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RAPPORTEURSHIPS "FACING CLIMATE CHANGE"

# "THE EFFECTS OF ULTRAFINE AIR POLLUTION PARTICLES ON HEALTH"

SESSION WITH **BARBARA MAHER.**

FUNDACIÓ
CATALUNYA
EUROPA

# The effects of ultrafine air pollution particles on health

## Invited speaker: Barbara Maher, Lancaster University

CONTENTS

This report is a synthesis of the debate with Dr. Barbara Maher in the conference series “Facing climate change”, organised by the Catalunya Europa Foundation as part of the Re-City project, in collaboration with BBVA. This session, entitled "**The effects of ultrafine air pollution particles on health”** consisted of a public lecture, a lunch-debate that brought together actors from the economic, social, political and business sector of Catalonia, and a meeting with academics. The activities were held in Barcelona at the Antoni Tàpies Foundation in November 2019. The content order along this report is thematic and does not represent the order in which it was presented by Dr. Barbara Maher.

# Biography

Barbara Maher is a Professor of Environmental Science at Lancaster University, and the Director of the Lancaster Environment Centre's widely acclaimed Centre for Environmental Magnetism and Palaeomagnetism. Her research focuses both on the health effects of magnetite particles in air pollution, and retrieving "palaeoclimatic, palaeoenvironmental& dating information from the magnetic records of Quaternary terrestrial sediments (soils, loess, tills, lake sediments) & deep-sea sediments". She uses magnetic methods to analyse a range of current environmental issues, including air pollution and water contamination. (Lancaster, NDa)

Maher completed her bachelor's degree at the University of Liverpool, staying on afterwards to complete her PHD on the Origins and Transformations of Magnetic Minerals in Soils in 1984. Following the completion of her doctorate, Maher became a NERC Research Fellow in the Department of Geophysics at the University of Edinburgh. After this, she became a lecturer at the University of East Anglia (UEA), becoming Reader at the same University in 1998. She was also chair of the INQUA (International Union for Quaternary research) Dust and Climate Working Group from 2008 - 2016. (Lancaster, NDb)

Maher has been the recipient of a number of awards and prizes, including the Schlumberger Award of the Mineralogical Society of Gt Britain & Ireland (2014). The award recognised her work in applying magnetic methods to environmental issues as having pioneered the now international use of environmental magnetism by environmental scientists (Lancaster, 2013). She also received the Pilkington Teaching Award (2013), a Royal Society Wolfson Research Merit Award (2006- 2012) and the Institute of Physics' award of the Chree Medal and Prize (2005). She was Chair of the Rock Magnetism Group at the International Union of Geophysics and Geodesy between 2002 – 2006 (re-elected from 2006 – 2008), and Vice-president of the Quaternary Research Association from 2008 - 2010 (Lancaster, NDa)

Her work was exhibited on a BBC television programme "Trust me! I'm a doctor", in a special episode named "The Big Air Pollution Experiment" (BBC, ND). The programme followed her 2013 research, which showed that planting tree lines on roadsides filtered the number of particulates reaching the inside of people's houses. They found that the pollution collected inside people's houses where the trees had been planted outside over the tested period, was 50-60% lower than in houses with no trees outside. In 2018, Maher also participated in a BBC Radio 4 episode of Inside Science, which discussed whether the UK government's Clean Air

Strategy was strong enough for sufficiently addressing the issue of air pollution.

Her 2016 research on "Magnetite Pollution Particles in the Human Brain" brought her work further into the limelight. A Guardian article (Carrington, 2016) praised the work, as it was the first to raise the possibility of a causal link between the presence of externally derived magnetite particles in the human brain and Alzheimer's disease (Maher et al, 2016). The study, published in the Proceedings of the National Academy of Sciences, analysed the brain tissue of 37 people, aged between three and 92 years of age, in the UK and Mexico, finding large amounts of particles.

