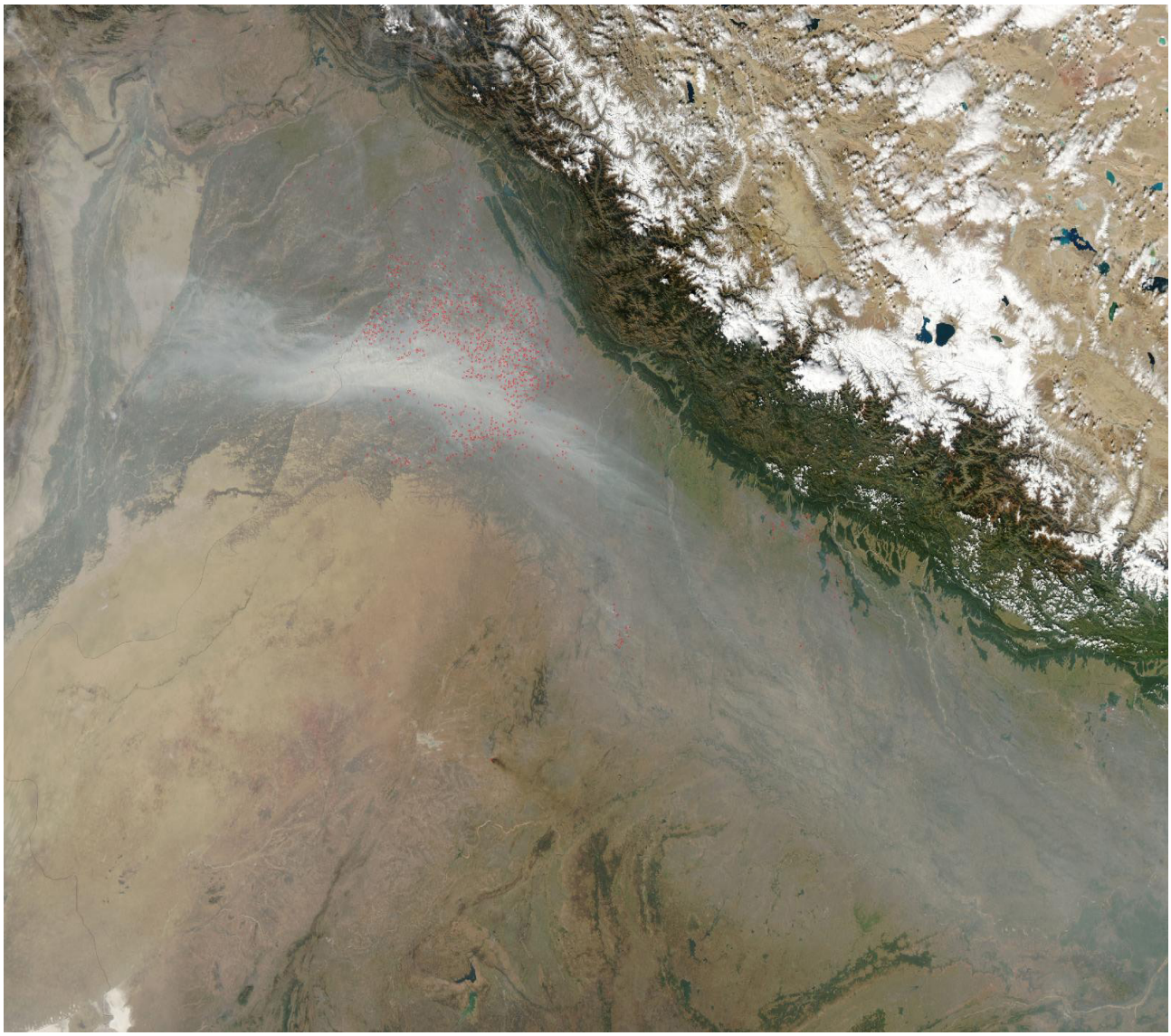
POLICY NOTE 2020:01

Summary of the International workshop on "Effects of air pollution and climate extremes on agriculture and health in South Asia" - Integrating Climate Action with Air Action in Indian Cities



CICERO
Center for International Climate Research

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Summary of the International workshop on “Effects of air pollution and climate extremes on agriculture and health in South Asia” - Integrating Climate Action with Air Action in Indian Cities

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Project: CiXPAG - Interaction of Climate Extremes, Air Pollution and Agro-ecosystems (2015-2019)

