Effects of net-zero policies and climate change on air quality

Summary

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Cover image Fossil fuel power stations in the English Midlands on a winter morning. These are being replaced by renewable sources of electricity, notably by offshore wind turbines. © pro6x7.

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Policy priorities

The combination of net-zero policies to tackle climate change will accelerate current progress towards clean air in the UK. Options within the range of control measures to achieve net-zero present an opportunity to choose win-wins for climate and clean air and avoid measures which slow the clean-up of the air we breathe.

Expected evolution of critical air pollutants under net-zero measures and climate change

Particulate matter

Outdoor population exposure and effects of particulate matter (PM) on human health are expected to decline as a result of control measures already enacted and many net-zero policies. However, PM will still pose a significant health risk through to 2050 and effects due to indoor exposures will become more important. Additional efforts to reduce PM will therefore be required.

Ozone

Effects of ozone (O_3) on human health and ecosystems/crop production are expected to remain at similar levels to those of 2020 through to 2050, driven mainly by global O_3 background, which in turn depends substantially on natural and anthropogenic methane (CH_4) emissions and other O_3 precursors, including wildfire emissions. International action to reduce CH_4, in combination with national efforts, offer an effective control measure.

Nitrogen

In the absence of large reductions in ammonia (NH_3) from agriculture, UK emissions of NH_3 are expected to grow in response to a warmer climate and will dominate nitrogen deposition and effects on ecosystems and contribute substantially to human health effects through to 2050. Control measures on NH_3 emissions at the UK scale would be effective in mitigating this risk.

Nitrogen dioxide

Emissions and effects of nitrogen dioxide (NO_2) on human health in the UK are expected to decline steadily over the next 20 years as a result of net-zero policies and control measures already enacted.

Net-zero measures which may require mitigation to protect air quality

Combustion of biomass

Combustion of biomass has the potential to lead to reduced net GHG emissions relative to fossil fuels, but could lead to air pollutant emissions, especially particulate matter with a diameter less than 2.5 µm ($PM_{2.5}$).

Cultivation of crops for biofuels

Increased cultivation of fast-growing crops for biofuels may, depending on the land use change, lead to increased biogenic volatile organic compounds (BVOCs) emissions, downwind O_3 and secondary organic aerosol formation.

Hydrogen as a combustion fuel

Use of hydrogen as a combustion fuel has the potential to increase emissions of nitrogen oxides (NO_x), a precursor to O_3 and $PM_{2.5}$.

Image:
Oilseed rape, a crop used to produce biodiesel. © TomAF.

Summary of report findings

Climate change and air pollution are related issues that merit a co-ordinated policy response. Climate change presents a demonstrable and rapidly growing threat to humanity and nature, while air pollution is estimated to account for around seven million premature deaths per year globally[1] and more than 28,000 per year in the UK[2].

About this report

Greenhouse gases (GHGs) and air pollutants have some common sources, notably the use of fossil fuels for power, transport and heat. Some GHGs contribute to poor air quality, such as CH_4, which has contributed substantially to increased O_3 in the troposphere. Air pollutants also influence the climate, some having a warming effect (eg O_3) and some a cooling effect (eg sulphur). Therefore, many policies to reduce GHG emissions will also benefit air quality and vice versa.

Some GHG reduction measures are more beneficial for air quality than others and these can be selected to address climate change and air quality in the most efficient and economical way. However, there are also sources of air pollutants which do not emit GHGs and hence will not be targeted by climate policies. In these cases, air quality-specific measures are needed to further reduce effects of air pollution on human health and the environment.

This report provides scientific evidence to support the design of UK-based policies that maximise the benefits for air quality at the same time as supporting progress towards the target of net-zero GHG emissions by 2050. It also identifies some measures at global scale that are needed to control O_3 over the UK.

