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Mobilising Uncertainties in Air Pollution Science in Copenhagen

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Abstract

In this short article we discuss three different ways of measuring air pollution in Copenhagen, Denmark, in relation to the potential for using technoscientific tools and expertise to influence public policymaking meant to curb pollution. Based upon a mix of data ranging from scientific literature and public reports to interviews with scientific and lay stakeholders, we outline how the introduction of Google's Project Air View, in combination with an increase in citizen engagement in air pollution, has come to play a key role in the re-invigoration of local concerns over air pollution. Previously, expertise on the city's air pollution has been the domain of established scientists operating fixed monitoring stations, but this recently stable relation between science and policy is currently being replaced by an assemblage of contrasting views on air pollutants. Our analysis suggests that the measurements of emerging pollutants by Google's project and by citizens themselves have impelled policymakers in Copenhagen to accept, to engage with and act upon new scientific uncertainties. We see this as giving rise to a degree of humility where emerging modes of knowing air pollution are treated as complementary with established ones.

Keywords

Uncertainty, air pollution, science, technology, humility

Introduction

Air pollution is frequently demonstrated to be a growing problem across the world (e.g. Fuller 2018). The reason is not only that the sources of pollution may be multiplying, but that new technoscientific ways of identifying and measuring this pollution bring awareness of new types of particles that have so far been inadequately considered for their effect on respiratory health. The most recent particle type to catch both scientific and public attention is ultrafine particles (UFPs). These particles are despite much recent research still subject to uncertainty and ongoing debates about what should be the relevant thresholds for exposure. There are limits to both what is known about air pollution, and to what is known about the effects of air pollution, which may be much worse than the existing data shows (Landrigan et al 2018). As a result of this lack of scientific certainty different international and state organisations have responded with each their own policies. The WHO has for example instead of guidelines for regulation formulated four 'good practice statements' for how to identify UFPs (World Health Organization 2021: 150). Yet as suggested by several researchers in science and technology studies, these guidelines along with recognised thresholds for exposure inform the development and deployment of the scientific gaze embodied in the concrete equipment, which measures air pollution (Iuel-Stissing et al 2020; Haarløv n.d.). Scientific findings depend on what the scientist is looking for, and how they do so.

These epistemic limitations of distinct scientific gazes raise multiple questions for the constitution of the interface between science and policy. One important question – the one we will focus on in this short article – is the role the above-mentioned uncertainties are allowed to play in this interface. To extrapolate on this question, we will focus on the way that air pollution in the city of Copenhagen, Denmark, has lately come under scrutiny by a variety of actors, including scientists, citizens, local governments and large corporations. Until recently, the measurement of the city's air pollution was virtually a monopoly held by pollution scientists from the Danish Centre for Environment and Energy at Aarhus University (DCE), who are operating a set of permanent and nationally distributed monitoring stations. These stations have provided longitudinal data on air pollution in single locations since the early 1980s. However, two new types of technoscientific input have destabilised this monopoly. The first is the advent in the 2010s of handheld particle trackers in the hands of engaged citizens performing do-it-yourself (DIY) measurements of pollution in select locations, and the second is the Project Air View (PAV) from 2018 consisting of a Google Street View Vehicle equipped with state-of-the-art particle sensors used to conduct mobile measurements of air pollution in all streets of Copenhagen. These two introductions – the DIY sensors and the PAV – have expanded and challenged what was until recently a fairly one-dimensional perspective and authority on the measurement of air pollution in Copenhagen.

