Air in the age of the city

Rob MacKenzie

NATURAL ENVIRONMENT RESEARCH COUNCIL

EPSRC
Engineering and Physical Sciences Research Council

Image from http://videohive.net/item/fast-city-drive-02/476188

Topics:

1. How trees can exacerbate **city-wide smogs**.
2. Trees, green walls, and **street-level air quality**.
3. Counter-intuitive effects of **built-up urban areas** on air pollution.
4. How large-scale **urban structure** affects pollution emissions
5. The **"3n-legged race"** to urban sustainability

Physics, Chemistry, Biology, Physical Geography, Human Geography

Systems science

Urban form I

The built land surface can affect air pollutants in four ways:

1. Trapping pollutants in the urban canopy (**fumigation**)
2. Producing swirls and eddies in the air that mix pollutants away from the ground (**vertical mixing**) ; and
3. Slowing the horizontal wind and so reducing the rate of movement of pollutants away from a source (**horizontal dilution**)
4. Transfer of pollutants from the air to the surface (**deposition**)

Urban form II

Cities are often surprisingly green

Green Infrastructure can affect air pollutants in all of the previous ways and in one additional way:

1. Emitting volatile organic compounds (VOCs) that form **ozone**

Urban air pollution

Ozone (O_3)

Nitrogen dioxide (NO_2) & Nitric Oxide (NO)

Microscopic Particulate Matter (PM10 or PM2.5)

Volatile Organic Compounds (VOCs)

Pictures from M.Z. Jacobson, *Atmospheric Pollution*. Left: Pedestrians in the 1950s, Hollywood Citizens News Collection, Los Angeles Public Library. Right: Los Angeles on 23 July 2000, Jacobson.

Chronic & acute air pollution effects

Recent estimates of annual premature death:

50,000 in the UK

1.34M worldwide

Reducing annual average UK concentration of PM2.5 by 1 μg/m^3 (out of 20 μg/m^3) would save approx 4M life-years for those born in 2008.

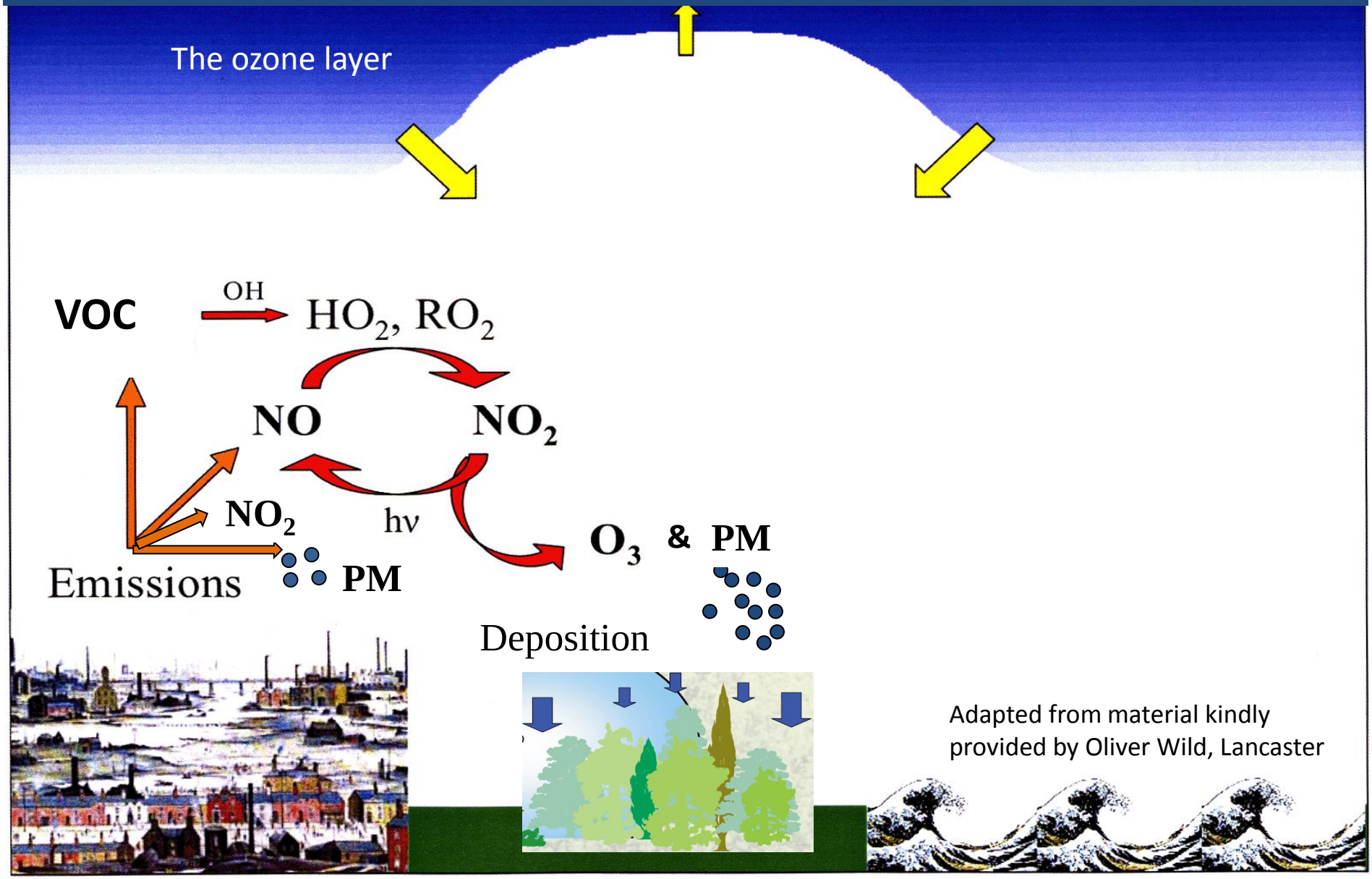
The 2008 PM burden affects UK mortality equivalent to a loss of life expectancy from birth of approximately six months.

Committee on the Medical Effects of Air Pollutants (2010)

Pictures from M.Z. Jacobson, *Atmospheric Pollution*. Left: Pedestrians in the 1950s, Hollywood Citizens News Collection, Los Angeles Public Library. Right: Los Angeles on 23 July 2000, Jacobson.

Atmospheric chemistry in & around cities

Colbeck, I. and A. R. MacKenzie, *Air Pollution by Photochemical Oxidants*, Elsevier, 1994.
See also M.Z. Jacobson, *Atmospheric Pollution and Global Warming*, Cambridge Univ. Press, 2012



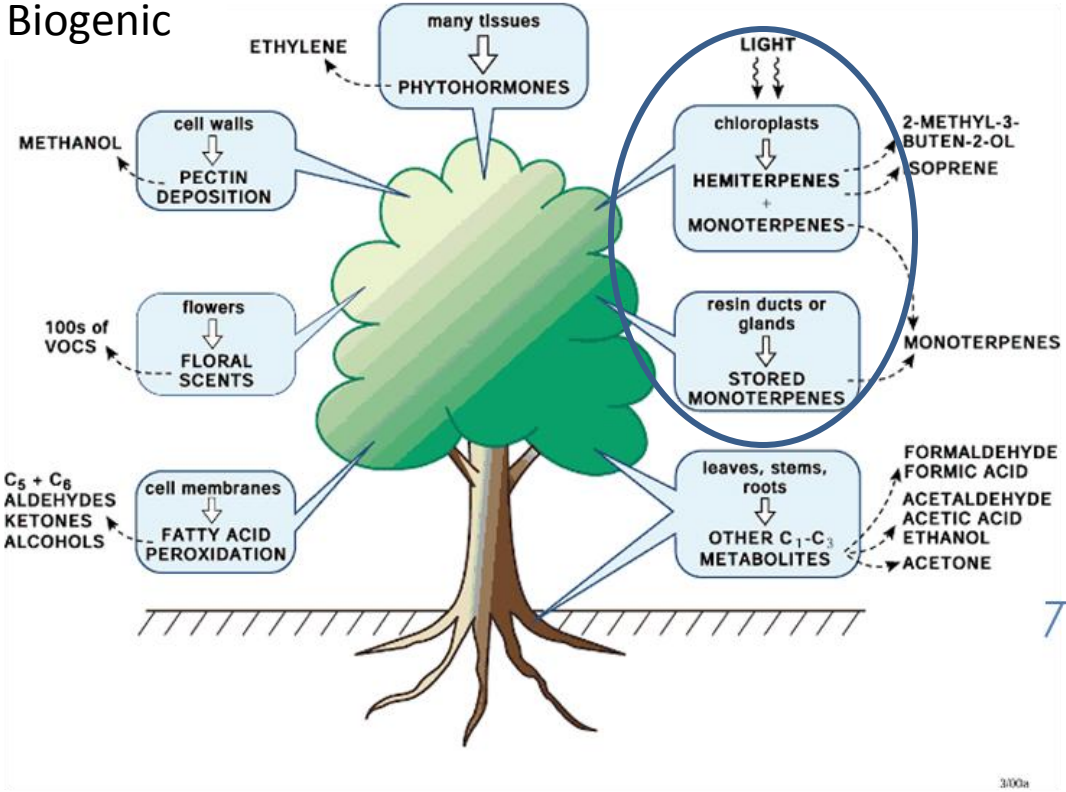
Adapted from material kindly provided by Oliver Wild, Lancaster

How trees can exacerbate smog pollution

With Nick Hewitt , Tom Pugh, Sue Owen, Rossa Donovan, Ben Langford, Kathryn Emmerson and the URGENT and OP3 team

Sources of Volatile Organics

Biogenic



Anthropogenic

Tree emissions depend on

- Species
- Light
- Temperature
- Time of day (circadian)
- Environmental stress

Vehicle emissions depend on

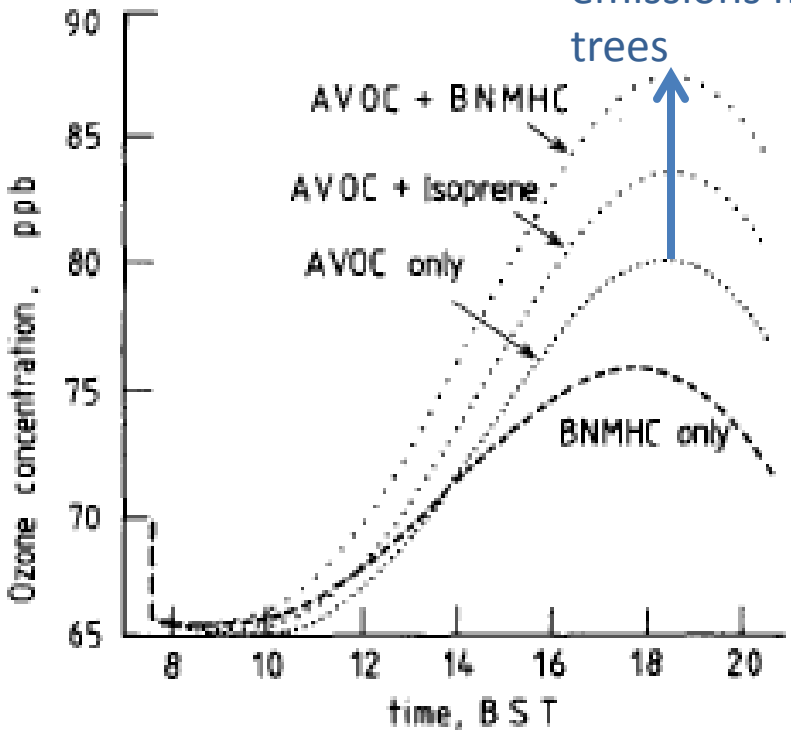
- Engine size & type
- Speed
- Ambient & engine temperature
- Driver behaviour

Vegetation emits VOCs. In and around cities, VOCs from trees mix with nitrogen oxides and VOCs from traffic to exacerbate ozone pollution in smog episodes.

