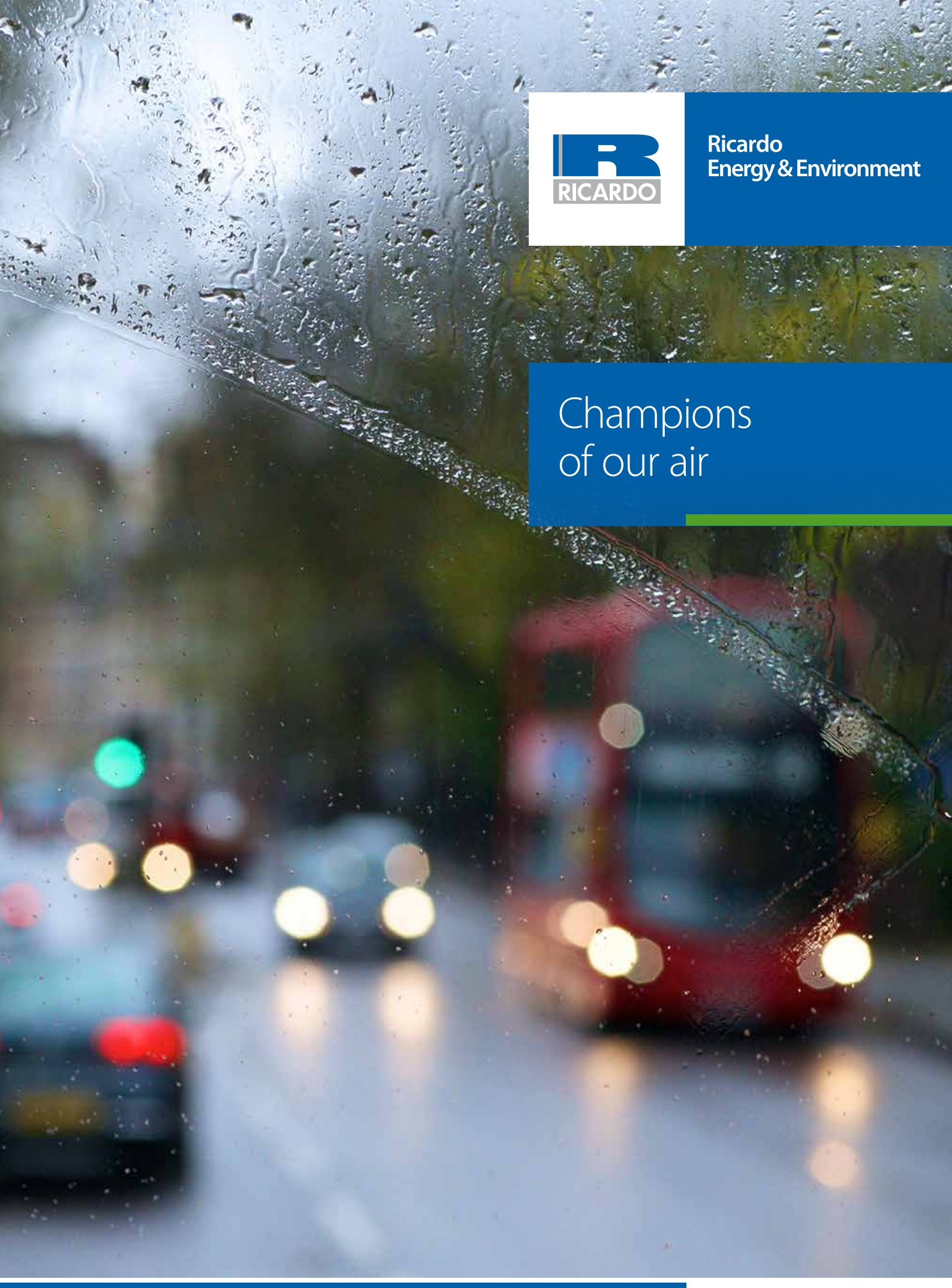

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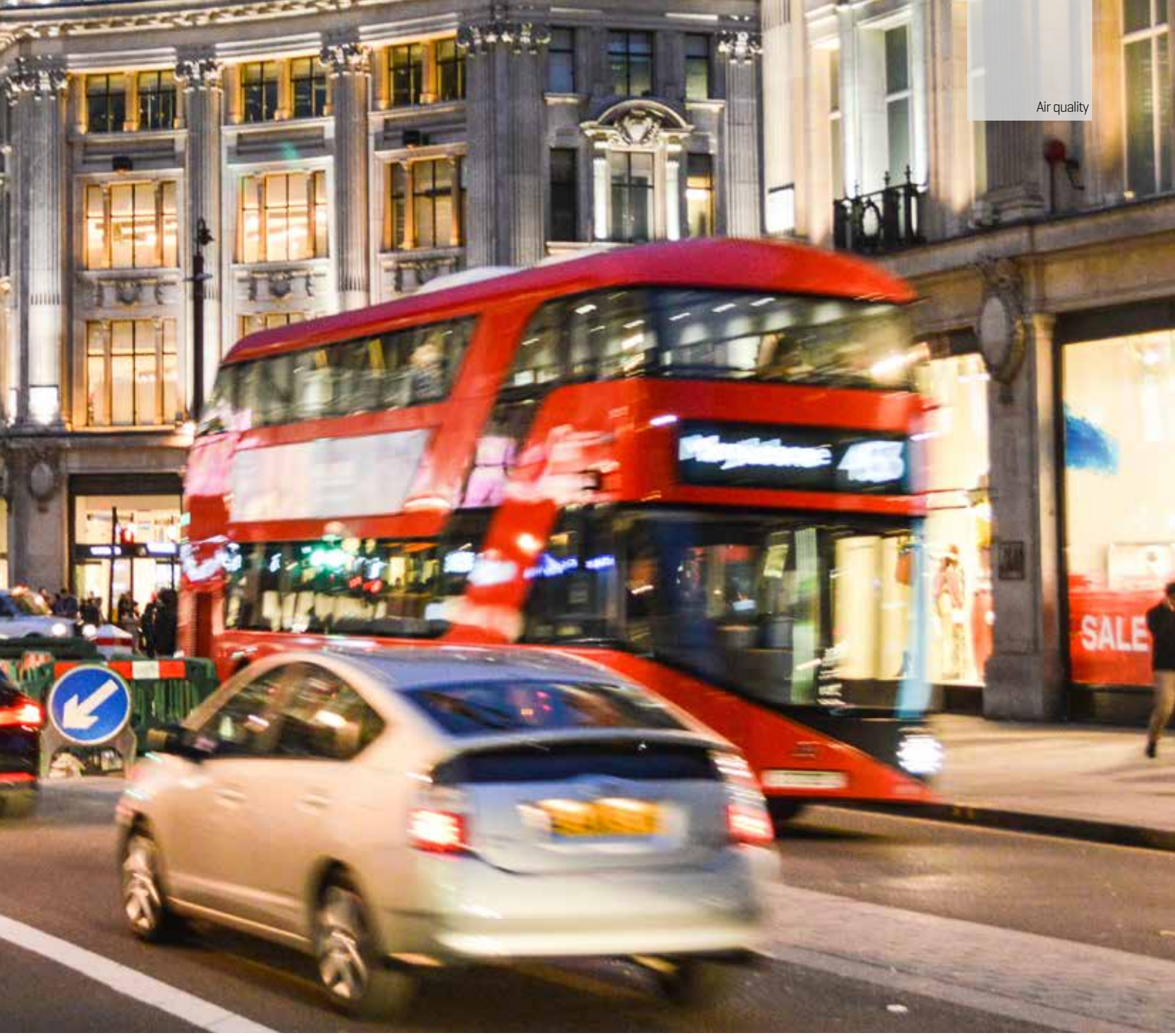
# Champions of our air

Street-level air quality in European towns and cities is running significantly above EU limit values in many densely populated areas. Most problematic is the rise of harmful nitrogen dioxide ($NO_2$) at street level – largely an unintended consequence of the past 15 years of regulations focusing closely on carbon dioxide ($CO_2$) and diesel particulate emissions. Air quality experts from Ricardo Energy & Environment explain how excessive oxides of nitrogen (NOx) arise and how new models in the pipeline promise to make tomorrow's diesel vehicles clean on all counts.




There can be little doubt that Europe has a problem with nitrogen dioxide ($NO_2$) emissions. This is a pollutant that can directly harm human health and, disconcertingly, monitoring has revealed that, in many urban areas, concentrations of $NO_2$, especially at street level where it is most harmful to young and old, remain high in many locations.

Overall, Europe's steadily tightening vehicle exhaust emissions standards have been highly successful in controlling vehicle pollution over the past four decades. Average emissions of $CO_2$ and greenhouse gases from new vehicles have more than halved since $CO_2$ rules were first proposed in the late 1990s; hydrocarbons and carbon monoxide from modern engines are now at microscopic levels, and particulate matter – soot – has been all but eliminated from diesel exhausts.

But there is one area where this otherwise successful strategy has come unstuck – NOx, or oxides of nitrogen. Dr David Carslaw is Ricardo Energy & Environment's knowledge leader for air quality and scientific development. He is also a specialist on urban air pollution at the University of York. Yet even from his high-level viewpoint in the air quality debate he confesses surprise at the way the issue of NOx has been allowed to develop.

'If you had asked me 15 years ago whether we would be as concerned about air pollution as we are now, I would have said no. At that time we expected emissions legislation to reduce total NOx from vehicles substantially, but what has happened is that those reductions haven't occurred.'

