CLEAN AIR FUND

ACCELERATING ACTION ON TROPOSPHERIC OZONE

A Strategic Roadmap for 2025–2030

CONTENTS

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EXECUTIVE SUMMARY

Tropospheric ozone is a powerful but under-addressed greenhouse gas and super pollutant that poses a triple threat to climate stability, public health and food and ecosystem security.

Unlike many other pollutants and gases, ozone is not emitted directly but is formed through complex chemical reactions involving methane, nitrogen oxides (NOx), carbon monoxide (CO) and non-methane volatile organic compounds (NMVOCs) in the presence of sunlight. Many of these 'precursors' are co-emitted from key sectors such as transport, energy, waste and industry. The relationship between ozone and its precursors is non-linear, so reducing just one precursor in isolation may not reduce ozone – and could even increase it under certain atmospheric conditions. These interactions make ozone a uniquely challenging pollutant to manage, but it cannot be ignored. As the world rapidly warms, levels of tropospheric ozone are projected to increase in all business-as usual scenarios,[1] exacerbating the most damaging impacts of climate change and harming health, agriculture and ecosystems.

Responsibility for reducing ozone typically falls to sub-national actors (i.e., cities and states) trying to achieve national air quality standards. Yet, this only tackles part of the ozone problem. Methane mitigation addresses some of the climate impacts of ozone as an unintended and indirect byproduct. The agricultural and ecosystem effects of ozone are almost not addressed at all. This fragmented approach cannot prevent ozone's projected increase, undermining global climate and health agendas.

Tropospheric ozone is complex, but we cannot let the technical complexities deter us from urgent and strategic action. Ozone is a systems problem, and we must treat it with a systems solution: one that is multi-pollutant, multi-level and cross-sectoral. This roadmap calls for an integrated approach to tackling tropospheric ozone based on three principles:

1. **Multi-pollutant approach:** A multi-pollutant strategy considers how to address multiple pollutants together rather than addressing them one by one. The latter is the traditional approach within air quality management and climate change mitigation. But as a secondary pollutant with a non-linear relationship to its precursors, tackling ozone via a precursor-by-precursor approach could bring unintended consequences of increasing levels of ozone. A multi-pollutant approach ensures that actions on air quality, super pollutants and greenhouse gases are mutually reinforcing, maximise co-benefits and avoid unintended consequences.

2. **Multi-level governance:** Coordinated action across global, regional, national and sub-national levels of governance – the laws, treaties, institutions and decision-making structures that shape how pollutants are managed – is essential to pull together the fragmented system in which tropospheric ozone is – or is not – currently managed. Such an approach would ensure that ozone is considered coherently by stakeholders within multiple policy arenas, supports more effective and predictable outcomes and avoids counterproductive policy choices.

3. **Cross-sectoral lens:** Tropospheric ozone harms lungs and warms our planet, and precursor emissions come from a multitude of sources, from cement production to wildfires. As such, multiple sectors must be considered when developing and implementing solutions to mitigate the wide-reaching impacts of this super pollutant. A cross-sectoral approach identifies opportunities for alignment within existing policies and practices, while also embedding ozone in areas where it has not previously been considered.

IMPACTS OF THE TROPOSPHERIC OZONE ON CLIMATE, HEALTH, AGRICULTURE AND ECOSYSTEMS:

0.23°C
global warming to date

500,000
premature deaths per year

$0.5 trillion
economic costs per year

Up to 26%
loss in global crop yields

11%
loss in forest productivity

Ozone is not just a scientific puzzle, but a real-world pollutant rising in many regions, even where other pollution is falling. The next five years are a decisive window for climate and sustainable development. To limit global warming to 1.5°C, as outlined in the Paris Agreement, global greenhouse gas emissions must be reduced by 45% from 2010 levels by 2030 and reach net zero by 2050.[2] At the same time, we must reduce super pollutants like methane, tropospheric ozone and black carbon to secure fast climate benefits and avoid crossing critical tipping points. Action on tropospheric ozone is uniquely positioned to help achieve climate and health goals if we strategically utilise the policies, platforms and frameworks already in place. If taken to their full potential, reductions of tropospheric ozone precursors, alongside reductions of methane, could result in 0.30 °C of avoided warming by 2050.[3]

This roadmap outlines a strategy to 2030 that builds on existing climate and air quality platforms while embedding ozone into broader systems of governance. Previously, we made **The Case for Action on Tropospheric Ozone**, based on the promise of fast, cross-cutting environmental and health gains. This roadmap focuses on how to put those recommendations into motion. Our goal is to describe what needs to be done and to chart a clear path towards implementation, illustrate how it can be delivered and what support systems are required. Building a new 'campaign' to tackle tropospheric ozone is unlikely to be an effective use of time, effort and funds. We urge a pragmatic approach, integrating ozone action into existing opportunities, strategies and systems. This could transform what is currently fragmented and invisible into powerful joined-up action.

This roadmap is structured around four pillars:

1. **Scientific evidence into policymaking.** Closing gaps in data, modelling and understanding of ozone's impacts across spatial and temporal scales.
2. **Integrated policy and governance.** Embedding ozone within global frameworks, regional agreements and national climate and air quality plans.
3. **Accelerating targeted measures**. Scaling up practical, multi-sectoral solutions within and outside of existing decarbonisation efforts.
4. **Increased awareness through communications.** Elevating ozone in political discourse and supporting a shared understanding of its impacts and solutions.

Together, these workstreams provide a coordinated, actionable plan to reduce tropospheric ozone, protect public health, safeguard food and ecosystems and help deliver meaningful climate mitigation by 2030.

If taken to their full potential, reductions of tropospheric ozone precursors, alongside reductions of methane, could result in

0.30 °C

of avoided warming by 2050.[3]

PART 1:

BUILDING THE FOUNDATION FOR INTEGRATED OZONE ACTION

1. INTRODUCTION: THE CRITICAL ROLE OF TROPOSPHERIC OZONE IN WARMING OUR CLIMATE, HARMING OUR HEALTH AND HURTING OUR ECOSYSTEMS

WHAT IS TROPOSPHERIC OZONE AND WHAT ARE ITS IMPACTS?

Climate impacts: Tropospheric ozone (O_3) is a greenhouse gas. It is responsible for approximately 0.23°C[i] of present-day warming and it is one of the super pollutants that are collectively driving half of global warming.[4] Tropospheric ozone is different from the ozone layer, which protects us from harmful radiation (see figure 3). It is unique because it is not directly emitted. Instead, it's formed in the atmosphere through chemical reactions involving a suite of pollutants in the presence of sunlight. These pollutants, known as precursors, include methane (CH_4), nitrogen oxides (NOx), non-methane volatile organic compounds (NMVOCs) and carbon monoxide (CO). These precursors are emitted from a range of activities and sectors, including transport, industry, livestock and energy, as well as wildfires and some natural sources.

Notably, higher temperatures increase chemical reaction rates in the atmosphere, increasing ozone formation.[5] This means that warmer temperatures linked to climate change can contribute to periodic episodes of significantly elevated tropospheric ozone levels, resulting in a vicious feedback loop. Alongside deep decarbonisation, tackling tropospheric ozone precursors could result in 0.30 °C of avoided warming by 2050,[ii] complementing efforts to limit warming to close to the Paris Agreement goal of 1.5 °C.[6]

Health impacts: Tropospheric ozone is also an air pollutant with direct impacts on human health. At the ground-level, ozone is a significant risk factor that contributes to the development and worsening of respiratory diseases such as asthma, chronic obstructive pulmonary disease (COPD) and other respiratory conditions.[7,8] There is also a growing link between ozone exposure and metabolic disorders, affecting those with diabetes and cardiovascular conditions.[9,10] Exposure is also an equity issue, as ozone is most harmful to vulnerable populations, including children, the elderly, individuals with pre-existing medical conditions, as well as those in lower socioeconomic groups. In recognition of these impacts, the World Health Organization (WHO) has set a population exposure target for ozone as part of its Air Quality Guidelines.[11] These guidelines for ozone have been tightened over time to reflect the growing evidence of its health harms. Estimates indicate that ozone exposure is responsible for approximately 500,000 premature deaths annually,[12] although new research puts the figure much higher, at nearly 1.6 million deaths from short- and long-term exposure.[13] The associated healthcare costs are estimated to exceed half a trillion USD.[14]

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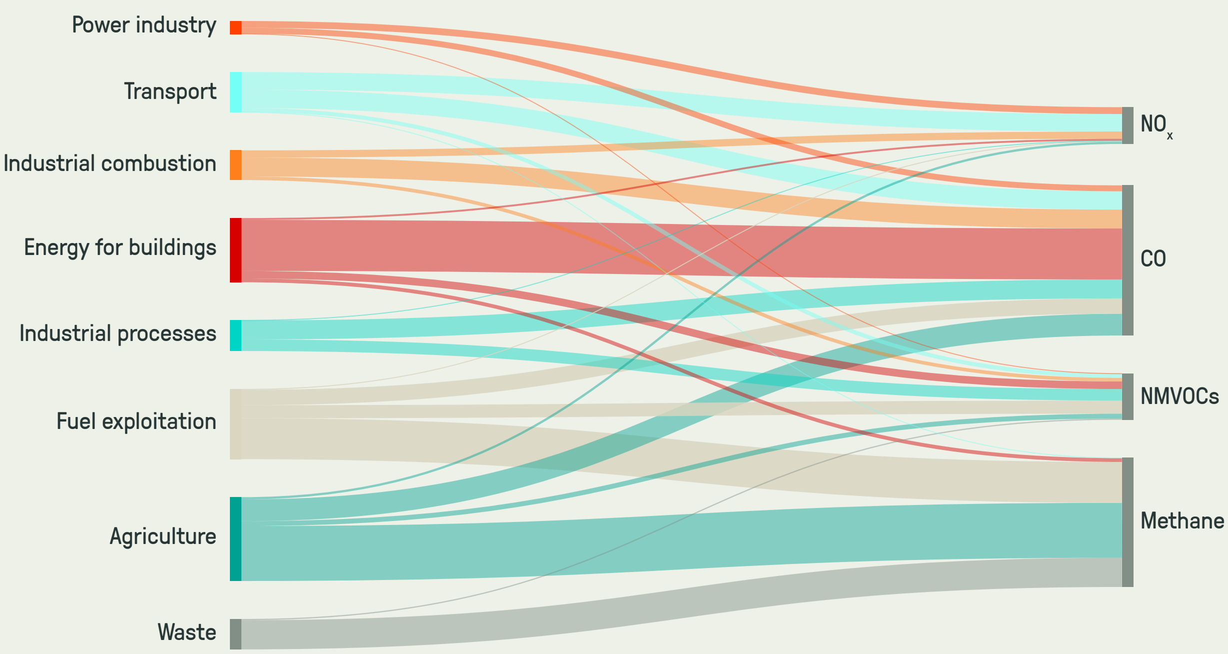
i Warming to date estimate is from IPCC Assessment Report 6, Chapter 7, with a mean value of 0.23°C following a concentration-based calculation method. This value captures climate forcing of tropospheric ozone (large positive forcing) and stratospheric ozone (small mostly negative forcing). A similar value (0.25°C) can be calculated through data provided in IPCC Assessment Report 6, Chapter 6 by extrapolating from tropospheric ozone precursor emission contributions to warming.

ii Methane reductions and methane-mediated ozone reductions are projected to result in 0.19 degrees of avoided warming. Reductions of non-methane ozone precursors (NMVOCs, CO, NOx) are projected to result in 0.11 degrees of avoided warming by 2050. Taken together, these pathways could result in 0.30 degrees of avoided warming.