It corroborated other research which explored the links between particulates and Alzheimer's disease (Plascencia-Villa et al, 2016), and research linking air pollution to Alzheimer's and to types of brain damage (Jung et al, 2015; Kavanaugh et al, 2012; Carrington, 2016)

# Summary

## *Nanoparticles are a threat to public health*

Barbara Maher, an expert in air pollution and health and Director of the Lancaster Environment Centre, closed our "Facing climate change" cycle with a conference on "The effects of ultrafine air pollution particles on health". Known as PM (particulate matter) by the scientific community, these are very thin, light-weight and therefore difficult to detect particles present in the atmosphere. This makes them very dangerous, as they can easily penetrate the human body. The smaller these particles are, the more easily they enter the body. In fact, they can reach organs such as the heart, liver, kidneys or, the thinner ones, even the alveoli of the lungs where they reach the blood flow and can travel throughout the body. These small particles can also directly reach the brain through the nose.

"This is a huge threat to public health, but the problem is that there are still no environmental networks to measure nanoparticles because the European Union has not established any regulations in this regard," said Barbara Maher. Their toxicity depends on their origin, composition and size. Most of them are loaded with carbon, are rich in metals and can be very magnetic. Nanoparticles come mainly from industrial areas, exhaust pipes, additives added to fuels or from the wear of brakes and vehicle engines, as well as combustion from maritime transport, airplanes and railways.

## *Air pollution nanoparticles contribute to neurodegenerative diseases*

One of the conclusions of Maher's research is the relationship between nanoparticles and diseases such as Alzheimer's, shown through the examined presence of metals in the brains of some patients. Up until recently, it was thought that magnetite nanoparticles, which contribute to the development of Alzheimer's disease, wereformed within the human brain. However, thanks to Maher's research, it is now evident that there is an external origin of magnetite nanoparticles coming from air pollution.

In the case studied in Mexico and England, metals such as iron and titanium or other very rare ones such as cobalt and platinum have been found in the brain. Another very worrying fact is that there are more and more cases in young people, such as a 3-year-old boy who had magnetite in his heart and brain tissues.

Undoubtedly, pollution is a potential risk factor but there are others such as a person's genetic constitution, diet, brain activity or cognitive reserve, which influence the development of the disease.

## *Electric cars and green barriers to reduce pollution.*

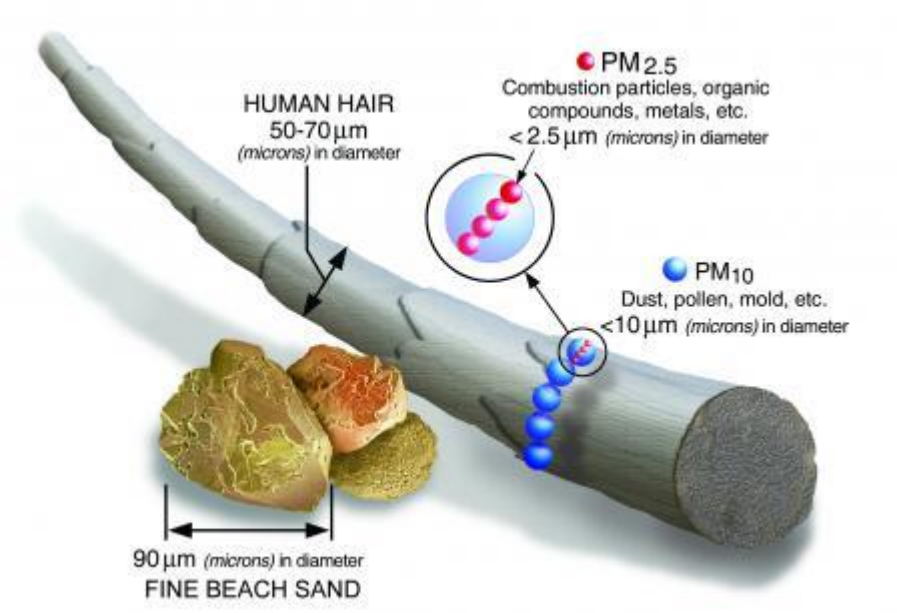
Barbara Maher advises against living in close proximity to streets or on roads with more traffic. According to a study conducted in Canada, living within fifty meters of a highway increases the risk of receiving contaminating particles from 7 to 11 percent. For this reason, Maher supports the use of electric vehicles to reduce pollution and the introduction of well-located green areas and trees for creating natural barriers that protect homes and buildings from contaminating nanoparticles. This can be a very effective measure, as demonstrated by an experiment at Lancaster University. Silver birch trees were planted in front of a group of houses, and the result showed that houses behind the tree line enjoyed better air quality. She also advised taking care with poorly sealed chimneys, and reducing the use of laser printers, that are often pockets of toxic nanoparticles.

