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Health impact and monetary cost of exposure to particulate matter emitted from biomass burning in large cities

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HIGHLIGHTS

- Health and monetary impact assessment of exposure to PM from biomass burning.
- 200 excess deaths annually (for a 900,000 population) are expected in the cold season.
- The respective monetary cost ranges from 200m€ to 1.2b€.
- Monetary cost of health burden compounds the fiscal burden of austerity measures.

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ABSTRACT

The study deals with the assessment of health impact and the respective economic cost attributed to particulate matter (PM) emitted into the atmosphere from biomass burning for space heating, focusing on the differences between the warm and cold seasons in 2011–2012 and 2012–2013 in Thessaloniki (Greece). Health impact was assessed based on estimated exposure levels and the use of established WHO concentration–response functions (CRFs) for all-cause mortality, infant mortality, new chronic bronchitis cases, respiratory and cardiac hospital admissions. Monetary cost was based on the valuation of the willingness-to-pay/accept (WTP/WTA), to avoid or compensate for the loss of welfare associated with illness.

Results showed that long term mortality during the 2012–2013 winter increased by 200 excess deaths in a city of almost 900,000 inhabitants or 3540 years of life lost, corresponding to an economic cost of almost 200–250m€. New chronic bronchitis cases dominate morbidity estimates (490 additional new cases corresponding to a monetary cost of 30m€). Estimated health and monetary impacts are more severe during the cold season, despite its smaller duration (4 months). Considering that the increased ambient air concentrations (and the integral of outdoor/indoor exposure) are explained by shifting from oil to biomass for domestic heating purposes, several alternative scenarios were evaluated. Policy scenario analysis revealed that significant public health and monetary benefits (up to 2b€ in avoided mortality and 130m€ in avoided illness) might be obtained by limiting the biomass share in the domestic heat energy mix. Fiscal policy affecting fuels/technologies used for domestic heating needs to be reconsidered urgently, since the net tax loss from avoided oil taxation due to reduced consumption was further compounded by the public health cost of increased mid-term morbidity and mortality.

1. Introduction

Indoor biomass burning for residential heating is a major source of indoor and outdoor air quality degradation. One of the major components of biomass burning is emitted PM. The association of biomass burning PM with potential health effects, as well as their toxicity potency in comparison to other PM combustion sources have been investigated through a controlled study of human exposure to wood smoke, epidemiological studies (observational or interventional), as well as with toxicological tests — a very comprehensive review on both perspectives was carried out by Naeher et al. (2007).

To date, solely a single controlled study of human exposure to wood smoke has been published (Barregard et al., 2006). Inflammatory mediators and coagulation factor levels of the exposed subjects were altered and free radical-mediated lipid peroxidation increased after wood smoke exposure. Although this is the only controlled study of wood smoke exposure published to date including a small number of subjects (13), it is suggestive of wood smoke-associated systemic inflammatory effects.

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The majority of information regarding direct human health effects associated with wood smoke exposure is derived from a relatively large number of epidemiologic studies that have documented respiratory effects of residential wood burning, especially in children (Naeher et al., 2007). One of the earliest studies was conducted in Michigan by Honicky et al. (1985) who compared respiratory symptoms in 31 children who lived in homes with wood stoves with an equal number of children who lived in homes without wood stoves. Exposure to smoke from wood stoves resulted in exacerbation of severe symptoms of respiratory diseases. Related health effects research in Seattle shows associations between PM2.5 exposure and lung function decrements in children (Koenig et al., 1993), visits to the emergency departments for asthma (Norris et al., 1999), hospitalizations for asthma (Sheppard et al., 1999), and increases in asthma symptoms in children (Yu et al., 2000), as well as increases in exhaled nitric oxide (Koenig et al., 2005). Considering that wood burning is one of the major sources of exposure to fine PM in the Seattle area, the related studies resulted in significant associations between wood burning PM and adverse health outcomes. Another study examined the relationship of woodstoves to otitis media and asthma in a case–control study of home environmental air pollutants in Springville, NY (Daigler et al., 1991). Use of biomass burning sources resulted in increased incidence rate of several adverse health effects such as otitis media and severe shortness of breath. Thus, indoor biomass burning was identified as the second most important source of exposure to fine PM after environmental tobacco smoke (Ostro et al., 1991).

In the study of Happo et al. (2013) health-related toxicological properties of PM1 emissions from five modern and two old technology appliances were examined. Mice were intratracheally exposed to a wide range of particulate samples and then bronchoalveolar lavage fluid (BALF) was assayed for indicators of inflammation, cytotoxicity and genotoxicity. The results indicated that although older technologies emit higher amounts of PM1 per energy unit produced, PM1 emitted from modern appliances induced higher inflammatory potential, probably due to ash-related compounds.