In this short article, we rely upon a mix of data drawn from scientific literature, public reports and interviews[1] with scientific and lay stakeholders to present these three different technoscientific views of air pollution in Copenhagen. We conceptualise them here as joined in a single virtual assemblage of technoscientific exchange characterised by intermittent competition and – conversely – collaboration. The assemblage is a space where both authorised experts and lay non-experts have managed to carve out appropriate niches for their insights and each type of actor has become forced to acknowledge the others' presence and legitimacy, even if they sometimes are in disagreement over the weight of each others' voices and from which premises they speak. While the alternative views on air pollution in Copenhagen provided by the DIY sensors and the PAV have destabilised status quo in terms of what is legitimate scientific input to urban pollution mitigation policy, we suggest that this destabilisation has become an advantage for several of the stakeholders by providing more data and perspectives on a complicated problem forcing the established actors to provide further nuance to their analyses. Yet we also see it – with

1 Rasmus Tyge Haarløv conducted 23 semi-structured interviews with scientists, Copenhagen citizens and other stakeholders in 2021 and 2022.

inspiration from Sheila Jasanoff – as a necessary step in furthering the public acknowledgement of unknowns and 'unknown unknowns' in air pollution science (Jasanoff 2021: 29), by publicly demonstrating the limitations of the individual scientific approaches and methodologies.

As argued by Jasanoff among others, the governance structures of high modernity with their reliance on rationality and science have all too often been driven by a hubris of technocratic expertise ignoring the existence of the above-mentioned unknowns (2003: 227). To counter this, she has over the years pleaded to replace this narrow nexus of science and policy with institutional mechanisms and schemes of governance that include greater citizen participation and the incorporation of a wider range of experience and views in science-informed policymaking (Jasanoff 2021). Her pleading has included a reference to what she calls 'technologies of humility' defined not solely as material technologies, but as "methods, or better yet institutionalized habits of thought, that try to come to grips with the ragged fringes of human understanding – the unknown, the uncertain, the ambiguous, and the uncontrollable." (2003: 227). They are technologies that allow a combination of stakeholders to jointly approach the uncertainties involved in technoscientific understanding (e.g. 2003, 2018a). This has in a more recent publication turned to a call for humility more generally (i.e. without the 'technologies of') in technoscientific development and in the policymaking (2021: 12).

To achieve such humility is by no means easy, but we can take inspiration from Jasanoff's terminology both to guide us in terms of envisioning what might be the outcome of the destabilisation of scientific consensus over air pollution that we are analysing, and conversely use our case to suggest what the conditions for the emergence of humility in policymaking might look like. Concretely, we argue that the three different ways of seeing and measuring air pollution in Copenhagen provide the opportunity for decisionmaking based upon such humility, because the combination of actors in our assemblage demonstrate that none of them can provide a complete and satisfactory picture of air pollution in the city on their own. While by no means perfectly empowering or being any ‘perfect fit’ with Jasanoff’s vision (some voices still manage to speak louder than others and become associated with more authority, partly because they represent more resources), the three ways – stationary measuring stations operated and monitored by Danish scientists, citizens using hand-held particle trackers, and the specially equipped Google vehicle collecting data about particles in the city’s streets – together promote the destabilisation of technocratic hubris. The assemblage of different perspectives on air pollution has also in turn demanded responses from policymakers and regulators by producing new awareness of the uncertainties involved in assessing the consequences that transformations of urban design or transportation may have for human health at different locations. Yet, we do not want to imply that the acknowledgement of uncertainties is something new or in itself enough for humility in policy. Citizen groups have also read reports and written opinion pieces or letters to politicians before digital technologies and new technoscientific opportunities gave them the means to strengthen their argumentation and communication (e.g. Callon and Rabeharisoa 2008), and personal identification with a disease – combined with novel strategies of approaching mainstream science – was part of what enabled nonscience AIDS activists to influence official biomedical research practices in the 1980s and 1990s (Epstein 1998). In comparison, the science focused on the regulation of air pollution has yet to fully accept citizen input into its debates, although some of our interlocutors do believe that it is currently improving through the new technoscientific opportunities and partnerships.[2] Regardless, the empowerment of citizens seems clearer when its conditions are created through organised intellectual stimuli and tools for political mobilisation akin to what Jasanoff has suggested (2003, 2018a, 2018b).