Ecosystem and agricultural impacts: Tropospheric ozone is a super pollutant, meaning it's part of a powerful group of pollutants and gases that are more potent tonne for tonne at warming the climate than CO_2.[15,16] Ozone is short lived, with a life span in the atmosphere of just a few weeks on average, although this can fluctuate depending on the season and the weather.[17] Despite this short lifetime, elevated levels of tropospheric ozone cause significant damage to plants and ecosystems. It reduces the ability of forest ecosystems to sequester carbon, and damaged forests are then unable to provide a carbon sink, meaning that more carbon dioxide is left in the atmosphere contributing to global warming processes.

Tropospheric ozone also accelerates the leaf aging process in plants and severely damages crops, leading to reduced grain size, fewer seeds, slower growth rates and less resilience to environmental stresses. Globally, it is estimated that tropospheric ozone accounts for up to 26%[iii] crop yield loss on staple crops such as rice, maize and wheat, which billions of people rely on, threatening food security.[18] At the global and regional scale, the crop loss due to ozone exposure is comparable or even higher than losses attributed to other stressors like low soil nutrient availability, pest attacks, heat and aridity. Total global economic losses due to ozone crop damage could amount to $35 billion annually.[19]

FIGURE 1: RELATIONSHIP BETWEEN GLOBAL TROPOSPHERIC OZONE PRECURSOR POLLUTANT EMISSIONS AND THEIR ASSOCIATED EMISSION SOURCES AND SUB-SECTORS



Data source: EDGAR emission inventory. Note figure does not include emissions from wildfires.

iii Estimated crop yield losses due to tropospheric ozone exposure vary significantly depending on crop species, geographic region, local ozone concentrations and modelling assumptions. Recent studies have reported Relative Yield Losses (RYL) for wheat and rice to be ~21–26% and 9-10% over India. Over China, national mean RYL for wheat is estimated 11.45 %–19.74 %. These estimates are based on experimental data and models, but vary with location, crop type and co-occurring stressors like heat and drought. While ozone poses a substantial risk to global food security, the exact magnitude of its impact should be carefully interpreted.

SETTING OUT A ROADMAP FOR INTEGRATED ACTION

Urgent implementation is critical to slowing ozone-driven warming, protecting public health and building climate-resilient food and ecosystems. As global temperatures rise and emissions patterns and interactions grow increasingly complex, tackling ozone requires a shift from siloed approaches to a coordinated, multi-pollutant strategy. Implementing a holistic approach to reducing tropospheric ozone recognises ozone formation as a systems-level issue influenced by multiple, interacting pollutants from the local to global scale. This document outlines such a strategy.

To build this roadmap, we gathered data through focus groups, workshops, an online survey and other formal and informal engagement opportunities. Nearly 100 stakeholders were consulted, spanning government, academia, industry and more.

This roadmap identifies where action on tropospheric ozone is already occurring, often indirectly or unevenly, and identifies where more deliberate integration and engagement are needed to activate a whole-system response. First, we must understand the nature of the tropospheric ozone problem.

2. THE CHALLENGES OF REDUCING TROPOSPHERIC OZONE

Tropospheric ozone is complicated, but it's not impossible to tackle, nor is its complexity unique – we have previously managed similar challenges like reducing sulphur emissions to mitigate the devastating ecosystem impacts of acid rain. We cannot let the challenges of ozone management become a barrier to action as this will delay benefits, deepen harms and pass the burden on to the most vulnerable in our society. Facing up to the complexities of tropospheric ozone, not just from a chemical perspective but from a policy point of view, will allow us to see new entry points for progress within existing systems.

WHY IS TACKLING TROPOSPHERIC OZONE DIFFICULT?

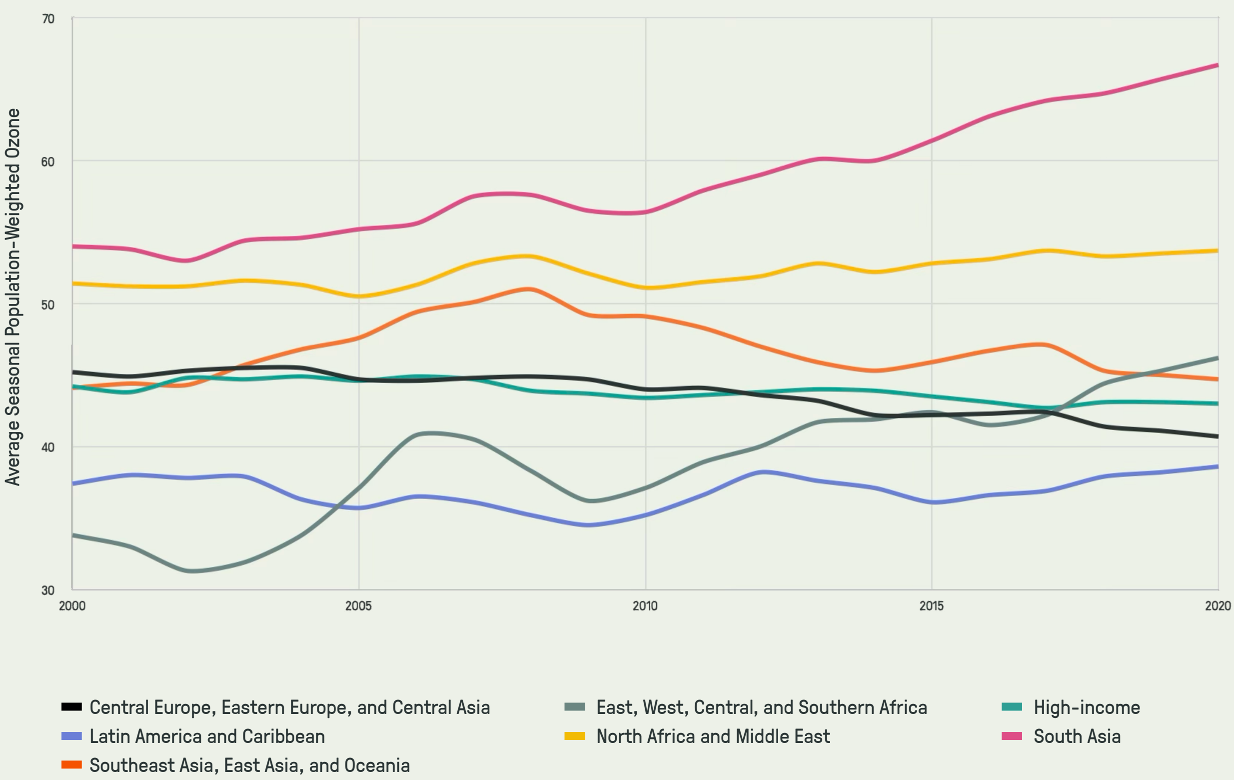
Tropospheric ozone has increased by between 2-12% per decade since 1995, depending on the region (see figure 2).[20] While there is technical awareness and expertise on how to reduce ozone, implementing these measures proves challenging. The complex mix of precursor pollutants, emissions sources and environmental factors make reducing tropospheric ozone difficult for scientists and policymakers at all levels. Not all reductions of precursor emissions will correspond to local reductions in tropospheric ozone levels. A region's specific mix of precursor pollutants and meteorological and climatic conditions determines whether reducing methane, NOx, NMVOCs and/or CO is the most effective route. In certain cases, a decrease in a precursor emission may even increase local tropospheric ozone levels (see Box 1). Furthermore, managing tropospheric ozone within the Global South is particularly challenging due to limited monitoring infrastructure, even in major urban centres, and constrained capacity to apply technical tools like air quality models, which are essential for effective ozone control.

Air quality regulations typically address pollutants like NOx, NMVOCs and CO. To tackle the complexity of ozone's non-linearity, decision-makers need to have a deep understanding of the local mix of precursor pollutants and their sources. Much of the knowledge and understanding of how to do this has come from the air pollution sector and advances in air quality management over the past 40 years. However, even in locations where efforts to reduce ozone have previously been successful, such as in Los Angeles, ozone levels have plateaued or increased. This stagnation or increase is not necessarily due to poor air quality managment, but because the long-range transport of ozone precursors can elevate background ozone concentrations over different continents.[21] And in China, where national and sub-national air quality efforts have significantly reduced particulate matter, and made some progress on reducing ozone, levels of ozone are steadily increasing.[22]

The other significant precursor to ozone is methane, which sits within the remit of the climate sector. Methane is a super pollutant and greenhouse gas with significant warming potential and is responsible for about 40% of tropospheric ozone formation.[23] The Global Methane Hub and the Global Methane Pledge are leading reduction efforts. Some 159 countries have pledged to meet a collective, global target of reducing methane emissions by at least 30% by 2030 (from 2020 levels). The Pledge has also mobilised more than $2 billion since it was launched in 2021.[24]

With these commitments in place, the methane movement is shifting towards implementation across waste, agriculture and energy. This is more critical than ever because despite these collective efforts, global methane emissions have increased by 26% over the past 25 years.[25] Recent research also shows that methane emissions are increasing at a much higher rate than predicted.[26] While some of this additional methane may come from natural sources like wetlands, this sudden and fast increase suggests that current methane reduction efforts alone are not enough to offset this growth. Rising methane emissions account for approximately half of the increase in tropospheric ozone levels observed to date.[27]

FIGURE 2: ANNUAL AVERAGE POPULATION-WEIGHTED GROUND-LEVEL OZONE CONCENTRATIONS (2000-2020)



Data source: Health Effects Institute (2024) State of Global Air 2024. Special Report. Boston, MA: Health Effects Institute.

BOX 1:
THE COMPLEXITIES OF TROPOSPHERIC OZONE

Tropospheric ozone is challenging because it is a secondary pollutant and the product of a dynamic, non-linear system. Tropospheric ozone's complexity falls into several categories:

COMPLEX CHEMISTRY:

- Tropospheric ozone precursors (methane, NOx, CO and NMVOCs) interact in complex, non-linear ways in the atmosphere. Their relative ratios, atmospheric lifetimes and reaction pathways all determine how much ozone is produced in a given place and time.
- Some precursors, like VOCs, come from natural sources like plants, and these biogenic sources are often not captured in models that only focus on anthropogenic emissions. This gap complicates emission control strategies.

NON-LINEARITY:

- Ozone formation is not proportional to precursor levels. In some environments, for example, reducing NOx will decrease ozone, but in others, this reduction in NOx can paradoxically increase ozone.
- This non-linearity means that reducing emissions of one precursor may backfire without a simultaneous reduction in others. The relationship between precursors can change over time and vary between relatively small areas – different areas of the same city might experience ozone levels driven by different mixes of precursors. Local chemical regimes and atmospheric conditions must be understood before designing policies.

SUNLIGHT:

- The chemical reactions that create tropospheric ozone occur in the presence of sunlight (UV radiation). Cloud cover can reduce the UV intensity and slow these chemical reaction rates, meaning that ozone formation is affected. Seasonal and daily variations in sunlight mean that ozone concentrations fluctuate significantly even with constant precursor emissions.