Finally, Barbara Maher complained about the lack of institutional support and warned of the risks of not acting. She asked governments to accelerate changes and take urgent action, stressing that doing nothing when we already have this knowledge will lead to decreased intelligence in human beings as a species and an increase in cases of dementia and other diseases.

# The effects of ultrafine air pollution particles on health

## *Airborne Particulate Matter*

Particulate Matter, also known as PM or particle pollution, consists of a mixture of solid particles and liquid droplets found in the air. Some particles, such as dust or smoke, are large or dark enough to be seen with the naked eye. However, PMs are so small they can only be detected using an electron microscope. PMs can be classified according to its size: PM10 are inhalable particles with diameters that are generally 10 micrometers or less; while PM2.5 are inhalable particles with diameters that are generally 2.5 micrometers or less (this means that a PM2.5




particle is 30 times smaller than a single human hair, Figure 1).

**Figure 1:** PM 2.5 and PM10 particles compared to grain of fine beach sand and human hair (EPA).

PM is composed of a mix of carbon rich aerosols and inorganic, primary and secondary components. The main sources of PM are transport, construction and industry, among others. The mix always contains carbon, usually produced from the incomplete combustion of fuel, while other components tend to be solid, inorganic particles, rich in metals and strongly magnetic. This can happen as a result of the abrasion of vehicle brake pads, which are very rich in iron nanoparticles. PM can also contain biological components such as bacteria and fungus. The particular mix depends on the location, meaning that air pollution is of course different in different cities. In Barcelona, the main sources of air pollution are the airport and port, not only because of the high number of airplanes and cruise ships, but also because of airport and harbour machinery and merchant ships. Overall, Airborne PM is a cocktail of different

ingredients, making it a challenge to identify which of these components is most damaging to human health.

While PM10 is relatively large, smaller particles, such as PM 2.5, can reach more parts of the body. Maher's research goes beyond PM2.5, she focuses on airborne particles that measure less than a micrometer, the so-called nanoparticles (NP). They are so small that they can reach the lung alveoli, and from there they reach red blood cells. Once in the bloodstream they can reach every human tissue, including the brain. They can also reach the brain directly via the nose, through the neurons of the olfactory bulb, the sensory organ responsible for sense of smell (Figure 2). Once inside the cells they can kill them through oxidative stress, causing tissue damage and affecting human health.

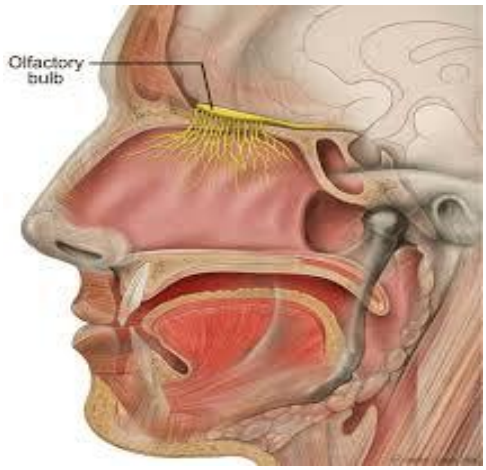



**Figure 2**: Olfactory Bulb and neurons, shown in yellow, through which nanoparticles can directly reach the brain after being inhaled through the nose(retrieved from: https://www.re-city.net/admin/assets/uploads/files/e66ef-barbara-maher-ppt.pdf).

