Upper Respiratory Infections and Otitis	Perinatal Conditions	Childhood-Cluster Diseases	Congenital Anomalies	Total
HIC	34	33	13	6	5	3	2	1	1	1	100
UMIC	31	31	12	14	5	3	2	1	1	1	100
LMIC	10	5	4	12	15	24	14	6	9	1	100
LIC	10	5	4	13	15	24	14	6	9	1	100
World	32	32	12	8	6	4	2%	2	1	1	100

Abbreviations as in Table 1.

$$\textit{Country Level}:\ HEAP1_{c,t} = \sum_{p} \%BoD_{p,c,t} * THE_{c,t}$$

$$\textit{Global Level}:\ HEAP1_{t} = \sum_{r} HEAP1_{r,t}$$

where indexes include region (r), time (t), and pollution risk factor (p). In addition to global totals, we also can aggregate by region (eg, Asia, South America) or income level (eg, low income). The Institute for Health Metrics and Evaluation and WHO NHA databases are the sources for BoD and THE estimates, respectively.[32,33]

HEAP2 Methodology. HEAP2 relies on pollution-attributable fractions (PAFs) related to the pollution-related diseases determined in previous research in specific geographies and aggregates across disease rather than by pollution risk factor. Specifically:

$$\textit{Country Level}:\ HEAP2_{c,t} = \sum_{d} \%BoD_{d,c(ir),t} * PAF_{d} * THE_{c,t}$$

$$\textit{Global Level}:\ HEAP2_{t} = \sum_{c} HEAP2_{c,t}$$

where indexes include country (c), time (t), disease (d), and income region (ir). We assume that the PAFs determined in the prior research for select countries are applicable to other geographies. PAFs are estimated as shares that represent the percentage decline in disease or injury that could be achieved if the risk were reduced.

The National Institute for Public Health and Environment of the Netherlands estimated the relative weights of each condition over total BoD by income regions (how important a health condition is over the total BoD in different income regions—eg, the relative weight of cancer over perinatal conditions is higher in high-income countries [HICs] than in LMICs).[34] We selected the conditions affected by our scope of pollutants.

Using these and other data, WHO estimated the shares of different environmental risk factors for an extensive list of health endpoints. We have selected the environmental risk factors related to pollution: water and sanitation, indoor pollution, outdoor pollution, and chemicals.[35] Each PAF reflects the share of disease that would be eliminated if the pollution were not present.[36]

HEAP3 Methodology: Disaggregating HEAP1 Across Diseases and Care Settings. HEAP3 allocates pollution attributable health expenditure HEAP1 across 3 main diseases categories—(1) communicable diseases; (2) noncommunicable diseases, and (3) accidents—and 2 types of clinical settings: (1) inpatient and (2) outpatient care. We retained the assumptions from the HEAP1 model but also assumed that shares of HEAP by disease category and by clinical setting were constant across countries within the same income category (eg, HICs have larger spending shares on noncommunicable diseases than low-income countries [LICs], but we assumed these shares were equal across all HICs). We segment countries into 4 income level strata: high income, upper-middle income, lower-middle income, and low income, as per World Bank designations. Hence, to determine a country's total expenditure by disease category (DC) and setting (S), our formula is:

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Table 6. Health Expenditure Attributed to Pollution Broken Down by Selected Disease Groups Across Country Income Group (in %)

Income Regions	Cancers	Asthma	Cardiovascular Diseases	Chronic Obstructive Pulmonary Disease	Malnutrition	Lower Respiratory Infections	Upper Respiratory Infections and Otitis	Perinatal Conditions	Childhood-Cluster Diseases	Congenital Anomalies	Total
HIC	80	81	80	59	71	59	60	66	57	78	76
UMIC	18	18	18	34	16	13	14	15	13	18	19
LMIC	1	1	1	7	11	25	24	17	27	4	4
LIC	0	0	0	1	1	3	3	2	3	0	0
World	100	100	100	100	100	100	100	100	100	100	100

Abbreviations as in Table 1.

Country/Setting/Disease Category Health Expenditure Estimate

$$HEAP3_{c,t,s,dc} = HEAP1_{c,t} * DC\ Share_{dc,c(ir)} * Setting\ Share_{s,c(ir)}$$

We can aggregate these estimates to generate country, regional, or global totals for specific clinical settings or disease categories.[‡,10,37,38]

The share of health expenditures by disease category in high income countries were generated from select country studies.[39,40] The analysis also used OECD data to establish the pattern of expenditure[10] for inpatient and outpatient care.[§]

Prior work indicates that expenditures for chronic diseases exceed spending on communicable diseases and accidents in HICs, and LICs tend to spend proportionately less on chronic disease despite their already limited health expenditure per capita levels.[41] In LICs, chronic diseases like cancer are often ignored once diagnosed. On the other hand, communicable diseases have received considerable attention within LICs, as well as funding from international donors (private and public). This influences the pattern of THE distribution for this spending category in LICs.

