AIR POLLUTION – PARTICULATE MATTER

Public Health Impact of Particulate Matter

Author: Darryl Quantz MFPH, MPH, MSc, Consultant in Public Health, Greater Manchester Health & Social Care Partnership.

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Poor air quality is the largest environmental risk to public health in the UK, as long-term exposure to air pollution can cause chronic conditions such as cardiovascular and respiratory diseases as well as lung cancer, leading to reduced life expectancy.

The size of particles and the duration of exposure are key determinants of potential adverse health effects. Particles larger than 10 μm are mainly deposited in the nose or throat, whereas particles smaller than 10 μm pose the greatest risk because they can be drawn deeper into the lung. The strongest evidence for effects on health is associated with fine particles (PM$_{2.5}$).

There is an extensive body of evidence that long-term exposure to particulate matter (PM) increases mortality and morbidity from cardiovascular and respiratory diseases. As shown in Figure 1, it is predicted that between 2017 and 2035, 1,327,424 (±9,927) new cases of disease would be attributable to PM$_{2.5}$, equivalent to 2,248 new cases of disease per 100,000 people. The highest numbers of these cases are predicted to be from coronary heart disease (CHD), diabetes and COPD.

Figure 1: Conditions associated with exposure to PM$_{2.5}$
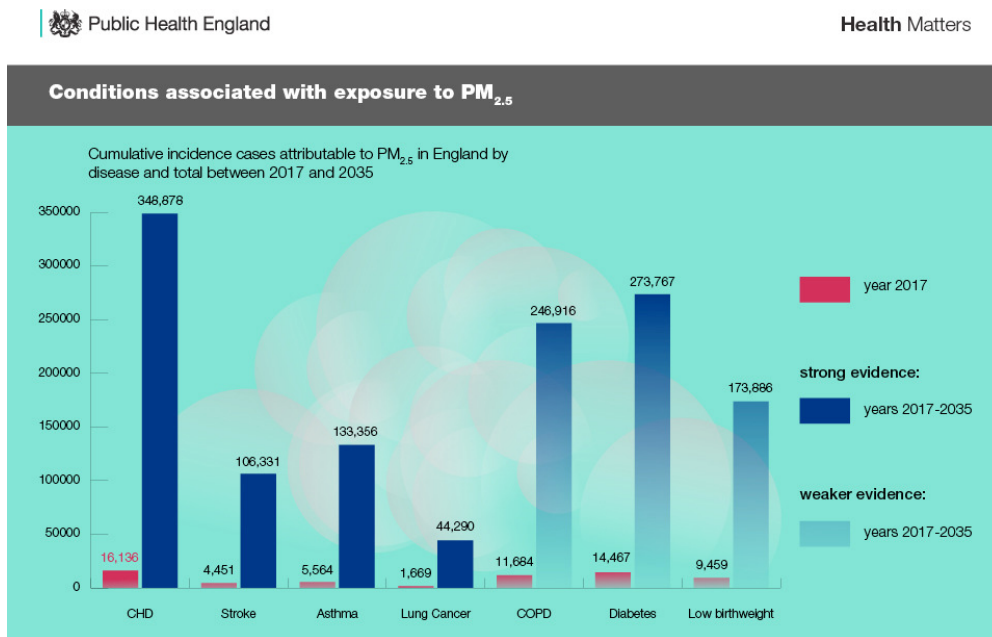
The UK Health Forum and Imperial College London, in collaboration with and funded by Public Health England (PHE), developed a modelling framework and estimated that a 1 $\mu g/m^3$ reduction in fine particulate air pollution in England could prevent around 50,900 cases of coronary heart disease, 16,500 strokes, 9,300 cases of asthma and 4,200 lung cancers over an 18 year period.

Air pollution also contributes to health inequalities. Although air pollution can be harmful to everyone, some people are more affected because they live in a polluted area, are exposed to higher levels of air pollution in their day-to-day lives, or are more susceptible to health problems caused by air pollution. The most vulnerable face all of these disadvantages.

COMEAP (Committee on the Medical Effects of Air Pollution) is aware of emerging evidence regarding possible links between air pollution and the transmission and/or severity of COVID-19. As such, action to improve our air quality and reduce associated inequalities becomes even more imperative.

