ORIGINAL RESEARCH

Estimating health impacts and economic costs of air pollution in the Republic of Macedonia

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Abstract

Aim: This paper assesses the magnitude of health impacts and economic costs of fine particulate matter (PM) air pollution in the Republic of Macedonia.

Methods: Ambient PM_{10} and $PM_{2.5}$ monitoring data were combined with population characteristics and exposure-response functions to calculate the incidence of several health end-points known to be highly influenced by air pollution. Health impacts were converted to Disability-Adjusted Life Years (DALYs) and then translated into economic terms using three valuation approaches to form lower and higher bounds: the (adjusted) Human Capital Approach (HCA), Value of a Statistical Life (VSL) and the COI (cost of illness).

Results: Fine particulate matter frequently exceeds daily and annual limit values and influences a person's day-to-day health and their ability to work. Converting lost years of life and disabilities into DALYs - these health effects represent an annual economic cost of approximately €253 million or 3.2% of GDP (midpoint estimate). Premature death accounts for over 90% of the total health burden since this represents a loss of total life-long income. A reduction of even $1\mu g/m^3$ in ambient PM_{10} or $PM_{2.5}$ would imply 195 fewer deaths and represent an economic savings of €34 million per year in reduced health costs.

Conclusion: Interventions that reduce ambient PM_{10} or $PM_{2.5}$ have significant economic savings in both the short and long run. Currently, these benefits (costs) are 'hidden' due to the lack of information linking air quality and health outcomes and translating this into economic terms. Policymakers seeking ways to improve the public's health and lessen the burden on the health system could focus on a narrow set of air pollution sources to achieve these goals.

Keywords: air pollution, health and economic costs, particulate matter.

Conflicts of interest: None.

Introduction
According to the Global Burden of Disease (2010) estimates (1), the crude mortality rate from ambient particulate matter (PM) pollution in Macedonia was 80.6 deaths per 100,000 in 2010. In comparable neighboring states such as Serbia, it was 71.8 deaths per 100,000; in Croatia it was 69.4 per 100,000; in Hungary 92.0 per 100,000; and 70 per 100,000 in Slovakia. The total Disability-Adjusted Life Years (DALYs) attributable to PM were about 1,480 per 100,000 in Macedonia (but, up to 1,600 in Hungary) (1).
The main sources of this ambient condition were the use of solid fuel for heating households in the winter, as well as the impact of industry and traffic. Uncontrolled urbanization is also a significant source of particulate matter. In 2009, an average annual concentration of $90\mu g/m^3$ was registered in Skopje. Compounding the situation, poor air circulation is another reason why the capital city of Skopje has one of the worse air conditions in winter.
Air pollution is also significant throughout the European region, with only nine of the 34 Member States reporting PM_{10} levels below the annual WHO air quality guideline (AQG) of $20\mu g/m^3$. Almost 83% of the population in these cities is exposed to PM_{10} levels exceeding the AQG levels (2).
Results from a recent project *Improving Knowledge and Communication for Decision-making on Air Pollution and Health in Europe* (Aphekom), which uses a traditional health impact assessment method, indicated that average life expectancy in the most polluted cities could be increased by approximately 20 months if long-term $PM_{2.5}$ concentrations were reduced to WHO guidelines (3). One recent study in Macedonia found that an increase of PM_{10} by $10\mu g/m^3$ above the daily maximum permitted level $(50\mu g/m^3)$ was associated with a 12% increase in cardiovascular disease (2).

Methods
To estimate the health impacts and economic costs of air pollution, the approach required overlaying data from multiple sources. The method used ambient air quality data *[information received from the Ministry of Environment and Physical Planning (MoEPP)]* for PM_{10} and $PM_{2.5}$, health statistics – annual deaths by disease type; frequency of chronic bronchitis, asthma, infant mortality; and health cost data *(information received from the Institute of Public Health and Health Insurance Fund)*, exposure-response functions from health studies *(information from international and local literature)* and population characteristics – age groups, gender, urban/rural population *(information from the state Statistics Bureau)*. These data were combined for a municipal (city) - level analysis.