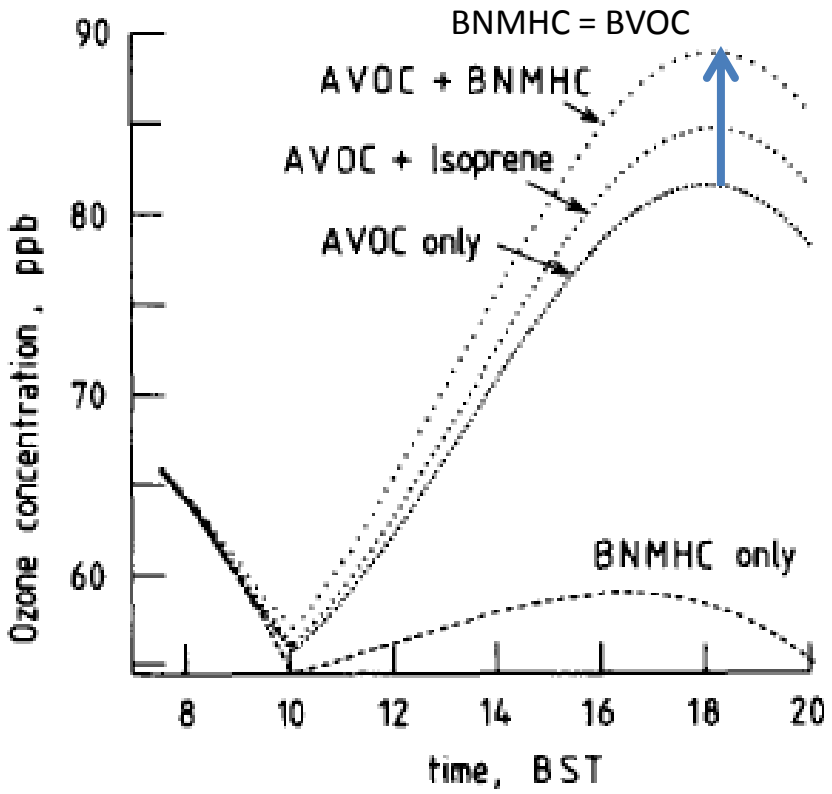
First European study (1991): London & SE England

Peri-urban air

Effect of VOC emissions from trees

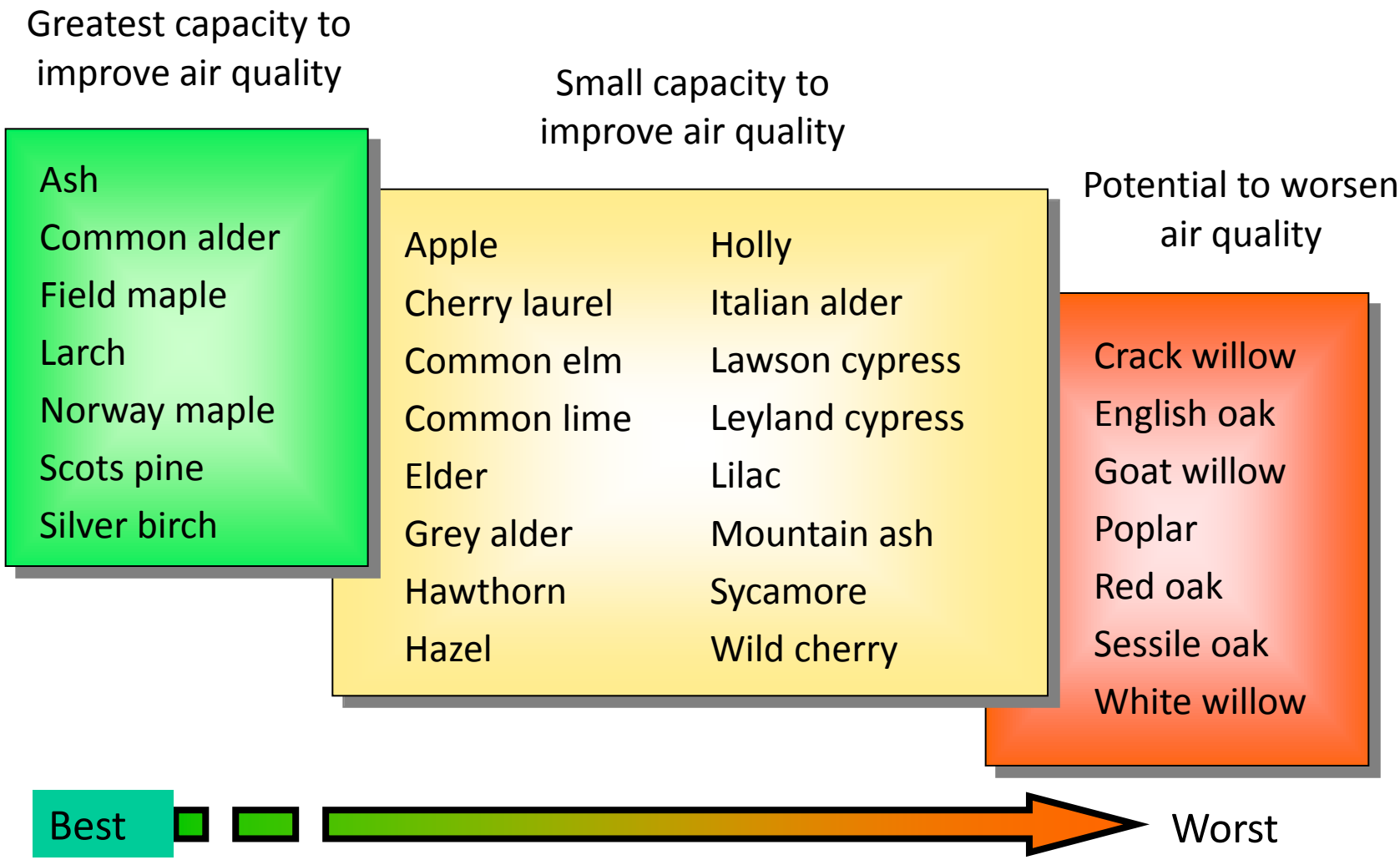


Urban plume



MacKenzie, A. R., R. M. Harrison, I. Colbeck, and C. N. Hewitt, The role of biogenic hydrocarbons in the production of ozone in urban plumes in southeast England, Atmos. Environ., 25A, 351-359, 1991.

Urban Tree Air Quality Score



www.es.lancs.ac.uk/people/cnh/UrbanTreesBrochure.pdf

Trees as carbon stores

All the trees in the West Midlands hold three weeks' worth of emissions of CO_2 from the conurbation

Carbon sequestration rate

High	Medium		Low
Crack willow	Apple	Italian alder	Common elm
Goat willow	Ash	Lilac	English oak
Larch	Cherry laurel	Mountain ash	Field maple
Lawson cypress	Common alder	Norway maple	Hazel
Leyland cypress	Common lime	Red oak	Holly
Poplar	Elder	Scots pine	Sessile oak
Silver birch	Grey alder	Sycamore	
White willow	Hawthorn	Wild cherry	

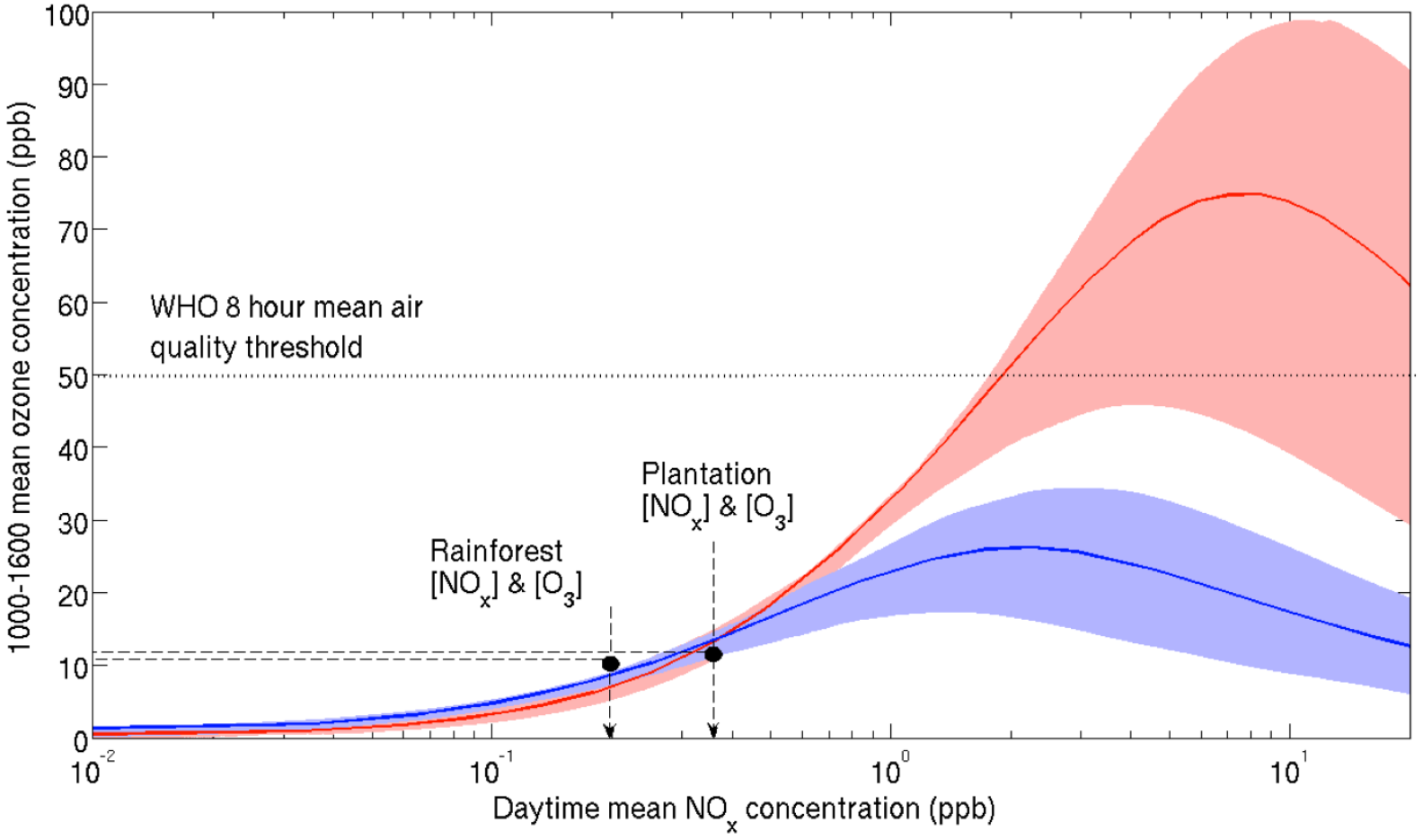
Donovan, R., S. Owen, N. Hewitt, R. MacKenzie, H. Brett, The Development of an Urban Tree Air Quality Score (UTAQS): using the West Midlands, UK Conurbation as a Case Study Area, VDM Verlag Dr. Müller, 392pp, 2010.