Groups that are more affected by air pollution include:

- older people
- children
- individuals with existing cardiovascular or respiratory disease
- pregnant women
- communities in areas of higher pollution, such as close to busy roads
- low-income communities

Contributions of Sources to PM$_{2.5}$ in Greater Manchester and Composition

Author: Professor Hugh Coe, Professor of Atmospheric Composition, University of Manchester.

- Particulate matter is composed of primary particulate and secondary particulate material. Primary particles are emitted into the atmosphere as particles and so can be directly linked to sources; secondary particulate is formed as a result of chemical reactions in the atmosphere changing volatile gases to less volatile products that can form new particulate.

- PM$_{10}$ (particulate mass less than 10μm in size) includes PM$_{2.5}$ (particulate mass less than 2.5μm in size) and larger particles. The larger, coarse mode fraction, is typically made up of primary material from construction, road dust, tyre wear, sea salt, and agricultural dust, for example during ploughing or harvesting under dry conditions that is re-suspended as a result of air turbulence.

- PM$_{2.5}$ also has primary sources but also a substantial secondary contribution.

- The main primary contributions to PM$_{2.5}$ come from road traffic exhaust, tyre and brake wear, cooking, and solid fuel combustion.

- There are relatively few studies of source apportionment of $PM_{2.5}$ in Greater Manchester, these are based on short term studies but GM is likely typical of many cities in the UK including London.

- Our previous work in London shows that primary traffic exhaust, cooking and solid fuel make approximately equal contributions to urban background air in wintertime. In summertime the split between cooking and traffic exhaust remains the same but solid fuel is reduced.

- There is significant uncertainty surrounding cooking emissions, however controls are in place to address this source.[1]

- Particle removal from modern vehicle engines is efficient.

- Non exhaust road traffic $PM_{2.5}$ from brake and tyre wear is poorly characterised, particularly as the fleet is continually changing.

- Solid fuel burning from wood or coal makes a significant contribution to $PM_{2.5}$ in wintertime. Emissions increase markedly due to activity when the outside air temperature decreases below 5°C.

- Emissions vary hugely as a result of many factors including fireplace/stove type, fuel used, fuel quality and water content, operational differences such as the way additional fuel is added and fuel/air mix, flue type and maintenance.

- The distribution of solid fuel emissions is not well known, but may reflect suburban lifestyles rather than being similar to traffic. Current monitoring of $PM_{2.5}$ may not adequately capture this.

- There is considerable variation in the contribution of secondary material to $PM_{2.5}$ but the fraction is typically 30-80% of the total $PM_{2.5}$ mass.

- The secondary material arises from the oxidation of SO_2, NO_2 and volatile organic compounds (VOC) that are emitted into the gas phase but then react to form sulphuric acid, nitric acid and a range of secondary organic compounds.

- These are relatively involatile and condense onto existing particles or, in the case of sulphuric acid and some organic compounds, form new ultrafine particles.

- Ammonia condenses along with sulphuric acid and nitric acid. Nitric acid will not condense onto acid $PM_{2.5}$ so often needs ammonia to condense.

- These processes take place over timescales of hours and so are city-scale to regional in extent.

- Ammonia sources in the city arise from sewerage and also from vehicle engine catalytic convertors yet to reach operating temperature (cold start)

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[1] The contribution of PM2.5 from commercial cooking is primarily controlled through planning regulations, which include the control of fumes. Applicants must submit a kitchen fume extract strategy for approval based on appropriate UK guidance. Emissions are also controlled to a lesser degree through complaints received and acted on by local authorities via the Environmental Protection Act 1990. Controls can also be imposed by local authority Food and Health & Safety inspection programmes, normally via the Health & Safety at Work Act 1974, which is mainly focused on indoor air quality.

- Agriculture is a very large source of regional ammonia.

- Secondary organic aerosol (SOA) formation is not well characterised. The main VOCs that lead to formation are aromatic compounds from traffic exhaust but also from solvents and other evaporative sources. Biogenic compounds emitted from trees are also an important source of particle formation compounds.

- The amount of SOA formation can increase substantially when NO and NO_2 is present, since the mix of NO, NO_2 and VOCs promotes an increase in chemical processing and drives different chemical pathways for formation of secondary particulate.