Maher highlighted the fact that pollution regulations are currently based on measuring PM10, which are less dangerous. This is problematic because by implementing measures to reduce PM10, the presence of nanoparticles in the atmosphere has increased. She calls for a change in air pollution monitoring and regulation, to change the focus to airborne particles that are more dangerous for human health, namely PM2.5 and nanoparticles.

## *Ultrafine air pollution and the human brain*

Given the quantity of nanoparticles present in the air we breathe, and how easily they can contaminate our blood stream, it is crucial to understand how they affect us and which of these particles are most detrimental to our health.

Maher's 2016 study, titled "Magnetite pollution nanoparticles in the human brain", reported for the first time that some of the particles found in human brains were rounded and strikingly similar to combustion-derived PM - also called "spherals". Particles that come out of an engine or chimney at very high temperatures become melted droplets with a spherical shape. Hence,

spherical magnetite particles found in human brains could only be of exogenous origin. Figure 3 shows a human brain sample with magnetite nanoparticles of both endogenous and exogenous origin.

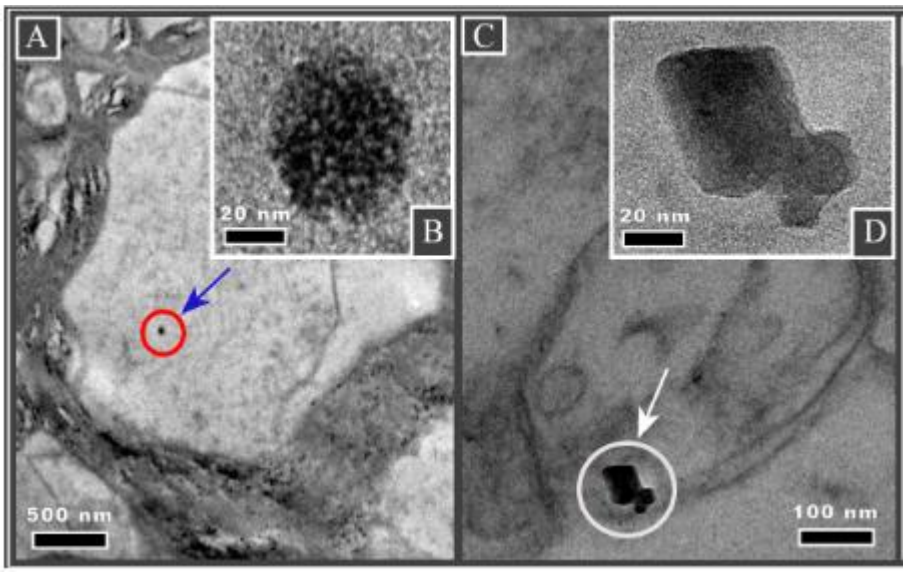



**Figure 3**: Human brain sample with magnetite nanoparticles of A) exogenous (spherical) and C) endogenous (square) origin (Maher et al, 2016).

This was ground-breaking, as it was previously thought that all magnetite particles within the brain were formed by the brain itself, and that magnetite in the brains of Alzheimer's patients was a product of the disease. Magnetite, a mix of Fe2+ and Fe3+, is an effective element for enriching free radicals which are toxic to brain cells, making it a possible risk factor for neurodegenerative diseases, Alzheimer's included. This discovery therefore showthe potential of air pollution to become a major public health issue.

According to Maher, previous studies have noted that both iron and magnetic forms of iron were enriched in the brain of Alzheimer's disease patients. What is new with Maher's research is that this accumulation can be caused by air pollution. It has also been shown that brains affected by Alzheimer's disease contain many plaques associated with high metal concentrations, and that magnetite particles could enhance the toxicity of β-amyloid, a plaque-forming protein, enhancing brain damage. This makes tackling pollution even more essential.