2 A bigger challenge, as we see it and as indicated by Jasanoff in a recent commentary (2018b), is that government regulation – when facing uncertainties produced by science – tends to favour markets and industry over citizens. This is easily the result when critical scientific voices are destabilised by corporate science (e.g. Oreskes and Conway 2010; Kirsch 2014). We briefly return to this discussion in the conclusion, but to go in-depth with it is, however, beyond the scope of the present article.

Background: new perspectives on air pollution particles

Our own empirical attention to the implications of technoscientific understandings of air pollution for the governance of ‘air quality’ was sparked by the advent in Copenhagen of the specially equipped Google Street View Vehicle. Between November 2018 and August 2019, Copenhagen was only the second city globally to have a Google car with particle sensors drive through its streets[3].

The PAV’s official aim was to inform decisions on sustainable urban life and transport planning and was welcomed by the municipal government to help counter criticism from the EU Commission that Copenhagen did not live up to the EU regulations on nitrogen dioxide emissions. A more fine-grained mapping of air pollution scalable to the city’s street level was considered helpful to urban planning and for identifying local sources of emissions that could be reduced. To provide these data, the PAV collaborated with researchers from Denmark and the Netherlands, who helped equip the vehicle with sensors, with data collection and analysis.

This introduction of a new form of particle measurement – taking on both old and new particle types – coincided with the growing popularity of DIY particle sensors among citizen groups. While often deemed unreliable by experts, hand-held devices have nonetheless allowed citizens (as well as some think-tank employed scientists) to provide their own situated data collections to challenge scientific or political status quo (see Pritchard, Gabrys and Houston 2018; Dalsgaard, Haarløv and Bille 2021). These measurements are highly mobile and can better identify specific local sources of pollution.

The combined advent of the PAV and DIY sensors has allowed concerned actors to focus on particle types and sizes so far inadequately covered by the mainstream scientific measurements. Most importantly, these include the UFPs, defined by having an aerodynamic diameter

3 The material referred to in this and the following sections is presented and analysed in more detail in a forthcoming PhD thesis (Haarløv n.d.).

less than or equal to 0.1 µm (100nm or PM0.1). Fine particulate matter (also referred to as PM2.5 of size 2.5 µm or less) has for many years received the most attention, and these particles are associated with a wide range of diseases contributing to premature mortality (e.g. Rabl, Spadaro and Holland 2014). Long-term studies of the impact of UFPs have yet to be completed (Merrifield 2020), and the latter are currently not covered by thresholds or exposure limits, even though there is a growing consensus that they have a large potential for adverse health impacts compared to the larger sized particles (e.g. World Health Organization 2021). UFPs may be carriers of toxins and their small size and high surface-to-mass ratio allow them to penetrate deeper into the lungs and from there to other organs (see Schraufnagel 2020). Our interviews with air pollution scientists pointed out that measuring particles of this size involves several challenges. Due to their small size UFPs often behave more like gasses, and they are characterized by ongoing transformation in terms of chemical and physical properties. Different types of equipment may also have difficulties distinguishing particles which have clumped together from single, larger particles.

In summary, the two introductions – the PAV and the DIY sensors – expanded and challenged what had until then been the authority on the measurement of air pollution in Copenhagen provided by fixed monitoring stations. By empowering different actors, the new and competing perspectives on air pollution have created alternative means of defining both the quantity of air pollution and how to regard the quality of air more generally. Partly by measuring air pollution in new locations and partly be focusing on the particles that due to scientific uncertainties have yet to be politically regulated. Below, we briefly outline the main scientific way of measuring air pollution, and we offer more details about the two new alternatives. We do this to accentuate what the uncertainties about UFPs (and thus indirectly air pollution itself) stem from, and how the perspectives highlight these uncertainties through their differences.