RESULTS

HEAP1 Findings. Table 1 provides an estimate of health care expenditure as a result of pollution disaggregated by pollution factor and income group. It uses the "naïve" assumption of a linear relationship between BoD and health care expenditure at the country level (see Discussion for limitations). This method establishes a lower bound of $240 billion for global expenditure on pollution-related health. Note that using this method, HICs and upper-middle income countries (UMICs) together represent more than 80% of global expenditure as a result of pollution but account for just 36% of BoD.

Tables 2 and 3 reflect the percentage shares of expenditure by pollution risk factor (Table 2) and by income level (Table 3). A color code has been applied to differentiate 10%-20%, 21%-49%, and 50%-100% categories.

The low percentage shares for the APMP category in LICs and LMICs belies the epidemiological burden that this pollution source exacts in these countries. The very limited direct cost share likely is more a reflection of the much lower direct health expenditure, particularly for chronic diseases, in these countries than a reflection of prevalence or incidence of diseases caused by pollution. It is also likely that there are major effects on productivity

‡For other *health* care cost analysis for specific diseases, see National Institute of Health (NIH), National Heart, Lung and Blood Institute. Available at: http://www.nhlbi.nih.gov/about/documents/factbook/2012/chapter4.

§The OECD study refers to Canada, the Czech Republic, Finland, France, Germany, Hungary, Japan, Korea, Israel, the Netherlands, Slovenia, Sweden, and Switzerland. Share of inpatient/hospital expenditure by group of diseases for a sample of HICs and corresponding tables for breakdown values provide the OECD model, based on calculation of expenditure per disease for a handful of rich countries that are members of the OECD. In their study, the OECD used a weight distribution of health expenditure for hospital (inpatient) costs as a percentage of THE and ambulatory (outpatient) costs as a percentage of THE. HICs spend around 67% of their inpatient HE on noncommunicable diseases and only 10% on communicable and childhood-cluster diseases. When looking at outpatient costs, this distribution is even more extreme (probably because of lack of data), and the communicable—childhood-cluster segment is limited to 1%; conversely, 68% of ambulatory costs go to treating noncommunicable diseases.

Table 7. HEAP1 by 3 Main Categories of Diseases for Inpatient Care (in billions USD)

Inpatient	Infectious & Child Cluster	Chronic	Accidents	Nonattributable	HEAP Analysis 1
HIC	11	75	10	16	112
UMIC	9	63	8	13	94
LMIC	3	19	3	4	29
LIC	0	3	0	1	5
World	24	160	22	34	239

Abbreviations as in Table 1.

and forgone income—cost measures that are not included.

Given the HEAP1 methodological assumptions, APMP results in the highest share of direct health care expenditures relative to the other pollution risk factors. This is particularly the case in HICs, where nonhousehold air pollution accounts for 89% of the expenditure share (and lead accounts for almost all the rest). Generally, industrialized countries have efficient water and sanitation infrastructure as well as modern housing stock, so there is virtually no BoD (or spending) related to HAP, water, or sanitation. In UMICs, APMP remains the most important risk factor, but HAP is the second. If BoD related to HAP is concentrated in the lower-income groups within these countries (perhaps those with less advanced housing stock), we may be somewhat overestimating the risk factor share because these groups likely are responsible for proportionally less spending on health care than those in higher income strata within these regions.

Lastly, the lack of public health infrastructure and basic sanitation facilities in LMICs and LICs are reflected in the relatively high shares of direct expenditure as a result of water and sanitation. Nevertheless, the critique discussed earlier is also valid if those who experience water and sanitation pollution are from the lower portion of the income distribution within these LMICs and LICs.

Table 3 indicates which income groups bear significant direct health expenditures for each of the pollution risk factors. Although policymakers may find it tempting to concentrate efforts in countries where the expenditures are greatest, it is important to recall that the lack of spending in LICs and the much higher epidemiological burden (and the unrepresented productivity costs in the course of time) may also be considered for limiting the impact of pollution on health.