The report has four roles:

- it provides evidence of solutions that can address climate change and air quality together;
- it explains how climate change affects air quality;
- it highlights net-zero policies that could have an adverse impact on air quality; and
- it identifies sources of air pollution that will not be tackled by net-zero measures and therefore require additional actions.

1. World Health Organization. 2021. Air Pollution. Available at: https://www.who.int/health-topics/air-pollution#tab=tab_1
2. Public Health England. 2019. Review of interventions to improve outdoor air quality and public health. March 2019. Available at: https://www.gov.uk/government/publications/improving-outdoor-air-quality-and-health-review-of-interventions

The UK context

Historical

The UK's focus on GHG reduction over the last two decades has followed several decades in which air quality was a more visible challenge and often a higher priority for policy makers.

From the Industrial Revolution until the mid-20th century, coal smoke and sulphur dioxide (SO_2) were the pollutants with the most impact on human health and the environment. Following the 1952 London Smog, in which more than 12,000 people died[3], the UK passed the 1956 Clean Air Act, considerably reducing urban emissions of smoke from coal. Sulphur emissions were addressed by measures including the 1979 UN Economic Commission for Europe's Convention on Long-range Transboundary Air Pollution.

In the late 20th century, renewed concerns over air pollution effects on human health led to a new series of measures to reduce transport-related and industrial emissions of PM, NO_x and volatile organic compounds (VOCs), as well as O_3, a secondary pollutant generated by photo-chemical processes from NO_x and VOC emissions.

Present

These controls have greatly reduced air pollution in the UK – as well as changed its composition – but significant sources remain. While fuel and exhaust-related PM emissions from vehicles have been substantially reduced, they are now exceeded by non-exhaust emissions, such as those from tyres and brake systems[4].

NO_2 concentrations have declined, but remain a threat to human health in hot spot areas.

NH_3 emissions also remain close to 20th century levels, mainly from farming sources such as manure, slurries, fertiliser and waste. NH_3 contributes to secondary PM.

O_3 remains a significant pollutant and rising emissions of CH_4, another powerful GHG, contribute to the formation of O_3 in the troposphere.

Looking ahead

While the UK has the clear target of net-zero GHGs by 2050 to address climate change, there is, so far, no equivalent pathway of air pollutant emission targets through to 2050. The establishment of more specific net-zero policies for the next three decades provides an opportunity to consider climate change and air quality together and achieve the twin goals of cleaner air and net-zero GHG emissions.

3. Bell ML and Davies 2001. Reassessment of the lethal London fog of 1952: novel indicators and chronic consequences of acute exposure to air pollution. Environmental Health Perspectives. doi: 10.1289/ehp.01109s3389
4. Air quality expert group 2019. Non-Exhaust Emissions from Road Traffic. Department for the Environment, Food and Rural Affairs. Available at: https://uk-air.defra. gov.uk/library/reports.php?report_id=992

Effects of climate change on air quality

Before examining impacts of net-zero policies, the report considers how climate change itself is expected to affect air quality in the UK by influencing emissions, atmospheric processing and transport of many pollutants. Some of these effects are likely to slow or temporarily reverse improvements in air quality. They are also likely to lead to changes in the seasonal and geographical variations in air quality.