Once the research confirmed that exogenous magnetite nanoparticles were present in human brain samples, the next step was to examine the quantity and quality of these particles. Maher's research did so by using magnetic technology and HRTEM (High-resolution Transmission Electron Microscopy) a microscope for visualizing nanoparticles.

The Olfactory bulb is the only part of the body that does not meet the protective blood brain barrier, and therefore allows particles to be directly inhaled into the brain. Magnetite nanoparticles and other metal bearing particles with a size of less than 200 nanometres can

enter directly through the nose, spreading to other areas of the brain including the hippocampus and cerebral cortex, both regions affected in Alzheimer's disease. The study focused on the frontal cortex, the brain area that nanoparticles would first meet if entered through the olfactory bulb.

Two sets of samples were analysed by Maher and her team, one from Mexico City consisting of brains from young people, and the other from Manchester consisting of brains from older people. The first observation was that they found millions of magnetite particles per gram of brain tissue. Strikingly, metals such as carbon and titanium or other very rare ones such as cobalt, platinum and syrium - a fuel additive - were found in the nanoparticles isolated from brain samples. This is worrying because these metals are not naturally present in the human body, unlike iron. Although brain samples also contained magnetite particles grown endogenously, for every one of these, there were roughly 100 spherical particles derived from air pollution. Striking similarities between what they had found in the brain samples and what is found in the atmosphere were found. Sources of the particles could have included fuel combustion and frictional heating from brake pads, which are surprisingly very magnetic - up to 30% of the pads themselves are composed of magnetic powder, which is actively added to them.

Another observation from Maher's study was that many of the highly magnetic brain samples were from young (< 40 years at death) Mexico City residents exposed to high levels of airborne particulate pollution, as well as those older Manchester cases (> 65 years at death) with severe to moderate Alzheimer's disease. This is particularly worrying because it means that there are more and more cases of younger human brains with nanoparticles present. At the most extreme end was the case of a 3-year-old boy with nanoparticles in his brain and heart tissues (Maher et al, 2016; Calderon-Garciduenas et al., 2019). Maher also highlighted research conducted in Barcelona by ISGlobal researcher Jordi Sunyer (2017) on the effects of pollution on children. According to this study, prenatal exposure to air pollution is associated with changes in children's brains related to behavioral disorders.

Importantly, inflammation in the brain can be a precursor to seeing the more dramatic symptoms of Azheimer's disease, when behavioural and emotional changes start to occur. Some people are starting to show these symptoms earlier and earlier, leading Maher to ask whether magnetic particles could be the insult triggering the chain of inflammation.

## *Location affects exposure*

Once air pollution is shown to have side-effects on human health, it is wise to identify locations with higher concentrations of airborne nanoparticles, so that we can act either by reducing it or by preventing human exposure.

Maher referred to a study which compared exposure to nanoparticles in different locations, including the inside of cars, and indoor vs outdoor exposure (Yifang Zhu, 2007). Shockingly, the

inside of vehicles can be more polluted than the outside. She also referenced research by Chen et al (2017) which investigated the links between living by major roads and the incidence of Parkinson's, dementia and Multiple Sclerosis. The research found that 7-11% of dementia cases in Canada occurred in people living close to busy roads. Maher pointed out that not all those exposed would develop dementia - there were of course other contributing factors, such as diet, genetic background and physical activity levels. She called for larger studies for a more complete picture.

Data on air pollution composition and exposure should be used to build awareness and to influence changes in personal habits. There is a need to identify less-polluted areas that can be visited by vulnerable people such as the elderly and children, for sports or clean walking routes. Maher referred to mobile phone apps, such as London Air, that give users real time information on pollution around cities, so that certain places can be avoided. Maher also explained that staying one metre away from vehicles passing by, reduces exposure to airborne nanoparticles by one third. This means that even small changes in personal habits, such as how far away you stand from the road while waiting to cross, can make a difference.