Stationary measurements and modelling

The measurement standard, which the two new modes of measuring air pollution have been supplementing, revolves around a number of fixed monitoring stations that are both scientifically and politically endorsed. Researchers from the DCE have for more than 30 years been responsible for monitoring air pollution in Denmark in collaboration with the Danish Environmental Protection Agency among others. They collect data from 20+ stationary sensors across the country. Three of these are situated in Copenhagen, where the most important one since 1983 has been located outside the City Hall at the heavily trafficked main Copenhagen thoroughfare, H.C. Andersen's Boulevard (HCAB). The different air pollutants recorded include, but are not limited to nitrogen oxides, ozone, carbon monoxide, sulphur dioxide, and different particles sized PM10 and PM2.5.[4] The fixed monitoring stations thus measure a greater number of pollutants than the PAV and the handheld devices, and they do so in different ways.

The strength of stationary measurements like the one at HCAB has been consistency allowing for a view of air pollution over time (apart from a debate over its exact location in relation to traffic when for example the closest traffic lane was converted from a bus lane into a regular traffic lane). Yet the spatial representativity of its measurements have been debated and are by some (Ellermann 2014) seen as questionable due to the lack of precise siting criteria. Due to its location, the data from this station may say little about the severity of air pollution in other streets or even in different segments of the same street. To make up for this, the DCE deploys modelling, which can consider different factors affecting particle counts such as wind and temperatures and is capable of making predictions.[5]

In summary, the main concerns with the stationary measurements have been their representativity – both with regards to the types of

4 The measurements for each can be accessed through charts and diagrams on the DCE website (DCE 2022).

5 See DCE 2022.

pollutants covered by stations, and their location. This is where the two recent types of measurement come in. Apart from being more focused and mobile, the PAV and the handheld devices address particle types previously invisible to policymakers. What we find important, however, is not so much which type of measurement covers the most, or is the most accurate, but that there is an emerging intellectual dynamic – a process of institutionalizing the scientific processes necessary for humility – within the assemblage of different perspectives. There is a high temporal and spatial variability in air pollution, which increases with decreasing particle size (see Kumar et al 2014), and this variability is part of the existing scientific uncertainty, which has been underscored by the PAV and the DIY sensors. We will therefore present in more detail how the other two perspectives contrast with or supplement the stationary measurements, but also how they have engaged with and responded to each other.

Citizens counting particles

Citizens who are concerned with environmental issues can take part in local environmental committees known as 'Miljøpunkter' ('Environmental Points') for Copenhagen neighbourhoods. One of the objectives of these committees is to promote the consideration of environmental concerns and sustainable developments in the city.

Our example here comes from the committee representing citizens in the City Centre. Over a period of a few years, members of this committee conducted measurements of UFPs firstly near the kindergartens of the neighbourhood, and then in collaboration with members of the committee of the suburb Nørrebro they sampled UFP measurements with a particle tracking device near bus stops of bus route 5A, one of the busiest bus lines in Scandinavia with 20 million annual passengers (2014). For this they used a P-TRAK Ultrafine Particle Counter, which measures particles ranging from 0.02 μm in size to 1 μm (20 nm to 1,000 nm). The P-TRAK device is rather expensive (more than US$8,000), but it is recognized by some air pollution scientists as much more reliable than cheaper DIY trackers. For the measurements along the bus route, the settings of the device were set to measure average concentration values for UFP in intervals of one minute. The result of the efforts was a report published in 2016 (Miljøpunkt Indre By og Christianshavn 2016).[6] Among its findings were the identification of huge fluctuations between background and peak concentrations of UFPs. Bus stops were sites with extreme concentrations (some busses emitted more particles than the device could handle), and generally there was an eightfold drop in numbers from weekday rush hours to a car free Sunday (measured when large parts of Copenhagen were fenced off due to a local marathon). There was also a distinct difference between windy and calm days. The authors interpreted their overall findings to mean that traffic was by far the largest contributor to particle emissions, and the emissions along bus routes – frequently running next to bicycle lanes and pavements – were seen as a severe health hazard.