Palm oil is an important foodstuff. It is also increasingly used as a carbon neutral biofuel.

Tropical oil palm plantations are even larger sources of VOCs than the forests originally present.

MacKenzie, et al., The atmospheric chemistry of trace gases and particulate matter emitted by different land uses in Borneo, *Phil. Trans. Roy. Soc. Lond. B*, 366, 3177-3195, doi:10.1098/rstb.2011.0053, 2011.

Next to cities the mix of nitrogen oxides from traffic and VOCs from oil palm plantations could produce harmful concentrations of ozone



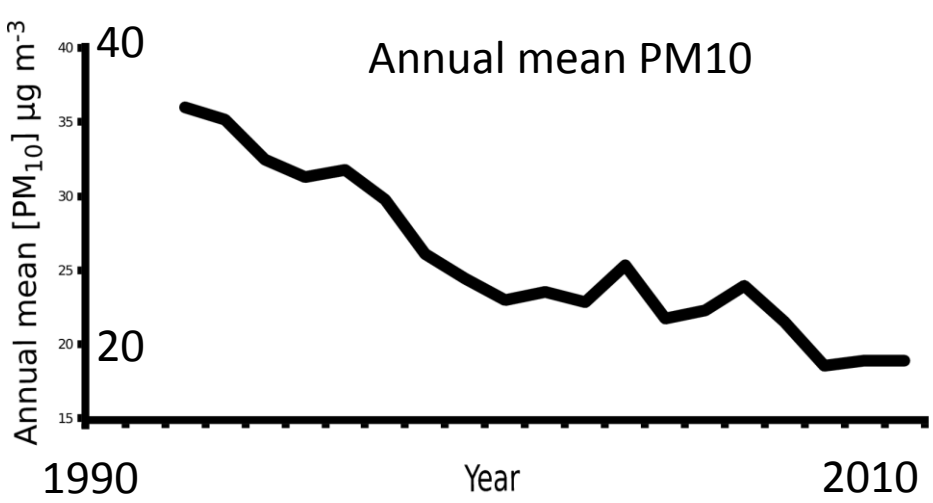
Hewitt, MacKenzie, et al., Nitrogen management is essential to prevent tropical oil palm plantations from causing ozone pollution, *Proc. Natl. Acad. Sci.*, 106, 18447-18451, 2009

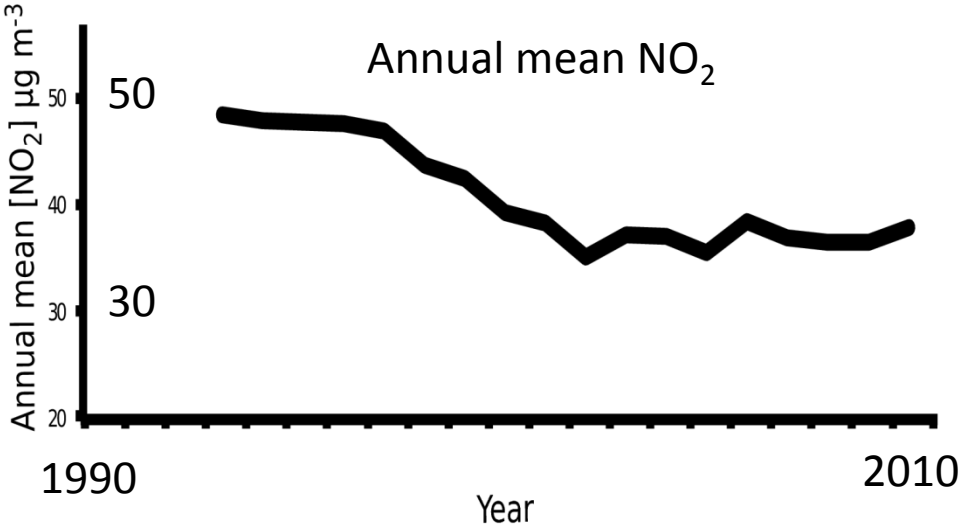
Trees, green walls, and street-level air quality

With Tom Pugh, Nick Hewitt , and the Urban Futures team

Nitrogen Dioxide and PM are of prime concern for urban Air Quality

Roadside pollutant concentrations. Defra (2010) Air pollution in the UK 2010.





Policy has focused on **emissions** control (at tail-pipe or through traffic control).

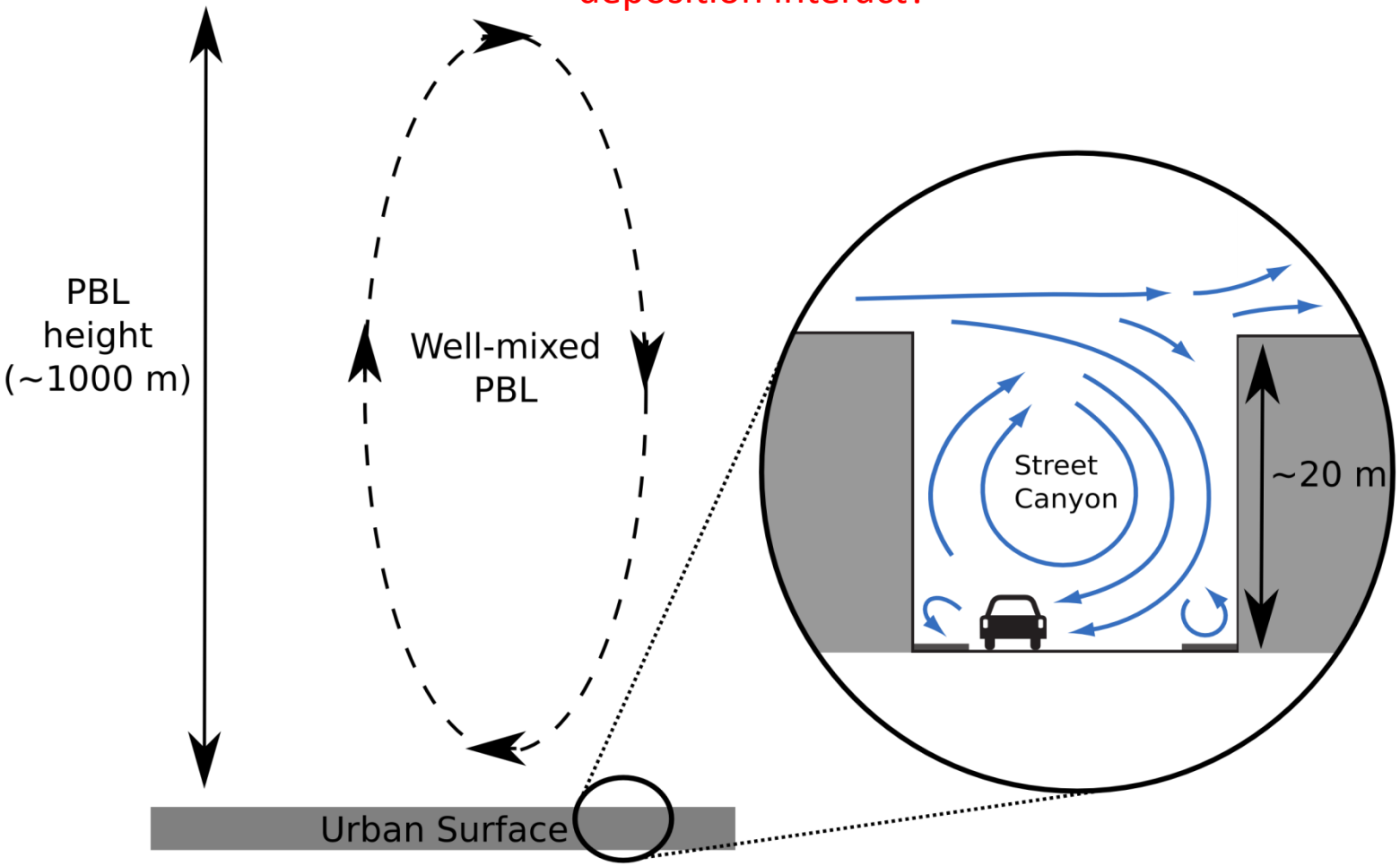
Concentration = f(Emissions, Mixing, Deposition, Chemistry, Advection)

Effect of urban built form

$$C = f(E,M,D)$$

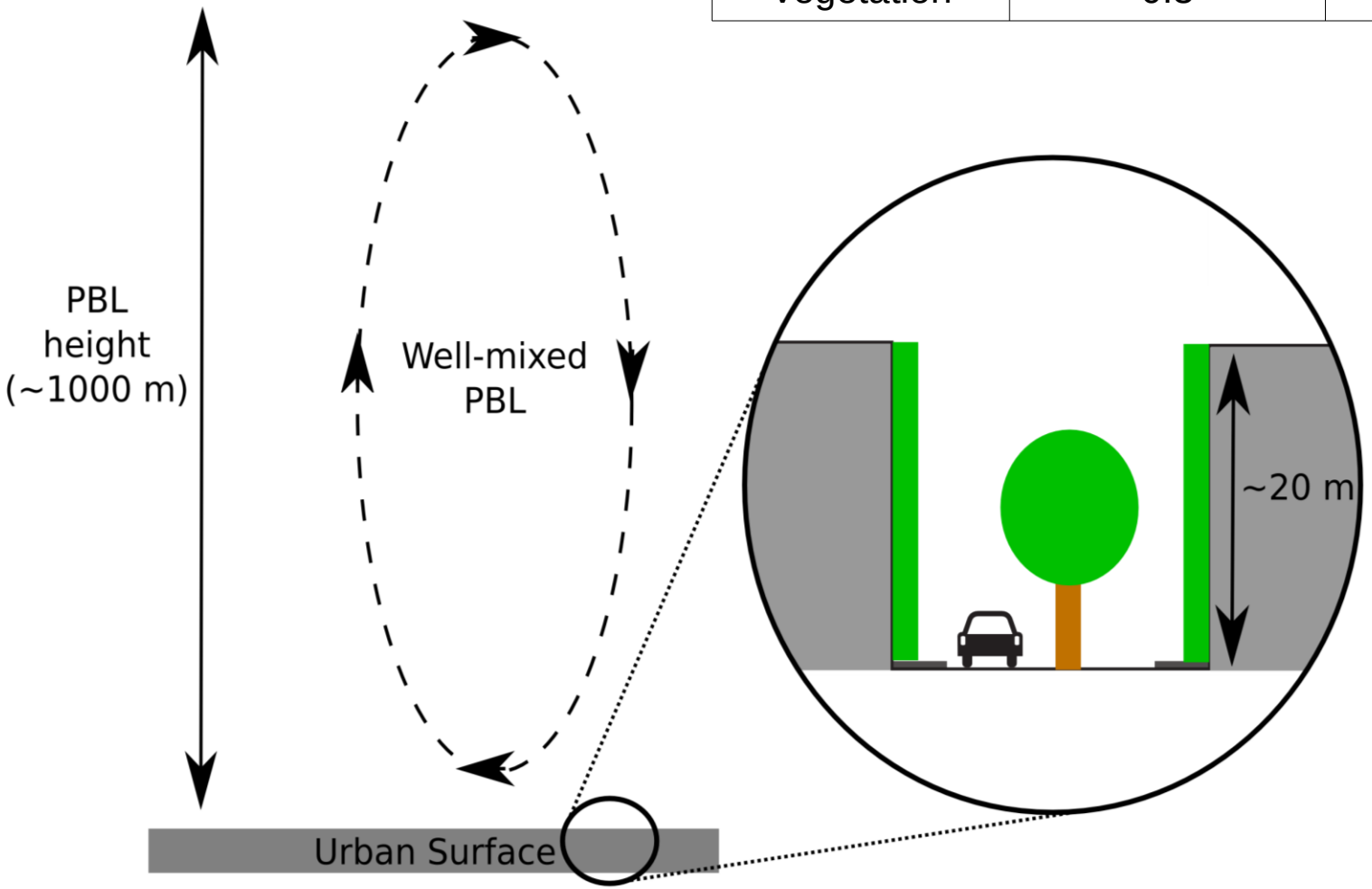
$$\frac{dC_i}{dt} = -\frac{V_{d,i}}{z} \cdot C_i$$