TEMPERATURE:

- Ozone formation accelerates in heat because higher temperatures increase the rate of photochemical reactions. Heat also stimulates more biogenic emissions of NMVOCs. This means that tropospheric ozone tends to be a bigger problem in hotter, sunnier locations.
- This heat sensitivity creates a feedback loop where, as our planet warms, there is more ozone, and more ozone also causes additional warming. This also exacerbates ozone's regional climate impacts, where ozone's radiative forcing is stronger in some areas than others.[28]

WEATHER:

- Ozone pollution is highly weather-dependent. In some locations, clear skies and low wind might prevent pollutant dispersion, concentrating ozone and its precursors. Wind patterns can also transport ozone and its precursors across regions and borders.
- Even with declining precursor emissions, adverse meteorological conditions can lead to persistent or unexpected ozone spikes. This complicates attribution and forecasting.

TOPOGRAPHY:

- Geographic features like valleys, mountains and basins can intensify local ozone formation and lead to hotspots, especially in cities surrounded by hills or mountains.

HUMIDITY:

- Humidity is context-dependent and can complicate modelling and prediction efforts. Low humidity (under 50%) can lead to ozone formation because it allows for greater penetration of sunlight in the atmosphere and can increase chemical reactions. In contrast, higher humidity promotes precipitation and reduces radiation, thereby suppressing ozone formation.[29]

- However, a warming climate is also increasing humidity levels in certain regions. Increased humidity influences the overall greenhouse effect of climate change, and regional differences can further complicate the relationship between heat, humidity and ozone.[30]

SPATIAL AND TEMPORAL VARIABILITY:

- Ozone can vary hourly, seasonally and geographically, across urban and rural areas. Ground-level ozone levels typically peak in the afternoon and during hot summers. Regulating ozone generally requires a multi-scale, time-sensitive strategy.

CROSS-SECTOR AND CROSS-BORDER IMPACTS:

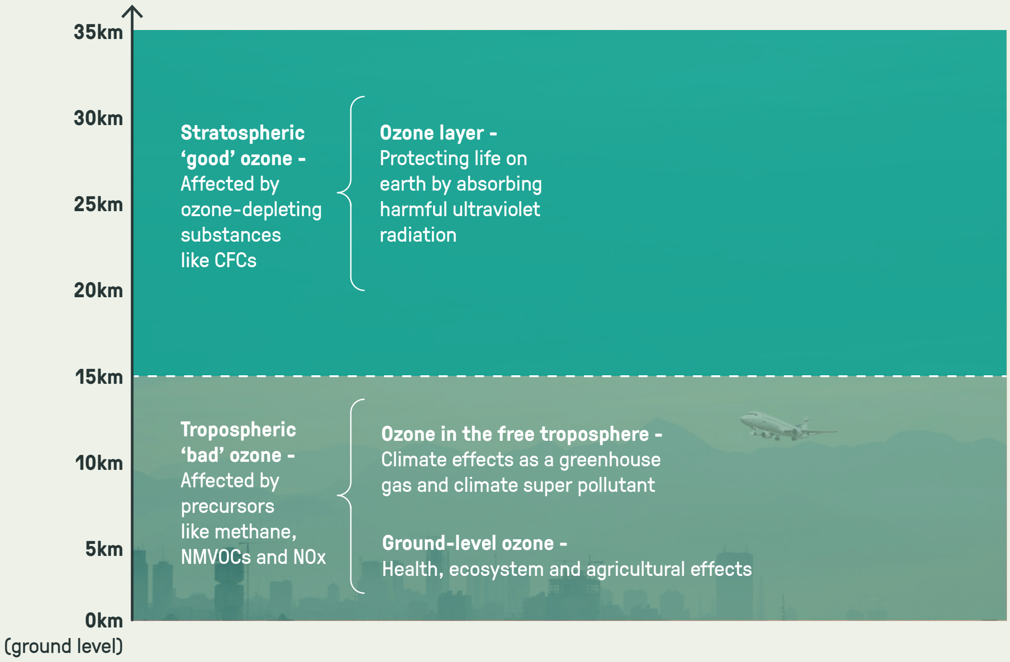
- Precursor emissions come from multiple sectors like energy, transport, agriculture, industry and natural systems (e.g., forests). These precursors, and ozone itself, can travel across regions and borders, so effective ozone control requires coordination across sectors and between jurisdictions.

UNDERSTANDING THE ATMOSPHERE AND HOW OZONE IS MANAGED

The chemical and spatial complexities of tropospheric ozone are mirrored by jurisdictional complexities that make ozone challenging to manage effectively across all its impacts – climate, health and ecosystems and agriculture. We must understand the atmospheric space in which ozone exists in order to fully address it.

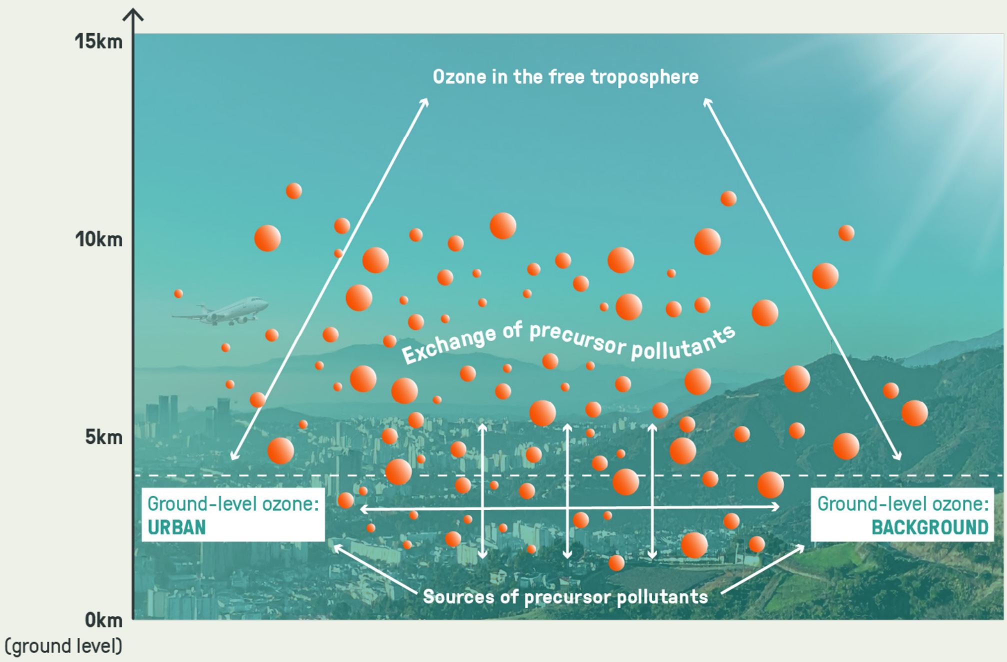
Ozone exists in two layers of the atmosphere, the troposphere and stratosphere (see figure 3). It is important that the presence and role of each is not confused:

FIGURE 3: GOOD VS BAD OZONE



Ozone in the upper layers of the atmosphere, called stratospheric ozone, is 'good ozone' which protects us by absorbing harmful ultraviolet radiation through the ozone layer. Closer to the earth's surface, in the troposphere, is where we find 'bad ozone' (see figure 4).

FIGURE 4: ZOOMING IN ON THE TROPOSPHERE



The term 'tropospheric ozone' generally refers to all ozone in the troposphere, however this is not one distinct problem. At the ground level, ozone's impact in urban areas is largely on human health, due to the population density of people living in cities.

Free tropospheric ozone (FTO) is ozone found in the middle and upper parts of the troposphere, above the ground level but below the stratosphere. Increases in ozone at this level affect the climate more than ozone at the ground level. FTO is formed both by the movement of precursors up from the ground-level and exchanges between the stratosphere and troposphere. Importantly, ozone in the free troposphere can also be transported back down to the surface, therefore adding to ground-level ozone.

The troposphere also contains background ozone. This refers to ozone formed from natural events like a wildfire, transboundary pollution sources or meteorological events like a stratospheric intrusion.[iv,31] In rural environments with lower population density, background ozone's impact is largely seen on crops and in forests.

Precursor pollutants move across the troposphere, so what happens in one area may affect the chemical balance of the atmosphere in another area. For example, a wildfire in a rural area may result in a spike in ozone in an urban area, while an increase in emissions of precursors in an urban area may result in more ozone in a rural area.

These distinctions within the troposphere are important because they are linked to how ozone is managed across air pollution and climate policies. Practical strategies and practices within the air pollution and climate change sectors generally follow different approaches due to the differing nature of the pollutants and gases at play.

Air pollutants, such as particulate matter and NOx, are released into the atmosphere and can remain close to where they were emitted, although these pollutants can also be transported throughout regions and across international borders. These pollutants have a direct health link, causing harm to those who are most exposed and most vulnerable, like children and the elderly. The drive to reduce these pollutants comes from a public health perspective, as cities and regions aim to improve the health of their citizens, reduce medical costs and increase overall economic productivity.

Stakeholders within the climate community are typically focused on reducing emissions of greenhouses gases, such as carbon dioxide, because of their powerful warming potential. Carbon dioxide is a well-mixed greenhouse gas, meaning that it is relatively evenly distributed in the atmosphere regardless of where it was emitted and it can remain in the atmosphere for hundreds of years. With climate warming being driven by changes in total global emissions, policy formulation therefore also tends to be driven by global level agreements and multilateral processes.

Despite its far-reaching health, ecosystem and climate impacts, current policy frameworks treat ozone in fragments (see figure 5). Urban ozone is generally addressed under national and city-level air quality legislation and there is some monitoring of ozone through regional air pollution agreements, while the climate implications of ozone in the free troposphere are generally not addressed by any single stakeholder. It tends to be indirectly affected by methane mitigation strategies under global climate agreements or national-level methane mitigation plans. Background ozone, with its significant impacts on ecosystems, agriculture and biodiversity, is rarely a direct priority for environmental ministries or international negotiations. There is currently no single mechanism that connects these approaches under a unified objective to reduce the total tropospheric ozone burden.

iv Stratospheric intrusions occur when ozone-rich air from the upper atmosphere descends into the lower troposphere, temporarily raising ground-level ozone concentrations.

FIGURE 5: TYPES OF OZONE AND ITS MANAGEMENT

TYPE OF TROPOSPHERIC OZONE	DIRECT IMPACT	CURRENT MANAGEMENT
Ground-level, urban	Health	Controlled by air quality policy and standards at the national and sub-national level.
Ground-level, background	Agriculture, ecosystem	Managed through regional air quality agreements and generally included within national air quality standards, but not a focus of agriculture or ecosystem stakeholders. Methane mitigation covers much of this area.
Free tropospheric	Climate	No existing climate agreements cover this. Methane mitigation is the main indirect form of climate action on ozone.

Critical gaps in understanding, prioritisation and decision-making around how to best reduce levels of tropospheric ozone persist. The current approaches to managing tropospheric ozone tend to focus on one part of this complex problem that cuts across multiple levels of government, sectors and political remit. Levels of tropospheric ozone are predicted to increase in all business-as-usual scenarios as the world continues to warm.[32,33,34,35,36]

3. POLICY GAPS AND FRAGMENTATION: THE CHALLENGE OF GOVERNING TROPOSPHERIC OZONE

Within this fragmented, technical system, tropospheric ozone is regulated indirectly, inconsistently and often as a byproduct of other priorities like methane mitigation. The strategy presented in Part 2 of this roadmap aims to unlock progress by working with and through the existing frameworks for regulating climate and air pollution at the global, regional, national and sub-national levels. It's first important to understand why these frameworks currently exist, at what levels of governance and their limitations.