The approach to estimating health impacts and economic costs encompassed five steps:
- Collection of monitored, ambient concentration data on PM_{10} and $PM_{2.5}$
- Calculation of exposed population
- Exposure-response functions
- Calculation of physical health impacts (mortality, morbidity, DALYs)
- Monetizing health impacts

Collection of monitored data on fine particulate matter
Currently, the Ministry of Environment and Physical Planning (MoEPP) has a network of 19 Automatic Monitoring Stations: seven in Skopje, two in Bitola, two in Veles and one in Kicevo, Kumanovo, Kocani, Tetovo, Kavadarci, village Lazaropole, and two near the OKTA oil refinery (near the villages of Miladinovci and Mrsevci). Stations measure SO_2, NO_2, CO, PM_{10}, $PM_{2.5}$, ozone, benzene, toluene, ethyl benzene and BTX – although some stations do not measure all pollutants *[monitored PM$_{2.5}$ measurements began in November, 2011 in*

Karpos and Centar. In cases where $PM_{2.5}$ is not actually monitored, observed PM_{10} is adjusted by the ratio $PM_{2.5}/PM_{10}$. The ratio, based on recent observations, is estimated at 0.71 in the case of Macedonia; and is within ranges found in other international studies. See Ostro (4) for a discussion]. This information is available electronically through their air quality portal (available at: http://airquality.moepp.gov.mk/?lang=en).

Calculation of exposed population

Population information for 2010 was used focusing on the working population as well as vulnerable segments of society *(for example, those under the age of five or older than 65 are considered more vulnerable to the effects of air pollution – that is more prone to develop acute or chronic respiratory ailments).*

Exposure-response functions

The selection of exposure-response functions was based on epidemiological research between PM_{10} and $PM_{2.5}$ and mortality and morbidity. For mortality, exposure-response functions for long-term exposure to $PM_{2.5}$ were (4):

Relative risks (RR) were calculated as:

Cardiopulmonary (CP) mortality: $\quad RR = [(X+1)/(X_0 +1)]^{0.15515}$
Lung cancer (LC) mortality: $\quad RR = \exp[0.23218 (X-X_0)]$
ALRI mortality in under-five children: $\quad RR = \exp[0.00166 (X-X_0)]$
with: X = current annual average $PM_{2.5}$ concentration for CP and LC among adults, and PM_{10} concentrations for ALRI among children and X_0 = target or baseline $PM_{2.5}$ concentration.

Information on the crude death rate (CDR), CP, LC and ALRI data were used to set the mortality baseline. For morbidity, exposure-response coefficients (annual cases per 100,000 population) for PM_{10} from Ostro (4,5) and Abbey *et al.* (6) were applied. Ostro (4) reflects a review of worldwide studies, and Abbey *et al.*, (6) provides estimates of chronic bronchitis associated with particulates (PM_{10}).

A baseline for PM concentrations

A baseline level (natural background concentration) for $PM_{2.5}$ = 7.5 µg/m^3, as suggested by Ostro (4), was used *(some argue that the baseline should be set at zero since the literature does not support the existence of a concentration level of which there are no observable effects. However a baseline of zero is not realistic since natural background concentrations hover between 10-15 µg/m^3 in Macedonia – and one would only look at investments which could reduce ambient concentrations to this level (i.e. at least from a benefit-cost standpoint of weighing alternative investments).*
Given a $PM_{2.5}/PM_{10}$ ratio of 0.71 using observations in Macedonia, the baseline level for PM_{10} is 10.6 µg/m^3. These baseline concentrations were applied to both large and medium/small urban areas.