How do mixing and deposition interact?

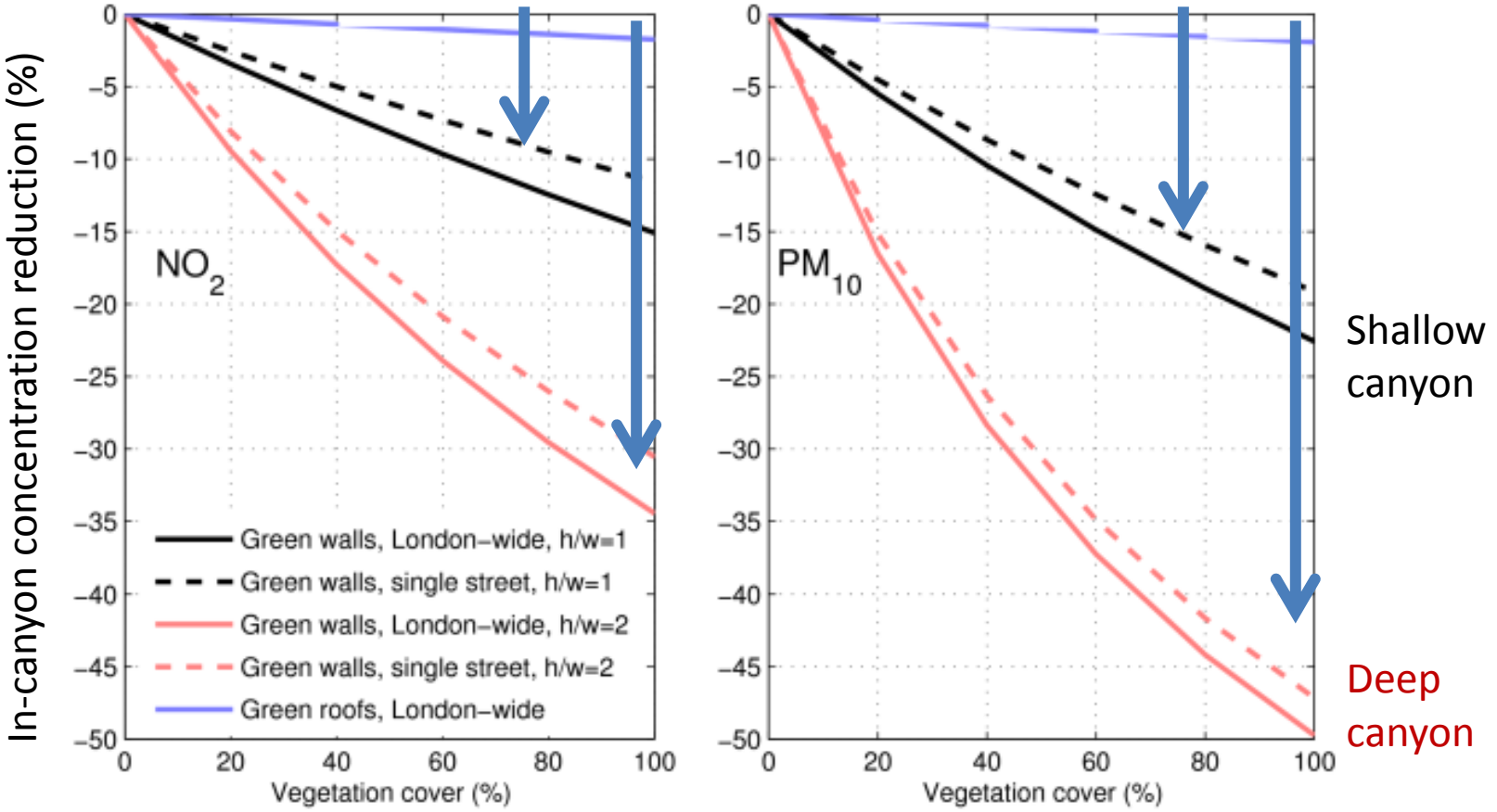


Street canyons: gardens, green walls and street trees

Surface	Typical NO_2 V_d ($cm\ s^{-1}$)	Typical PM_{10} V_d ($cm\ s^{-1}$)
Concrete/Brick	0.015 - 0.05	0.02 (vertical)
Vegetation	0.3	0.64



Green walls can be much more effective than green roofs…(central London example)



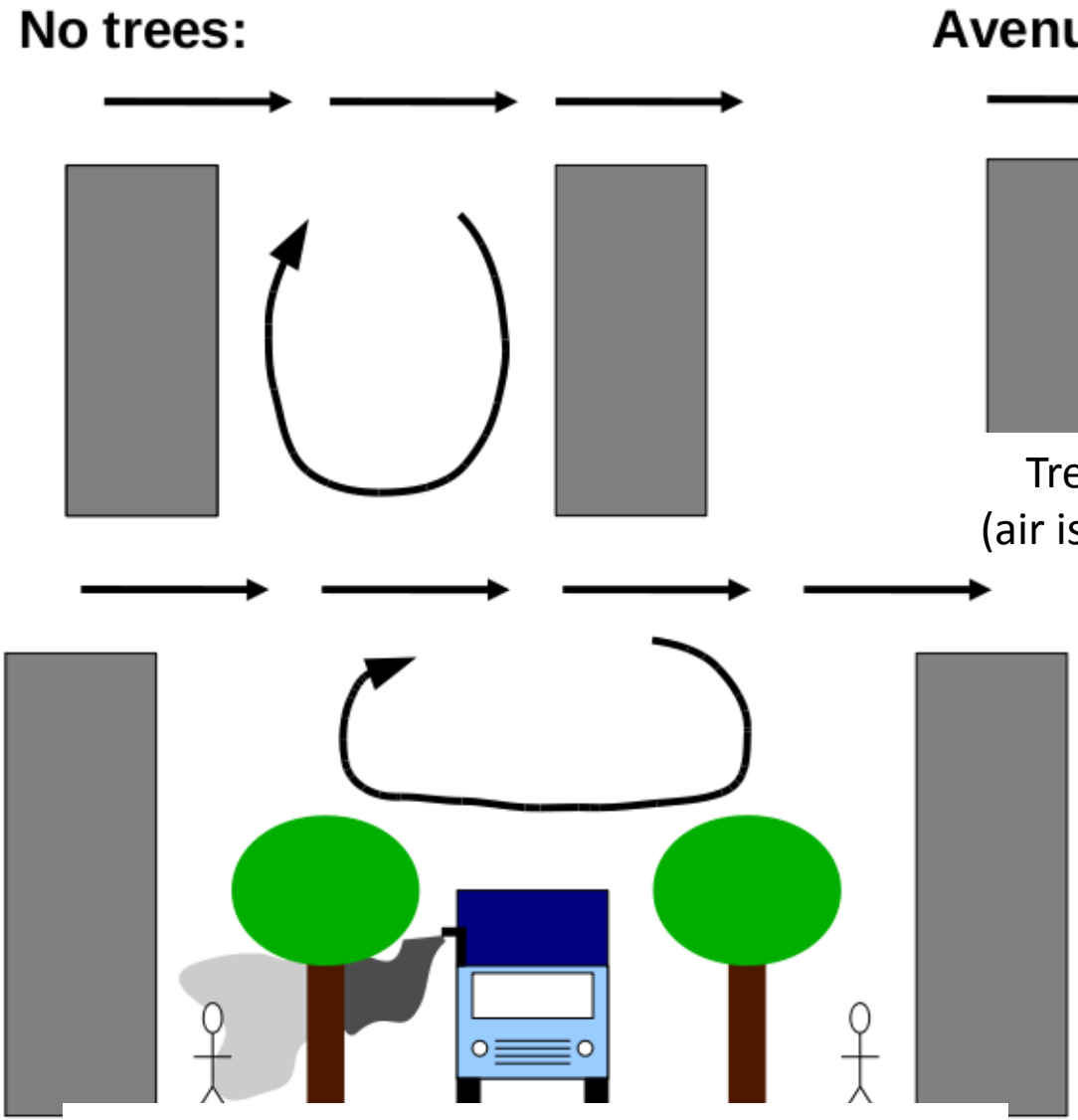
…and can clean air in a single canyon (**localism**). Bottom-up policy becomes possible. Political traction.