We define these multiple levels of governance and their scope as follows:

GLOBAL:

- This refers to inter-governmental and multi-lateral processes, systems and bodies including the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC) as focal points for climate change action, the WHO for health, including the impacts of air pollution, and the United Nations Food and Agriculture Organization (FAO) within food and agriculture systems.

- Action at this level makes sense for climate change because greenhouses gases are well-mixed, meaning that they are evenly distributed in the atmosphere regardless of where they are emitted.

Generally, actors within these processes are focused on actions to reduce greenhouse gas emissions, whilst also increasing focus on adaptation measures to manage the effects of unavoidable climate change. However, at this global level of governance, nearly all agreements and actions are voluntary and non-binding. There are no penalties for non-compliance. Global-level processes tend to focus on achieving high-level agreements to act, broad targets by which to measure such actions and comparable, consistent and transparent reporting approaches to enable progress to be tracked.

REGIONAL:

- Regionally, there are many air quality agreements and initiatives and some legally binding agreements. Agreements to act on air pollution at the pan-country and government level evolved earlier than similar processes for climate change. The tangible and local nature of air pollution alongside relatively easier technical solutions allows for easier implementation of regional targets and control.

- Managing air pollution through a regional approach allows policymakers and practitioners to take a more nuanced approach to pollution that may be produced in one area, but drift across international borders. This 'smog diplomacy' is a critical component of managing transboundary air pollution, like the **ASEAN Haze Agreement** in Southeast Asia.

- Climate change is indirectly addressed at the regional level as a co-benefit of some regional air quality efforts, and there are some climate-specific regional approaches like the European Union's (EU) **Emissions Trading Scheme** and its regional climate targets. Regional-level action tends to incorporate and build upon high-level agreements, targets and principles for action agreed within global-level processes.

NATIONAL:

- At the national level, governments set air quality standards and separate greenhouse gas emissions reduction targets for their country. Governments set out a pathway to achieving these targets in detailed plans that also include sectoral targets and regulations. Nationally Determined Contributions (NDCs) and climate action plans are critical here, which feed into the global climate sphere. Critically, such plans also cover adapting to the impacts of now unavoidable climate change. National level action tends to incorporate and build upon the agreements, targets and principles for action agreed as part of global and regional level processes.

SUB-NATIONAL:

- While many countries set air quality standards at the national level, the responsibility for addressing these standards and implementing corresponding measures sits at the sub-national level. Air quality standards are typically managed at the state- and city-level through local airshed plans. This is important from both a sectoral perspective and a human health perspective. National-level climate plans are often operationalised at the local level as well.

- Sub-national, city- and local-level action is required to address the granular impacts of climate change and air pollution and realise the benefits of bottom-up measures. However, action at the sub-national level is at times constrained by the broad national lens through which policies are adopted. Equally, sub-national, city and local governments often also set their own targets – typically aimed at contributing to national-level commitments. Such targets tend to be supported by plans and policies that seek to harness additional opportunities to improve air quality or reduce greenhouse gas emissions that are uniquely available at the local level.

WHERE DOES TROPOSPHERIC OZONE SIT WITHIN DIFFERENT LEVELS OF GOVERNANCE?

No set of bodies at any governance level has yet adopted a comprehensive framework that addresses all dimensions of the ozone problem: climate, health, agriculture and ecosystems.

This fragmentation results in measures that address only one dimension of this problem rather than long-term systemic and coordinated strategies. A summary of the status quo of tropospheric ozone governance is below:

GLOBAL:

Climate: There are currently no global-level agreements mandating the reduction and management of tropospheric ozone. Despite being a greenhouse gas, tropospheric ozone is not part of the Paris Agreement or acknowledged in commitments on 'all greenhouse gases' because these frameworks focus on gases and pollutants that are directly emitted. The climate and health impact of tropospheric ozone is extensively mentioned within IPCC guidance, but it's not included in any UNFCCC mandates. The UNFCCC and the Paris Agreement use the terminology and definitions from the Kyoto Protocol, which identifies a basket of six primary greenhouse gases for monitoring and mitigation: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). These gases are collectively referred to as the 'Kyoto basket'. As noted above, signing up to the Paris Agreement and other global climate frameworks is voluntary for countries and the requirements are non-binding. Reporting any information regarding tropospheric ozone, or indeed other super pollutants, is not mandated, although it is welcomed. The systematic reporting and formal inclusion of ozone control measures in climate negotiations would pave the way for their integration into the financial mechanisms of implementation under the UNFCCC and the Paris Agreement, enabling access to funding, technology and capacity-building support for their effective deployment.

Tropospheric ozone's exclusion from the Kyoto Basket has made it the 'forgotten greenhouse gas'. However, the IPCC is developing new guidance to support countries to develop emission inventories for short-lived climate forcing gases. This will complement the requirements for reporting the existing basket of six greenhouse gases stipulated in the UNFCCC Emission Inventory Guidelines. This guidance will be published in 2027 and is expected to reduce some scientific uncertainties around ozone through an improved inventory of precursors.

Through methane, tropospheric ozone is addressed indirectly as an additional outcome of climate action, although this is not an explicit goal of methane mitigation. Methane is a greenhouse gas with a lifespan of around 12 years, so its impact on ozone is more global and diffuse, primarily influencing background and free tropospheric ozone where climate impacts are most pronounced. Reductions in methane alone may reduce a proportion of ozone's climate impact, but it will not deliver direct health and ecosystem benefits as these areas are impacted by ozone derived from shorter-lived, highly reactive precursors like NOx and NMVOCs. Efforts to control ozone are often challenged by this tension between global precursors like methane and more local ones like NOx and NMVOCs. For example, in Europe, modelling suggests that even ambitious domestic methane reductions would lead to only modest improvements in ozone levels in the region by 2050 because ozone formation is influenced by methane emitted in other parts of the world.[37]

Health, agriculture and ecosystems: There are other global level regulations outside of the climate sphere. For example, the WHO sets targets for healthy levels of ozone concentrations (see Box 2). However, nine out of ten people globally are still exposed to levels that exceed WHO guidelines.[38] The WHO's guidelines are voluntary and non-binding, but national governments use them to set their own evidence-based targets. The WHO's **2025 Road Map for an Enhanced Global Response to the Adverse Health Effects of Air Pollution** sets an ambitious target to reduce mortality from anthropogenic air pollution by 50% by 2040, but it does not explicitly address tropospheric ozone. This may be due to the limited availability of country-level ozone data. Other global bodies, like the FAO or the UN's Convention on Biological Diversity (CBD), do not have any specific focus on ozone as an issue relevant to food insecurity or ecosystem damage. Both link their work to the UN's Sustainable Development Goals (SDGs), which cover air pollution and climate action, and the Kunming-Montreal Global Biodiversity Framework (GBF) includes targets on reducing pollution and minimising climate change's impact on biodiversity, but does not explicitely mention tropospheric ozone.

REGIONAL:

Tropospheric ozone is found in regional air quality legislation around the world. There are also many sub-regional agreements on air pollution (e.g., the Canada-United States Air Quality Agreement or the North-East Asia Clean Air Partnership). Some of these agreements are binding, while others are voluntary.

Europe, Canada, US and Russia: One of the most successful regional air quality agreements is the Convention on Long Range Transboundary Air Pollution (CLRTAP), agreed in 1979, and the associated **Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-Level Ozone**, adopted in 1999. The CLRTAP is focused on reducing emissions and the long-range transport of harmful pollutants, initially across Europe and North America. Under this agreement, the EU has seen a gradual and overall downward trend in urban population exposure to elevated ozone concentrations from a high of 64% in 2003 to 19% in 2022.[39] The Gothenburg Protocol also provides binding air pollution targets for the EU's National Emissions Ceiling legislation. Under the United Nations Economic Commission for Europe (UNECE), the Gothenburg Protocol is under revision through the end of 2026. While ozone is already part of the agreement, there is scope to see key precursors, like methane, added to the regulation. If methane is added to the Protocol, this could set the first legal mechanism to address methane beyond the voluntary commitments under the Global Methane Pledge.

Latin America: There is no regional agreement in place, but the **Intergovernmental Network on Atmospheric Pollution for Latin America and the Caribbean** was established in 2008 to convene authorities who manage air quality within the region. The United Nations Environment Programme (UNEP) acts as the secretariat for the Network with the aim of capacity building and sharing information. The Network produced an **air quality action plan for 2022-2025**, which highlights super pollutants including tropospheric ozone.

Africa: In 2024, the United Nations Environment Assembly passed a resolution calling for the establishment of the **Africa Clean Air Program** (ACAP) backed by the African Union Commission and the African Ministerial Conference on Environment, as well as UNEP, the Stockholm Environment Institute and the Climate and Clean Air Coalition (CCAC). ACAP is currently under development through the CCAC's Clean Air Flagship initiative.

Asia Pacific: Since 2022, the UN Economic and Social Commission for Asia and the Pacific (UNESCAP) has brought together air quality practitioners for its **Regional Action Programme on Air Pollution** (RAPAP) to promote regional cooperation and exchange best practice. RAPAP has no enforcement mechanism and several sub-regional agreements operate under it, like the **Acid Deposition Monitoring Network in East Asia** and the **Malé Declaration** in South Asia. Monitoring ozone is part of these agreements.

NATIONAL:

While ozone is generally included within national-level air quality targets, just a few countries explicitly mention tropospheric ozone within their NDCs, including Brunei and Micronesia.[v,40] An analysis of the latest NDC submissions shows that only twelve countries include all tropospheric ozone precursors[vi], but some do quantify the health benefits of air pollution, which likely includes tropospheric ozone.[41] The Global Methane Pledge reports that over 90% of countries include methane within the scope of their NDC, but only 35 NDCs quantify methane's mitigation potential or set a target for its reduction.[42]

SUB-NATIONAL:

Most countries that set ambient air quality directives include ozone in their targets. Historically, most progress on tropospheric ozone has been found at the state- and city-level through targeted action to reduce ozone at the ground level. For example, India has made progress in this area with its State-level Air Quality Action Plans and State Pollution Control Boards. Los Angeles, Mexico City and Beijing are exemplars in ozone management at the city-level, although all still face challenges in maintaining the previous pace of ozone reductions. In many parts of the Global South, air quality plans are often confined to major cities and primarily target particulate matter, with limited attention to ozone. State and other local environmental authorities tend to have some remit for delivering national-level climate action plans.

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v Note that the United States' NDC also explicitly mentions tropospheric ozone, but this NDC is not active at the time of publication of this report.

vi Benin, Central African Republic, Costa Rica, Eswatini, Gabon, Ghana, Liberia, Morocco, Samoa, Togo, Tonga and Tuvalu.

BOX 2:

TROPOSPHERIC OZONE AND THE WORLD HEALTH ORGANIZATION

The WHO has set guidelines for tropospheric ozone following decades of research on its health impacts.[43,44,45] These evidence-based recommendations aim to support national policy and legislation, guiding efforts to lower pollutant levels and reduce the global health burden associated with air pollution. The guidelines currently recommend a short-term exposure limit for ozone of 100 µg/m^3 over an 8-hour period and a long-term limit of 60 µg/m^3 for peak season ozone. The latter metric, introduced in the most recent update to the guidelines in 2021, is the first ever long-term exposure metric for ozone and represents the average of daily maximum 8-hour concentrations over the six consecutive months with the highest six-month running average ozone concentration.