- In summertime, more frequent and intense heat waves are likely to lead to more episodes of O_3 and PM. This reflects the build-up of local emissions under stagnant meteorological conditions along with increases in precursor emissions from vegetation and soils, more moorland fires, and inflow of pollutants from mainland Europe. In contrast, wintertime air quality is likely to improve as the cold stagnant conditions that lead to pollutant accumulation are expected to become less frequent.
- The responses of air quality to climate change will vary across the UK, with the southeast more exposed to stagnant meteorological conditions, high temperatures and continental inflow. The difference between urban and rural air quality is expected to narrow in response to changes in both emissions and meteorology.
- Changes in temperature, humidity and precipitation will alter the emissions, formation, processing and removal of PM, affecting its composition and distribution. While increased removal by rainfall is beneficial, greater formation of PM from organics and NH_3 is a concern.
- Emissions of NH_3, CH_4, BVOCs and soil NO_x are expected to increase with temperature, creating an additional motivation to reduce such emissions now. Reducing NH_3 emissions would decrease PM concentrations and benefit biodiversity by reducing the deposition of reactive nitrogen on sensitive ecosystems.
- O_3 will remain an important global and regional pollutant throughout the period to 2050 and beyond. Climate-driven increases in input from the stratosphere, increased formation from climate-sensitive precursor emissions, especially of CH_4 from wetlands, and increased wildfires will lead to increased O_3 in many parts of Europe. In the UK this will be offset by greater O_3 destruction in air from the Atlantic, a consequence of a warmer, more humid atmosphere. International action to reduce CH_4 and other O_3 precursors would therefore be a win-win for climate and air quality.

Image
Large scale wild fires have been a global feature of recent years and are both a source of air pollutants and CO_2. © David Fowler.

Effects of net-zero measures on air quality

The transition to net-zero will deliver significant improvements in air quality as a co-benefit. The policy challenge is to maximise these improvements while retaining the GHG mitigation. Many of the actions taken to achieve net-zero are unequivocally positive for air quality. In other areas, action can be taken to enhance the air quality benefits, often through small changes. In a small number of areas, net-zero measures may have adverse impacts on air quality that require mitigation or swapping those measures for others that have no adverse effects on air quality (see Figure 1).

The short atmospheric lifetimes of most air pollutants mean that positive health benefits start as soon as the source of pollution is removed, providing a rationale for the prioritisation of net-zero measures that also deliver significant air quality co-benefits.