Calculation of physical health impacts (mortality, morbidity, DALYs)

Using the population information and the exposure-response functions, mortality and morbidity impacts were calculated through the conversion of impacts to DALYs *(DALYs = sum of years of potential life lost due to premature mortality and the years of productive life lost due to disability).* The DALY method weights illnesses by severity: a mild illness or disability (e.g. morbidity effects) represents a small fraction of a DALY and a severe illness represents a larger fraction (e.g. mortality = 1 DALY). Weights used in this context were adapted from Larsen (7) and are presented in Table 1.

Table 1. Estimated health impacts of air pollution, urban and rural, 2010
(Source: World Bank, 2012)

Health impacts	DALYs /10,000 cases
CP mortality (PM$_{2.5}$)	80,000
LC mortality (PM$_{2.5}$)	80,000
ALRI mortality (PM$_{10}$)	340,000
Chronic bronchitis (PM$_{10}$)	22,000
Hospital admissions (PM$_{10}$)	160
Emergency room visits (PM$_{10}$)	45
Restricted activity days (PM$_{10}$)	3
Lower respiratory illness in children (PM$_{10}$)	65
Respiratory symptoms (PM$_{10}$)	0.75
Total	

Monetizing health impacts
To create a set of bounds three alternative valuation approaches were used: the (adjusted) Human Capital Approach (HCA) *[the adjusted version avoids the issue of assigning a value of zero to the lives of the retired and the disabled since the traditional approach is based on foregone earnings. It avoids this issue by assigning the same value – per capita GDP – to a year of life lost by all persons, regardless of age]*, Value of a Statistical Life (VSL) and the COI (cost of illness). The HCA estimates the indirect cost of productivity loss through the value of an individual's future earnings. Thus, one DALY corresponds to one person's contribution to production, or GDP per capita. This method provides a realistic lower bound for the loss of one DALY. The VSL measures the willingness-to-pay (WTP) to avoid death – using actual behavior on the tradeoffs between risks and money. The VSL is calculated by dividing the marginal WTP to reduce the risk of death by the size of the risk reduction. Measured this way, the value of one DALY corresponds to the VSL divided by the number of discounted years lost because of death. The VSL typically forms an upper bound measure of health damages. The COI approach estimates the direct treatment costs associated to different health end-points (e.g. hospitalization, restricted activity days, and doctor visits). Mortality was valued using HCA as a lower bound and the VSL as an upper bound. For morbidity effects the COI was estimated as a lower bound and willingness-to-pay to avoid a case of illness was applied as a higher bound of cost (WTP was assumed to be two times the COI).

Results
Air quality data support the finding that particulate matter is one of the most serious concerns in the country. Ambient PM$_{10}$ concentrations frequently exceeded the EU standard of 40μg/m^3 over the years (Figure 1).
Using information on ambient PM$_{10}$ and PM$_{2.5}$ in conjunction with the methods outlined above, it is estimated that in Macedonia 1,350 deaths occur annually from cardiopulmonary disease and lung cancer (Table 2). These deaths are considered 'premature' in the sense that air pollution contributed to their early demise – since many factors actually influence a persons' lifespan (e.g. smoking, exposure to the outdoors, job, etc.). Particulate matter can also influence a person's day-to-day health and their ability to work. In 2011, levels of PM$_{10}$ and PM$_{2.5}$ were primarily responsible for 485 new cases of chronic bronchitis, 770 hospital admissions, and 15,200 emergency visits.