Despite this, implementation has been limited. Only 15 countries have adopted the short-term ozone exposure guideline as a national air quality standard and no country has yet adopted a long-term ozone exposure metric. More than 90% of people globally are exposed to ozone levels above WHO guidelines, and there is growing evidence that the health and mortality impacts of ozone are significantly underestimated.[46] Even the EU, in its 2024 air quality directive update, aligned with the WHO's 8-hour metric but did not adopt a long-term standard. This may be due to the regional nature of ozone pollution, its complexity and the perceived challenges for governments of meeting strict targets, but it also suggests that countries may be uncertain about how to implement a long-term target.

A 2024 update to the systematic review that informed the 2021 WHO guidelines found a stronger and more statistically robust association between annual mean ozone exposure and respiratory deaths compared to the peak-season metric currently in use.[47] Nevertheless, the WHO has not yet issued guidance to help countries navigate this emerging evidence.

Without long-term metrics in national air quality standards, ozone levels and their chronic health impacts will not be systematically assessed and will remain under-recognised. This creates a risk that policy responses will remain reactive, focused on short-term pollution episodes (e.g. temporary restrictions during high pollution days), rather than proactive strategies to control precursor emissions and protect public health in the long term.

Clear guidance, along with a strategy for integrating long-term ozone metrics into national standards, is essential to strengthen the global response to ozone pollution and protect public health.

The WHO's guidelines for ozone remain the main source of global guidance and ambition for tropospheric ozone. However, without widespread adoption of both short- and long-term metrics, their influence will remain limited in driving policy change and action. The absence of long-term exposure limits in national legislation is a blind spot for chronic ozone-related health outcomes, especially in regions where populations are exposed to elevated background levels for much of the year.

The complexity of chemical reactions in the atmosphere, rising temperatures and shifting weather norms due to climate change alongside a fragmented policy landscape, suggests that status quo management of tropospheric ozone is insufficient to deal with this growing problem. The next section outlines our proposal for leveraging existing opportunities to help reframe the tropospheric ozone problem.

PART 2:

DELIVERING THE PATH FORWARD: A ROADMAP FOR ACTION

4. A STRATEGIC IMPERATIVE: INTEGRATED ACTION ON TROPOSPHERIC OZONE AND SUPER POLLUTANTS

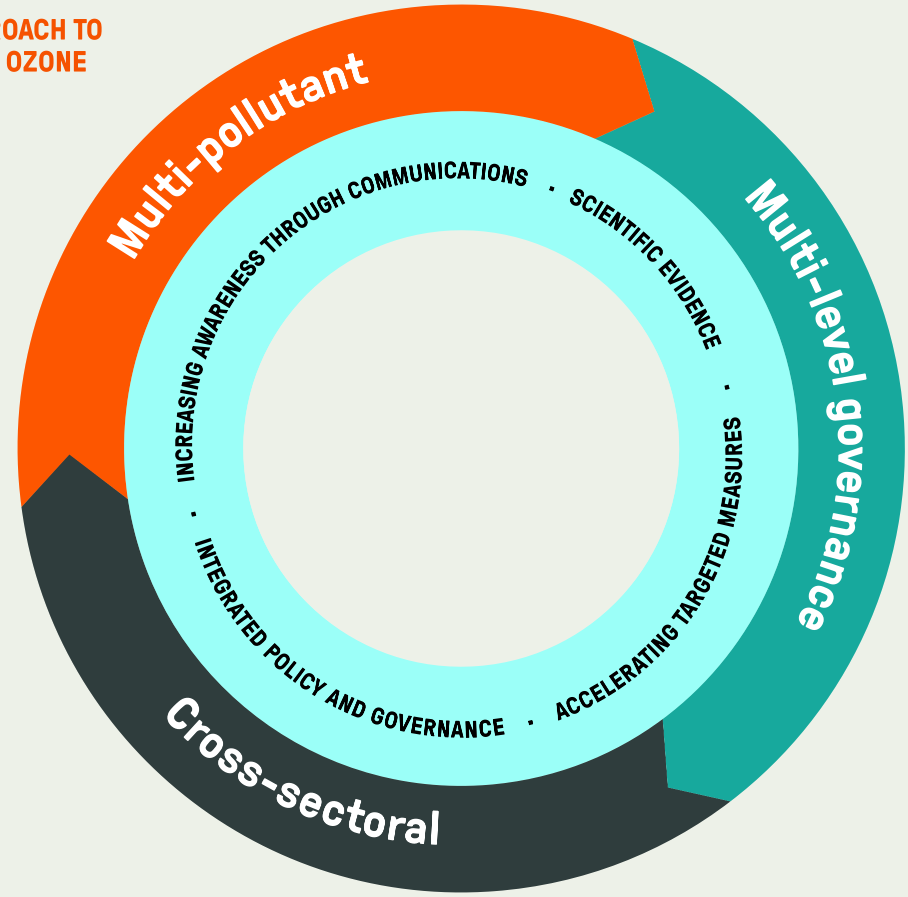
In Part 1, we illustrate how tropospheric ozone and its precursors are inadequately addressed within this complex policy and regulatory environment. This roadmap proposes embedding action on ozone into existing policy structures, not by creating parallel systems, but by leveraging current opportunities and aligning with ongoing efforts. With the right momentum, integrated action on ozone precursors could result in 0.30°C degrees of avoided warming by 2050.[48]

For this approach to succeed, several enabling conditions are essential:

- **Political visibility:** Ozone mitigation must be positioned as more than a niche technical topic, but rather understood and recognised as a fast-acting climate and public health solution.
- **Policy integration:** Stronger links are needed between ozone and broader greenhouse gas, air quality, health, biodiversity and agricultural policies.
- **Cross-border cooperation:** Strengthening transboundary agreements and regional airshed planning is needed to support more effective, collective mitigation of ozone precursors at their source.
- **Technical capacity and tools:** Governments need improved access to modelling platforms, integrated assessment tools and emissions data.
- **Knowledge sharing:** Peer learning, case studies and international collaboration platforms are necessary to speed up adoption of best practices.
- **Tailored support:** Dedicated capacity development can help countries co-design and implement context-specific ozone strategies.

These key conditions foster a 'polycentric' approach to governance of tropospheric ozone, where decision-making is shared across global to local scales.[49] The aim is to improve policy coherence across climate, air quality and agriculture, while also centring equity by prioritising support for those most affected and least equipped to respond to ozone and its impacts.

FIGURE 6: A SYSTEMS APPROACH TO MITIGATING TROPOSPHERIC OZONE



To deliver integrated ozone action, four priority areas are outlined in this roadmap:

- **Scientific evidence into policymaking:** Addressing critical gaps in the scientific foundation needed to inform effective guidelines and policies to control and adapt high tropospheric ozone levels and its precursors across multiple spatial scales.
- **Integrated policy and governance:** Embedding ozone and super pollutants in global and regional climate, air quality, health and ecosystem agreements. Promoting multi-pollutant planning and cross-ministerial collaboration at the national and sub-national level.
- **Accelerating targeted measures:** Delivering concrete actions that reduce ozone precursors – especially methane and NMVOCs – through both existing decarbonisation pathways and additional sectoral measures (e.g., aviation). Also identifying synergies and policy trade-offs to ensure coherence.
- **Increased awareness through communications:** Improving the visibility and understanding of tropospheric ozone and other super pollutants among policymakers by translating complex science into clear, actionable insights. Engaging new stakeholders within the most affected sectors, like agriculture and ecosystems with targeted approaches. Strengthening the narrative across existing air quality and climate initiatives, framing ozone as a key connector and strategic entry point for near-term action.

Taken together, these areas can enable a clear and coordinated path forward.

4.1 SCIENTIFIC EVIDENCE INTO POLICYMAKING

There is a strong, existing evidence base around the impacts of tropospheric ozone. The uncertainty lies in the granularity of this knowledge, both in terms of scale and time. Climate models are unable to capture ozone's local climate impacts, while air quality models generally can't predict long-term outcomes as they're intended to run for a short period of time. Filling geographic and vertical monitoring gaps and enhancing modelling resolution and impact indicators would help shrink today's large uncertainty band around ozone. A stronger, more defined evidence base will enable decision-makers to make more confident and informed choices about effective mitigation pathways.

It is essential to advance the scientific foundation for action on tropospheric ozone before 2030 to inform critical policy milestones within this strategic period. For example, within global climate policy, the IPCC's mid-cycle AR7 output in 2028, which is also a UNFCCC Global Stocktake year, and the Pre-2030 Global Mitigation Progress Review in 2029 are key scientific junctures ahead of the conclusion of the first Global Stocktake and the launch of the post-2030 climate architecture. Such moments can provide important visibility for ozone as a priority issue and inject robust, timely science into decision-making processes.

To realise these opportunities, the following scientific gaps must be addressed in the next five years:

FIGURE 7: TROPOSPHERIC OZONE SCIENTIFIC GAPS

Monitoring, Observations and Emission Inventories		
WHAT IS THE RESEARCH GAP?	**WHY IS THIS IMPORTANT?**	**SCALE**
Urban, background and free troposphere monitoring and the completeness and accuracy of localised emissions inventories remains a key gap, particularly outside of a few high-income countries.	▪ The science that dictates the formation, fluctuations and presence of local atmospheric concentrations of tropospheric ozone is relatively well established. The application of this science, often within models, is severely limited by the availability of granular observational data, leading to significant variations in completeness and accuracy of emissions inventories. ▪ Emissions and monitoring data are crucial inputs to developing and validating accurate and granular localised models of tropospheric ozone to formulate mitigation pathways. Without this data, stakeholders have a limited ability to model and manage ozone accurately, and this hinders mitigation. This is particularly crucial for low- and middle-income countries that may not have access to the relevant data and/or capacity to action it. ▪ Monitoring networks must also include a balance of urban and rural ground-level stations, as well as above-ground-level measurements to capture both locally derived and background ozone contributions alongside its presence in the free troposphere.	National to sub-national
Lack of larger scale atmospheric observations, like satellite-based measurements.	▪ Existing satellites have limitations in vertical resolution and accuracy in the free troposphere. With more and better larger-scale data, it would be possible to undertake a more comprehensive assessment of the fluctuating presence of ozone at different spatial scales and the resulting impacts on climate warming, health, agricultural production and ecosystems. Aligning this with existing greenhouse gas monitoring approaches and networks could be explored.	Regional to global

Air pollution and health		
WHAT IS THE RESEARCH GAP?	**WHY IS THIS IMPORTANT?**	**SCALE**
Lack of long-term health data for tropospheric ozone including: ▪ The long-term link between ozone exposure and impacts on cardiovascular, metabolic, nervous systems and reproductive health. ▪ Long-term epidemiological studies in mortality on low- and middle-income countries where monitoring and data infrastructures for ozone may be limited.	▪ Health evidence is key to ensure public health policies are informed by the most up-to-date evidence, support revisions to the WHO Air Quality Guidelines and engage stakeholders on the health impacts of tropospheric ozone. ▪ Additional research on cause-specific morbidity and mortality, especially among vulnerable populations, can lead to more comprehensive health impact assessments and more effective interventions. ▪ A consistent and conclusive body of evidence that unequivocally links long-term ozone exposure to overall mortality may further advance the update of WHO guidelines and the adoption of more protective national air quality standards. ▪ Enhanced air pollution monitoring data, improved health data with greater spatial and temporal resolution and increased health research in low- and middle-income countries are essential to ensure equitable and effective policy responses worldwide.	Global to national