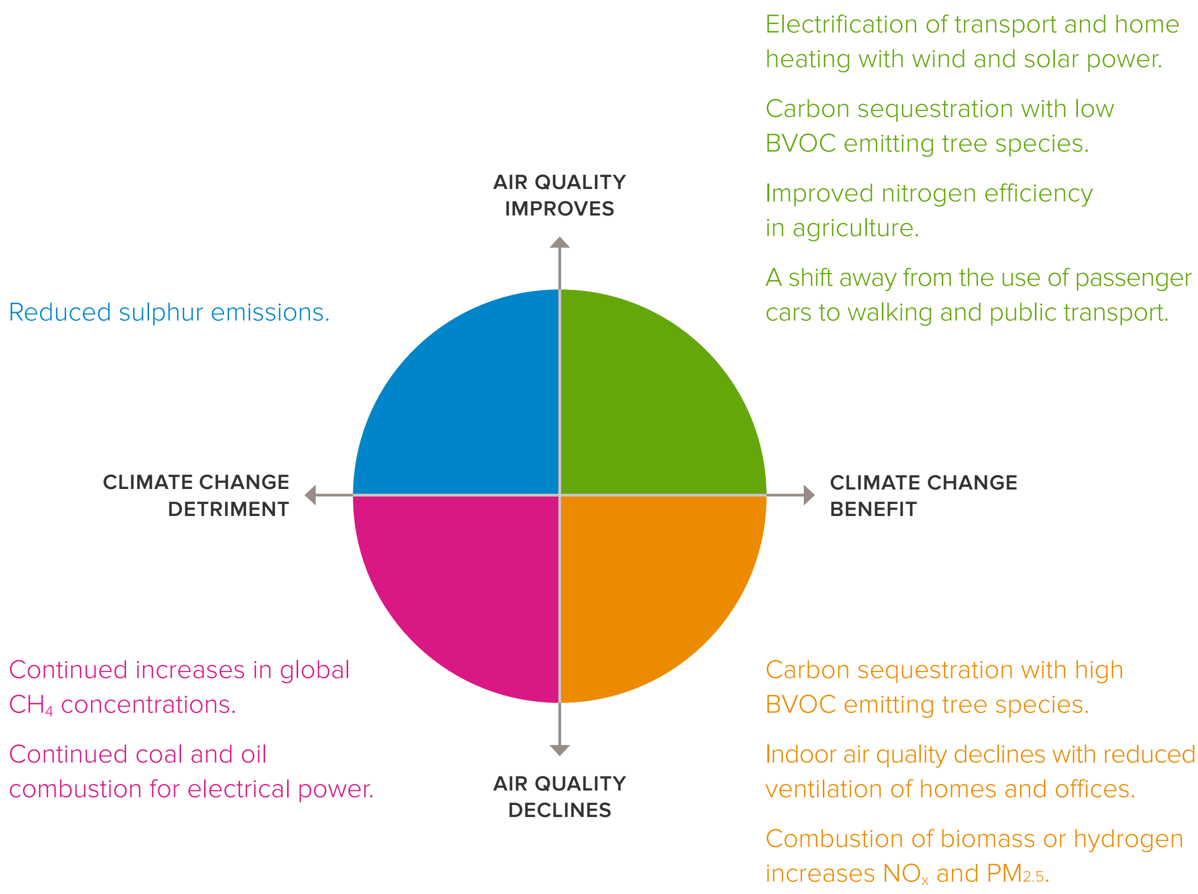
Opportunities with clear co-benefits

- Replacing fossil fuel derived electricity with decarbonised electricity will lead to substantial reductions in emissions of NO_x and SO_2 and hence in $PM_{2.5}$ and O_3.
- 'Active travel' measures that encourage a shift away from car use to walking, cycling and public transport provide both decarbonisation and improvements in air quality, as well as health benefits that extend beyond improving air quality. Reducing demand can decrease emissions that are challenging to address through technology alone, such as non-exhaust PM from road vehicles and aviation jet turbine emissions.
- Improved efficiency in the management of nitrogen in the agricultural system has the potential to reduce NH_3, nitrous oxide (N_2O) and NO_x emissions in most cases. This would feed through into lower concentrations of $PM_{2.5}$ on a regional scale and a reduction in nitrogen deposition onto ecosystems. Measures to reduce dairy and red meat consumption would reduce NH_3 and CH_4 emissions, contributing to cleaner air and the net-zero target, as well as benefiting health.

FIGURE 1

Effects of policies on air quality and climate change

Net-zero measures have a range of impacts on air quality and climate change, providing incentives to maximise benefits for both. This figure illustrates the different responses of air quality and climate change to examples of net-zero measures and controls on air pollutant emissions.



Opportunities to enhance net-zero policies to benefit air quality

A transition to a fully battery electric vehicle fleet should bring significant improvements in urban air quality, benefiting many disadvantaged areas. However, emissions of non-exhaust particles from friction and abrasion such as from tyre, brake and road surface wear, and the resuspension of road dust, will continue to be a significant source of $PM_{2.5}$ emission, even from a fully electric vehicle fleet.

These emissions could increase if average vehicle mass and numbers were to increase, as it may with larger batteries. This ongoing air quality issue can be mitigated by use of regenerative braking, smoother driving through vehicle autonomy, and the use of new pollution control technologies such as particle capture from brake callipers and low emission tyres.

In addition, one consequence of the reduction in urban NO_x emissions is an increase in O_3 concentrations because of a reduction in the chemical suppression of O_3 that takes place via reaction with nitric oxide (NO). The benefits of NO_2 reduction are likely to outweigh any O_3 disbenefit at the roadside, but this effect should be recognised, and regional O_3 pollution mitigated through policies that also reduce O_3 precursor emissions of VOCs.