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Abstract: The CiXPAG project co-organized a workshop in Delhi in November 2019, on the “Effects of air pollution and climate extremes on agriculture and health in South Asia”, together with local partners Society for Environment Education & Development (SEED) and Clean Air Asia (CAA). The workshop brought together experts from research and relevant stakeholders to discuss the state-of-knowledge and awareness of combined pollution and climate change impacts on agriculture, and to discuss gaps of knowledge and a roadmap ahead for science, policy and implementation. Some key points brought forward are the need to increase monitoring of ozone, better understand the links between urban and rural areas (both in terms of pollution transport, but also in socio-economic terms), use “airshed-” rather than local approaches for mitigation, to tailor dose-response curves specifically for Indian crop varieties, and to model impacts of different stresses such as heat, water, irrigation and ozone, to identify and prioritize which stresses are most urgent to address. Both urgency, adaptation besides mitigation, and socio-economic and political context for adaptation were pointed out as key issues.

[Norwegian] CiXPAG prosjektet har organisert en workshop i Delhi i november 2019 om “Effekten av luftforurensning og ekstreme klimahendelser på jordbruk og helse i Sør-Asia”, sammen med lokale partnere Society for Environment Education & Development (SEED) og Clean Air Asia (CAA). Workshopen samlet eksperter fra forskning og relevante aktører for å diskutere 1) status til kunnskap og 2) kjennskap om kombinerte forurensning og klimaendringseffekter på landbruket, 3) eksisterende kunnskapshull og 3) produsere et veikart for videre arbeid i forsking, politikk og implementering. Noen viktige punkter som ble fremmet var behovet for å øke overvåking av ozon, øke forståelse for forbindelsene mellom urbane og landlige områder (både mht. transport av forurensning, men også i samfunnsøkonomiske betydning), bruke en «airshed» tilnærming i stedet for lokale tilnærminger for redusere konsekvenser, å skreddersy doseresponskurver spesielt for indiske avlingssorter, og for å modellere påvirkninger av forskjellige typer stress som varme, vann, irrigasjon og ozon, for å identifisere og prioritere hvilke belastninger som er mest presserende å adressere. Både det korte tidsperspektivet, tilpasning i tillegg til avbøtende tiltak, og sosioøkonomisk og politisk kontekst for tilpasning ble påpekt som sentrale temaer.

Language of Report: English

Image on cover: Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite. This image was acquired on October 2009. NASA archives show these fires as routine every year.The fires are outlined in red squares, in this zoomable map. The smog and smoke is the thin white-gray strip stretching from northwest India to the east along India's major rivers.Though no single fire is large or particularly smoky, the fires cumulatively produce a heavy veil of smoke that swaths northern India in early winter - contributing to its winter smog. This cluster of fires burns every year in October and November.The fires are in an agricultural region where October marks the end of the Kharif crop (autumn crop) and the beginning of the Rabi crop (spring crop). The fires are set by farmers, who are clearing the land between harvest and planting. Other than being a major source of air pollution, the burn practice is a loss of fodder and biomass fuel.

Contents

1 Workshop synthesis

The international synthesis workshop on "Effects of air pollution and climate extremes on agriculture and health in South Asia" - Integrating Climate Action with Air Action in Indian Cities objectives are:

1) to present and discuss our current knowledge on combined and individual effects of air pollution and climate extremes on agriculture and health;
2) raise awareness of the urgency of these issues in society and policy, and;
3) explore different options on how to deal with these combined issues.

The workshop brings together experts from research and relevant stakeholders to:

1) discuss the current state of the art, and
2) connect science with policy and practice, to
3) co-produce a roadmap in support of climate and clean air science, policy and action.

The workshop built on the key findings of the CiXPAG project and the conclusions of the GAP-Forum seminar held nearly 10 years ago in Delhi to discuss what we have learned in the last decade, what CiXPAG and current knowledge have contributed, and what knowledge gaps remain. The workshop concluded with a reflection on the way forward.

Guiding questions for the workshop were:

- Do the participants agree that the framing of CiXPAGs key findings is useful for different stakeholders?
- Can the participants add additional key findings?
- What are the knowledge gaps for science, and what are the knowledge gaps for policymakers? Are we producing the science that is needed? For whom is it useful?
- Are there other stakeholders (e.g. agronomists, economists, social scientists) that we should connect with and what would be the best 'entry points' for such a connection?
- Do the findings have different consequences depending on context, vulnerability, resilience of farmers/consumers?
- Do we have enough science evidence to support formulation of air quality guidelines for ozone for vegetation (crops) and/or health in India?
- What should those guidelines/limits be?
- Do we have enough evidence to support development of mitigation and adaptation options?
- What should these mitigation & adaptation options be?