Climate		
WHAT IS THE RESEARCH GAP?	**WHY IS THIS IMPORTANT?**	**SCALE**
Tropospheric ozone's climate warming effect as estimated in the latest IPCC Sixth Assessment Report (AR6) is subject to significant uncertainty, with uncertainty bounds in modelling estimates spanning warming and cooling effects.	▪ Further investment to test, compare and better understand ozone's role as a climate forcing agent will help develop more accurate global climate modelling. ▪ If the IPCC clarifies ozone's radiative forcing effect, this guidance would likely cascade into other global climate processes, like the UNFCCC, and national governments would have a mandate to take action on ozone from a climate perspective.	Global to national to sub-national
There are acute gaps in understanding of regional and localised climate impact of tropospheric ozone.	▪ Significant additional research is required to better understand the influence of regional – and if possible – localised concentrations of tropospheric ozone on climate warming. In particular, further understanding is required around the spatial variation of the warming effect associated with tropospheric ozone, the key drivers for this and the extent to which this may be affected by the presence of other atmospheric pollutants, such as particulate matter. ▪ With an understanding of more localised climate impacts, regional and national-level stakeholders will have a more accurate picture of ozone's climate impact in their area and could develop more tailored climate mitigation/adaptation plans.	Regional

Agriculture and ecosystems		
WHAT IS THE RESEARCH GAP?	**WHY IS THIS IMPORTANT?**	**SCALE**
Lack of understanding of how crop impacts and ecosystem damage from tropospheric ozone manifests regionally or locally and the resultant impacts on crop yields and biodiversity.	▪ This gap is particularly acute in the Global South, which is typically more affected by issues of food security and where crop damage from climate warming is also likely to be more significant. This gap also undermines conservation efforts in vulnerable regions. ▪ Location-specific data would allow national governments and international bodies to accurately assess the scale of ozone-related crop and plant damage, so they can design effective mitigation or adaptation measures. ▪ This data is particularly important for biodiversity and ecosystem monitoring frameworks, as ozone's impact is currently not covered within these agreements.	National to sub-national
Major gap in understanding the protective and adaptive measures that could be taken to reduce agricultural impacts during high-ozone episodes.	▪ Guidance on crop selection, crop protection, assessment of ozone vulnerabilities of crops and forecasting ozone episodes remains a major research gap to be addressed. ▪ A comprehensive assessment and recommendation of protective measures would enable climate-smart agricultural policies and protect agricultural livelihoods. ▪ This could also allow governments to unlock climate-adaptation finance and build more climate resilient societies.	Sub-national

Integrated assessment modelling and tools		
WHAT IS THE RESEARCH GAP?	**WHY IS THIS IMPORTANT?**	**SCALE**
There are limited integrated assessment capability and tools to support policymakers in developing muti-pollutant policies that account for the interactions between pollutants like tropospheric ozone and other greenhouse gases.	▪ Filling this gap would allow for evidence-based decision making and give policymakers the ability to design cost-effective, synergistic mitigation policies for tropospheric ozone. This need is particularly acute for ozone due to its secondary pollutant nature and its complex chemistry. Its impact at the local, regional and global levels is also highly dependent upon interactions across several other air and super pollutants. ▪ Development of such tools is likely to require further empirical research to improve our understanding of pollutant interactions, how these are manifested at different spatio-temporal scales, alongside how to represent this within a modelling environment. Such tools must also be targeted towards and useable by local and national policy makers. ▪ Further and enhanced integrated assessment capability is also required to better understand the health, agriculture, ecosystems and climate benefits and trade-offs associated with potential policy interventions.	National to sub-national
Need for geographically diverse case studies to guide policy tool development.	▪ A case study approach offers a valuable method to test and refine model development, highlight key evidence and research gaps and generate actionable insights across diverse geographic regions and spatial scales. ▪ Focus should be particularly placed on supporting policy makers in the Global South, who may face significant limitations in location-specific data, monitoring infrastructure and scientific capacity. ▪ Targeted case studies could support more context-relevant decision-making, while also building local evidence bases and enhancing global equity in ozone policy and research.	Regional to sub-national

Closing the scientific gaps surrounding tropospheric ozone provides the evidence, tools and confidence necessary to develop targeted, effective and equitable policy responses. It would enable a shift from reactive regulation to proactive, integrated environmental governance.

4.2 INTEGRATED POLICY AND GOVERNANCE

Building the scientific evidence base for tropospheric ozone is critical, but to drive real-world impact, this evidence must be strategically deployed to close policy gaps and integrate ozone into existing governance frameworks.

This section identifies where and how ozone can be embedded within climate, air quality, health, ecosystem and agricultural policies. This section does not prescribe fixed actions, as implementation must be tailored to national and local contexts. Instead, it identifies desired policy outcomes, why they matter and what opportunities they present, if supported by the right enabling conditions. The goal is to build ozone into the architecture of existing systems in ways that are practical, scalable and politically feasible. We believe that applying the lens of tropospheric ozone within these spheres of influence can help nudge forward progress to mitigate climate warming, improve air quality and health and secure more resilient food and ecosystems.

At each level of governance there are different policy arenas in which targeted action could push this topic forward:

FIGURE 8: DESIRED POLICY OUTCOMES FOR TROPOSPHERIC OZONE

Global		
POLICY ARENA	**DESIRED OUTCOMES**	**WHAT OPPORTUNITIES DOES THIS CREATE?**
IPCC	▪ Tropospheric ozone is fully integrated into IPCC climate assessment and modelling frameworks, with improved representation of its radiative forcing, precursors and feedbacks in AR7 and Special Reports on Short-Lived Climate Pollutants (SLCPs) methodology and cities. ▪ Super pollutants (many of which are ozone precursors) are included within the IPCC Guidelines for National Greenhouse Gas Emission Inventories and accompanied by associated guidance.	▪ The IPCC is the definitive global body for assessing climate science and sets the scientific standards on which global and national climate policies are based. It informs international climate negotiations like the UNFCCC processes. ▪ While the IPCC acknowledges ozone as a short-lived climate forcer, its climate forcing potential remains poorly understood and inconsistently represented in global models and policy guidance. ▪ If the IPCC clarified uncertainties around tropospheric ozone and recommended the reporting of precursors within national emissions inventories, this would elevate ozone within mitigation narratives alongside methane and drive integrated greenhouse gas-air pollutant planning frameworks. It would also empower countries to integrate ozone into their climate targets via their NDCs and unlock climate finance mechanisms for ozone.

Global		
POLICY ARENA	**DESIRED OUTCOMES**	**WHAT OPPORTUNITIES DOES THIS CREATE?**
WHO	▪ WHO produces specific guidance on emerging evidence and a strategy for integrating long-term ozone metrics into national standards, catalysing adoption of protective air quality standards and public health interventions.	▪ The WHO provides the global benchmarks for air quality and health. Its air quality guidelines are not binding. However, they strongly influence the setting of national ambient air quality standards and public health policies as they incorporate the highest standards in scientific evaluation where many national health and environmental ministries cannot afford or do not have the capacity to do such analysis on their own. The WHO guidelines give countries a mandate to tackle air pollution, and clarity on the long-term targets may catalyse more monitoring and public health investment in ozone. ▪ No single country has adopted a long-term metric for ozone, suggesting that countries need help to do so. Detailed guidance on integrating long-term metrics into national air quality guidelines will ensure that ozone is systematically monitored, evaluated against WHO guidelines and addressed through appropriate policy and mitigation strategies to protect public health. ▪ Stronger WHO guidance would also trickle down into regional air pollution agreements and regulation and drive cross-sectoral investment in air quality and health co-benefit policies.
FAO	▪ Tropospheric ozone is mainstreamed into FAO's food systems resilience and climate-smart agriculture frameworks, resulting in targeted technical guidance, risk assessments, crop insurance schemes, early warning systems and policy support that helps countries reduce ozone-related crop losses and strengthen agricultural adaptation strategies.	▪ FAO leads on food systems resilience, however ozone's impact on crop yields remains overlooked in its core tools and advice. ▪ Mainstreaming ozone into FAO's technical support and policy frameworks would promote awareness of ozone-related crop loss and integrate ozone into climate-smart agriculture and resilience and adaptation strategies. It could allow agricultural stakeholders to work more and better with the air quality field. ▪ It might also provide the agricultural sector with a positive narrative, communicating how it's acting on climate change, an area in which the sector is under pressure to demonstrate progress.
Convention on Biological Diversity	▪ Tropospheric ozone is recognized as a threat to ecosystem health under the Kunming-Montreal Global Biodiversity Framework (GBF), leading to its integration into National Biodiversity Strategies and Action Plans (NBSAPs), risk assessments, pollution reduction targets and the development of ozone adaptation and mitigation strategies to protect sensitive species, forest ecosystems and agricultural biodiversity.	▪ The GBF is a landmark agreement adopted in 2022 by 196 countries, aiming to halt and reverse biodiversity loss by 2030. The GBF does not mention ozone or any of its precursors, but ozone action aligns with Targets 7 and 8 which cover pollution and climate change respectively. ▪ If ozone was included in the GBF's technical guidance, which is currently under revision, this would validate ozone's importance within biodiversity and ecosystem initiatives, driving further data collection and prioritisation. ▪ This guidance would also provide a pathway for countries to include ozone in their NBSAP, the primary mechanism through which countries implement the GBF. This would also open biodiversity funding for ozone from multilateral funds like the Global Environment Facility or other development banks.

Regional		
POLICY ARENA	**DESIRED OUTCOMES**	**WHAT OPPORTUNITIES DOES THIS CREATE?**
Air pollution agreements	▪ Regional air pollution agreements expand their mandates to include methane and NMVOCs, where not currently included, and VOCs, enabling coordinated action on ozone precursors and enhancing technical capacity through cross-border knowledge sharing and joint mitigation programs for specific sectors. ▪ Such agreements add additional measures to compel signatories to act, including reduction commitments and sectoral targets, timetables, compliance review bodies and other accountability mechanisms. ▪ Agreements link to climate and development goals, aligning air pollution targets with broader climate frameworks, including NDCs, to enable integrated planning and expand political buy-in. This linkage also enables access to climate finance and other development funding for air pollution.	▪ Generally, tropospheric ozone and many of its precursors are already integrated into many regional air pollution agreements. However, there is a major opportunity to add any missing precursors (e.g., methane) to these agreements. ▪ Most of these agreements are non-binding and voluntary. They often focus on reporting and monitoring, as well as increasing capacity and technical capabilities of practitioners. Most agreements do not mandate pollution reductions or compel action. The Gothenburg Protocol is a notable exception that sets binding targets for parties and could be a model for strengthening other regional agreements. ▪ Adding compliance and accountability mechanisms into non-binding regional agreements would require significant political buy-in from national governments. However, if it's possible to link air pollution targets with broader climate goals, this could unlock climate finance. ▪ Additionally, by linking to these broader goals beyond air pollution and health, these agreements could also incentivise improving institutional and sectoral coordination between environment, health, climate and agriculture ministries. Linking regional air quality agreements to the NDCs of participating countries could also be an effective mechanism for translating non-binding regional commitments into enforceable national action.