If we can build in GLASS we can build in GREEN

Image Source Page:
http://www.flickr.com/photos/nnecapa/2830785109/

Corporation Street, Birmingham

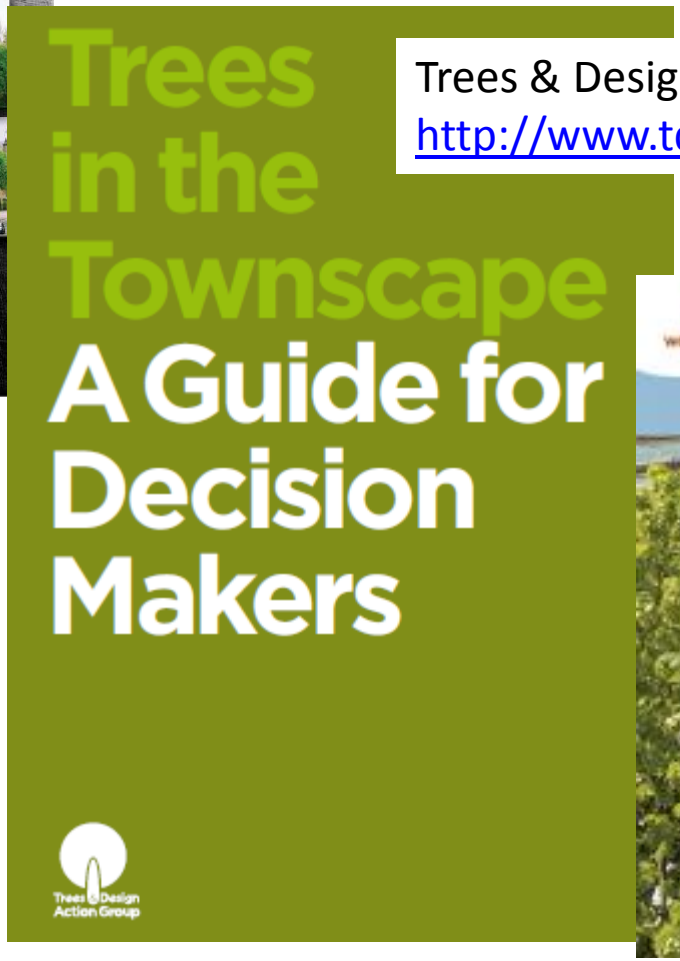
“Green Infrastructure”…Trees vs green walls



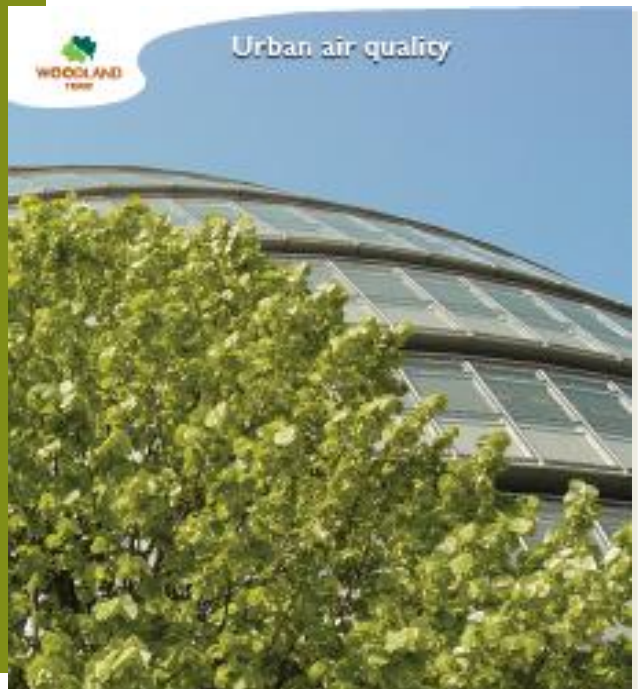
Trees + canyon = **filtered avenue**
(air is cleaner than on regional scale).

Pollution + street canyon + trees = **fumigation**.

NERC URGENT programme (2001)
http://www.es.lancs.ac.uk/people/cnh/UrbanTreesBrochure.pdf



Trees & Design Action Group (2012):
http://www.tdag.org.uk/trees-in-the-townscape.html



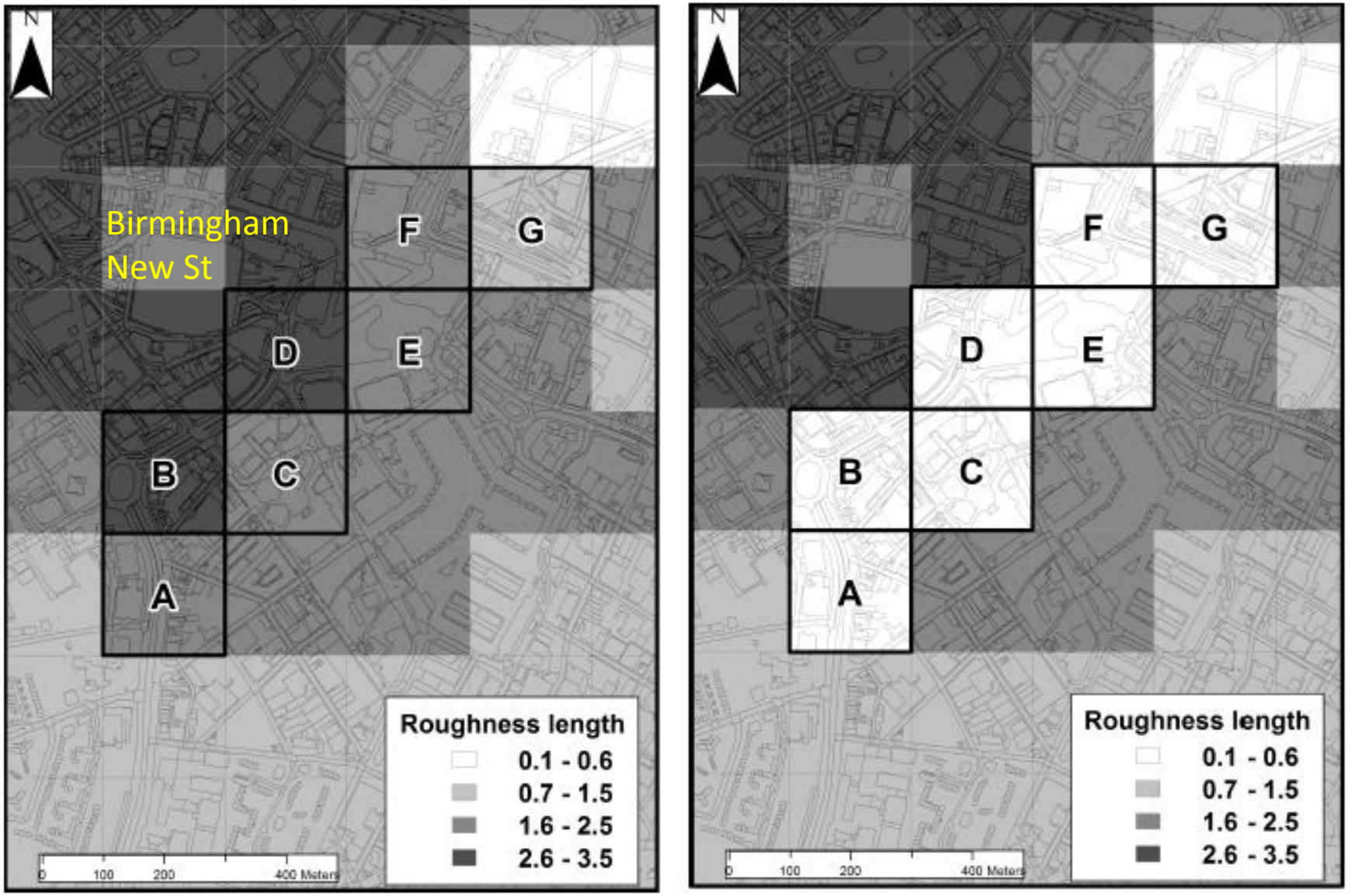
Woodland Trust (2012): http://www.woodlandtrust.presscentre.com/Media-Library/Urban-Air-Quality-774.aspx

Counter-intuitive effects of built-up urban areas on air pollution

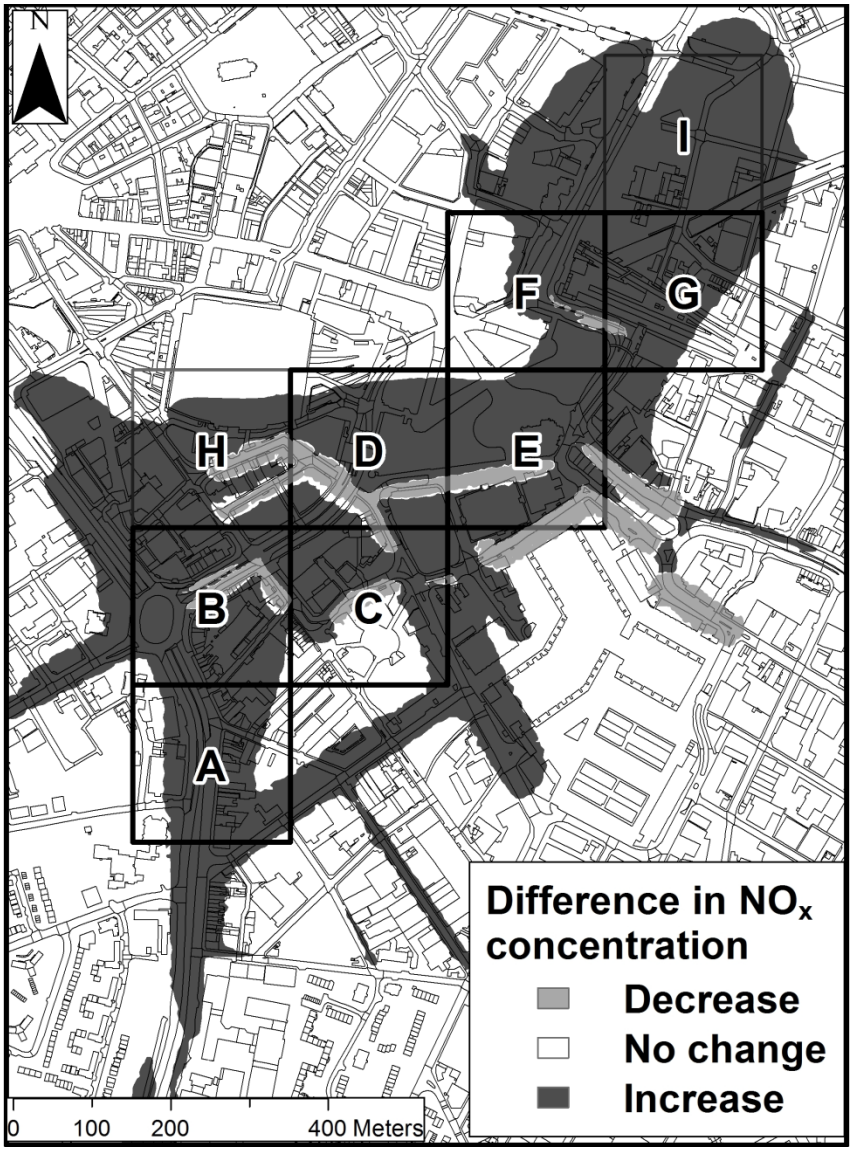
With Matt Barnes, Duncan Whyatt, Nick Hewitt , Xiaoming Cai and Cambridge Environmental Research Consultants