Figure 1. Annual average PM$_{10}$ concentration at each automatic monitoring station in µg/m^3 (*Source: Ministry of Environment and Physical Planning, 2012*)
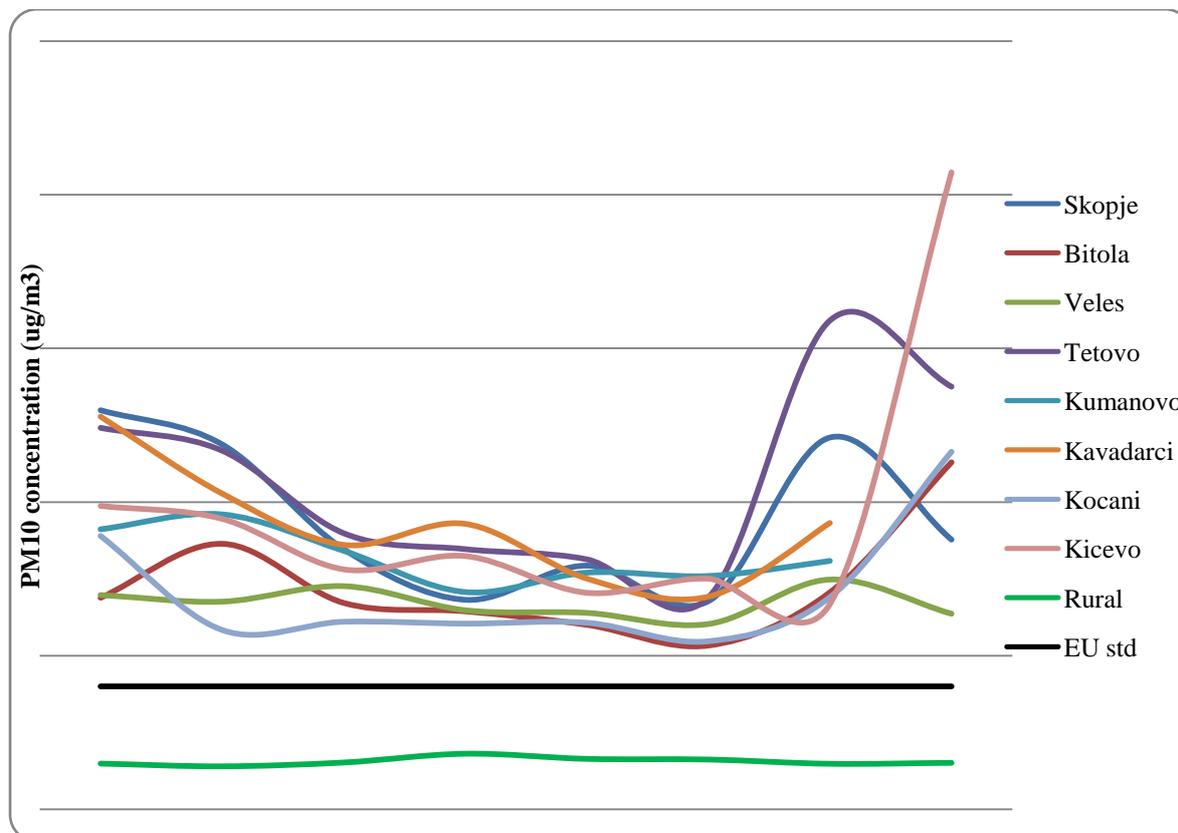
What do these translate to in terms of a total cost to society? Converting lost years of life and disabilities to DALYs (or disability-adjusted life years) - these health effects represent an annual economic cost of €253 million or 3.2% of GDP (Table 2). Note that premature death accounts for over 90% of the total health cost since the loss of life is a loss of total (future) income. People also suffer from the day-to-day consequences of respiratory diseases. It is estimated that several thousand work-years are lost annually from chronic bronchitis, asthma, hospital admissions and days of restricted activity.

These estimates are consistent with other recent studies – such as Kosovo where annual deaths were estimated to be in the range of 805-861 from cardiovascular disease and lung cancer (8). It should be noted that our estimates are mid-points (middle) with lower and higher ranges reflecting different assumptions made on the PM$_{2.5}$/PM$_{10}$ ratio and the population's exposure to air pollution.

What are the potential benefits of reducing particulate matter? If Macedonia were to lower PM$_{10}$ and PM$_{2.5}$ to EU limit values this would avoid over 800 deaths and thousands of days in lost productivity – representing a health cost savings of €151 million per year (Table 3). A reduction of even 1µg/m^3 in ambient PM$_{10}$ and PM$_{2.5}$ would result in 195 fewer deaths (1,648 fewer DALYs) and imply an economic savings of €34 million per year in reduced health costs.