HEAP2 Findings. Table 4 presents pollution-related health expenditure in billions of USD across country income levels for each selected disease group. Table 5 presents the relative share of health care expenditure across country income levels by selected disease groups. Table 6 presents the relative share of health care expenditure of selected disease groups by country income levels. This method establishes an upper bound of about $660 billion for global expenditure on pollution-related health. It is worth noting that cancer and asthma account for the highest total expenditure related to pollution globally and in both HICs and UMICs. Upper and lower respiratory infections are the most significant in LMICs and LICs. Overall health care expenditure is income related, with HICs accounting for the largest share of pollution-related expenditure.

HEAP3 Findings. HEAP3 is a variation of HEAP1 with health expenditure that clusters BoD and expenditure under the 3 main disease categories:

Table 8. HEAP1 by 3 Categories of Diseases for Outpatient Care (in billions USD)

Outpatient	Infectious & Child Cluster	Chronic	Accidents	Nonattributable	HEAP Analysis 1
HIC	1	76	4	30	112
UMIC	1	64	4	25	94
LMIC	0	20	1	8	29
LIC	0	3	0	1	5
World	2	163	10	65	239

Abbreviations as in Table 1.

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Table 9. HEAP1 by 3 Categories of Diseases for Outpatient Plus Inpatient Care (in %)

	Infectious & Child Cluster	Chronic	Accidents	Total
HIC	12	80	8	100
UMIC	10	79	10	100
LMIC	56	39	5	100
LIC	55	37	8	100
World	15	77	8	100

Abbreviations as in Table 1.

infectious diseases, chronic diseases, and accidents. The total spending pattern is therefore the same as in HEAP1 but clustered by major group of disease. Tables 7-9 indicate that chronic diseases account for the most significant health care expenditure related to pollution at all different country income levels, which is much higher in the HICs and UMICs.

DISCUSSION

HEAP1 Analysis. HEAP1 assumed a linear relationship between the share of pollution risk factor of BoD and THE. This allowed the establishment of a plausible lower bound of US$240 billion annually.

HEAP1 Advantages. The main advantage of the HEAP1 approach is that reasonable recent country-level data are available for 2013 for both BoD and THE.

HEAP1 Limitations. The HEAP1 approach has several limitations. First, from countries that use disease-related reimbursement of health care, we know that health care expenditure is not evenly distributed across disease categories. Second, this method gives equal weight to both acute infectious diseases and chronic diseases, and also equal weight to expensive-to-treat cardiovascular diseases and cancer compared with less-expensive-to-treat respiratory diseases. It can therefore be assumed that this approach underestimates actual expenditure on health care related to pollution for countries at upper income levels (UICs and UMICs).

At the same time, many lower-income countries are in the process of going through or have already gone through an epidemiological transition from infections to chronic diseases, with rising incidence and prevalence of chronic diseases like cardiovascular diseases and cancer. However, these diseases often are not fully treated, so assuming a liner relationship may overestimate spending in these countries. This method therefore probably overestimates actual expenditure on health care related to pollution for countries at lower income levels (LMICs and LICs) because of the relative share of respiratory problems associated with pollution in these countries.

Because the share of global health care expenditure in UICs and UMICs is much higher than in LMICs and LICs, HEAP1 overall is still a credible lower bound. Total health care expenditure linked to pollution is therefore likely higher than US$240 billion annually.

HEAP2 Analysis. HEAP2 uses 2 adjustments identified in previous research, the percentage of BoD per disease and the PAF per disease, to estimate the health care cost caused by pollution. This has allowed the establishment of a plausible upper bound of US$660 billion annually.

HEAP2 Advantages. The main advantage of the HEAP2 approach is that it uses the limited data that are available on the cost of treating a few specific diseases in some OECD and developing countries. The cost of treating these diseases can be mapped to BoD categories for those and other countries.

HEAP2 Limitations. The HEAP2 approach has several limitations. First, disease-level health care expenditure patterns from a few known OECD countries were applied to other UICs, UMICs, LMICs, and LICs (adjusted for individual country income levels). However, health spending on chronic diseases is much lower than that on infectious diseases outside the OECD group of countries

Table 10. Comparison of the Risk Factor Approach (HEAP1) With the Disease Approach (HEAP2) in billions USD

Income Regions	HEAP1	HEAP1% THE	HEAP2	HEAP2% THE	Difference	THE
World	239	3%	658	9%	175%	7,353
HIC	112	2%	503	9%	349%	5,778
UMIC	94	7%	124	9%	32%	1,306
LMIC	29	12%	28	12%	-3%	243
LIC	5	19%	3	11%	-40%	27

Abbreviations as in Table 1.

and even within lower-income OECD countries. This method therefore probably overestimates actual expenditure on health care related to pollution for most of the countries for which real data were not available. Second, although diseases were selected based on their pollution risk factor (APMP, HAP, water, sanitation, and lead), the adjustment coefficient for HEAP2 is still a global linear measure, whereas the relationship between pollution risk factors and the selected diseases is not linear.