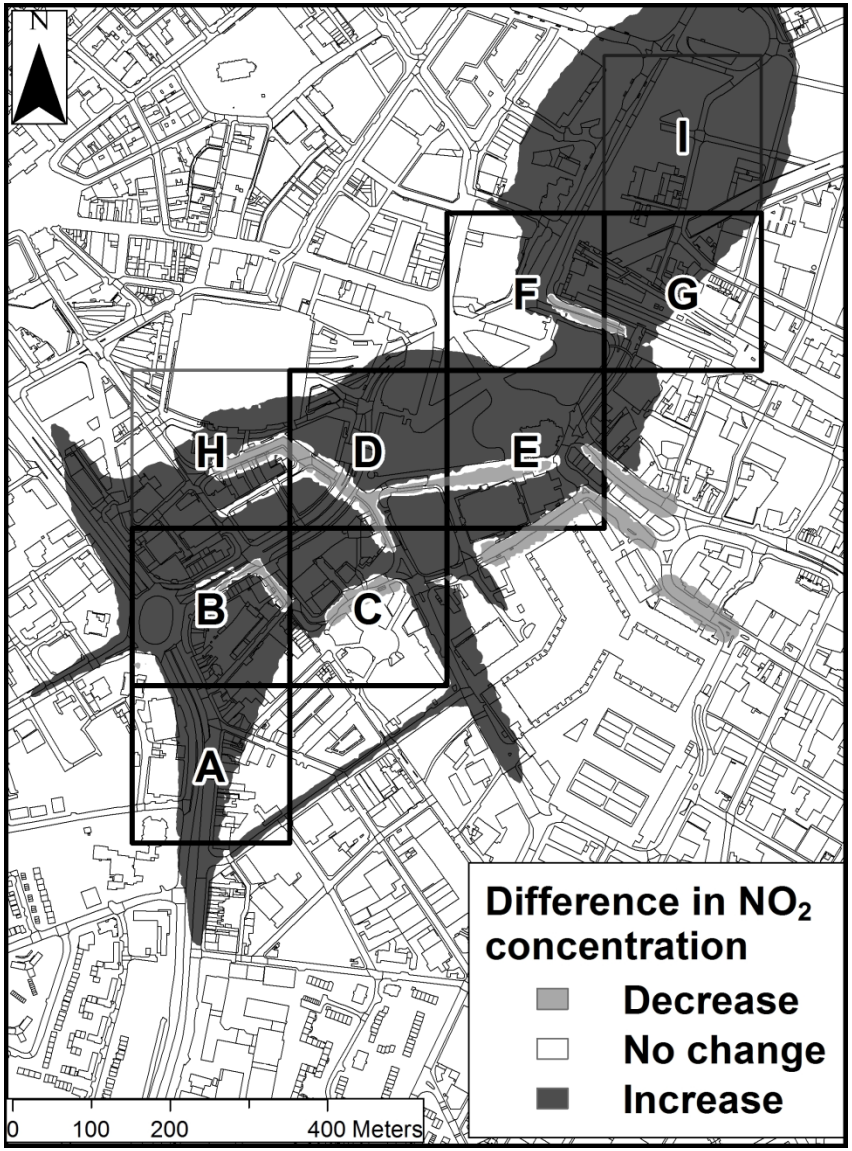
Barnes, …MacKenzie, et al., Spatially-varying surface roughness and ground-level air quality in an operational dispersion model, Environ. Pollut., 2013, 185, 44-51, DOI: 10.1016/j.envpol.2013.09.039

Imagine knocking down all the buildings in an urban area (but keeping the roads): what would happen to ground-level air pollution?



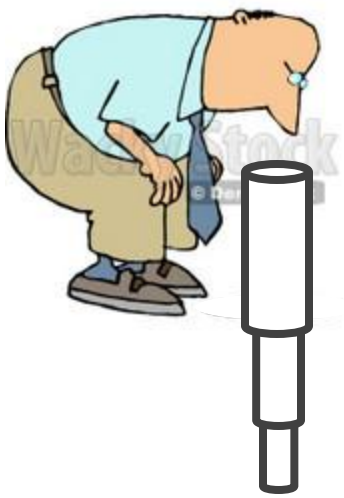
Reducing roughness increases ground-level pollution in model



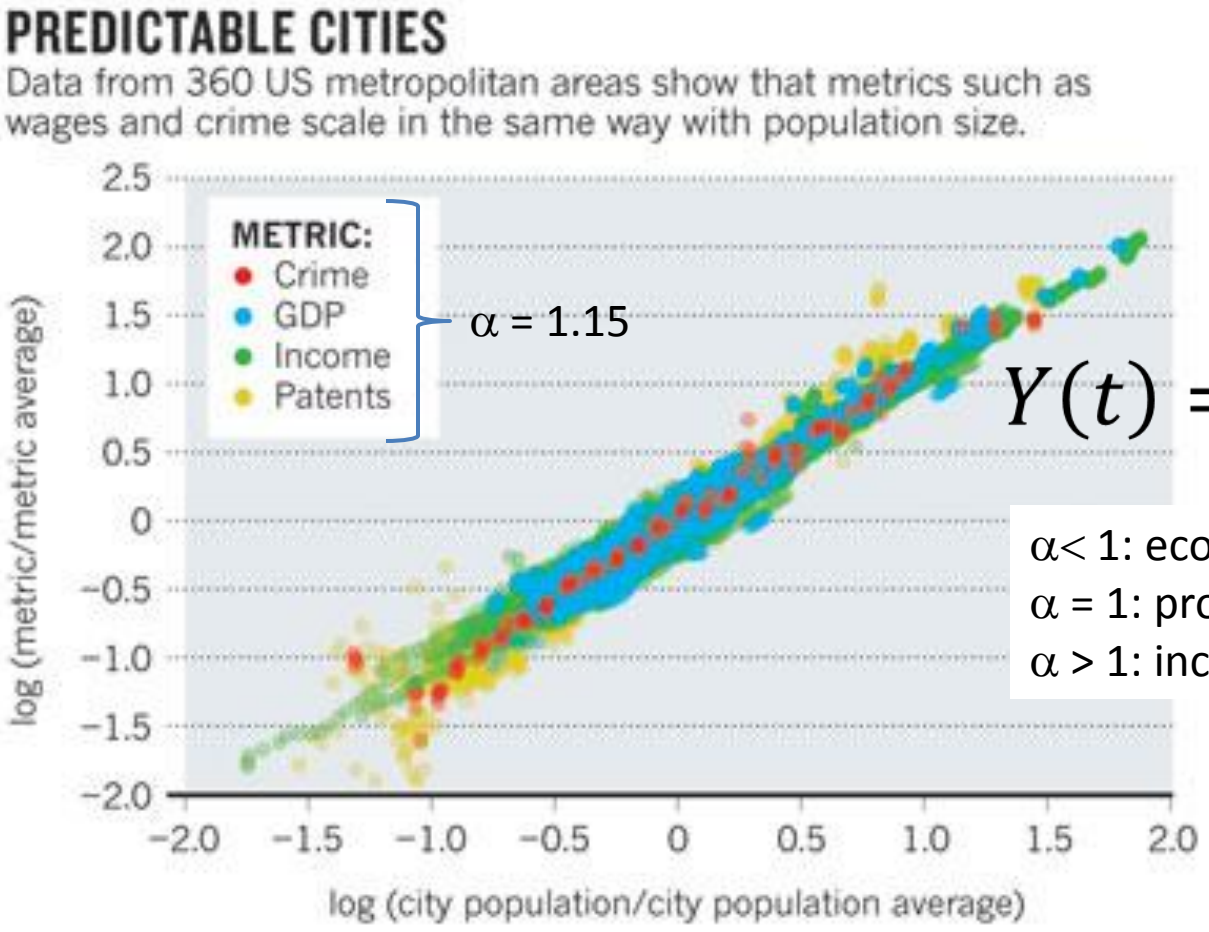


How large-scale urban structure affects pollution emissions: The fourth spatial dimension of cities

