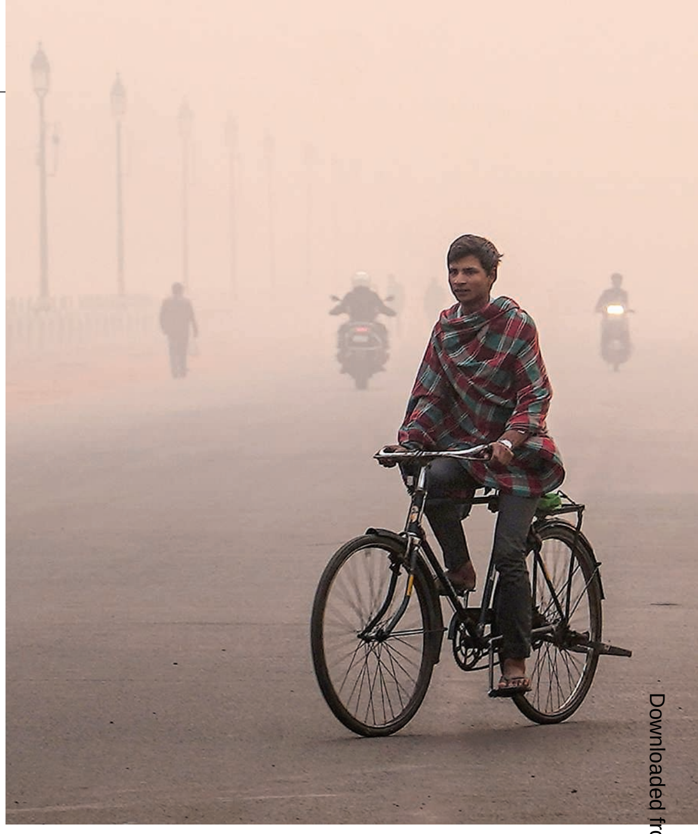

AIR QUALITY

Keeping air pollution policies on track

Focusing on trends rather than compliance can lead to more effective policies

By **Gary W. Fuller** and **Anna Font**

Around the world, thousands of instruments are measuring air pollution. The World Air Quality website (*1*) provides near-real time air pollution data from stations across North America, Europe, and through the Middle East to Southeast Asia and across Australia and New Zealand. Occasionally, one of these data points leaps into the news. Beijing frequently made the headlines in the early part of this decade but, for the past 2 years, Delhi has started to dominate newspaper reports as crop burning in the surrounding area adds to the city's considerable air pollution woes. Like many cities, Delhi now faces huge challenges to reverse its deteriorating air pollution. Most air pollution policies focus on compliance with specific pollution limits, but progress has often been slow. More effective progress may be achieved by focusing on the rate of change.

Measurements from air quality monitoring stations are often used for public information, but their main purpose is to determine compliance with legal limits. However, a focus on attaining regulatory thresholds can lead to isolated actions in the worst affected places and can incentivize polluting up to the threshold in compliant areas. With little or no evidence of zero-effect thresholds for air pollutants (*2*), it would be better to focus on reducing concentrations and exposure across the whole population. Switching the emphasis to trends and rates of change, rather than compliance, would provide a transparent connection between policy measures and outcomes. For instance, China is a long way from meeting the World Health Organization (WHO) guidelines for $PM_{2.5}$ (atmospheric particulate matter with a diameter of less than 2.5 μm), but major investments in air pollution controls that focused on targets for improvement, rather than attaining limits, have led to reductions in $PM_{2.5}$ concentrations across 74 Chinese cities by 33% between 2013 and 2017 (*3*).

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The need for this change in emphasis, and feedback into policy, was strikingly illustrated by the recent diesel car emissions scandal, where car manufacturers produced vehicles that passed regulatory tests but produced much more pollution when used on the roads. In Europe, where policies had favored diesel vehicles since the mid-1990s, this led to upward trends in ambient nitrogen dioxide (NO_2) concentrations, in contrast to projections of falling concentrations based on ever tighter exhaust emission standards. This divergence between policy and reality was plain to see prior to 2010, when air quality limit values came into force. It was extensively reported in the scientific literature (*4*), but feedback mechanisms between research and policy were insufficient for these warnings to affect the policy process. Consequently, almost a decade after the required date, most European countries have yet to meet legal limits for NO_2 (*5*).

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FOCUSING ON TRENDS

Reframing air pollution measurement in terms of assessing trends takes us back to the purpose of the world's first air pollution measurement network. This was set up in the United Kingdom in 1912 to track air pollution changes in a time before legal standards for ambient air pollution were conceived. In 1936, John Switzer Owens, the superintendent for observations, quantified changes in urban air pollution from 25 years of smoke abatement (*6*). His data showed that policies were not being successful everywhere and provided vital information for campaigners to apply pressure to underperforming city authorities. Unfortunately, the second world war began before the impacts could be seen.