Table 2. Number of annual cases, DALYs per year and economic cost in million Euros, 2011 *(Source: authors' calculations)*

Health impact	Annual cases[*]	Total DALYs per year	Annual economic cost (€ million)
Cardiopulmonary & lung cancer mortality ($PM_{2.5}$)	1,351	10,809	232.0
ALRI[†] mortality (PM_{10})	1	17	0.1
Chronic bronchitis (PM_{10})	485	1,066	3.0
Hospital admissions (PM_{10})	770	12	0.4
Emergency room visits (PM_{10})	15,200	68	0.9
Restricted activity days (PM_{10})	3,213,000	964	8.6
Lower respiratory illness in children (PM_{10})	22,400	146	1.5
Respiratory symptoms (PM_{10})	10,197,000	765	6.8
Total		*13,847*	*253.3*

[*] Mid-point estimates using a baseline for $PM_{10} = 15$ µg/m^3 and $PM_{2.5} = 7.5$ µg/m^3

[†] ALRI: Acute Lower Respiratory Infections.

Table 3. The potential health 'savings' associated with reductions in PM_{10} and $PM_{2.5}$ (€ million) *[Source: authors' calculations]*

Level of reduction in ambient PM_{10} and $PM_{2.5}$ (µg/m^3)[*]	Reduced DALYs	Annual health savings (€ million)
0	0	0.0
1	1,648	34.1
5	4,894	98.9
10	6,636	133.6
15	8,059	161.5
20	9,275	184.9
EU standards met[†]	7,840	151.5

[*] Example reductions were equally applied to both PM_{10} and $PM_{2.5}$ at the same time.

[†] $PM_{10} = 40$ µg/m^3 and $PM_{2.5} = 20$ µg/m^3.

Discussion

There is significant evidence of the effects of short-term exposure to PM_{10} on respiratory health, but for mortality, and especially as a consequence of long-term exposure, $PM_{2.5}$ is a more robust risk factor than the coarse part of PM_{10} (particles in the 2.5–10 μm range). All-cause daily mortality is estimated to increase by 0.2 - 0.6% per 10 μg/m^3 of PM_{10} (9). Furthermore, it has been estimated that exposure to $PM_{2.5}$ reduces life expectancy by about 8.6 months on average in the European Region. Results from the study "Improving Knowledge and Communication for Decision-making on Air Pollution and Health in Europe" (Aphekom), which uses traditional health impact assessment methods, indicates that average life expectancy in the most polluted cities could increase by approximately 20 months if long-term $PM_{2.5}$ concentrations were reduced to WHO annual guidelines (10).

Monitored PM_{10} and $PM_{2.5}$ concentrations have repeatedly exceeded EU standards in Republic of Macedonia and have contributed to short-term and chronic respiratory disease. This study estimated an annual (mid-point) loss of approximately 1,350 lives with thousands of lost-productive days, indirectly costing the economy upwards of €253 million or 3.2% of GDP in 2011. The specific exposure-response functions used in this study were

borrowed from the international literature – however the orders of magnitude have been shown to be robust in many developing country applications after adjusting for local conditions (4,5,7,8).

From a policy standpoint, it is important to note that these estimated costs are generally "hidden" since they are not normally quantified, and benchmarked to the value of economic activity that generated the pollution (i.e. GDP). Likewise the distribution of this burden is shared between the general public and the health care system – so total costs are not transparent. The results should motivate policy makers to be more focused on preventative measures, among them, local green options to reduce particulate matter including energy efficiency, fuel switching and the adoption of cleaner technologies. The benefits from such actions should find their way into the benefit-cost analysis of associated investments since the health "savings" could offset the investment costs of greening interventions.

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