# Potential solutions for reducing exposure to air pollution

Maher's research clearly indicates that exposure to airborne PM could indeed be an environmental risk factor for neurodegenerative diseases such as Alzheimer's Disease, a risk that is exacerbated by higher concentrations in certain settings. For Maher, this makes reducing air pollution even more necessary and urgent. We should start by taking individual action to reduce our own exposure and press for government policy and intelligently designed urban greening. This section outlines some potential solutions.

### *You cannot manage what you do not measure*

First of all, a better nanoparticle monitoring system is essential. Maher said that it was crucial to place stations around cities for measuring PM2.5 and nanoparticles, and to stop measuring PM10, in order to identify zones where it was particularly urgent to act, such as those housing the most vulnerable. These measuring stations should not only be placed by roadsides, but also in underground metro stations, given the quantity of nanoparticles deriving from train brakes and the lack of ventilation in these areas.

Since roadside particles tend to get attached to roadside leaves (see Figure 4), it is therefore possible to map roadside pollution by measuring the content and composition of particles on the leaves.

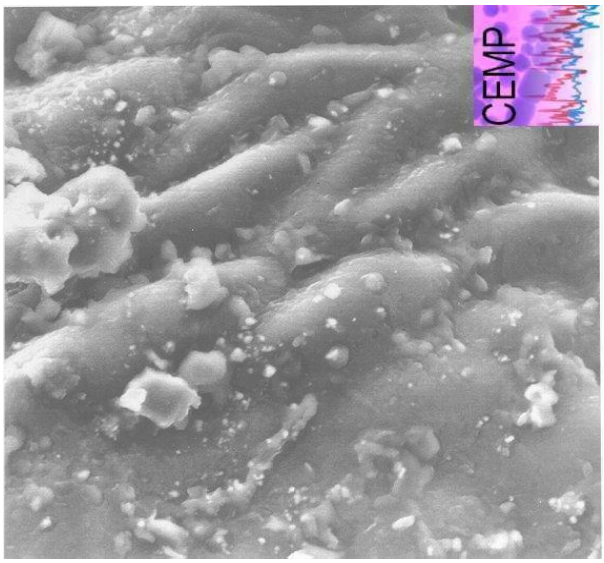



**Figure 4**: PM on roadside leaf showing particles, some originating from vehicle combustion (spherical) (retrieved from: https://www.re-city.net/admin/assets/uploads/files/e66ef-barbara-maher-ppt.pdf).

In Barcelona, Xavier Rodó, ICREA Research Professor and Head of the Climate & Health programme at ISGlobal, is developing a research project in a new air quality laboratory that will monitor the city, the AIRLAB, about the effects that anthropogenic pollution enhanced by the ongoing climate change may have on human health. Monitoring the air we breathe from a height of 15m a.s.l. they can obtain samples of air pollution (PM10, 2,5 and NPs) and analyse their composition by different techniques, such as mass spectrometry and laser fluorimetry. Figure 5 shows a clean filter sample, a sample after 8 hours of exposure and a portion of a sample obtained after 24h exposure (notice the change in colour that reflects what a person inhales during these periods of time and accumulates in the lungs).