Net-zero measures that may require mitigation to protect air quality

- Carbon capture and storage (CCS) technologies may involve the consumption of large volumes of chemicals needed for the carbon dioxide stripping process. Possible fugitive emissions of volatile chemicals used in CCS can be controlled through the application of process after-treatment, and by selecting the materials on the basis of low toxicity and environmental impacts.
- While the expansion of decarbonised and nuclear infrastructure to replace fossil fuel assets will lead to air quality improvements, the transition period may have air quality impacts as a result of the temporary use of back-up power facilities, such as diesel farms, to supply capacity in peak periods, as well as construction activities. Mitigations can be introduced to manage such impacts, including enhanced requirements for after-treatment of combustion sources and dust suppression during construction.
- In the residential sector, technologies such as heat pumps and photovoltaics lead to unequivocal local air quality improvements. However, use of hydrogen or biogas boilers would likely lead to some emissions of NO and NO_2, which could be mitigated through enhanced requirements for emissions control and possibly new after-treatment technologies. Minimising leakage of hydrogen will maximise the climate and air quality benefits.

- Indoor air quality can be influenced, either positively or negatively, by net-zero measures. Delivering better indoor air quality in homes, workplaces and public buildings will require independent strategies as it is also influenced by human behaviours, product standards for buildings and furnishing materials, and the use of consumable products.

- Increased cultivation of fast-growing crops for biofuels and the planting of trees to create green urban spaces could lead to increased BVOC emissions, leading to additional O_3 and secondary organic aerosol formation. These impacts can be significantly reduced through use of low-emitting species, such as cultivars of beech and lime, while avoiding large-scale planting of high emitting cultivars of species such as willow and oak.

- Actions on agricultural emissions should avoid 'pollution swapping' to deliver air quality benefits. For example, a switch away from ammonium nitrate fertilisers to urea could increase NH_3 emissions, although partial mitigation is possible through reduced overall consumption and improved farming practices.

- Combustion of biomass can reduce net GHG emissions relative to fossil fuels but could lead to air pollution emissions. After-treatment of emissions from biomass is likely to be cost effective at industrial scale, but possibly less effective at reducing emissions from domestic wood burning stoves or pellet boilers. Avoiding the use of biomass combustion in areas of high population density will be a key mitigation.

- Many of the key pollutants are secondary in nature, being formed in the atmosphere rather than emitted directly, including much of $PM_{2.5}$ and all O_3. These pollutants often have a non-linear relationship to their precursor emissions. In general, the term 'non-linearity' refers to a less than proportionate decrease in the secondary pollutant when the precursor emissions fall. Reducing the secondary emissions thus depends on continued action on the relevant primary emissions. For example, sustained reductions in emissions of NH_3 and NO_x are likely to be needed before substantial UK-wide reductions in resulting secondary PM are experienced. As $PM_{2.5}$ has a longer atmospheric lifetime than NH_3 or NO_2, this will demand continued international cooperation to reduce transboundary transport of pollution.

- Aviation has limited options for decarbonisation and thus for the foreseeable future it seems likely that airports will remain hotspots for air pollution due to emissions of PM, NO_x and VOCs from aircraft, as well as from road traffic and ground operations.

Areas for ongoing investigation

Effects of poor air quality on human health due to PM will likely remain despite the gradual reduction in exposure. There is strong evidence of adverse effects at exposures well below current levels and no identified safe lower concentration limit. The differential toxicity of particles is currently not well understood, which makes it challenging to determine the health impacts of changes in PM composition.

As emissions of pollutants continue to decline from historically dominant sectors such as power generation and road transport, where the emissions are generally well-quantified, a larger proportion of the remaining emissions will originate from diffuse sources where emissions are often not well quantified, such as cooking, ad-hoc burning and agricultural emissions. These changes will require further work on the UK National Atmospheric Emission Inventory.

The changes in pollutant concentrations expected through to 2050 will have implications for their measurement in terms of the appropriate locations of monitoring sites and the relative importance of different source types. For example, there may be less need for roadside monitoring sites as vehicle exhaust emissions diminish.

Image:
Livestock, an important source of methane and ammonia emissions in the UK © vm.

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