Two sources were used to examine the possibility of comorbidity in the United States: the National Cancer Database and the SEER-Medicarte Database.[42] The medical literature on clinical studies on the treatment of comorbid conditions was also examined. Although there are no comprehensive data on comorbidity globally, the data in these sources give an approximation of the potential error as a result of the comorbidity. In many cases the rate is 5% or less.[43]

Finally, many of the other limitations discussed earlier under HEAP1, such as mismatch between THE and disease patterns, still apply in the case of HEAP2 estimates.

Table 10 provides a detailed description of the differences between the 2 methodologies.[||]

HEAP3 Analysis. HEAP3 is a variation of HEAP1 with health expenditure that clusters BoD and expenditure under 3 main disease categories: infectious diseases, chronic diseases, and accidents. Total health care expenditure related to pollution using this method is therefore also a lower bound of US$240 annually.

HEAP3 Advantages. HEAP3 allows the data to be presented in a way that highlights the important chronic disease aspect of pollution, which has particular implications for middle- and lower-income countries where health systems are still focused more on infectious diseases. It therefore has important policy implications primarily for middle- and lower-income countries and development agencies that support, influence, or finance parts of health sector policies and programs in these countries.

HEAP3 Limitations. The HEAP3 approach also has limitations. First, precision and policy specificity are lost in aggregating data in up to 3 major disease categories. Second, many of the other limitations discussed earlier under HEAP1 and HEAP2, such as the mismatch between THE and disease patterns and the nonlinearity of spending patterns, also apply in the case of HEAP3 estimates.

CONCLUSIONS

Based on this study, the health care cost of man-made pollution affecting air, soil, and water is substantial, ranging from a lower bound of US$240 billion to an upper bound of US$630, depending on the methodology used. Although only 14% of the global total for pollution-related health care spending is in LMICs in our primary (lower bound) model, the relative share of spending for pollution-related illness is a significant part of overall health expenditure in very low income countries. The findings from the study merit action in 3 areas.

1. Generating Discussions

Much more work on disease-specific costing is needed to derive a more precise estimate for health care expenditure related to pollution. It could be years before national health accounts are able to provide useful data that allow such precision. It could also be years before the combinations of routine health information systems and surveys are sufficiently robust to narrow the uncertainties in BoD estimates for data-poor LICs and LMICs. The study therefore provided a valuable order-of-magnitude estimate while waiting for more detailed and precise costing studies to be completed.

2. Use of the Findings to Inform Policy Discussions

Even the lower bound of estimates gives sufficient reason to take action in this neglected area of public health. Recognizing health risks from pollution, and prioritizing them, are first and foremost the responsibilities of country analysts and policymakers. It is important to note that these are not merely nice things to do, but investments with potentially high returns. Countries will need to decide when and how to adjust priorities within current resource envelopes and determine the priorities on which to spend marginal revenues.

3. Stimulating Reflection About Development Assistance for Health

When evaluating the value of public health or environmental programs that prevent or limit pollution-related illness, development partners

[||]HEAP1 uses pollution weights by risk factor, whereas HEAP2 uses weights by specific disease. Global values add up every item in the analysis: HEAP1 = sum (risk factors) and HEAP2 = sum (selected diseases).

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need to consider not just the health benefits but also the tangible cost in terms of expenditure on health care generated by such pollution.

There are 3 considerations for development assistance for health. First, and in tandem with country-level policy processes and priorities, funders of development assistance for health are reminded of the growing evidence of the health effects of pollution and the potential returns on investments that address the causes of such pollution, not just treating the resulting illnesses.

Second, pollution control and prevention have multiple co-benefits and will advance attainment of sustainable development goals. Pollution prevention is at the very heart of sustainable development goal 3.9, which calls on the global community to "substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution."

Finally, 1 major challenge is that although the health impact of pollution is in the health sector, the upstream interventions to prevent even worse pollution have to be implemented in the environmental, agriculture, industrial, energy, and other sectors of the economy. Effective interventions therefore require suprasectoral leadership at the levels of heads of state.

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