Apart from putting UFPs on the agenda, the report also further nuanced what was known about the fluctuations of particles across time as well as space. The report, acknowledged by scientists as an important input (Bredsdorff 2016), allegedly became a strong argument forcing the company responsible for municipal bus routes to invest in busses powered by natural gas – allegedly with lower emissions (Miljøpunkt Nørrebro 2022). In this way the citizen-driven counting of particles came to affect both science and corporate decisions affecting the urban environment. In May 2019, Danish Parliament furthermore passed regulation demanding particle filters on heavy vehicles in Copenhagen, a policy which the environmental committees may be partly responsible for pushing with their report (Miljøministeriet 2020).

In summary, apart from the novelty of focusing on the local distributions of UFPs as a source of pollution these measurements were characterised by flexibility – combining mobility (being free to move to locations with a suspected large source or concentration of emissions) with the option of being stationary albeit for shorter periods.

6 A later report by the environmental committees of Nørrebro and Bispebjerg confirmed their findings (Jensen, Knudsen and Hansen 2018).

They were on the other hand limited by their lack of scalability over time as well as space and thus how well their measurements could be compared to other periods, locations and types of particles. No matter what, the DIY measurements claim superiority in regard to location by allowing measurements where people actually are, and where they breathe the air unfiltered.

Google's Project Air View

The background for Google's PAV has been outlined briefly above. In line with the DIY measurements, the PAV also expanded the range of particles under scrutiny by focusing on UFPs, black carbon (soot) and NO2. These substances were shown on the PAV website thus mapping other particles than those covered by the stationary monitoring. The PAV vehicle drove regularly through Copenhagen during daytime hours over a period of 16 months.[7] The average street-by-street measurements are today presented on a map on a website, where streets are coloured according to the severity of the pollution (Google Environmental Insights Explorer 2022, see also Kerckhoffs et al 2022). Like the DIY measurements, the PAV showed that local variations in concentrations could be as much as eightfold within and between streets.

The advantage of the PAV was its ability to meet the challenges of scale by providing what Google itself referred to as 'hyperlocal' air pollution data insights, but – like the DIY measurements – the PAV did not provide the long-term or frequent measurements given by stationary stability. Multiple additional challenges have been mentioned by our interlocutors. For the PAV vehicle to drive through a road segment could be a matter of a limited number of seconds (Kerckhoffs et al 2022: 7174). Such short time intervals would mean that the simultaneous presence of a truck or bus would skew the data, and for example UFPs would be difficult to capture accurately partly due to their volatility and partly due to "the high variance (noise) in mobile measurements for specific locations" (Kerckhoffs et al 2022: 7180). In addition, larger roads would be covered multiple times, whereas smaller road segments would perhaps only be traversed a few times resulting in thin data sets. It also was not clear how the data would be affected by the movement (stops, starts, waits, vibrations) of the vehicle itself (see Kerckhoffs 2021). Another concern was that data were collected in the middle of the road as compared to the location of stationary measurements at the side of the road or at the façades of buildings (Kerckhoffs et al 2022: 7181). Finally, the particles measured by the Google vehicle did not strictly adhere to the standard particle size range of UFPs making it difficult to compare with other measurements or to integrate the PAV findings with other scientific observations (Ellermann et al 2021). Nonetheless, some of the scientists working with the PAV data have recently argued for the benefits of using a mixed modelling framework integrating PAV data collected over time with land-use regression models focused on developing maps of particle concentrations (Kerckhoffs et al 2022).

As a summary, the PAV re-invigorated public attention to air pollution partly because of the media interest in the contribution that a Big Tech company could give to this field, but also partly because it added new and so far unconsidered perspectives to where air pollution could be found and which types of particles it consisted of. The PAV data sets were not easy to integrate with other scientific measurements, but they still came to be an important supplement for citizen groups and decisionmakers.