- Although source apportionment studies in Greater Manchester are limited, recent work in London has shown that primary contributions to $PM_{2.5}$ are approximately 30% of the total.

- Reducing $PM_{2.5}$ below a 10 µg/m^3 threshold will be challenging by targeting primary emissions alone, however, at local level it is this fraction that offers the opportunity for the most immediate gains.

- Given that, it is suggested that campaigns focussing on solid fuel burning, cooking and emissions from road traffic including non exhaust emissions would make the most immediate impact.

The figure below comes from a paper by Young et al., 2015 https://www.atmos-chem-phys.net/15/6351/2015/acp-15-6351-2015.pdf).
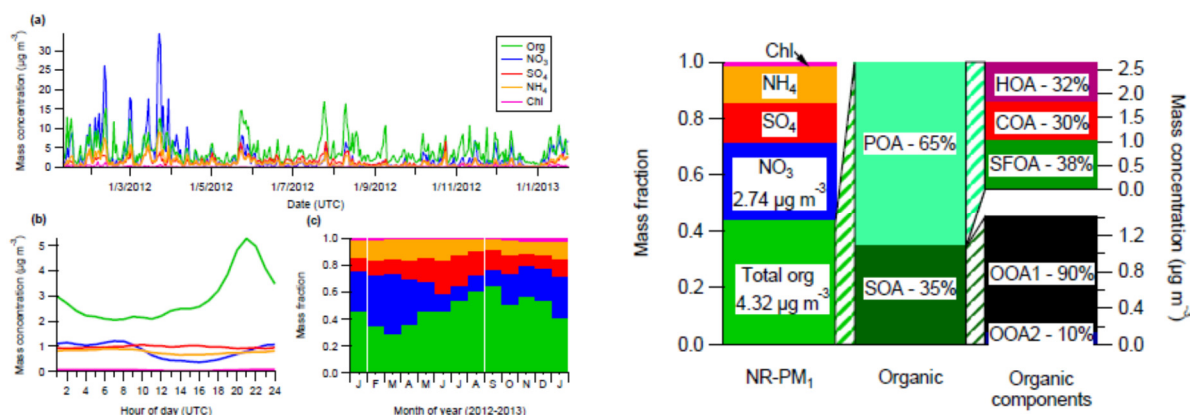
The figure shows the results of $PM_{2.5}$ source apportionment for an urban background site in London (North Kensington). The data were collected over a full calendar year, shown in the left panel. Chemical analysis of PM_1 was carried out at a 30 minute time resolution. The instrument retrieves the mass of different chemical components and independent factors were determined from the organic chemical signatures. The average contribution over a year is around 55% inorganic (sulphate, nitrate and ammonium) and 45% organic matter. The organic composition was used to derive distinct chemical signatures that characterise the contribution made by sources of primary organic aerosol (POA) from road traffic (HOA – Hydrocarbon-like Organic Aerosol); solid fuel burning (SFOA – Solid Fuel Organic Aerosol) and cooking (COA – Cooking Organic Aerosol). This amounts to 65% of the total organic aerosol or 30% of the total. Some of the organic aerosol mass comes from secondary processes in the atmosphere (SOA). The inorganic contributions to the PM_1 (sulphate, nitrate and ammonium) are all secondary in nature and are

produced by chemical reactions in the atmosphere. The secondary contribution is all formed on a regional scale. Of the POA, 32% comes from traffic, 30% from cooking and 38% from solid fuel burning. The POA from traffic and cooking are quite constant throughout the year. The COA fraction is uncertain and requires more study to improve this number. The SFOA contribution is greater in wintertime. It is to be expected that similar contributions occur at urban background sites in Manchester.

Since the inorganic fraction and the SOA are all formed on regional scales, it is challenging to see how effective control measures can readily be put in place at the city/GM scale though NO_x reductions will help reduce nitrate. Large sources of ammonia arise from the agricultural sector, and part of the SOA precursors arise from biogenic sources such as trees. This means that policy measures aimed at reducing $PM_{2.5}$ at source must target the POA fraction. On average this is around 30% of the total $PM_{2.5}$. A complete reduction of the POA fraction would only reduce PM_1 measured at the North Kensington site example presented above from the average annual value of 9.9 μg/m^3 to 7.4 μg/m^3.

