We're wreaking as much havoc on the Earth's nitrogen cycle as we are on the carbon cycle, and the consequences could be just as serious. But this is a global crisis that few know about. Mark Sutton and Clare Howard describe how scientists from many disciplines are working together to spread the word.

Distilling nitrogen science

The chances are you already know something about nitrogen. You probably recall that it makes up 78 per cent of the Earth's atmosphere in the form of N_2 gas. It is extremely stable, with the result that other, more reactive nitrogen compounds, such as ammonia and nitrates, occur in only trace amounts in the natural environment. These nitrogen compounds are even more important, as they form the building blocks for the amino acids, proteins and DNA that are essential for life itself.

What you may not realise is that the world's nitrogen cycle is now massively disrupted, weaving a tangled web of environmental problems. Over the last century, humans have doubled the rate of formation of reactive nitrogen through fertilizer production and fossil-fuel burning. If carbon and climate change seem to top the public agenda, consider that nitrogen pollution affects both, while also causing air and water pollution that reduces life expectancy and threatens biodiversity. It does this by increasing formation of the greenhouse gas nitrous oxide (N_2O); by affecting rates of plant growth and decomposition, altering species competitiveness and diversity; and by forming harmful gases and particles in the air which we inhale with every breath.

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The difficulty is that the nitrogen cycle is extremely complex, while the traditional approach of scientific specialisation has fragmented our efforts to study it. Most of us are comfortable in our own disciplines, and it becomes a mammoth task to bring together the different aspects. But it is a task we must tackle if society is to make well-informed decisions for the future. As scientists, we need to bring together the evidence and distil nitrogen down to its very essence.

Establishing the European Nitrogen Assessment

European scientists have taken up this vision with great vigour over the past five years. Our starting point was establishing NitroEurope, supported by the European Commission 6th Framework Programme, in which 64 institutions have been collaborating to address how nitrogen affects greenhouse-gas balance. By combining field observations with experiments in which we manipulate nitrogen levels, and with modelling at plot, landscape and European scales, NitroEurope is allowing major advances in understanding how the nitrogen cycle affects climate.

But going the extra mile may have made the largest difference. Additional funding from the European Science Foundation allowed us to establish the first ever continental assessment of the many interacting nitrogen processes, threats and benefits. The result was the 'European Nitrogen Assessment' (ENA), which has been adopted as an activity of the UN-ECE Convention on Long-range Transboundary Air Pollution.

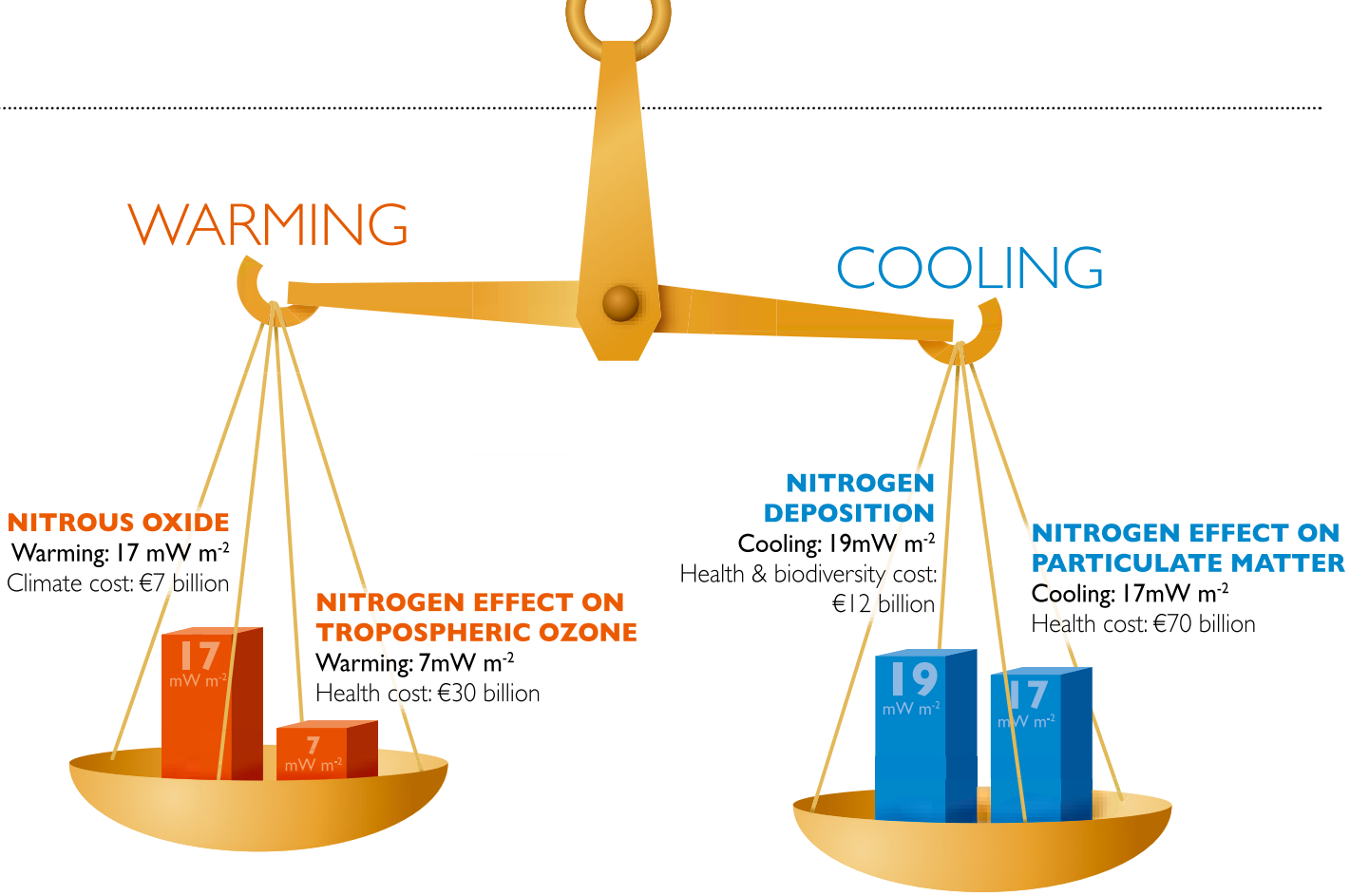
In setting the scope for the ENA, it quickly became apparent that we didn't only need to integrate nitrogen compounds and disciplines, but also the perspectives of scientists, industry and policy-makers. We recognised that there are many policies addressing aspects of nitrogen in the environment. But like the science, these were fragmented, with little overarching coordination of the bigger picture. If we were going to make progress, we not only needed to bring the science together, but also had to communicate it in ways that policy-makers and the public could understand.