A recent meta-analysis by Diette et al. (2012) concluded that inhalation of wood smoke at a relatively low level, had the potential to suppress the immunity of the respiratory system, resulting in increased susceptibility to infections as well as to several types of lung disease.

To date, only a limited number of studies have evaluated the results of shifting between biomass and conventional fuel for domestic heating (intervention studies). The most comprehensive study up to now is an intervention study in Australia carried out by Johnston et al. (2013) who evaluated the effect of community education campaigns, enforcement of environmental regulations, and a wood heater replacement program on daily mortality. This bundle of actions resulted in a 17 μg/m^3 reduction of ambient air PM10 in the wintertime, which, was reflected, in turn, in reduced annual cardiovascular and respiratory mortality, especially for males.

In their study in Austria Haluza et al. (2012) estimated that replacement of light oil by biomass as well as fossil gas would result in increased mortality and morbidity due to the related hike in PM ambient air levels. The higher the biomass energy share, the higher the PM attributed mortality and morbidity. Although interesting from the perspective of scenario analysis, the use of PM10 as input in concentration–response functions, does not seem to fully capture the variability on PM concentrations related to biomass burning. Thus inter-scenario differences might well be underestimated.

Despite the uncertainties related to monetization of air pollution related impacts, significant efforts have been made based on the Value-per-Statistical-Life (VSL) concept. Alberini et al. (2006) concluded that VSL is not significantly lower for older persons, but income was positively associated with willingness to pay (WTP). Roman et al. (2012) elucidated the uncertainties related to VSL for a reduction in mortality risks, while Ortiz et al. (2011) identified altruism towards children, and a strong income effect on WTP to avoid the loss of welfare associated with illness. In the recent years, scientific interest has shifted towards the assessment of climate change impact health costs. The respective cost is in the range of 100 billion euros annually in the EU-27 region (Watkiss and Hunt, 2012). Finally, the study carried out by Desaigues et al. (2011), aimed at the economic valuation of air pollution mortality. Based on a 1493 person survey carried out in 9 EU countries, the monetary value of a life year (VOLY) was estimated to be equal to 25,000 euro.

Over the last couple of years, the use of biomass as heating source was allowed in Greece as a CO_2-neutral means of space heating in the large metropolitan areas of Athens and Thessaloniki affecting more than half of the country's population. At the same time the use of light heating diesel was heavily taxed apparently to combat illegal trafficking of heating diesel. In the same period Greece faced a financial crisis with significant repercussions on the average household income. That combination of parameters resulted in increased use of biomass for residential heating in year 2012, followed by a significant increase of ambient air, indoor air and exposure to PM10 and PM2.5. In this study, we aim to quantify the health and socioeconomic effects related to that shift from light heating diesel to biomass burning, as well as to evaluate alternative scenarios of residential heating energy share.

2. Methodology

2.1. Exposure assessment

To better reflect the effect of biomass burning on public health, actual population exposure was estimated. Thus, indoor concentrations taking into account outdoor penetration as well as indoor sources (biomass burning among them) were estimated. The estimation was based on a mass balance model, that takes into account the major processes governing particle concentration i.e., emissions, deposition, indoor/outdoor exchange rate, and outdoor infiltration. A detailed description of the indoor air model and the related parameterization has been given by Sarigiannis et al. (2014) on the model and the related parameterization. In summary, the mass balance is described by the following formula:

$$V \cdot \frac{dC_{ind}}{dt} = Q \cdot (\inf \cdot C_{out} - C_{ind}) + E - k_{dep} \cdot C_{ind} \cdot V$$

where:

E	*the strength of the emission sources (mass / time)*
V	*the volumes of the indoor location*
C_{out}	*the outdoor concentration*
C_{ind}	*the indoor concentration of the indoor location*
Q	*the indoor–outdoor air exchange rate*
inf	*the infiltration fraction*
k_{dep}	*the deposition rate*

Particle penetration into buildings from the ambient air depends on pollutant species, geometry, surface materials and pressure drop across the leakage path. It is usually expressed by means of a dimensionless penetration factor; typical values of the latter for domestic environments were taken from the PTEAM study (Özkaynak et al., 1996). These values are normally distributed with a mean value of 1 and a standard deviation of 0.06. Background emission rates for PM10 and PM2.5 were taken equal to 5600 and 1400 μg/h respectively (not including indoor smoking or long-term burning activities). These values are considered to be representative of Greece (Hänninen et al., 2004). Biomass burning emissions into the indoor environment from open fireplaces and other biomass combustion sources (e.g., stoves) were estimated experimentally in our study, found to be equal to 2300 μg/h. Deposition of atmospheric aerosol particles on indoor surfaces (the floor, walls, ceiling and furniture) takes place via electrostatic and thermostatic processes, and it is significantly affected by the type of air mixing (turbulent vs.