Clearly it will be challenging to reduce $PM_{2.5}$ levels at many locations across UK cities to below 10 μg/m^3 based solely on tackling primary sources of $PM_{2.5}$ though reductions from this sector should no doubt be targeted.

Contribution from wood stoves and comment on the article from the Stove Industry Alliance on wood burning contributions to PM
(https://airqualitynews.com/2020/04/14/wood-burning-stove-industry-responds-to-coronavirus-warning/).

Author: Professor Hugh Coe, Professor of Atmospheric Composition, University of Manchester.

In a response to an article in AirQualityNews, the Stove Industry Alliance (SIA) provided a published response on 14th April 2020. The response argued that the assessment that more than a third (38%) of the UK's primary emissions of $PM_{2.5}$ was over-inflated and provided two reasons:

(1) The BEIS Domestic Wood Survey (Waters, 2016) identified that the UK National Atmospheric Emissions Inventory (NAEI) under-represented the contribution from domestic wood burning by a factor of three. In response the SIA has conducted its own survey based on a larger sample size and reports that the use was one-third of that reported by Waters (2016).

(2) The SIA argued that the emissions factors used within the NAEI were three times the level permitted under the Ecodesign legislation.

Regarding the first reason presented, there have been no independent reports to verify the SIA information and the BEIS Wood Survey remains the main source of information used to inform the NAEI.

Regarding the second reason, whilst the point made is certainly true, the lifetime of stoves in use in the UK is in excess of ten years and in many cases closer to 25 years.

Hence, while it may be that new stoves are compliant with the eco-design legislation, many stoves and fires in use across the UK are not. Furthermore, the usage rates of stoves are highly uncertain and, in any case, the relationship between the amount of fuel burned and the emitted PM is complex and dependent on fuel type, moisture content, stove type, stove loading and operation.

The SIA used these figures to derive a percentage of $PM_{2.5}$ due to domestic wood burning of 14.9% and argue that this is substantially less than the 38% quoted above.

However, the 38% quoted in AirQualityNews is derived from the Air Quality Expert Group report (AQEG 2017: https://uk-air.defra.gov.uk/assets/documents/reports/cat11/1708081027_170807_AQEG_Biomass_report.pdf) and the Kings College Defra funded study (Font et al., 2017: https://uk-air.defra.gov.uk/assets/documents/reports/cat05/1801301017_KCL_WoodBurningReport_2017_FINAL.pdf) and refers to primary $PM_{2.5}$ and not the $PM_{2.5}$ total.

This figure was determined by Font et al., (2017) using the national aethelometer network and supported by levoglucosan analyses. It is not clear whether the SIA report refers to the primary $PM_{2.5}$ amount, but it states that the 14.9% is "the fraction of $PM_{2.5}$ attributable" and should therefore be read as the fraction of the total $PM_{2.5}$. Since the primary contribution to $PM_{2.5}$ is substantially less than the total amount at almost every location in the UK, these figures are not inconsistent. As an example, in the data shown above from London, the primary contribution of wood burning (including all wood burning sources) to primary $PM_{2.5}$ is 38% but the contribution to the total $PM_{2.5}$ is 11%.

The SIA then criticize the two methods for determining the domestic wood burning contribution used by Font et al. (2017) on the grounds of specificity and also accuracy. It is certainly the case that the methods used cannot discriminate different types of solid fuel burning easily since they are simply based on characteristic properties of a fraction of the composition. Our work at the North Kensington site, as presented above, was not used by Font et al (2017) and uses an entirely different method. Though there are inherent uncertainties in all methods a very similar number is derived. From the time series in our data and the work of Font et al (2017) it is hard to conceive of another source of solid fuel burning other than domestic heating that systematically increases through the evening time, has a wide source area, is most prevalent in winter and increases substantially at weekends and when the temperatures decrease below 5°C.

In summary, while the SIA comments have some basis the actual figures appear broadly consistent with the emissions from the NAEI and, while there are uncertainties in the methods for determining the contributions from wood burning, multiple methods yield similar numbers, albeit with significant uncertainty. The temporal patterns of the signals make it very difficult to argue for sources other than domestic wood burning being responsible for the solid fuel contribution. Overall therefore, domestic wood burning is considered to make a major contribution to the primary $PM_{2.5}$ in wintertime and should therefore be a target for emissions reduction.