## Unintended consequences

'The rise in NOx is an unintended consequence of trying to do something else,' continues Carslaw, 'trying to control other emissions in diesel engines, such as carbon monoxide, hydrocarbons and, in particular, the emission of particles.'

The way that has been done, he explains, is through the introduction of the oxidation catalyst and the particle filter. 'It is ironic that $NO_2$ is actually really useful in aftertreatment, burning off the soot and hydrocarbons captured in the particle filter. So it is a good thing to have around as it lowers the temperature at which you can burn off the particles; it's very effective, and reduces the particles by over 90%.

'The unfortunate side-effect of that,' he continues, 'is that we have increased the amount of $NO_2$ in diesel exhaust, and that is the important part of the NOx-$NO_2$ story and the whole urban air pollution story.'

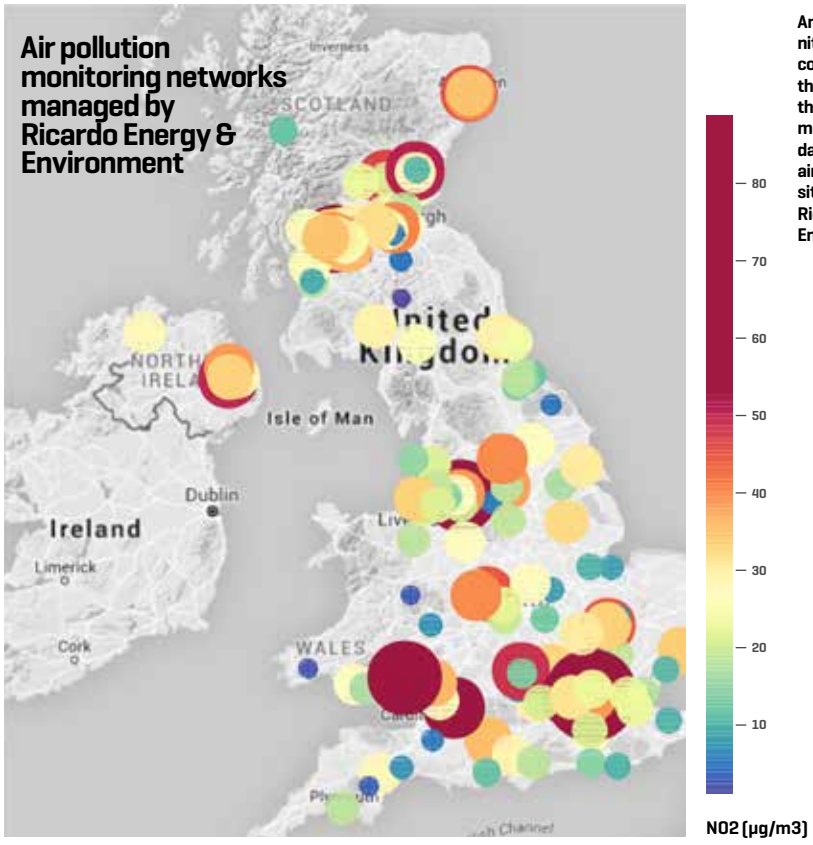
When it comes to NOx emissions, vehicles loom disproportionately large in the overall picture.

## NOx, NO and $NO_2$ – what's the difference?

**NOx is the cover-all term that includes nitric oxide (NO) and $NO_2$, which is more harmful to health. NOx is used in legislation to stipulate the maximum combined emissions of both species. Vehicles emit NO and $NO_2$, but in the atmosphere NO reacts with ozone to form $NO_2$, a process which takes a certain amount of time. It follows, then, that if a vehicle is a high emitter of NO, but is lower on $NO_2$, the NO from its tailpipe will have more chance to disperse before turning to harmful $NO_2$. Conversely, a vehicle with a high output of primary $NO_2$ will have a much more immediate effect on atmospheric concentrations in its local surroundings. Close to busy roads, primary $NO_2$ can account for up to three quarters of hourly limit exceedances.**

Not only are the exhaust gases emitted at ground level, where they have maximum impact, but they also occur largely in urban areas where there are more people in close proximity and where they do most damage to public health.

However, NOx arising from motor vehicle use is not a particular issue in the US and Japan, but a largely European problem – with the finger pointing directly at diesel. Europe has a very much higher proportion of diesel vehicles than other regions– roughly half of new passenger cars and virtually all light and heavy commercial vehicles are diesels. And as Carslaw's colleague Dr Beth Conlan, Ricardo Energy & Environment's business area manager for air quality modelling, points out, Europe has also taken enthusiastically to urban traffic control measures. Many towns and cities are restricting the use of private cars in central areas to leave only buses and taxis – invariably diesel powered – to populate the streets. This, she says, compounds the problem as 'canyons' of higher $NO_2$ concentration form in streets that are not wide enough to allow natural dispersion.