National		
POLICY ARENA	**DESIRED OUTCOMES**	**WHAT OPPORTUNITIES DOES THIS CREATE?**
NDCs	▪ A growing number of countries explicitly measure, report and reduce precursors to tropospheric ozone, including methane and VOCs, as an explicit reference to reducing overall levels of tropospheric ozone in their NDCs or long-term strategies and report their progress via the Biennial Transparency Report process. ▪ Countries use their NDC to illustrate clear co-benefits for ozone control, supported by national inventories and mitigation plans.	▪ NDCs are the backbone of national climate ambition and an ideal vehicle to embed ozone-related targets. NDCs also provide a pathway between global climate agreements and national legislation where countries must develop climate action plans domestically to reach the targets laid out in their NDC. ▪ Explicitly including ozone precursors, especially methane, VOCs and CO, would create alignment across greenhouse gas and air pollution priorities. An NDC capturing both ozone and its precursors would help countries capture the co-benefits across climate and health. ▪ Integrating ozone within NDCs would also firmly cement it as a climate issue, opening climate finance pathways for ozone control measures.
National air quality plans	▪ Enhanced capacity among national and sub-national governments to implement effective integrated air pollution management regimes prioritising ozone, NOx and PM2.5.	▪ Many countries that set national air quality targets include ozone within these plans. There is an opportunity for national governments to strengthen institutional and legal coordination among government bodies and the technical capacity of its practitioners. Additionally, policy makers could mainstream a multi-pollutant approach across environment and climate ministries, as well as sectoral management and regulation. ▪ More capacity, tools, technical support and resource sharing among practitioners and policymakers would help support this. See below for more on this.

Sub-national		
POLICY ARENA	**DESIRED OUTCOMES**	**WHAT OPPORTUNITIES DOES THIS CREATE?**
Local environmental authorities	▪ City and state governments implement ozone-specific action plans, including precursor monitoring, seasonal alert systems and sectoral interventions at the airshed level.	▪ Cities and sub-national government entities are on the frontlines of ozone control and handling the impacts of exposure, as these actors are responsible for delivering plans to reach national air quality targets. Cities are often early adopters of innovative air quality approaches, and national governments often look to them for their expertise and data when developing national monitoring, modelling and assessment systems. ▪ There is an opportunity for progress on tropospheric ozone at the sub-national level to feed upwards into national and regional air quality planning. ▪ Sub-national actors in the climate space, particularly at the state, region or province level could also deliver potential new approaches to managing the sub-global climate impacts of tropospheric ozone.

As mentioned, in addition to interventions in various policy arenas, building capacity across practitioners, policymakers and key stakeholders is crucial to making progress on tropospheric ozone. The development and widespread dissemination to national and local governments of guidance documents, case study assessments and recommendations that can support the greater integration of climate and air quality policy at more granular levels of governance is also important. Platforms like the **CCAC's Air Quality Management Exchange** (AQMx) already provide a foundation for technical resources, peer learning and regionally tailored assistance. Other initiatives and programmes like **Clean Air Asia's City Solutions Toolkit** or **ICIMOD's Air Pollution Solutions Initiative** offer practical resources and guidance to support on-the-ground implementation of clean air measures.

Alongside this, we also recommend developing a dedicated capacity development programme that includes tools, peer collaboration and tailored assistance specifically aimed at managing tropospheric ozone and its precursors. This could allow national and local policymakers to explore improvements in climate and air quality governance with counterparts in other countries and regions, and to request and co-design support that fits their specific policy, governance and wider context-specific needs.

BOX 3:
EXPLORING TRANSFORMATIVE ENTRY POINTS: COULD THE MONTREAL PROTOCOL SUPPORT TROPOSPHERIC OZONE ACTION?

While this roadmap focuses on integrating ozone into existing climate, air quality, health and agricultural and ecosystem frameworks, other less conventional avenues could offer transformative potential for long-term governance and accountability. One such route is the Montreal Protocol on Substances that Deplete the Ozone Layer, adopted in 1987 to protect stratospheric ozone, or 'good ozone'. The Protocol mandates a phased reduction in the production and consumption of Ozone-Depleting Substances (ODS).

The Montreal Protocol is widely hailed as one of the most successful multilateral environmental agreements ever established. It has phased out over 99% of ODS and is credited with enabling the recovery of the stratospheric ozone layer.[50] In 2016, the Kigali Amendment further expanded the Protocol's mandate to include hydrofluorocarbons (HFCs) – greenhouse gases that do not deplete stratospheric ozone directly, but contribute significantly to climate warming. This expansion set a precedent for the Protocol to address substances based on climate impact, not just ozone layer depletion.

There is emerging evidence that tropospheric ozone can act as an ODS under certain atmospheric conditions because it influences the climate and atmospheric composition in ways that contribute to stratospheric ozone loss mechanism.[51] More evidence in this area could open the door to classifying tropospheric ozone and its precursors within the scope of the Montreal Protocol. Doing so could bring major benefits, including:

- Mandated national reporting on ozone and precursor emissions (e.g., methane, NMVOCs, NOx);
- A structured compliance and review mechanism for signatories;
- Greater access to technical and financial support via the Protocol's multilateral funding mechanisms;
- Elevated political visibility for ozone alongside CO_2 and other climate super pollutants.

However, such an expansion would face significant political and technical challenges, particularly in today's complex political environment. It would require consensus among Parties, sustained diplomatic engagement and stronger scientific consensus on the ozone-depleting potential of tropospheric ozone under Montreal Protocol criteria.

Nonetheless, the precedent set by the Kigali Amendment and the Protocol's track record of innovation suggest that it remains a valuable long-term pathway worth exploring, especially if conventional frameworks prove insufficient to mitigate rising ozone levels.

Tropospheric ozone spans climate, health and environmental priorities, yet remains under-integrated in existing governance. Strategic embedding into current frameworks within the IPCC, WHO, NDCs and regional agreements could unlock fast, multi-benefit action. Doing so would accelerate implementation through targeted measures and strategic policy alignment.

4.3 ACCELERATING TARGETED MEASURES

Ozone policy is not a new domain, but by strategically advancing targeted win-win interventions, managing trade-offs and filling regulatory gaps, policymakers could unlock the full mitigation potential of tropospheric ozone.

WIN-WINS: ALIGNING OZONE REDUCTION WITH EXISTING EFFORTS

Governments and companies around the world are already implementing measures to decarbonise their economies, reduce methane emissions and tackle air pollution. These efforts, while often designed with separate objectives, are reducing key precursors to tropospheric ozone such as methane, NOx, CO and NMVOCs by cutting fossil fuel emissions and through traditional air pollution management approaches. Adding an ozone lens onto existing decarbonisation efforts where it's not generally considered could enhance their effectiveness and help avoid more global warming while unlocking a broader set of co-benefits across climate, health and ecosystems:

- **Methane mitigation:** Methane is responsible for up to 40% of tropospheric ozone formation, especially in the free troposphere, where its warming impact is greatest.[52] Tackling methane delivers rapid climate benefits and reduces ozone formation. Importantly, mitigating methane emissions largely associated with non-fossil fuel sources (from agriculture, livestock and waste management) is additional to fossil fuel combustion-focused decarbonisation interventions. To maximise the co-benefits of methane and ozone mitigation, the methane movement could take the following steps:
  - Update methane mitigation policy tools (e.g. MAC curves, marginal abatement cost models) to account for ozone-related co-benefits, such as avoided deaths, hospital visits or crop yield loss.
  - Incorporate ozone response modelling into methane-related country toolkits, sectoral guidance and technical assistance (e.g., for NDC implementation or methane roadmaps).
  - Provide capacity-building materials to help national and subnational governments understand the ozone dimension of methane action.
  - Build the health argument into methane mitigation through ozone management. This may facilitate stronger ties between methane actors and health institutions like the WHO, even unlocking health funding for the movement.
  - Leverage the methane movement's existing progress on agriculture and livestock to frame methane mitigation as a food security and ecosystem resilience measure, not just a climate one.

- **Fuel standards:** Existing fuel and emissions standards (e.g., International Maritime Organisation standards, the EU's 'Euro' Vehicle Emissions Standards, or fleet CO_2 reduction standards) and city-led low or zero-emission zones are already reducing NOx and black carbon emissions. Adding a stronger focus on ozone lens would:
  - Strengthen NOx and VOC emission control measures. This could also include a stronger focus on heavy-duty diesel vehicles and off-road machinery, which are among the largest contributors to NOx emissions in transport, construction and industry.
  - Provide further impetus for prioritising public and active transport infrastructure.

- **Energy transition:** Improvements in industrial efficiency and transitions to clean energy reduce methane, NOx and CO emissions. This includes promoting the accelerated adoption of zero-exhaust emission vehicles.

- **Residential energy:** Household fossil-fuel combustion (e.g., main gas, LPG, firewood, etc) emits both NOx and VOCs (alongside black carbon, another harmful super pollutant). Accelerating access to clean cooking solutions, for example electric cookstoves, would deliver major benefits for indoor air quality and help reduce ozone precursors.

- **Ecosystems and agriculture**: Many agricultural interventions reduce both greenhouse gases and ozone precursors as non-fossil fuel pathways to ozone reduction. Reducing or capturing methane from livestock and manure management, reduced field burning and more efficient fertiliser use are all ozone relevant. These should be formally recognised in climate-smart agriculture strategies, resilience frameworks and adaptation guidance. Tropospheric ozone's ecosystems impact needs to be captured within work that is already happening – it should be integrated into ecosystem vulnerability assessments and ongoing work to address carbon sink weakening.

TRADE-OFFS: MANAGING POLICY INTERACTIONS CAREFULLY

Policymakers are tasked with considering trade-offs, and the reality of tropospheric ozone's complexity is that a well-intentioned policy could inadvertently increase ozone levels.

For example, some climate-friendly solutions seek to reduce net atmospheric carbon emissions by burning biomass, biofuels or hydrogen – but these will have knock-on effects for air pollution and ozone. Hydrogen, for instance, is often promoted as a clean fuel because when used to generate electricity, significantly less or even no greenhouse gases or air pollutants are emitted. [53]

However, most hydrogen is produced using fossil fuels – either from gas ('grey hydrogen') or via electrolysis powered by fossil-based electricity ('blue hydrogen'). Only 'green hydrogen', made with renewable electricity, is emissions-free, yet it accounts for less than 1% of global production as of 2024.[54] Moreover, replacing fossil fuel gas with hydrogen in, for example, residential boilers, would eliminate carbon emissions, but still emit high levels of NOx, a key tropospheric ozone precursor.

While hydrogen fuel is not yet available at a large scale, policymakers must evaluate how interventions targeting other goals may affect ozone formation, and design policies with a holistic perspective of atmospheric emissions.

Other trade-offs to consider include:

- **NOx control strategies:** NOx is a harmful air pollutant with direct health impacts, and in some circumstances, reducing NOx will result in a reduction in tropospheric ozone. The chemistry is complex, so some efforts to reduce NOx, like the EU's 'Euro' vehicle standards, could also change precursor emissions profiles and as such the quantity of ozone produced. For example, NOx levels often influence methane, increasing methane's lifetime in the atmosphere and therefore increasing the likelihood of more ozone, but this depends on other precursor levels and meteorological conditions in a certain place.

- **Aerosol reductions:** Reducing emissions of aerosol-forming pollutants, such as ammonia and sulphur dioxide, reduces the presence of harmful fine particles, which is good for air quality and human health. However, under certain conditions, reducing aerosols in the atmosphere can increase ground-level ozone, as has been observed in Chinese cities.[55] But the pathways through which aerosols are reduced, and the associated reduction of co-pollutants, will determine whether ozone levels increase or decrease.