1.1 *Presentations*

Individual presentations can be found at the following website link:

https://www.cicero.oslo.no/en/publications-and-events/workshop-on-effects-of-air-pollution-and-climate-extremes-on-agriculture-and-health-in-south-asia

1.2 Workshop conclusions, reflections, identified knowledge gaps and way forward

Existing knowledge and focus:

- Workshop participants identified a growing body of knowledge, but a lack (and perceived unwillingness) of uptake and implementation of existing science and knowledge on the effects of pollution and climate events or climate change on crops and health.
- Current political and media focus on pollution targets particulate matter (total and PM10) pollution, which along with NO_2 and SO_2 are the key (and only) pollutants measured in Indian cities. The current debate therefore revolves much around the health effects and sources of these pollutants. In this debate, locally generated pollution as well as sources transporting pollution from rural and transboundary regions are hot topics with agricultural residue burning being of particular focus after recent poor air quality episodes in later 2019 in Delhi.
- The dialogue on air pollution in India is very skewed to the urban environment and impacts primarily because India has very little rural/agricultural space monitoring. In view of this research studies like this can be fed into the policy process.

Need for increasing awareness and monitoring:

- There is little awareness or discussion around ground level ozone as a pollutant, how it contributes to the formation of smog build-up in cities and regions, and how it affects not only health but also agriculture and crop yield.
- Therefore, there is a strong need to raise (public and political) awareness about the effects of ozone pollution on crops and human health, and about the interactions of pollution with climate change.
- Regional and local policy action to reduce (any) pollution and its effects are hampered by 1) too few monitoring stations to measure effects over time which only monitor four pollutants , and 2) a complex governance structure with variable levels of decision making ranging from city to airshed to districts to state and to the national level.
- The need to monitor ground level ozone due to its health impacts is being discussed but in very academic circles. There is a growing discussion to include ground level ozone as a criteria pollutant for health effects. Very few cities presently monitor ozone or dialogue around its impacts.
- While monitoring stations in general have increased, there is a need for increased spatially relevant and uniform distribution of monitoring, covering both urban and agricultural areas.
- Increased monitoring could help map the spatial connectivity between sources of air pollution and air pollution episodes and hence increase awareness of agriculture and health connections such as residue biomass burning and urban health, or the other way around: how are urban pollution emissions impacting rural ozone and PM concentrations and what impacts these pollutants are having on agriculture. Such monitoring would form the basis to identify and measure the impacts of emissions at different concentrations, which in turn would support the development of appropriate policy and implementation of appropriate air action plans.
- As the long-distance connections between sources and sinks/impact areas of pollution become clear, the workshop identified a need to approach these issues through larger scale airshed assessments for district planning rather than simply using local approaches.
- There is a perception that impact studies are not specific enough for Indian crops. There is a need to test both climate (and pollution) resilient crops, both new varieties and old breeds, to create specific Indian dose-response relationships.
- Resilient crops should then be tested in field conditions, as impacts under natural conditions tend to differ from both model results and (OTC) test results.
- A first step would be to model impacts of different stresses such as heat, water, irrigation and ozone, to identify and prioritize which stresses are most urgent to address. These results should

then be connected to crop breeders to help focus on varieties with resilience in these areas, and with agricultural extension services to communicate which varieties to use and which stresses to adapt to.

Way forward:

- Action to improve air quality and mitigate climate change is urgent: in the absence of (global) action on both issues, in 10 years' time there will be a very different world, with consequences for both climate and pollution levels and the consequences of these on society and (in context of this workshop) food production.
- The Clean Air scoreboard tool (CAST) could be a useful tool to assess air pollution and climate change resilience (in cities). Such a scoring and ranking system could prompt cities to form or improve Air Action plans and aim for being (or improving its status as) a Climate Smart City".
- Another route of action may be through the SDGs and suggested specific targets integrating climate, air, and environment. This would align air action and climate action policies with other development goals and give politicians a tool to work with to address these combined challenges. While the SDGs lack a specific goal for improving air quality, air quality is connected to other SDGs and sub targets implicitly. There is a need for research into how SDGs and air quality are connected, and which trade-offs and co-benefits air quality and climate action may have with the SDGs in the specific geographical context. There is also a realization that this would be time consuming, while time is of essence given the changes in climate extremes likely to occur in the coming decade.
- Action plans would need a clear identification of responsibility at the different levels of governance to ensure implementation.
- There is a need to include impact on agriculture and food security in the overall dialogue on air pollution in the country in an integrated manner.

At the more general level:

- India would need to adopt a more stringent climate policy and step up its NDCs to mitigate climate impacts on crop yields.
- At the same time as implementing mitigative action, adaptations are needed to increase resilience to unavoidable and embedded climate change.
- To ensure current and future action, there is a continued need for education, communication and public engagement.
- Innovative financial mechanisms may help securing financial support for clean air action.

