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Fine Particles: From Scientific Uncertainty to Policy Strategy

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Gaps in our knowledge should not be a reason for not making policy decisions. How can we define robust policy strategies, given the various uncertainties in the sources, exposure, and causes of health effects? Which uncertainties are most important? What are its policy implications? This contribution will describe policy strategies for particulate matter (PM) abatement that are consistent with certain sets of assumptions, as well as the risks that are associated with such strategies. What is an optimal strategy assuming that the fine particles ($PM_{2.5}$) are the main cause of health effects? And what would be the "mistake" of such a strategy, if "in the end" PM_{10} or carbonaceous particles prove to be the "real" cause? How can we make the policy strategy more robust and minimise its financial risks and health risks? This contribution describes a systematic way of dealing with the knowledge gaps in the policy process.

UNCERTAINTY AND INCERTITUDE

Within the source–effect chain of particulate matter (PM) one can find large uncertainties almost everywhere. Emission data are not very reliable, if compared with, for instance, SO_2 or CO_2. Emission data for PM_{10} and $PM_{2.5}$ seem to be incomplete. Currently we can only partly explain the background concentrations from these primary emissions and from the production of secondary particles in the atmosphere. Anthropogenic PM emissions might be underestimated—for example, the emissions from wood burning, from the aberration of tires and brakes, or from the resuspension of particles. Moreover, a substantial amount of the primary and secondary natural emissions is not taken into account (such as Sahara dust and biogenic organic particles), and the transcontinental influx might be underestimated. We can explain the formation of secondary inorganic particles from SO_2, NO_x, and NH_3 emissions relatively well, but our understanding of the secondary organic particles is still poor. We also know little about the water content of particles. Furthermore, large-scale models can only partly estimate the actual exposure of the population in the streets and in buildings.

All the uncertainties just mentioned seem to be mainly caused by the lack of (reliable) data and can basically be solved by better measurements. With statistical techniques (such as error propagation) we can estimate the likelihood that an abatement measure will reduce human exposure based on our estimates of the uncertainty margins in the input data.

However, the biggest challenge in the PM case is our lack of knowledge about the fraction that is really causing the problem. Or is it too much knowledge, because there are several "competing" theories to frame the problem? This incertitude cannot be treated in the same way as the uncertainties already mentioned (Hisschemöller & Hoppe, 1996; Van der Sluijs et al., 2003; Maas, 2003). We cannot attach a probability to either one of the other theories, and as long as one of these theories is not falsified, there remains a fair chance that such a theory might be correct. The real challenge in the PM debate is to acknowledge that there is not just one best theory, but that there are several ways to describe "reality," and to deal with this incertitude in the policy process.

CHANGING REALITIES

If we look back and see how the science has developed over the past decade, we can conclude that some modesty about our current knowledge is appropriate. In the 1950s we thought that black smoke was causing lung diseases and we reduced its emissions by over 80%. In the 1970s it was sulfur, which by now is also reduced by more than 80%. In the 1990s PM_{10} was identified as the cause. Current policies aim at a reduction of PM_{10} by more than 80% in the European Union (EU). But still, if we look at health indicators like lung cancer and prevalence of chronic obstructive pulmonary disease (COPD) we do not see much change. Other determinants like "lifestyle" seem to be more dominant than air pollution (Murray & Lopez, 1996). In the past decades in the Netherlands, for example, lung cancer and COPD per 1000 women increased due to an increase in smoking (National Compass Public Health, 2005). A much closer look into the available epidemiological data

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is required to detect an association between PM exposure and health. Currently—based on American studies (e.g., Pope et al., 2002)—the association between $PM_{2.5}$ exposure and health seems to be stronger than between PM_{10} and health, and although an effect of PM_{10} is not completely ruled out, $PM_{2.5}$ seems to replace PM_{10} as the focus of the policymakers' attention (Mechler et al., 2002). In Europe this finding is not yet confirmed. $PM_{2.5}$ and PM_{10} are part of the conventional theory, although toxicological explanations behind its damaging effects are hypothetical (Buringh & Opperhuizen, 2002a, 2002b).

Relatively few epidemiological research funds are focused on the alternative views that, for instance, specific PM compounds such as carbonaceous particles (organic carbon, elementary carbon, polyaromatic hydrocarbons [PAH]) could be causing the problem (WHO, 2004; Kameda et al., 2005), or certain heavy metals, or the ultrafine particles. Incidentally, for some of those PM species, more toxicological evidence is available than for $PM_{2.5}$ or PM_{10}! So the PM_x case cannot be excluded either. Moreover, strong associations can also be found between cardiopulmonary diseases and, for instance, traffic noise (Kempen et al., 2002), the quality of housing, and the diet of low-income families (Eschenroeder & Norris, 2003). It cannot be ruled out that health effects are caused by an accumulation of sources in low-income neighborhoods close to highways, of which PM exposure and NO_2 exposure are only a minor part.

Do we know for sure that $PM_{2.5}$ is the final answer? Science should not suggest more certainty by selecting only one of the possible explanations, despite the fact that correlations show that such a theory is (a bit) more likely. If scientists cannot falsify a competing theory, policymakers have a problem. They have to deal with the possibility that one of the theories is correct, but they cannot know which one (Jasanoff, 1990; Slovic, 1999)—at least, not before, say, 2010 or 2020. They could of course gamble on one theory, but this might be a waste of money (despite the advanced monetarized benefit estimates that go with the theory). How can policymakers minimize the risk of wasting money? How can they minimize health risks? Incertitude is no reason for political lethargy! Especially not as the health effects that occur are real.