**Annual mean nitrogen dioxide concentrations across the UK in 2015 where the data capture was more than 90%. The data are from 244 air pollution network sites managed by Ricardo Energy & Environment.**

### Why the focus on NOx?

In their early enthusiasm to control $CO_2$ and noxious emissions such as particulate matter (PM) and hydrocarbons (HC), the EU policy makers focused on NOx as the regulatory metric while $NO_2$ emissions were not specifically controlled. Carslaw's white paper on urban air quality, which was published in 2005, revealed that $NO_2$ emissions were actually rising and many locations were exceeding the legal thresholds.

The issue has become doubly concerning as more health studies reveal the extent of the damage done to human health by $NO_2$. In the UK right now, says Conlan, some 5% of overall deaths are due to air pollution, resulting in 29,000 deaths each year.

'It is only now [following a reorganisation of responsibilities] that directors of public health within local authorities are beginning to think of air quality,' she says.

In the early 1990s, notes Carslaw, the focus had been very much on particulate pollution and the measures were successful. 'It is very easy with the benefit of hindsight to say that we should have done something different, but the health evidence at that time was pointing much more towards particulates than $NO_2$.

'It is understandable why we got into this situation,' he continues, 'but it also illustrates that it is important to tie up the engineering developments with what actually happens in the atmosphere – and this is where I think Ricardo is uniquely placed in terms of understanding that impact.'

In particular, strong links have been forged between the air quality team based at Harwell and the automotive emissions and aftertreatment chemists led by Jon Andersson at Shoreham. This has led to a unique understanding of the complex science of both disciplines, providing insights that have not previously been available.

Between 2000 and 2013, reports the European Environment Agency, 'the fraction of the urban population exposed to $NO_2$ concentrations in excess of the EU limit value and the identical WHO guideline value gradually decreased to around 10%, with a minimum of 8% in 2012. At 27%, the highest proportion of the urban population exposed occurred in 2003.'

The EU limit values for $NO_2$ exposure relate to annual $NO_2$ concentrations above 40 µg/m$^3$. There is an additional hourly limit of 200 µg/m$^3$, with only 18 exceedances permitted per year. One of the worst examples is Oxford Street in London – a thoroughfare closed to traffic other than public service vehicles. This is one of the most heavily polluted corridors in the world and with daytime $NO_2$ concentration spikes as high as 642 µg/m$^3$, well in breach of statutory European limit values. In 2015, its annual mean $NO_2$ concentration was more than triple the limit value, with the location counting 1,335 exceedances of the 200 µg/m$^3$ hourly threshold during the year. Last year, the street had breached its annual allowance for hourly violations by 4 January. Data are unavailable for this year as the monitoring station was malfunctioning, but Putney High Street, another London pollution black spot, exceeded the annual limits on 8 January 2016.

## Why is progress so slow?

Given the frequency of exceedances of the 2010 concentration limits in so many urban locations across Europe, street-level $NO_2$ is the focus of intensive research. 'Most member states are struggling to achieve those limits because we haven't seen the reduction in emissions that had been expected. They're not necessarily worse since 2010, but they're not getting better fast enough,' explains Carslaw.