Changes and challenges to air particles as technoscientific objects

The deployment of such different modes of measuring air pollution hints at two of the big and unresolved questions in contemporary air pollution science. The first question is how what constitutes 'a particle' as pollutant, and how these particles as indicators of pollution should be measured. The second question is the extent of the adverse health

7 The PAV's own methodology is described in several publications (e.g. Apte et al 2017).

effects caused by particle pollution.

Taking the first question, our interviews with scientists indicated that scientific uncertainty over the impacts of air pollution will remain until UFPs (but also other 'new' particles such as black carbon) are studied further. The current challenges in measuring UFPs include a) that much equipment only goes down to 30 nm (many particles are smaller than that), b) that equipment cannot distinguish single particles from multiple particles 'glued' together, and c) that UFPs display a frequently changing behaviour as either particles or as gas (including swiftly changing status from gas to particle or to be deposited on surfaces). In addition, the three modes of measuring air pollution outlined above base their measurements on different tools aiming at different scales and temporalities. The changing circumstances afford sometimes contrasting perspectives on where and how particles exist, and thus how to characterise air pollution. Some measurements take place over short (but meaningful) intervals, while others take place over years in one location. The particles themselves can be scaled differently in terms of how they 'behave' in the air, how they travel, and when they are present. Some types of particles (PM2.5) appear to be constantly present as background pollution while others (UFPs) appear mostly at peak times, because they settle quickly or are carried away by winds. The challenge is that the different technoscientific tools deployed to count particles – and the particle counts themselves – are by some scientists then sometimes regarded as incommensurable rather than complementary. The different tools focus on different size ranges and the different measurements are difficult to integrate both in analysis and in regulation.

Regarding the second question, it is still unclear whether UFPs and other new pollutants (e.g. black carbon) are for example more damaging for the human respiratory system than the more well-studied particle fraction PM2.5. The above-mentioned uncertainties pertaining to data on particle types, presence and behaviour contribute to the uncertainty over their impact on human health, because the 'translation' or the affordance that different particles and the equipment that can measure them provide, varies across the different modes of measurement. According to a study in The Lancet (Landrigan et al 2018) an estimated 9 million people worldwide die prematurely due to air pollution every year. But this calculation of disability-adjusted-life-years (DALYs) or lost years of life depends upon a lot of assumptions, for example that the different particle substances are equally damaging. It is easier to see how the numbers – the calculations but also the measurements themselves – raise awareness or are used for political mobilisation despite (or perhaps because of) uncertainties. When it comes to policymaking, it is interesting that there are still no threshold limits for UFPs, nor are their potential health effects acknowledged in national regulations of neither industry nor traffic (see World Health Organization 2021; Merrifield 2022). Scientific uncertainties and their associated effects are often hidden in public or political communications of science whether it be scientific policy reports or debates in public media. Yet by bringing these fundamental uncertainties out into the open, the assemblage of different but potentially complementary views enables a heterogeneous range of actors to be included in the debates. Alas, some citizen groups may be empowered by new technoscientific tools and the results they generate to stress new uncertainties (see Dalsgaard, Haarløv and Bille 2021). These uncertainties can be mobilised politically for cleaner environments or in protests against specific industry or traffic initiatives, but they may also nudge people to make 'simpler' changes in their own lives such as shifting to electric vehicles.

In other words, the study of airborne particles in general, and of UFPs in particular, exemplifies the limits as well as uncertainties that research instruments and research settings play in technoscientific knowledge production, but also what political conclusions can be drawn from them. These uncertainties are currently mobilised by Copenhagen citizens to demand what in Jasanoff's terminology might count as (technological) humility by local companies and the municipal government in order not to exacerbate potential problems of air pollution. Yet, whether the destabilisation of scientific knowledge is sufficient for citizens to achieve their desired political effect is another question.