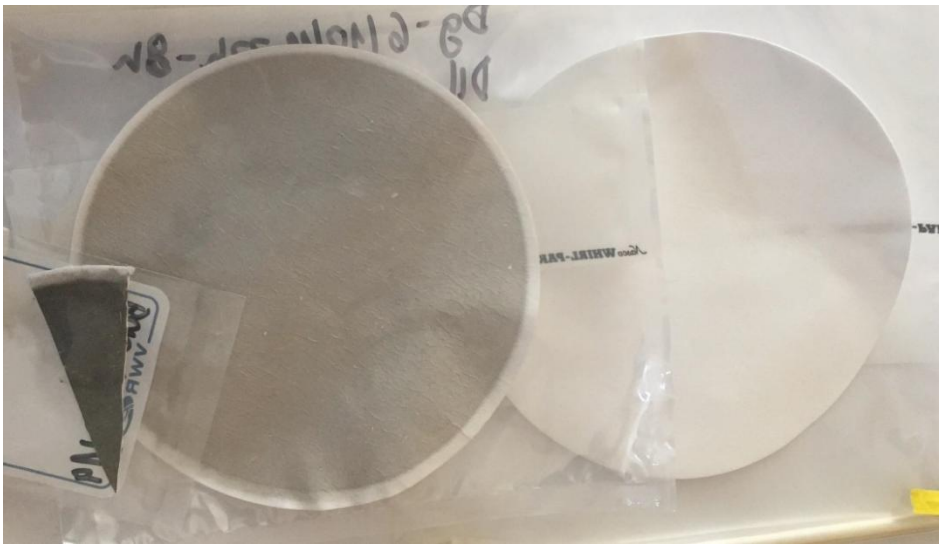


**Figure 5**: Three filters to obtain samples of air pollution. From left to right: 24h exposure, 8h exposure, clean filter sample (source: AIRLAB samples).

## *Roadside tree lines for reducing exposure to PM - The silver-birch tree experiment*

In her conference, Maher reviewed some suggestions for reducing air pollution, referring primarily to her 2013 research on the effect of roadside treelines on reducing pollution in adjacent houses. They found that TV screens at the front of the houses had higher levels of nanoparticles than those at the back, further away from the road. They also showed that the concentration of nanoparticles inside the houses with a treeline in front of them (house 31 in Figure 6) was lower than in houses without. This solution would not necessarily be an instant fix, but it could improve the situation.

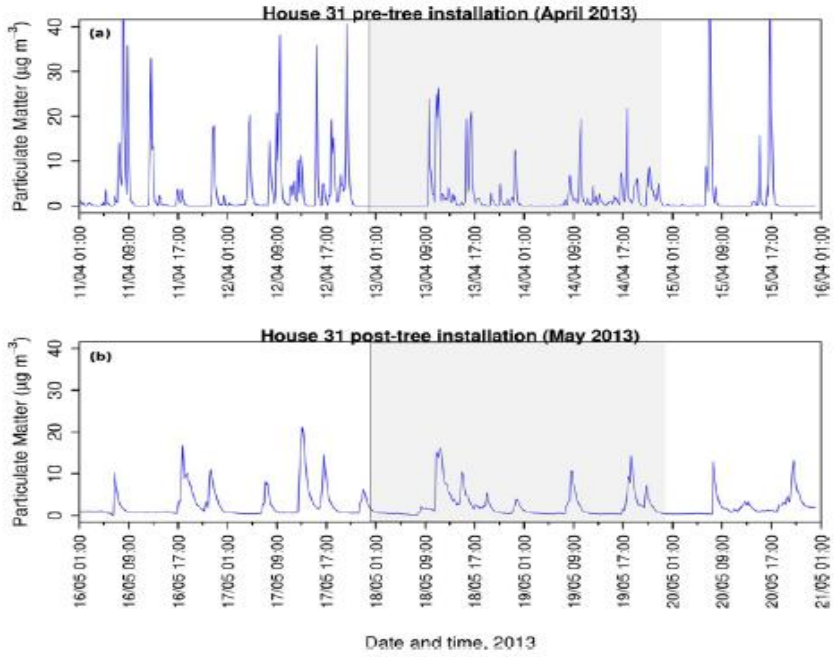



**Figure 6**: "PM10 concentrations inside house 31 during the periods (a) Apr 11−16, 2013 (pre-tree-line installation), and (b) May 16−21, 2013 (post-tree-line installation). The weekend PM10 peaks (light shading) are lower and start later in the morning than the weekday patterns. Note the reductions in PM10 after installation of the tree line" (Maher et al, 2013: p13739)