With Matt Barnes, Duncan Whyatt, Nick Hewitt



The fourth spatial dimension of 360 US cities

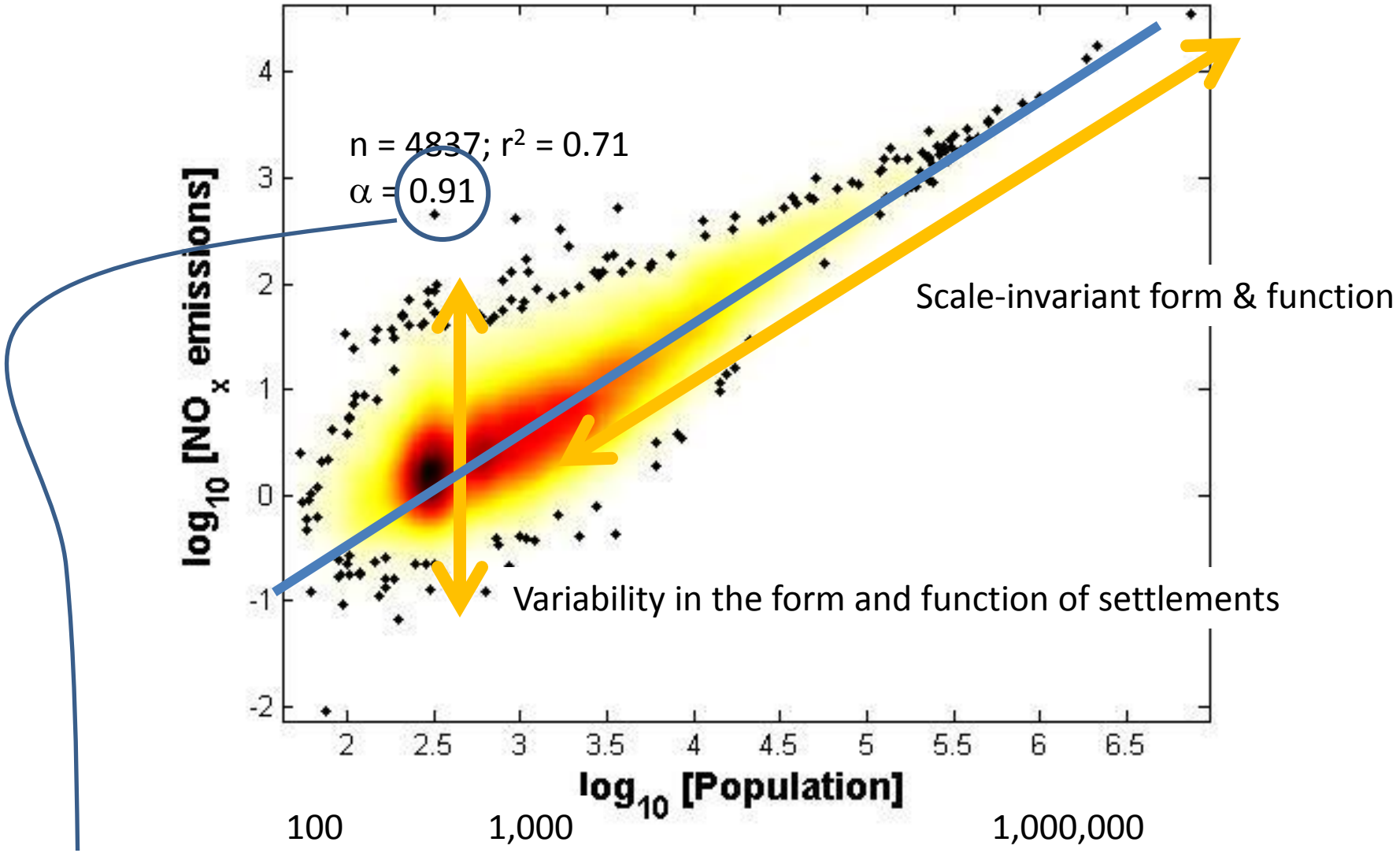


$$Y(t) = Y_0 N(t)^{\alpha}$$

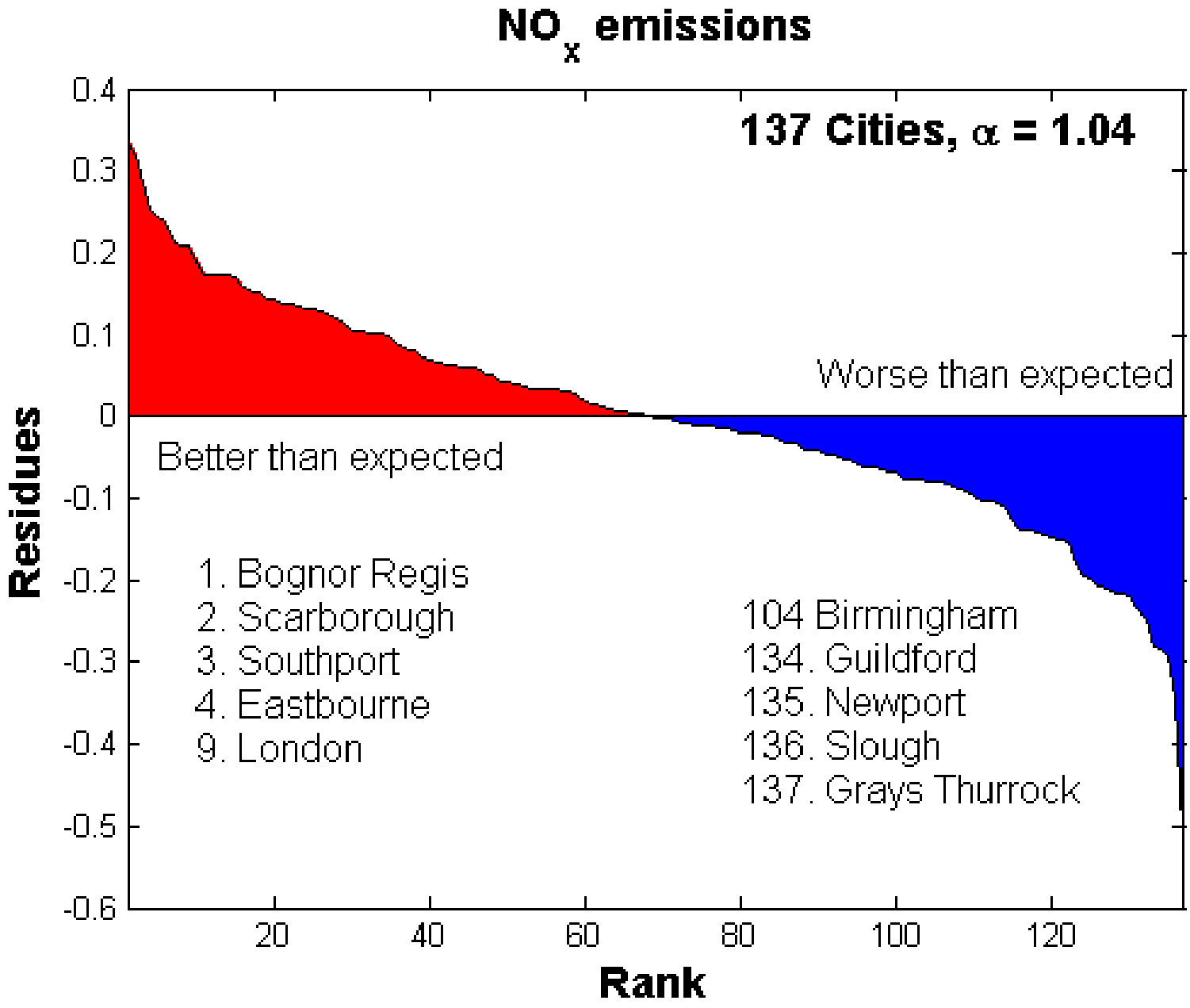
$\alpha < 1$: economies of scale
$\alpha = 1$: proportionality
$\alpha > 1$: increasing returns for scale

Luis Bettencourt & Geoffrey West (2010) A unified theory of urban living, Nature 467, 912–91

The fourth spatial dimension of 4837 UK settlements



Modest “economy of scale” when considering all UK settlements


NOx emissions
137 Cities, α = 1.04
Worse than expected
Better than expected
1. Bognor Regis
2. Scarborough
3. Southport
4. Eastbourne
9. London
104 Birmingham
134. Guildford
135. Newport
136. Slough
137. Grays Thurrock
Residues
Rank
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
20
40
60
80
100
120

The “3n-legged race” to urban sustainability

With the EPSRC Urban Futures Team and the University of Birmingham Future Urban Living Policy Commission

Urban Futures

Cities are built for people (or at least to exploit the potentials people offer)

http://www.redbubble.com/people/cameracrack/works/825377-busy-city

http://flickrhivemind.net/Tags/zebraxing

Sustainability and Interventions I

Sustainability, no matter what definition is used,

is all about the future - putting in place now **interventions** (solutions) to problems that will yield a positive rather than negative future legacy. The essential underlying question is:

"**how sustainable are these interventions?**", while the answer inevitably is:

"**it depends on how the future develops**".

The Future is plural

Futures thinking exploits the human capacity for change

Urban Futures are

- derived from **established philosophical positions**: Hobbes, JS Mill, Adam Smith, Schumacher.
- derived from global scenarios → **consistency** across scales

Derived urban futures can **pressure-test** sustainability solutions

Method gives rise to a **shared rationale** for interventions

can guide practice at every level from policy formulation through to implementation in specific sites, reducing the risk of “box-ticking”.

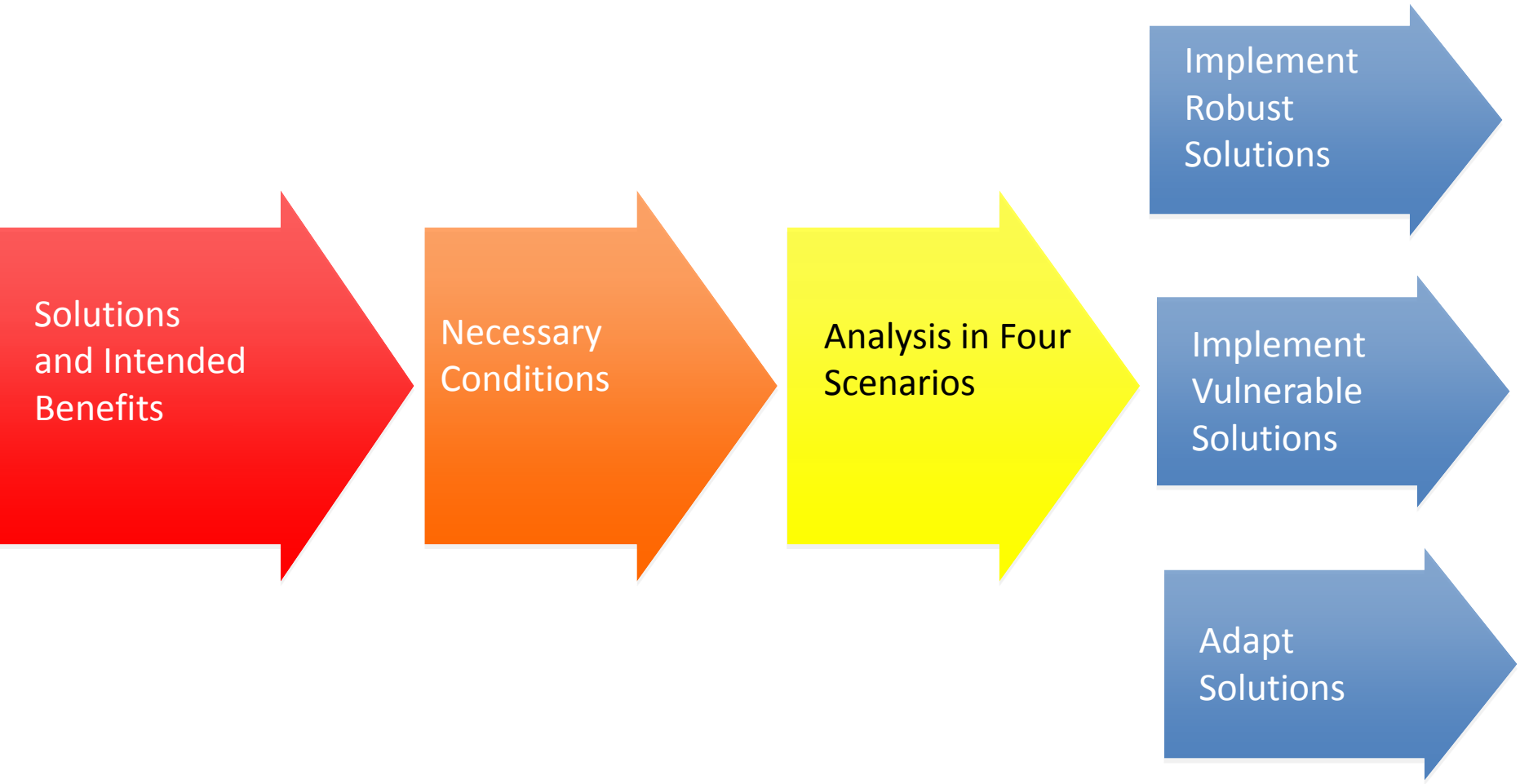
Sustainability and InterventionsII

An **intervention** must have an **intended benefit**,
but it is often lost in the design or decision chains of planning and development.