DIFFERENT REALITIES REQUIRE DIFFERENT POLICY STRATEGIES

For the remainder of this analysis I distinguish four "stylized" ways to define the PM problem or four different perspectives on how reality works. The four theoretical "families" are:

- "$PM_{2.5}$"—Focus on transboundary air pollution and secondary inorganic particles.
- "PM_{10}"—A large part will be $PM_{2.5}$ but also the abatement of primary emissions of coarse particles becomes part of the strategy.
- "PM_x"—Focus on the traffic related carbonaceous particles and ultrafines.
- "No PM"—Focus on living conditions in low-income neighborhoods.

Each perspective has its own policy strategy (see Table 1).

TABLE 1
Alternative Policy Strategies and Approaches

Strategy	Policy approach
Strategy 1: $PM_{2.5}$ is the problem	Focus on secondary particles from SO_2. NO_x, NH_3, VOC and on primary $PM_{2.5}$. Define cost-optimized national emission ceilings for these substances. Take into account the synergy with ozone and NO_2 exposure and the acidification and eutrophication problem.
Strategy 2: PM_{10} is the problem	Focus on cost-effective measures for primary PM sources that contribute most to local exposure, e.g., dust from building industry, cement, wood burning. A transboundary strategy is less important, only EU harmonization of technical standards in order to prevent "false" competition at the expense of the health of the local citizens.
Strategy 3: Specific traffic-related species are the problem (PM_x)	Apply stricter international standards for vehicles, ships, and refineries (focused on elemental and organic carbon [EC/OC], heavy metals, and primary ultrafines), substitute diesel in captive fleets of urban areas by zero-emission vehicles, close densely populated streets for heavy traffic, encourage the use of public transport.
Strategy 4: It is mainly a socio economic problem (no PM)	Improve living conditions and economic opportunities in poor neighborhoods (prevent further segregation), circulate heavy traffic around (or under) those neighborhoods. Design neighborhoods in such a way that car traffic is minimized. Only reduce those air pollutants that also cause other problems, like acidification, eutrophication, and ozone formation.

IN SEARCH OF ROBUSTNESS

If we look at the different strategies, it seems hard to find a way out of the policy dilemma. But there is some light at end of the tunnel, as one can identify:

1. Measures that are *"no-regret,"* that is, relatively cheap measures that the can be part of each strategy (although they are not always the most effective option).
2. Measures with large *cobenefits* for other environmental or health-related problems.
3. Potential *"regret"* measures, that is, measures that can worsen the problem if seen from another perspective, such as when a trade-off exists between different species of PM, or between other policy fields and the PM problem.

Measures that are good from all perspectives are, for instance, measures to reduce car traffic in living areas, either via traffic circulation schemes, the design of communities, or the stimulation of public transport. Further measures like cleaner fuels and improvement of energy efficiency are cost-effective and robust, as well as a ban on tobacco, wood burning, and barbecues. Some of these measures are cost-effective but limit the freedom of individual and might thus raise political resistance.

Measures with high cobenefits are, for instance, the reduction of carbonaceous particles, because they also contribute to the greenhouse effect. In addition, the reduction of secondary particles (via further reduction of SO_2, NH_3, NO_x, and VOC) entails cobenefits because this reduces acidification, eutrophication, ozone formation, and NO_2 exposure.

All particle abatement measures contribute to improvement of the visibility, but it remains unclear how much this cobenefit is worth in the European policy arena.

"Trade-off" measures that are good from one perspective but bad from another perspective are, for instance, technical PM measures that increase the emissions of ultrafine particles. There are also measures that are part of the greenhouse strategy that would be deleterious for PM exposure, such as a shift from petrol to diesel, or the promotion of biomass and waste burning (if not accompanied by strict emission standards).

After scrutinizing the different measures that can be part of a robust strategy, still a number of measures will remain that are really gambles. For these measures, the policymaker has two options: (1) Don't select them and take the risk that harmful health effects will remain to occur, or (2) select them (all) and take the risk of wasting money.

For these measures, science can help to quantify the risks in terms of health and money by applying a so-called paradox approach: First select those measures that are part of the optimal solution within a certain perspective (so-called utopian worlds), but then look at the effectiveness of such measures when applied in another perspective (the so-called dystopian worlds). With the confrontation of perspectives, the maximum mistake can be quantified, and this might help the policymaker in finding the right balance between environmental and economic precaution (see Figure 1).

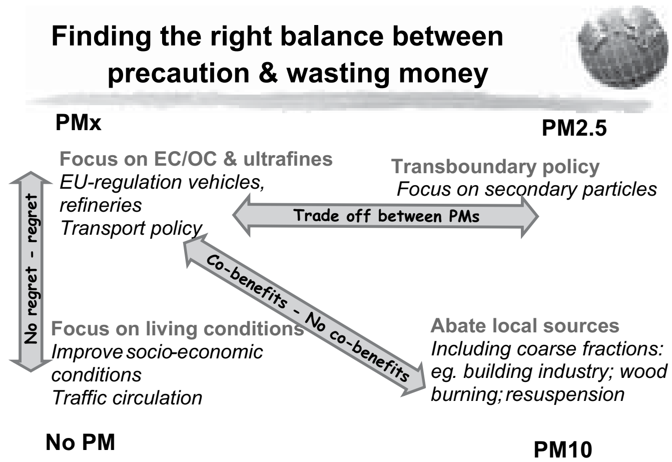

FIG. 1. Finding the right balance between precaution and wasting money.

In order to minimize possible mistakes, politicians can combine different strategies and not base their decisions on one theory alone. However, in the end they have to decide whether they want to be on the safe side and against what price.

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