More recently, trend analysis has been used to look at the effectiveness of air quality management, and a small number of studies have linked policies that changed an air polluting activity all the way through to changes in health. In Dublin, Ireland, the 1990 ban on bituminous coal sales reduced wintertime black smoke by 70% and decreased respiratory deaths by 15% (about 116 people per year) (*7*). In Launceston, Tasmania, the replacement of wood stoves with electric heating reduced the number of homes using wood as their primary heating from 66 to 30%, decreased winter $PM_{2.5}$ by 39%, and lowered male mortality rates by 11%, with a similar but not statistically significant decrease in female mortality (*8*).

Despite these positive results, the studies also revealed many confounders and difficulties with what initially appears to be a simple idea of focusing on trends in air pollution rather than legal compliance as an indicator of policy effectiveness.

THE WEATHER PROBLEM

The first and foremost confounder is the weather, which creates short-term variation in air pollution concentrations that are often greater than the impacts of a policy intervention. This problem is typically overcome by analyzing several years of data, along with adjustment for seasonality, but the need for long-term data results in delays in the policy feedback process.

Instead, new methods focus on predictive statistical approaches to remove the influence of the weather variability from datasets allowing step changes to be quickly detected. Random forest models (a form of decision trees) are the most practical available method. They use meteorological measurements as inputs and offer a substantial

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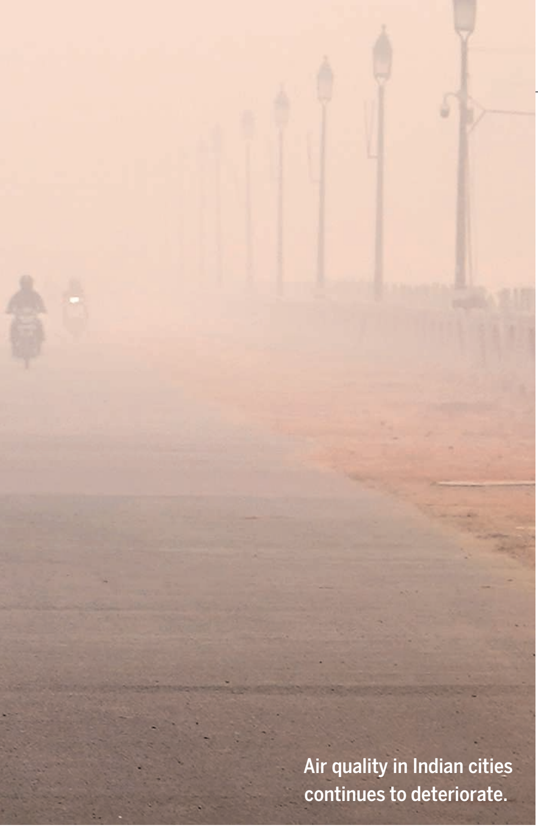

Air quality in Indian cities continues to deteriorate.

advantage over neural network methods because they are not simply a black box; instead, the relationships between predictor variables and the outcome can be inspected and interpreted (*9*).

THE SPATIAL PROBLEM

Many policies such as tightening exhaust emissions standards or low emission zones act over a wide area, and trends must therefore be summarized over many monitoring stations. Typically, this is done through simple averaging, but such an approach risks the loss of important data on the heterogeneity of policy responses, as first highlighted by Owens (*6*). Colette *et al.* (*10*) provided one possible solution by calculating trends in air pollutants in Europe as probability density functions, which summarize the overall trend distribution. The results showed that existing air pollution policies were not working everywhere.

Other studies have borrowed techniques used in meta-analyses of epidemiological studies to summarize not only the heterogeneity in trends but also the uncertainty in these trends. When applied to measurements from Paris and London for 2010 to 2017, this approach revealed that the policies used to control air pollution from traffic were not effective everywhere (*11*). For example, NO_2 concentrations from traffic were increasing alongside some of London's roads despite Europe-wide initiatives on exhaust controls and the tightening of city's low emission zone in 2012. Tighter emission standards on lorries and buses from 2010 onward were lowering NO_2 concentrations and filters on diesel vehicles were reducing overall particle pollution, but this was not happening everywhere. Trend analysis suggested that it would take London 193 years to meet legal limits at current rates of progress. More effective policies such as the new Ultra Low Emission Zone are clearly needed.

THE DATA COVERAGE PROBLEM

Further difficulties arise from changes in measurement infrastructure. With a focus on determining compliance, measurement networks are often in a state of near-continuous change. Stations in compliant areas tend to be closed and new ones opened in areas of suspected high concentrations. This preferential sampling leads to biases in any network average or trend (*12*) and a lack of long-term measurements. Despite the importance of NO_2 measurements for legal compliance, just eight urban areas in the United Kingdom had consistent roadside measurements of NO_2 between 2000 and 2017 (*13*), severely limiting opportunities for trend analysis and policy feedback.