Emerging messages

Many planning meetings, expert workshops and peer-review reports down the road, and the ENA was finally launched at the 'Nitrogen and Global Change' conference in Edinburgh this April. The outcome is a 600-page volume, including contributions from 200 experts. By examining existing science and policies, we assessed the nitrogen processes, scaled up from landscapes to Europe, compared benefits and threats, and identified options for the future.

As part of the distillation process, the ENA reduced an initial list of 21 problems to five key societal threats from excess nitrogen: water pollution, air pollution, greenhouse-gas balance, ecosystems and biodiversity, and soil pollution. If you want to remember that, just consider these as the 'WAGES' of too much nitrogen.

The biggest reactive nitrogen source in the European Union is fertilizer manufacture, which the ENA found adds 11 million tonnes of nitrogen to farmers' fields every year. The goal is to increase crop production and provide feeds for livestock. But reactive nitrogen is very mobile and only a small fraction ends up in food products. Most of it leaks into the wider environment – as ammonia (NH_3) into the air, as nitrate (NO_3) into water,



THE OVERALL NITROGEN COOLING EFFECT FOR THE EU is -16 mW m^{-2}, with an uncertainty range of -47 to +16

mW m^{-2} = milliwatts per square metre

Illustration: Nigel Hawtin

and by being turned back into N_2O and N_2 through the activities of denitrifying bacteria.

A further 3 million tonnes of nitrogen is fixed unintentionally to form nitrogen oxides (NO_x) by burning fossil fuels in vehicles, power stations and industry. The NO_x reacts with organic compounds and NH_3 to form ozone and particles in the air, which contribute to shortening lives by more than six months across much of Europe. Once deposited from the atmosphere, nutrient enrichment of natural ecosystems changes biodiversity, causes soil acidification and adds to agricultural run-off, polluting waterbodies and threatening fish populations. As you can see, the five nitrogen threats interact closely.

Importantly, the ENA also estimated the economic cost of nitrogen damage. While such estimates are inherently uncertain, the overall cost is €70-€320 billion per year for the EU, equivalent to £130 to £650 per person. This makes the point very plainly: nitrogen is a key issue for which urgent attention is needed.

The results highlight many challenging messages for society. For example, the ENA calculates that there are both climate warming and cooling effects of nitrogen emissions. We cannot bank on the cooling effects, though, because they lead to much bigger damage costs, due to the effects of air pollutants on human health and ecosystems (see figure). The ENA highlights seven key actions to reduce the adverse effects of nitrogen, while maximising the benefits. These include taking steps to make agriculture more efficient, improved combustion methods, better water treatment and reducing our consumption of energy and animal products.

The measures in agriculture are central, and include opportunities to reduce losses from fertilizers and manures through improved field application, allowing farmers to save on their fertilizer bills. For water treatment, the ENA highlighted that current technology focuses on denitrifying reactive nitrogen back to N_2, thereby wasting a valuable resource. The future challenge includes scaling up technologies to recycle sewage nitrogen safely and cost effectively.

So how do we continue to get the nitrogen message out? A summary published in *Nature* surely helped ('Too much of a good thing', 14 April 2011). But the biggest hit was one of the simplest. The ENA shows that only 15 per cent of the nitrogen in crop harvests goes to feed people – with the rest feeding the European livestock herd. At the same time, the average European citizen eats 70 per cent more protein than is needed for a healthy diet.

In our launch conference for 350 people, we therefore adopted a 'demitarian' menu – eat whatever you like, but the chef has used only half the normal amount of animal products. The outcome was something to think over; the closing survey showed that 92 per cent of the delegates felt they had not 'missed out' on the amount of meat served. ■

MORE INFORMATION

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Sutton MA, Howard C, Erisman JW, Billen G, Bleeker A, Grenfelt P, van Grinsven H and Grizzetti B, (2011) (Eds), *The European Nitrogen Assessment*, Cambridge University Press. **www.nine-esf.org/ENA**

The Barsac Declaration: Environmental Sustainability and the Demitarian Diet. **www.nine-esf.org/barsac-declaration**

The authors worked with Freakworks to produce the ENA launch video, now on YouTube: **www.youtube.com/watch?v=uuwN6qxM7BU**