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Fossil fuel combustion and $PM_{2.5}$ mass air pollution associations with mortality

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It is widely acknowledged that outdoor fine particulate matter ($PM_{2.5}$) air pollution is a major global public health threat: the World Health Organization has ascribed 4.2 million premature cardiovascular, respiratory, and cancer deaths worldwide per year to $PM_{2.5}$, and recently lowered its $PM_{2.5}$ guidelines to better protect health (World Health Organization (WHO), 2021a; World Health Organization, 2021b). $PM_{2.5}$ is regulated in many countries across the globe, and has been deemed the most consistent and robust predictor of mortality in evaluations of long-term exposure to air pollution (Cohen et al., 2017). Less well appreciated, however, is the fact that not all particles we breathe are the same, having differing sources, compositions, and, therefore, likely also having varying associated health implications per unit mass (National Academy of Sciences, 1999; National Research Council, 1980). As a result, the $PM_{2.5}$ pollution control measures that governments and businesses choose to focus their control efforts upon may well have varying levels of health benefits.

Unfortunately, to date, too few $PM_{2.5}$ health studies have attempted to parse the $PM_{2.5}$ mass health impacts to specific constituents, mixtures of constituents, or particle emission source, mainly due to lack of $PM_{2.5}$ composition data. The earliest such chronic $PM_{2.5}$ mortality study was a cross-sectional analysis I co-authored in 1987, looking at US particulate matter and annual mortality during 1980, based on a brief nationwide Inhalable Particle (IP) monitoring network (Ozkaynak and Thurston, 1987). We found that the mass of smaller sized particles, which we called fine particulate matter (before it was named $PM_{2.5}$), was more associated with annual mortality than larger particle mass. But, in that work, I also conducted a source apportionment of those effects, concluding that particles from coal combustion were suggested to be more significant contributors to US human mortality than soil-derived particles. The US $PM_{2.5}$ - mortality association was later rigorously confirmed by cohort studies (Dockery et al., 1993; Pope et al., 2002). The shutdown of the IP Network led to many years passing before the 1999 initiation of the US EPA's Chemical Speciation Network again allowed such nationwide $PM_{2.5}$ source and compositional studies to be conducted to further investigate our earlier findings. The Health Effects Institute (HEI) started the National Particle Component Toxicity (NPACT) initiative, a comprehensive research program in the US that combined epidemiologic and toxicologic approaches to evaluate whether some components and or sources of the PM mixture are of greater public health concern than others (Lippmann et al., 2013; Vedal et al., 2013). Results indicated that $PM_{2.5}$ from coal and oil combustion, and from traffic sources, were most strongly associated across adverse health outcomes, but particles from other sources could not be definitively excluded as having no adverse effects.

This edition of Environment International presents two new studies considering $PM_{2.5}$ source-specific mass, $PM_{2.5}$ constituents, and mortality. Both studies consider the US Medicare population database, although Wang and colleagues focus on the American Southeast (Wang et al., 2021). They conducted a population-based study, comprising Medicare enrollees (aged 65 or older) from 2000 to 2016, in order to explore the all-cause mortality associations with long-term exposures to five $PM_{2.5}$ major components (carbon, nitrate, organic matter, sulfate, and soil particles). While the analyses found that all five $PM_{2.5}$ components were statistically significantly associated with increased risk of mortality, the soil particle mass was noted as having a much smaller effect than the combustion-related $PM_{2.5}$ constituents, with the strongest associations found for sulfates and elemental carbon, proxies of fossil fuel/coal burning and (diesel) traffic $PM_{2.5}$, respectively, in the US.

Kazemiparkouhi and colleagues (Kazemiparkouhi et al., 2022) analyzed cause-specific mortality among all US Medicare beneficiaries between 2000 and 2008 with trace $PM_{2.5}$ constituents and a full source apportionment of $PM_{2.5}$. Despite using differing exposure estimation

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approaches, the two papers concur that the mortality effects of soil particles are much smaller than for other $PM_{2.5}$ components. In addition, the consideration of multiple sources in the nationwide analysis allowed for better discernment of associations by specific combustion source categories, indicating that biomass combustion $PM_{2.5}$ has lower impacts per Interquartile Range (IQR) than $PM_{2.5}$ from fossil fuel combustion sources, especially coal burning and traffic-derived $PM_{2.5}$. Furthermore, the Kazemiparkouhi et al. source-specific $PM_{2.5}$ findings for ischemic heart disease (IHD) deaths are reassuringly confirmatory to those previously reported by me and my colleagues (Thurston et al., 2016) when we similarly considered $PM_{2.5}$ mass constituent and source contribution impacts in the American Cancer Society (ACS) cohort, also finding the strongest IHD mortality associations with coal combustion and traffic $PM_{2.5}$, and the least with biomass burning and soil $PM_{2.5}$.

Taken together, these two new studies compellingly confirm past analyses indicating that the short- and long-term health effects of $PM_{2.5}$ can vary as a function of composition (Achilleos et al., 2017; Wang et al., 2014; Thurston et al., 2021), but also further suggest that analyzing the health effects of $PM_{2.5}$ as a function of source-specific mass may yield more consistent associations than with individual $PM_{2.5}$ constituents. This is likely due to the fact that individual constituents, such as copper or iron or elemental carbon, can derive from multiple sources, each source with its own characteristic aerosol mixture health impacts per $PM_{2.5}$ elemental constituent. Other recent toxicological and epidemiological evidence has indicated, consistent with these new study results, that the co-presence of acidic sulfur with metals, such as emitted by fossil fuel combustion sources, represent an especially toxic aerosol mixture (Fang et al., 2017; Weichenthal et al., 2021; Maciejczyk et al., 2021). A recent HEI sector specific analysis of $PM_{2.5}$ mortality has adoped an assumption of equitoxicity (i.e., every atmospheric particle has the same toxicity per unit mass, regardless of its chemical composition and physical properties) (McDuffie et al., 2021). The above considerations suggest that source sector specific $PM_{2.5}$ concentration–response coefficients are needed in future sector specific health effects analyses, and that the equitoxicity assumption may presently be underestimating the mortality contributions from fossil fuel combustion $PM_{2.5}$, while overestimating the mortality impacts of windblown dust and biofuel burning $PM_{2.5}$.

More $PM_{2.5}$ composition and health studies are needed to better quantify $PM_{2.5}$ concentration – health response risks as a function of air pollution source sector. However, these two new studies, combined with other available toxicological and epidemiologic evidence, already indicate to me that, in order to maximize the health benefits of air pollution regulations, a priority should be placed on controlling $PM_{2.5}$ air pollution from fossil-fuel combustion.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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