Conclusion

Returning to the concept of humility we can ask more directly what the implications for a governance or a politics of air pollution might be when three so different perspectives interact or are contrasted to each other. We have argued that the uncertainty generated by this assemblage has the potential to mobilise or empower actors, but whether this constructive disagreement gives sufficient space for policies driven by humility depends on other factors too, which become clear if we expand the scope to see how different citizen mobilisations have fared in Copenhagen.

The citizens of Copenhagen are already engaged in the management of urban air pollution. Thanks to a combination of municipal resources and citizen engagement, the public has the means to voice but also investigate their concerns. They have DIY tools of sufficient scientific quality, and there is a concentrated intellectual environment interested in dialogue with them (see Bredsdorff 2016). Copenhagen Municipality is in this way at the forefront of challenging established ways in which science is expected to inform policy based upon a consensus about its methods and conclusions. The relationships developed within this 'ecosystem' of engaged and technoscientifically informed publics has already had a direct albeit limited impact on the municipal administration of urban traffic (see Miljøpunkt Nørrebro 2022). However, similarly informed groups still face struggles, when their input is seen as a threat to jobs in industry. As mentioned above, the group "CPH Uden Udvidelse" (CPH Without Expansion) has deployed the findings of the Google PAV to criticise the measurements made by the Copenhagen Airport's own experts. They have argued that the latter measurements do not take into account peaks in emissions or how neighbours to the Airport experience the quality of the air, which they find to have been deteriorating in the years before COVID-19 put a temporary halt to the Airport's expansion plans. So far, their protests have been in vain, and the citizens in question often feel forgotten or ignored by politicians and industry (Bach 2021, see also Dalsgaard, Haarløv and Bille 2021). On a more optimistic note, another local environmental committee (Miljøpunkt Amager) used the PAV results to establish a collaboration with architects to experiment with urban interventions such as pollution buffers, fences and plastic domes. These infrastructures had the potential to limit air pollution exposure in selected locations such as near schools or at bus stops. While trees, hedges and other forms of 'green infrastructure' are broadly recognised as reducing air pollutants (Barwise and Kumar 2020), such limited engagements are easier to pursue because they act on symptoms (air quality) rather than causes (sources of emissions).

These responses to air pollution are interesting for the way that they are informed – or not – by the various measurements of pollutants. It is easy to speculate that the uncertainty generated by the differing measurements has been acceptable as a driver of policy in Copenhagen under the circumstances where it did not involve large costs for industry or where those extra costs could be converted to a long-term gain. The bus company could for example redefine their investment in new vehicles as a modernisation of its fleets, which would institute cheaper operating costs in the long run, whereas the Airport conversely has not wanted to abandon its ambitions of expansion. It is not the first time that the co-existence of different scientific approaches and uncertainties allows for 'counter-measurements' conducted by industry actors and the deployment of corporate science associated with sources of pollution (see Kirsch 2014). Informing policy is not the only purpose or benefit, though, of air pollution measurements. Educating or empowering the public for their own sake could be another. However, for citizens to be empowered in this way takes more than a website or an app that tells people the quality of today's air in a colour spectrum from green to red.[8] As mentioned in the introduction, citizen empowerment seems clearer, though, when it is facilitated by organised stimuli and tools for mobilisation as Jasanoff has proposed in her work. A step in the right direction has been Copenhagen's funding of municipal environmental

8 This is the frequent format for presenting information about air 'quality' publicly.

committees allowing both equipment (P-TRAK devices) and websites where citizen science results have been made public. This has spurned dialogue with more resourceful scientific actors (Google as well as established scientists).

Public engagement with measurements of air pollution in Copenhagen has come a long way since fixed monitoring stations began to measure classical pollutants in the 1980s. Yet whilst the inputs from the fixed stations have become insufficient for concerned citizens, the measurement of 'new' pollutants by the PAV and the citizens themselves has spurned policymakers in Copenhagen to embrace a willingness to engage with and act upon new scientific uncertainties. They have thus begun to demonstrate a measure of humility by complementing established modes of knowing air pollution with emerging ones.

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