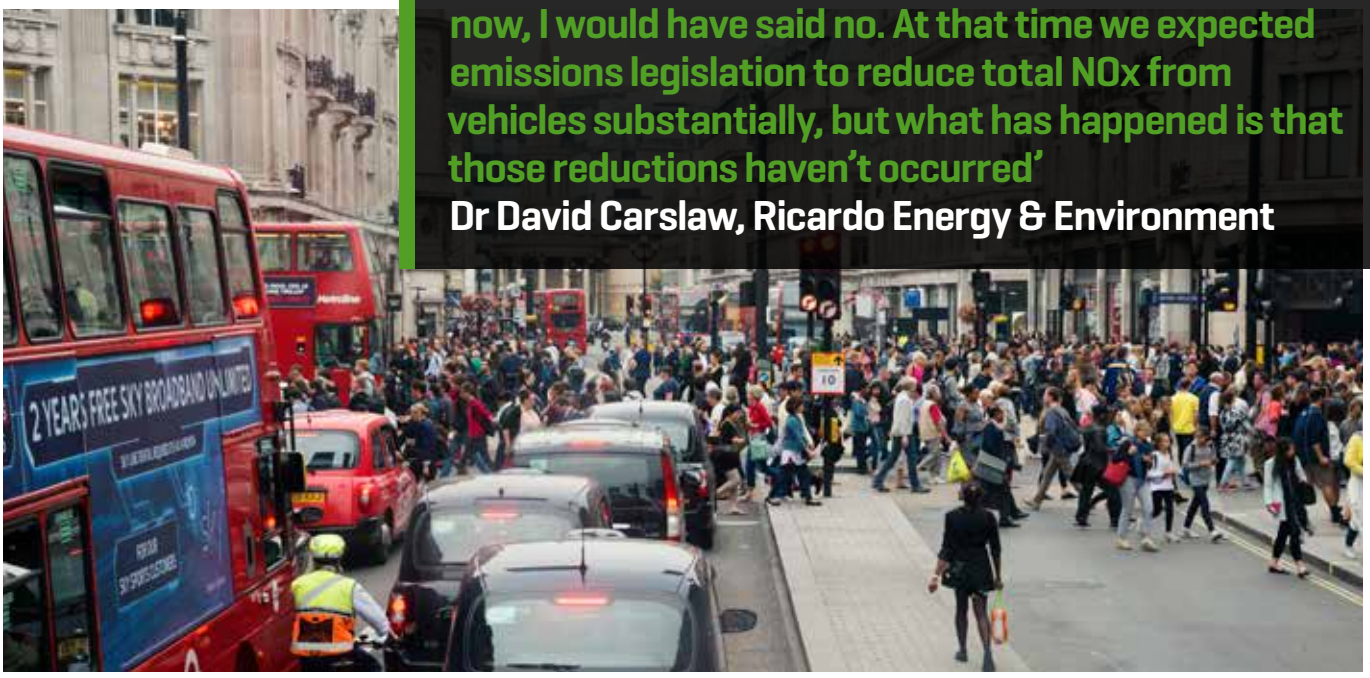
There are two principal reasons: the rapid growth of diesel passenger car sales, especially in the UK, and the earlier generations of emissions control technologies which use $NO_2$ to tackle other pollutants, without afterwards eliminating the excess. 'Those two things together produce the perfect storm,' he says.

Aside from the growth in diesel vehicle numbers, the key upset is in real-world emissions, especially in vehicles built to Euro 4 and Euro 5 standards between 2005 and 2014. These vehicles had been expected to have lower NOx emissions than their Euro 3 predecessors but, critically, most failed to deliver in everyday driving. With many millions still running strongly on Europe's roads, it will be a long time before they are phased out of the emissions equation. It was only with the introduction of Euro 6 in 2014 that specific technologies for the control of NOx began to be required.

The key thing now, says Carslaw, is that exhaust aftertreatment systems must actually work under urban driving conditions – regardless of what they do in laboratory based test cycles. There is a general feeling within the industry that the Euro 6c update, entering into force in 2017, will deliver genuine and reliable reductions in NOx emissions, and the extra dimension of legally mandated, real-driving emissions (RDE) levels provides much greater confidence that actual exhaust emissions values will closely match the predicted values fed into the air quality models.

**'If you had asked me 15 years ago whether we would be as concerned about air pollution as we are now, I would have said no. At that time we expected emissions legislation to reduce total NOx from vehicles substantially, but what has happened is that those reductions haven't occurred'**

**Dr David Carslaw, Ricardo Energy & Environment**



# Policy options to address urban air quality hot spots

With emissions of primary street-level $NO_2$ likely to reduce only slowly over time as the diesel fleet renews beyond Euro 6c, **Dr Beth Conlan** explains how her team focuses on supporting local and city authorities in deploying practical policy measures to improve urban air quality.

### What tools are available to tackle urban NOx?

We group our policy tools under 'avoid, shift and improve'. So that's encouraging walking and cycling, modal shift to buses and public transport, and improvements in technology.

### Could you give some examples you've been involved with?

As air quality professionals, we can often piggyback off traffic management to ask what the air quality benefit will be – we can use our leverage to attract more money to improve the situation. We can use traffic data, GPS data and area modelling to explore different solutions and then feed these back into our air quality models. In Maidstone, for instance, we modelled the reversal of the one-way system so the traffic went down the hill rather than up, to see what difference that would make.

### How do you account for the impact on the broader area?

We model that too, because displacement is a key factor. We quite often look at gating – for example we hold traffic outside the town or just away from the exposure area and, once the town centre is clear, the traffic flows through smoothly. Smooth flow is the key – stop-start is a killer as far as emissions are concerned. We are also working on a sensor system linked to SCOOT [an adaptive traffic management control system] so that you can change the traffic lights depending on the emissions in a particular place.

### Should diesels be penalised?

Once you get to Euro 6c, there is no reason to punish diesel vehicles, but if you're trying to get the emissions down, you do need to deal with the earlier ones. We only need to do something between now and Euro 6c. In 10 years' time I would estimate that 75% of the diesel fleet will be Euro 6c, so there is a time in which we need to act.

### What about other areas?

There are 700 air quality management areas in the UK that exceed the $NO_2$ air quality standard. The UK Government has just released new guidance for local air quality management, which local authorities have to implement. For years, the focus has been on monitoring, modelling, reviewing and assessing. Now we need to put in measures to 'just do something about it'.