However, this is largely a problem of the developed world. In many other places it is not changes in network design that confound analysis, but an absence of measurement stations. In 2015, the whole of Africa had just 15 monitoring stations; the city of Paris had more than three times as many (*4*). This is a big challenge.

One potential solution to address this coverage problem is satellite remote sensing. Although satellites cannot resolve the range of street-by-street exposure environments that prevail in cities, they can still provide important policy feedback. Krotov *et al.* (*14*) used 10 years of data from NASA's Aura satellite to highlight the successful reductions in NO_2 and sulfur dioxide (SO_2) concentrations across China, especially since 2012. However, they found that SO_2 concentrations more than doubled across India from 2005 to 2015 and NO_2 increased by 50%, as a result of new coal-fired power plants that operate without the types of abatement that are mandatory across Europe, the United States, and China. Satellite data could also provide a consistent method for global studies of air pollution exposure, rather than reliance on experimental design that can vary between localized studies.

FUTURE POLICIES BASED ON TRENDS

In addition to more air pollution measurements, incorporating a trends perspective and a feedback framework in air pollution management requires further steps. The first would be a legal imperative to take action even when limits are met. This requirement already exists in Canada, where continuous air quality improvement is mandated, and compliant areas are required to ensure that their air quality continues to improve. Similarly, European Union (EU) directive 2008/50/EC includes a target for reducing $PM_{2.5}$ concentrations over a 10-year period. The reduction target for each country depends on the mean national concentration in 2010, but does not carry legal force. Additionally, the use of a national average in the EU directive does not guarantee improvements for everyone; deterioration in one area can be offset by gains elsewhere.

Achieving better feedback for policy appraisal also requires a forensic approach to air pollution measurements. This would involve redesigning measurement networks to focus on sources, investment in long-term datasets, and ongoing analysis to determine rates of change rather than the simple reporting of compliance. An agile approach is also required from policy makers to take potentially unpopular decisions to strengthen actions if policies are not having the desired outcome. A similar approach has already been adopted in the United Kingdom for greenhouse gas emissions. Here, an independent committee monitors progress and sets reduction rates and timetables that must be met through policy.

With an estimated 4.9 million deaths annually as a result of air pollution (*15*), the global impacts of air pollution demand urgent action. In tandem with taking action to control sources, policy makers must make better use of air pollution measurements and develop feedback loops to ensure that policies remain on track and bring health benefits for everyone. ■

REFERENCES AND NOTES

1. https://waqi.info/
2. Q. Di *et al.*, *N. Engl. J. Med.* **376**, 2513 (2017).
3. J. Huang, X. Pan, X. Guo, G. Li, *Lancet Planet. Health* **2**, e313 (2018).
4. S. D. Beevers, E. Westmoreland, M. C. de Jong, M. L. Williams, D. C. Carslaw, *Atmos. Environ.* **54**, 107 (2012).
5. G. W. Fuller, *The Invisible Killer: The Rising Global Threat of Air Pollution: and How We Can Fight Back* (Melville House, London, UK, 2018).
6. J. S. Owens, *Trans. Faraday Soc.* **32**, 1234 (1936).
7. D. W. Dockery *et al.*, *Res. Rep. Health Eff. Inst.* **176**, 3 (2013).
8. F. H. Johnston, I. C. Hanigan, S. B. Henderson, G. G. Morgan, *BMJ* **346** (jan08 12), e8446 (2013).
9. S. K. Grange, D. C. Carslaw, A. C. Lewis, E. Boleti, C. Hueglin, *Atmos. Chem. Phys.* **18**, 6223 (2018).
10. A. Colette, M. Beauchamp, L. Malherbe, S. Solberg, *Air quality trends in AIRBASE in the context of the LRTAP Convention*, ETC/ACM Technical Paper 2015/4 (European Topic Centre on Air Pollution and Climate Change Mitigation, Bilthoven, 2015).
11. A. Font, L. Guiseppin, M. Blangiardo, V. Ghersi, G. W. Fuller, *Environ. Pollut.* **249**, 1 (2019).
12. G. Shaddick, J. V. Zidek, *Spat. Stat.* **9**, 51 (2014).
13. P. E. Lang, D. C. Carslaw, S. J. Moller, *Atmos. Environ. X* **2**, 100030 (2019).
14. N. A. Krotkov *et al.*, *Atmos. Chem. Phys.* **16**, 4605 (2016).
15. Heath Effects Institute (HEI), *State of Global Air 2018: a special report on global exposure to air pollution and its disease burden* (Heath Effects Institute, Boston, USA, 2019).

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