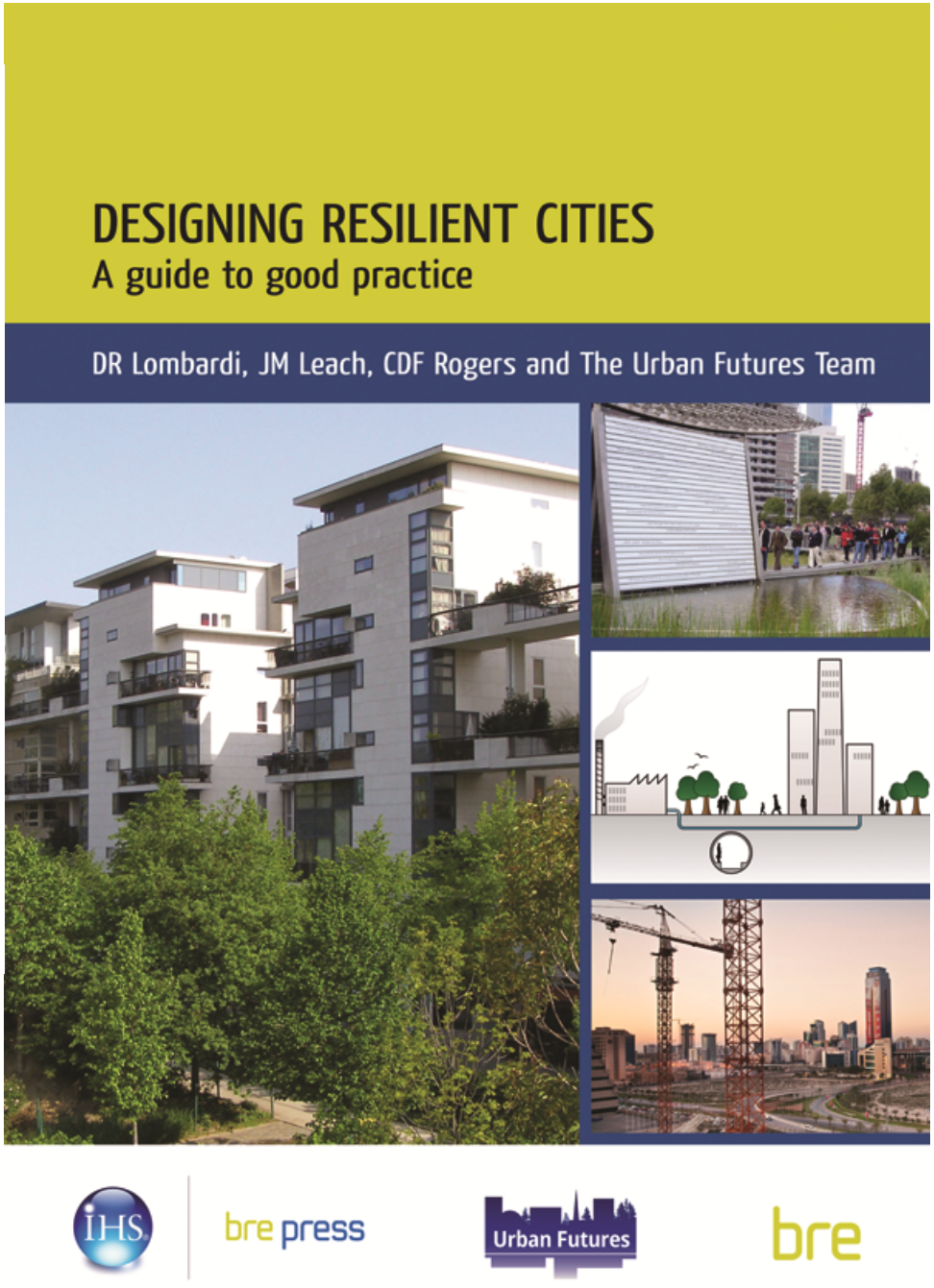
Any intervention can have **unintended drawbacks**.
Drawbacks are often **context-specific**, but so too are benefits.

MacKenzie, A.R., T.A.M. Pugh and C.D.F. Rogers, “Sustainable Cities: seeing past the trees”, Nature, 468, p765, 9 December 2010.

The Urban Futures Method

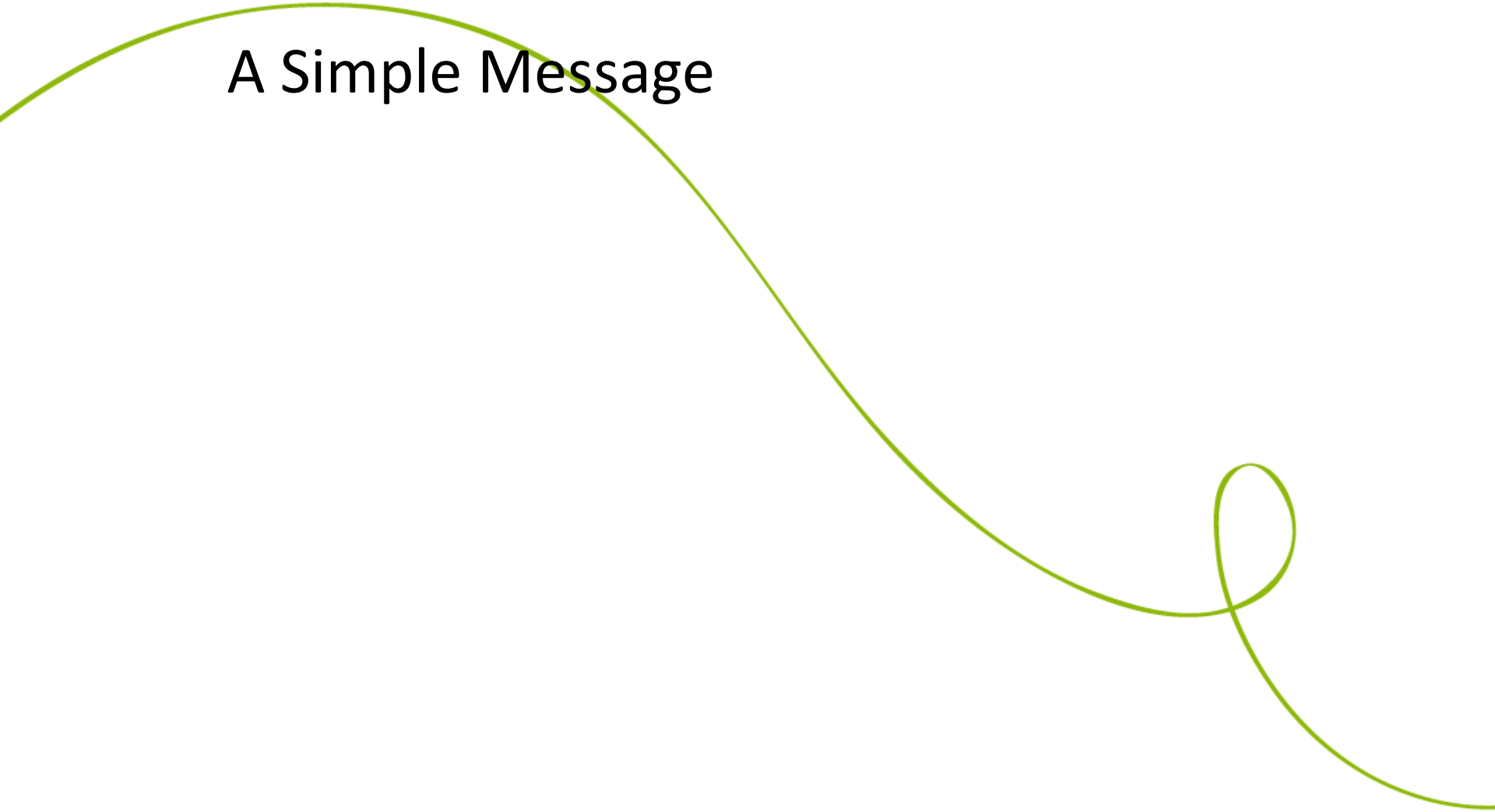


Community organisations Contractors Designers Developers Engineers Environmental consultants Supply chain members	Funding bodies Project managers Risk managers	Local authorities Policy and plan makers
Community-led projects		
Strategic development plans and projects		
Regeneration proposals		



Lombardi DR, Leach JM, Rogers CDF et al. (2012*) Designing Resilient Cities: a Guide to Good Practice*. IHS BRE Press, Bracknell, UK

A Simple Message



Responsive and resilient

cities are for life, not just for people

(and certainly not just to exploit the potentials people and/or finite natural resources offer).

WORLD VIEW *A personal take on events*

Emerging powers need a more-inclusive science

Fast-growing economies can learn from the West's mistakes and couple social and 'hard' sciences to address their own societal needs, says **Colin Macilwain**.

Fast-growing economies can learn from the West's mistakes and couple social and 'hard' sciences to address their own societal needs, says **Colin Macilwain**.

Rio's outdoor gyms reflect the work of researchers such as epidemiologist Pedro Hallal at the Federal University of Pelotas in southern Brazil, who is part of an influential movement to better understand the links between mothers' health, early-childhood exercise and lifelong health outcomes. This is the sort of societal research that the developing world needs as it expands its scientific influence.

"Let's forge this connection between the social science and the hard sciences," Michel Temer, vice-president of Brazil, told the 6th World Science Forum in Rio de Janeiro — the reason for my visit in November. The point was forcefully reiterated by Linxiu Zhang of the Chinese Academy of Sciences, and many other speakers.

Make no mistake: the geographical balance of power in global science is shifting. China has surpassed the United States as the world's largest PhD factory (see *Nature* **472**, 276–279; 2011) and about now, according to a 2011 report by Britain's Royal Society, it is scheduled to surpass the US volume of scientific literature in research journals. Brazil awarded 14,000 PhDs last year.

The shift is accompanied by real political determination from the emerging powers to couple the social sciences with 'hard' science and engineering to address society's needs. For their own pressing political reasons, the leaders of Brazil, China and other fast-growing economies need answers to mounting societal problems — water, food, health, energy and climate change, for example. That is not the case in the United States or Europe, where leaders' priorities are short-term and financial, and science is arranged to suit various stakeholders — notably firms that supply drugs and military equipment — as well as the needs of scientists themselves and their universities.

There are well-charted historical reasons for the West's narrow view of what constitutes science. Around 1900, scientists of the Royal Society of London distanced themselves from colleagues in the humanities (leading to the formation of the British Academy), and the US National Academy

MAKE NO MISTAKE: THE GEOGRAPHICAL **BALANCE OF POWER** IN GLOBAL SCIENCE IS **SHIFTING.**

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trating on technology-led pilots, even though the real roadblock is how people use the technologies we already have.

These are not abstract, philosophical questions: quantitative behavioural research could readily fill knowledge gaps and design processes that would enable people to better manage their energy use, for example. But it does not happen because EU research programmes are also designed around the needs of stakeholders: in this case, device manufacturers, power companies and university scientists and engineers who know the ropes from previous programmes.

Another closely associated issue raised at the Rio meeting is the fact that global science still has a huge problem with research 'silos', in which researchers are obliged to operate within insular, sometimes archaic disciplines. This was broached by physicist Luiz Davidovich, a director of the Brazilian Academy of Sciences in Rio, who called for the "reformulation of the university, towards interaction between disciplines". But the West's funding agencies and universities — as well as its publishing industry — are all set up in ways that have persistently stymied such change. An opportunity surely exists for emerging scientific powers to do things differently as they grow, by building an interdisciplinary outlook into their structures.

The World Science Forum is just one instrument that is attempting to address such problems. In 2012, the Global Research Council was created at the instigation of Subra Suresh, then director of the US National Science Foundation, as a vehicle for the wider governance of science.

Existing worldwide organizations have limited influence, however. The new global agenda is more likely to be driven by the most powerful of the emerging powers: China, in particular, but also Brazil, India, South Korea and South Africa. That group of emerging nations has the opportunity, right now, to build a science that will serve not just the interests of national oligarchies, or of researchers themselves, but of society at large. ■

Air in the age of the city

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The *Geophysica* team (from APE-POLECAT, APE-THESEO, TroCCiNOx and others)
The *OP3* UK-Malaysia-USA-Italy team
The *Urban Futures* team

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Thank you