### Are you advising local planning authorities?

Air quality is becoming an important part of the planning and development process, not just in air quality management areas. There's lots going on at the lower levels. For example, stipulating low-emission buses on key routes and, in Bradford, there's a policy that any new house with off-street parking has to have an electric vehicle charging point.

## Is there a quick fix?

From outright bans on diesel to totally traffic-free zones, there is no shortage of suggestions for quick solutions to the $NO_2$ crisis. However, the awkward reality, says Beth Conlan, is that any truly effective measures tend to be politically unacceptable and are discounted. Obvious policies, such as incentives to scrap earlier diesel models, can have unforeseen consequences.

'An accelerated move to Euro 6 would be good,' counsels Carslaw, 'but you do need to be careful. Some newer vehicles produce more NOx and $NO_2$ than older models. If you encourage Euro 5 at, say, the expense of Euro 1 and pre-Euro, you could paradoxically make the situation worse as far as $NO_2$ is concerned. It's only Euro 6 that truly changes things.'

Because $NO_2$ pollution tends to be a localised phenomenon, it lends itself to local actions such as traffic-light phasing, one-way systems to smooth out traffic flow and – perhaps less palatable politically – road pricing schemes to reduce morning and evening rush-hour spikes in traffic. Local encouragement of zero-emission electric vehicles and plug-in hybrids could have a role to play once they have achieved sufficient market penetration, a clear case of new technology being exploited to solve the $NO_2$ problems caused by the outgoing technology.

It is here, too, that new testing methods have a role to play in encouraging vehicles that perform cleanly in real-world driving as well as in laboratory tests. The introduction of the Worldwide harmonised Light vehicle Test Procedures (WLTP) emissions homologation test cycle, together with Real Driving Emissions (RDE) compliance requirements, will apply to new vehicle type approvals from Euro 6c onwards from 2017, and to all new vehicles from 2019. RDE shifts the onus firmly back to where emissions matter most – in real conditions, on actual roads and, especially, in the all-important urban areas where $NO_2$ pollution hits hardest.

Tougher annual retesting of vehicles in service is another frequent suggestion, but evidence points to it being a very expensive and somewhat blunt instrument with which to catch the relatively few rogue vehicles that are defective and polluting. Instead, the Colorado model of roadside remote sensing could be highly effective. The system analysis the exhaust plumes of large volumes of vehicles in real time, even in dense traffic, linking the readings with the number plate database in the state vehicle records. Vehicles that pass by clean three times in a row are exempted from the official pollution checks. The scheme has immense potential in aggregating the in-service emissions of all vehicle types, old and new. And, as proof of its effectiveness, data collected from this type of sensor in Switzerland and in Colorado helped scientists to identify the excessive NOx emissions being produced by VW and Audi models with two-litre diesel engines.

## Looking ahead

What really matters for the atmosphere and for health with the new RDE requirements is that we see a reduction in real-world emissions, stress Conlan and Carslaw. 'I don't buy the argument that cars will be allowed to emit more,'