Silver birch is particularly good at blocking particles due to the presence of small hairs on its leaves to which the particles easily attach. Unfortunately, the silver birch tree has no leaves for part of the year and cannot be used widely because it produces so much pollen. While evergreens are not quite as effective, according to another study by Wang and Maher (2019), other trees have shown promise in wind tunnel tests. The wind tunnel method blows air into a tube to replicate environmental conditions, in this case air from a diesel engine exhaust to

replicate summer conditions in Lancaster. The study found that other tree species, such as the yew, elder, maple and ash, were also effective for removing ultrafine particles.

Another factor to consider when installing tree lines is the size of the tree. Tree lines must not be overly dense or tall, as they would effectively act as barriers trapping pollution in roads, rather than filtering the air. As mentioned previously, the type of tree being used is also crucial, as well as the type of road where tree lines will be most effective (in wider roads tree lines are not particularly useful), and where they are most necessary (such as in areas housing more vulnerable populations such as elderly or children). Using schools as trial grounds for planting different green barriers and testing nanoparticles in classrooms before and after installation was suggested for testing what worked best and for building awareness. Using movable trees and measuring pollution levels before and after they are installed is another good option for pilot testing the effectiveness of different tree species.

For Maher it is also important to note that installing green spaces to reduce temperatures is not the same as using green areas to reduce pollution. If temperature effects are low, but pollution reduction potential is higher, urban greening to reduce pollution should be prioritised.

### *Public transport*

In further discussions, a number of other potential solutions emerged, aside from the use of tree lines. This included reducing transport use and making sure that public transport was electric and free.

Barcelona has a large fleet of buses, so the shift into a hybrid or renewable urban transport system will help to reduce the city's carbon footprint. *Transports Metropolitans de Barcelona* (the main public transport operator in the Barcelona Metropolitan Area) has 269 hybrid buses in the urban service, which means that 25% of the fleet (1,085) is Diesel-electric or gas-electric.

### *Filters to reduce air pollution*

Other suggested solutions included placing HEPA (High Efficiency Particulate Air) filters in houses, provided they only use renewable energy. These mechanical filters can trap particles as small as 0.3 microns. However, their main limitation is that they need to be regularly replaced as they quickly become blocked (Grabianowski, 2018). Maher proposed initially placing these filters in areas hosting vulnerable populations, such as school classrooms and playgrounds.

### *Raising awareness*

Finally, Maher mentioned the importance of raising awareness for changing people's habits. Nevertheless, direct action and a top-down approach is also required, and the media needs to be far more involved. She called for greater media coverage, and the need to demand that responsibility is taken for the illnesses caused by nanoparticles. She mentioned Client Earth, an organisation based in London who use the power of the law for environmental purposes, and their recent successes in holding the UK government to account over its air pollution policy.

They recently won a legal judgment which resulted in the courts having the power to judge whether or not the government is meeting its air pollution obligations, following a ruling that the government's policy at the time was inadequate (Guardian, 2018).

In Barcelona this year, the courts accepted a lawsuit from a father-of-two against Barcelona's local government, which complained that pollution levels exceeded limits but that too little was being done to confront this. The courts asked the local government to respond and review the evidence, though the final outcome has still not been reported (Lavanguardia, 2019)

## Concluding remarks

The evidence is mounting that airborne pollution can have many adverse effects on our bodies, with the potential to gravely affect our health in the long-term. Thus, we should start by taking individual action, as well as pressing for government policy. Some potential solutions proposed by Maher were the use ofroadside tree lines for reducing exposure to PM, reducing transport use and making sure that public transport is electric and free. Efforts to reduce our exposure to pollution must therefore be urgently accelerated by local and national governments, starting with how to correctly measure the most damaging forms of PM. Barbara Maher complained about the lack of institutional support and warned of the risks of not acting. She asked governments to accelerate changes and take urgent action.

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