- **Sustainable Aviation Fuels (SAFs):** There is an emerging movement for the aviation sector to shift to SAFs, which is a type of biofuel that reduces greenhouse gas emissions from airplanes. However, the ozone and air pollution impacts of SAFs remain poorly studied and SAFs are often chemically similar to conventional jet fuels, so may continue to emit high levels of NMVOCs. There are other emerging options, like synthetic SAFs (or e-SAFs), which are produced from green hydrogen.[56] Without an ozone lens, the adoption of new fuels and technologies risks inadvertantly altering, rather than meaningfully reducing the aviation sector's climate and pollution footprint (see below for more on aviation).

ADDITIONAL MEASURES: FILLING THE GAPS IN THE REGULATORY LANDSCAPE

Tackling some of ozone's unique complexities and precursors sits outside of existing decarbonisation and air quality efforts. Even with improved alignment and trade-off management, tropospheric ozone's unique formation chemistry and range of precursors means that additional, targeted policies will be required to close key regulatory gaps. This is particularly relevant for those high-emitting sectors for ozone precursors that are not associated with either fossil fuel combustion or methane emissions and therefore sit outside of existing climate change frameworks and are often not covered adequately by air quality standards and regulations. Alongside efforts to tackle hard-to-abate methane sources (e.g., livestock), parallel actions to reduce emissions of NMVOCs and CO, which are more directly linked to industrial, product use, and transport sectors, could offer a fast, cost-effective route to achieving near-term climate and air quality benefits.[57]

Key areas in which additional, targeted measures for tropospheric ozone mitigation and control are needed include:

Aviation:

- Emissions from aviation are a source of ozone precursors, particularly NOx and NMVOCs. High-altitude aviation emissions[vii] of NMVOCs, NOx and CO can amplify the climate impact of ozone formation by promoting additional ozone production and influencing the development of heat-trapping cirrus clouds, known as contrails.[58,59] The International Civil Aviation Organization (ICAO) sets all standards for international aviation and has established broad, non-binding commitments on reducing emissions from the sector. It provides no guidance or standards for non-CO_2 pollutants (i.e., super pollutants) from aviation,[60] despite some estimates that over 60% of aviation's impact on global warming could be from non-CO_2 effects.[61] Emissions from international aviation are not included in NDCs and there is little political pressure to tackle the ever-increasing climate impact from the sector.[62]

- Airport operations, often encompassing aging and poorly regulated fleets of ground-based support vehicles, can also lead to substantial emissions of NMVOCs, NOx and CO. In China, for example, Beijing Capital Airport emitted over 5 kilotons of NMVOCs in 2015 alone from typical airport operations like aircraft taxiing.[63] Such emissions can drive locally elevated ozone concentrations.

- With aviation emissions predicted to continue rising[64] and other sectors continuing to decarbonise, aviation's relative contribution to ozone formation is set to increase, meaning that the climate impacts will grow.[65]

- Aviation is a highly complex and political sector – its global nature means that emissions are not easily attributed to a single country, and it is also a key economic driver. Yet, a targeted ozone approach within the sector could provide a unique pathway to delivering climate and air quality improvements that other existing decarbonisation plans will not realise. Evidence gaps remain, but addressing ozone and other super pollutants within aviation could address a regulatory blind spot in one of the hardest-to-abate sectors, creating an opportunity for innovation and leadership in sustainable aviation policy.

vii High-altitude emissions largely occur when an aircraft is cruise altitude. Cruise is longest part of most individual flight cycles.

Non-energy sources of NMVOCs:

- NMVOCs are a large class of hundreds of compounds emitted from a wide variety of sectors and activities, including natural sources like trees. Most air pollution control regulation covers NMVOCs, but the diversity of sources and individual compounds makes them difficult to measure, track and regulate. NMVOC emissions from non-energy sources include solvent use in products like paint, adhesives and printing ink; chemical manufacturing and processing, including pharmaceuticals; consumer products including aerosol sprays, cleaning products and perfumes; agricultural emissions from pesticide application; and fugitive emissions from storage, transport and handling of gases and other products e.g., petroleum vapour losses during refuelling.

- Many of these sources are not linked to carbon emissions, so they're excluded from climate frameworks. NMVOCs are also often poorly and inconsistently represented within national emission inventories. It's also challenging for experts to measure and model NMVOCs due to the number of individual compounds, the complexity of their atmospheric chemistry and the paucity of emissions estimates. Ozone formation potential also varies by source of NMVOC. Effective ozone mitigation needs to move beyond traditional decarbonisation and air quality management routes to manage NMVOC emissions more holistically.

- There is an opportunity to develop sector-specific standards and guidelines for managing NMVOC emissions by integrating tropospheric ozone considerations into sectoral and corporate mitigation plans, **building on existing progress in corporate sustainability reporting**. Encouraging low-VOC alternatives and clearer product labelling, strengthening emissions inventories and monitoring and modelling capabilitites is also important. Many emerging economies have no formal controls on NMVOC emissions from chemical and solvent use, in part due to lack of reporting and data. Addressing this would close a major gap in technical capability and help enhance ozone control.

Wildfires:[viii]

- Wildfires are significant sources of CO_2 and black carbon. But they are also substantial emission sources for ozone precursors such as methane, NMVOCs and NOx. Estimates vary by location and by fire severity. However, one study found that in 2018, biomass burning in the Western United States contributed to 45% of total VOC emissions in the region.[66] Some estimates show that wildfires are responsible for 3.5% of global tropospheric ozone production annually, and as wildfires occur more frequently with increased warming levels, tropospheric ozone will rise as a result.[67]

- Wildfire emissions are generally not explicitly included in the accounting of NDCs, as NDCs primarily focus on anthropogenic sources. However, the growing impact of climate-driven wildfires is increasingly acknowledged, and many countries are beginning to integrate wildfire management, prevention and resilience strategies within their NDC frameworks. Yet, wildfires are largely missing from traditional decarbonisation goals and policies.

- Similarly, air pollution emissions from wildfires are frequently not accounted for. The EU allows for the deduction of pollution from natural sources from its inventories and the U.S. EPA allows states to exclude air quality data that has been influenced by an 'exceptional event' like a wildfire. However, climate change is expected to increase the frequency and magnitude of wildfires, which will in turn lead to increased NMVOC emissions and elevated tropospheric ozone levels. These events are becoming less exceptional and as their severity increases, the pollution becomes more intense and drifts across borders and regions, affecting multiple countries and populations at once. Needless to say, the public health impacts from wildfires are immense given the emissions of harmful particulate matter and the precursors that then contribute to high levels of ozone.[68]

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viii Wildfires are any unplanned or uncontrolled fire affecting natural, cultural, industrial and residential landscapes, as defined by the United Nations Office for Disaster Risk Reduction.

- Effectively managing wildfires as a source of tropospheric ozone requires a shift in the perspective of viewing wildfires as merely 'natural disasters' to recognising them as a critical, climate-driven priority area that demands proactive and integrated policy responses. This will require better integration of wildfire emissions into greenhouse gas inventories, re-evaluating 'exceptional events' rules within air quality management and explicitly integrating tropospheric ozone considerations within existing efforts to reduce and manage wildfires.

Ozone policy must evolve from isolated pollution control into a central pillar of integrated environmental strategy. If implemented strategically, with a full understanding of synergies, trade-offs and blind spots, ozone action would enhance outcomes across climate, health and ecosystems and agriculture.

4.4. INCREASED AWARENESS THROUGH COMMUNICATIONS

Low levels of awareness among mainstream climate and agricultural and ecosystem stakeholders is a major barrier to effective action on tropospheric ozone – and super pollutants more broadly. Successful delivery and implementation of this roadmap will rely upon effective communication of the impacts of tropospheric ozone and the many benefits of reducing it.

Tropospheric ozone is challenging to communicate because of its technical complexities – it's a secondary pollutant, it has a non-linear relationship with its precursors and its dispersal across different areas of the troposphere make it hard to grasp for a non-technical audience. Even within the air quality community, where awareness is higher, it remains crucial to frame ozone reduction as not just an air pollution issue, but also a strategic climate and health opportunity with cross-sectoral benefits.

A clear, strong narrative around ozone and its impacts, framed within the broader super pollutants movement, would create a pathway for stakeholders from all areas to get involved and push for integrated action. Messaging should highlight how ozone is not only a harmful pollutant in its own right, but also a marker of policy blind spots. For example, many methane or NOx mitigation efforts overlook their knock-on effects on ozone formation. Clear narratives that explain these interconnections, such as how methane reductions can also lower ozone and improve crop yields, would help drive cooperation across sectors.

This communications effort should not brand ozone as a new issue. Rather, ozone should be embedded more deeply in existing climate, health and agricultural and ecosystem narratives, where super pollutants are seen as central to achieving near-term climate action and long-term sustainability goals alongside decarbonisation efforts.

5. CONCLUSION: SEIZING THE OPPORTUNITY FOR INTEGRATED OZONE ACTION

Tropospheric ozone is a growing threat to climate, public health, agricultural productivity and ecosystems, but remains overlooked in science and policy. Action on it is largely underfunded. Despite decades of research and monitoring, significant gaps remain in our understanding of ozone, its impacts and effective interventions. These scientific uncertainties limit our ability to design precise, evidence-based mitigation strategies. At the same time, governance structures remain fragmented, with ozone falling between the cracks of climate, air quality, agriculture and ecosystem policy. Without a plan to mitigate tropospheric ozone, levels will continue to increase worldwide.[69]

This roadmap from 2025 to 2030 has laid out a coordinated, practical strategy – not building new policy regimes from scratch, but embedding ozone into the existing architecture of climate and air pollution governance.

To move from analysis to implementation, scientists, policymakers and funders must work in tandem. Immediate steps should include:

- Advancing the science on ozone's impacts on climate, health, agriculture and ecosystems, including locally specific damage thresholds and protective interventions;
- Strengthening global and regional emissions inventories to reflect ozone precursor emissions more accurately;
- Supporting WHO, IPCC, CBD and FAO processes to update guidelines, integrate ozone into risk frameworks and enable countries to act;
- Enhancing regional air pollution agreements and platforms to set targets, establish and maintain enforcement and promote transboundary cooperation;
- Building national and sub-national capacity to monitor, model and manage ozone through peer exchange and tailored tools;
- Elevating ozone in climate discussions, especially through NDCs, the IPCC AR7 cycle and global efforts to promote action on SLCPs;
- Promoting cross-sectoral, equity-centred solutions that support those most exposed and least equipped to adapt.
- Partnering with national and international philanthropic and finance institutions to integrate tropospheric ozone and its precursors, as well as super pollutants, into funding decisions and throughout the project life-cycle (from identification to evaluation).

We already have many of the tools we need. What's missing is a concerted effort to connect the science to governance, link ozone to near-term climate goals and ensure institutions and funders enable implementation. Done right, this effort will not only cut harmful ozone levels, but also deliver cleaner air, protect health, ecosystems and crops and accelerate climate progress in this critical decade.

The path forward necessitates:

- **Strategic Integration:** Embedding ozone considerations into climate, air quality, health and agricultural policies to ensure cohesive and comprehensive approaches.
- **Enhanced Collaboration:** Fostering partnerships across sectors and governance levels to facilitate knowledge sharing, capacity building and coordinated action.
- **Targeted Communication:** Raising awareness among stakeholders about the co-benefits of ozone reduction, emphasizing its role in achieving broader environmental and health objectives.

The time to act is now. Through deliberate, coordinated efforts, we can transform the challenge of tropospheric ozone into an opportunity for comprehensive environmental and societal advancement.

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