**'Yes, there will definitely be diesel cars in 2030, and though I have a nagging doubt that diesel may never be as clean as gasoline for as far as NOx is concerned, everything will have much lower emissions by then and it might not matter'**
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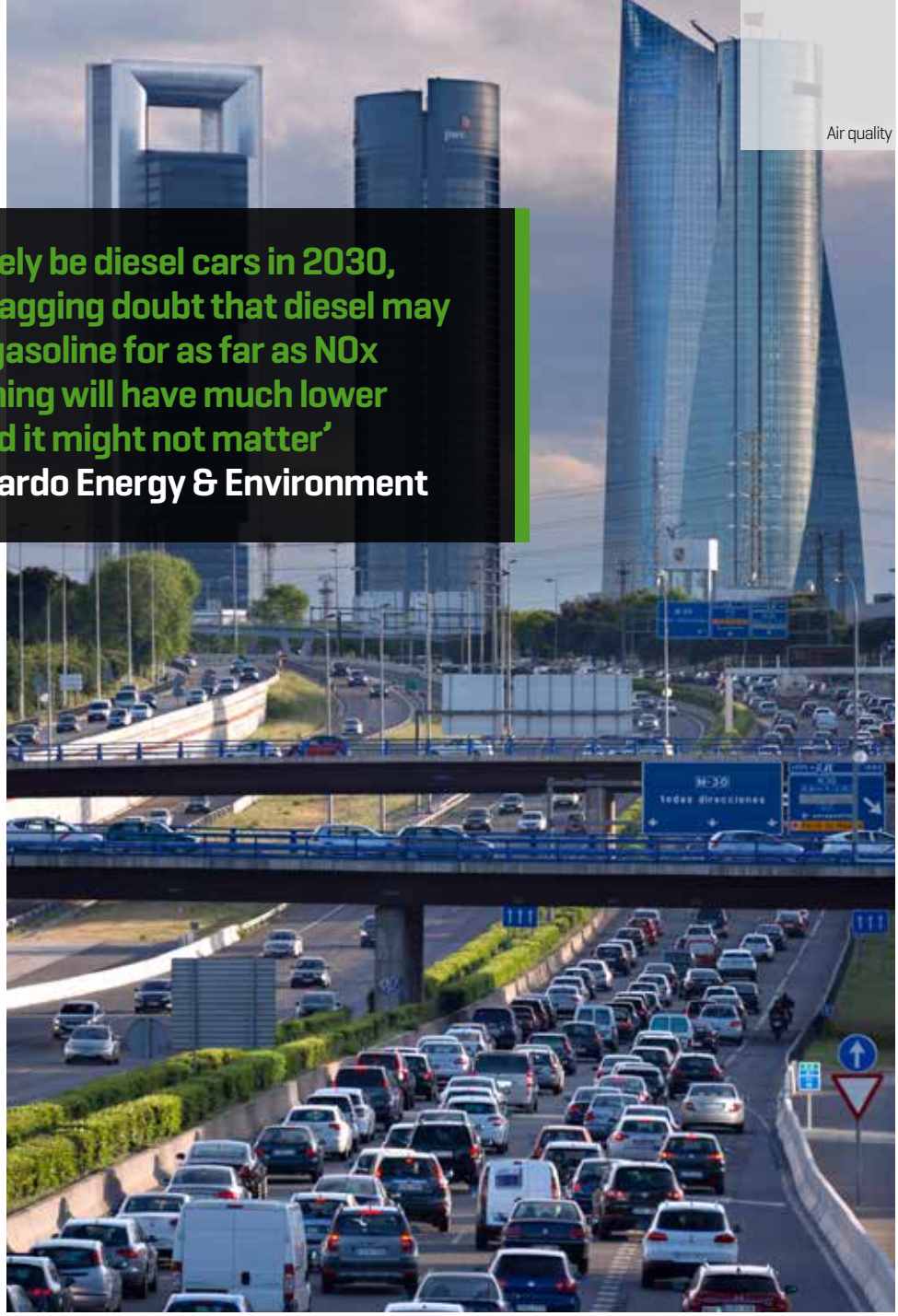
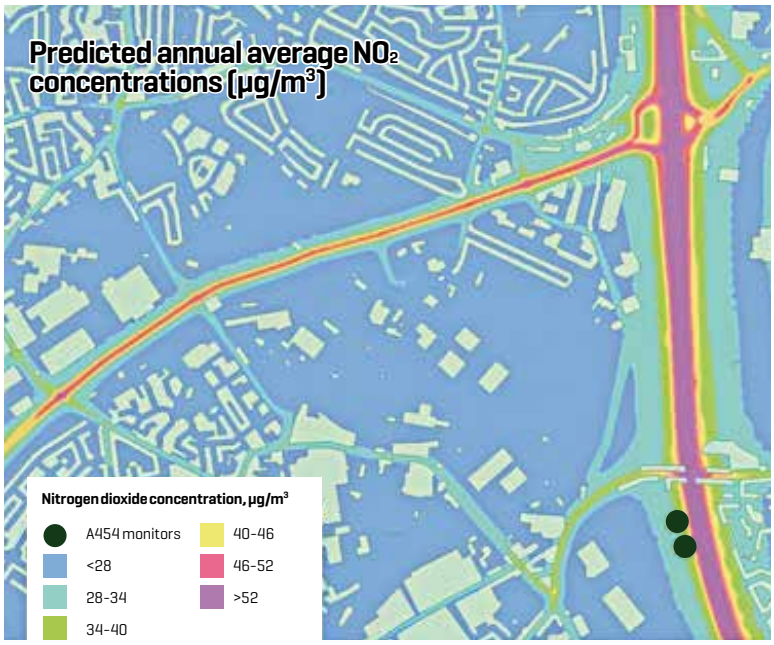


adds Carslaw. 'If we see a 50% reduction in NOx in real world driving with the early introduction of Euro 6 that will be good progress, with greater reductions to come with Euro 6c. We shouldn't lose sight of the fact that we should be focusing on changing what happens under real-world driving conditions.'

Looking further into the future, as emissions of the familiar regulated compounds begin to taper away, other pollutants could come into play. Perhaps, controversially, one of these could be non-exhaust particulates – in particular the fine dust deposited on road surfaces from vehicle tyres, brake discs and friction materials. With the near-universal fitment of particulate filters, this type of pollution is rising as a proportion of overall PM and could come to affect the heavy truck sector – as well as having the potentially paradoxical consequence of removing the zero-emission status from battery electric vehicles.

As for the frequently discussed question of the future for diesel passenger cars, Carslaw is unhesitating in his response: 'Yes, there will definitely be diesel cars in 2030, and though I have a nagging doubt that diesel may never be as clean as gasoline as far as NOx is concerned, everything will have much lower emissions by then and it might not matter.'




**Levels of $NO_2$ are much higher in urban areas, especially where there are queues of slow-moving traffic. The highest concentrations can be clearly seen on the approaches to junctions and on the expressway itself**

Amid all today's concerns about $NO_2$, it is all too easy to forget the major successes in other areas of emissions reduction achieved through the many steps of European automotive legislation. Yet, at the same time, there is a lesson in the $NO_2$ issue – measures that are effective in one domain can have unintended consequences in other areas. And it is here that the multifaceted capabilities of the Ricardo group come into their own: 'It's joining up the engineering and the atmospheric science that really allows you to understand what's going on,' says Carslaw, 'and this forms the basis for making the most robust decisions to improve air quality.'

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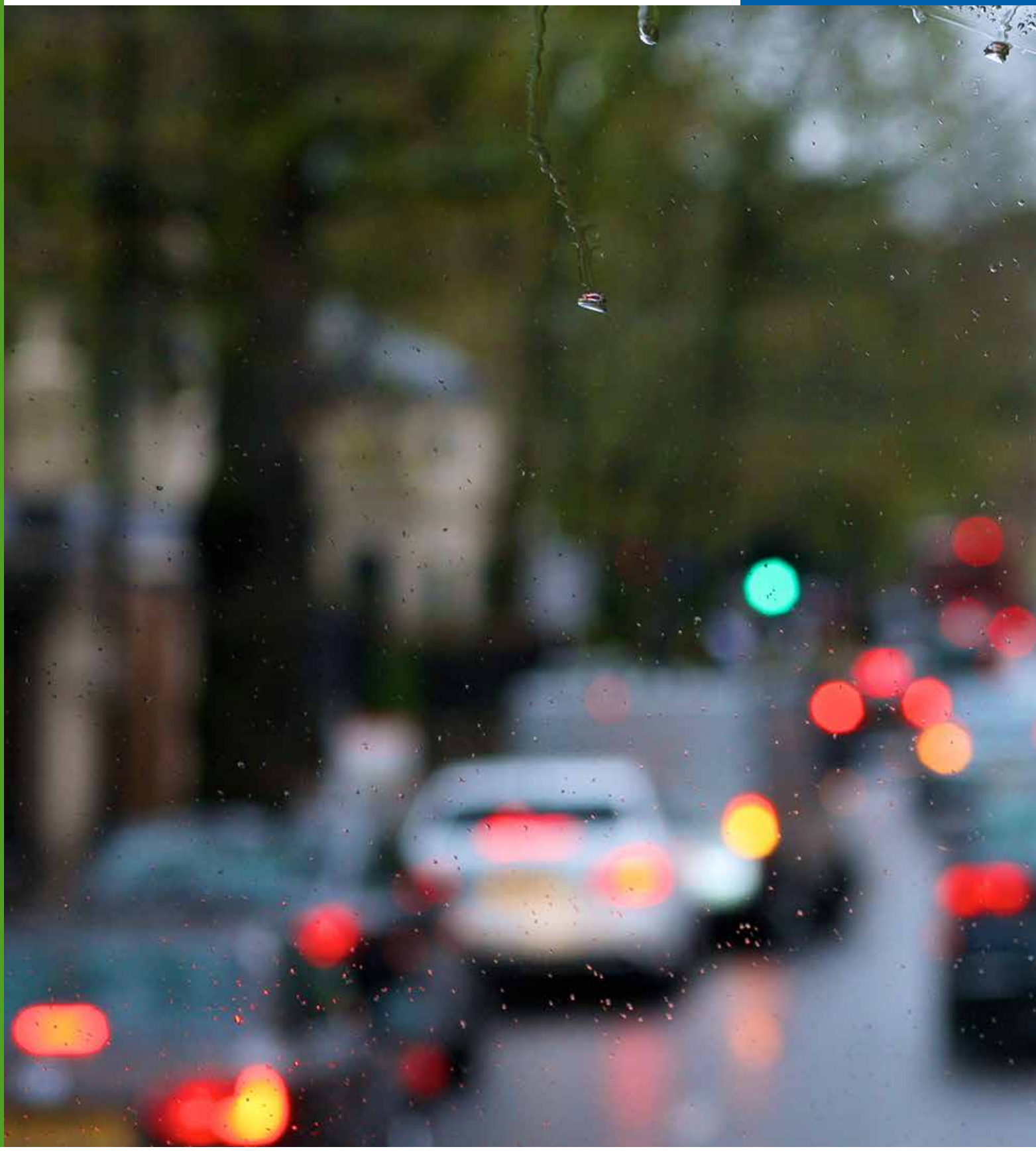

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