The roadmap chart shown in figure 1 tries to summarize the key points from the workshop, including 1) the need for air quality guidelines based on Indian (specific crops) dose-response relationships; 2) dialogues with stakeholders around such dose responses and effects, and to promote low emission agricultural practices; 3) the need to increase monitoring in a spatial and temporal way, both through air quality monitors, but also; 4) through impacts monitoring in the field and testing sites of combined stresses, which; 5) can be run in parallel with experimental models running projections on crop- and yield impacts for India specific crops, which 5) may also aid in prioritizing stresses and connect these to other communities such as crop breeders and agricultural extension services.

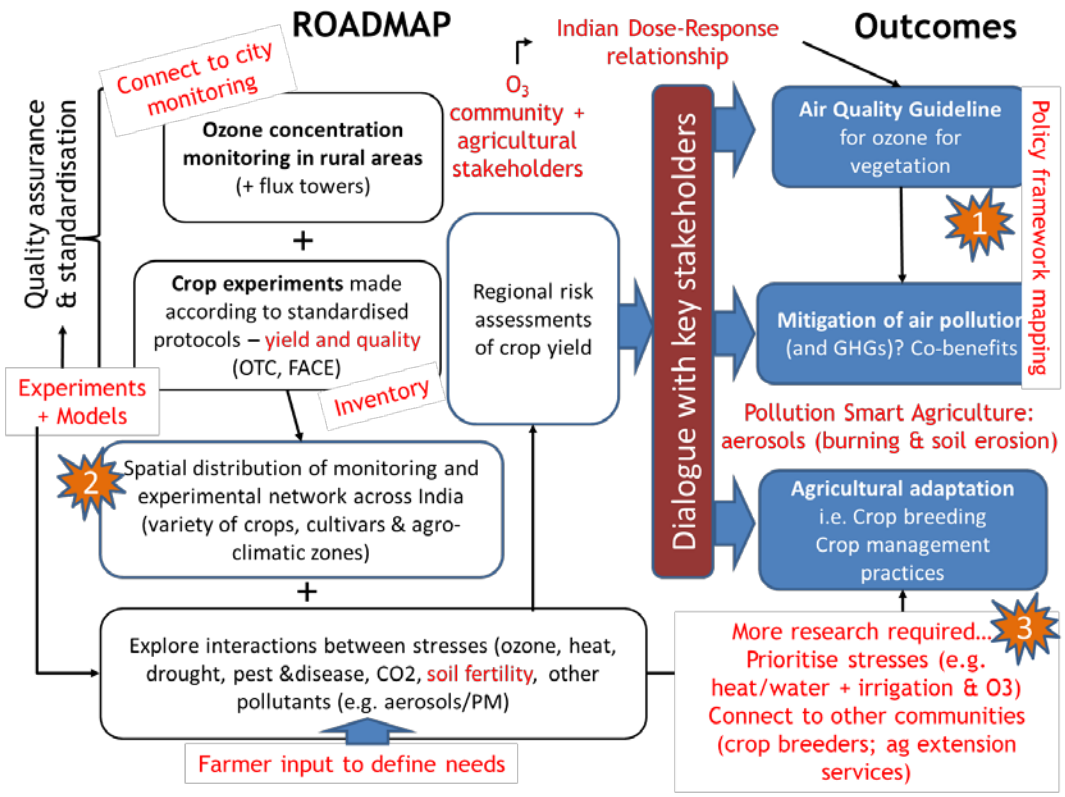


Figure 1: Roadmap chart from the GAP (2010) seminar adjusted with 2019 workshop conclusions (in red), also summarized in the bullet points above.

1.3 The importance of context:

Understanding of how key stakeholders such as farmers and other members of rural communities experience social and environmental changes is important to give context to the current and modelled yield impacts of climate and air pollution. The consequences of such impacts may have different importance in different contexts and may differ between countries such as India and Nepal, or between Indian states. A CiXPAG analysis of the experiences of rural transformations and environmental change in cases in India (Varanasi and Ambala) and Nepal (Chitwan and Kaski) indicates that the rural agricultural sector is facing many transformations simultaneously.

One aspect concerns demographic changes: An increase of migration from rural areas to urban areas is prevalent in both cases, mainly among young people who are less attracted to agriculture. In Nepal this migration is mainly overseas and long-term and educated youth do not go (back) into agriculture. In India this migration is mainly internal and short-term. In addition, family sizes are declining in both cases. A second issue is that sources of income are diversifying, and an increase of non-farm incomes are observed in both sites, in part as a result of this migration but also of inventive new ways to create an income. Different sources may include crops, livestock, roadside shops, wage labour, remittances, renting out tractor services, real estate, or private education institutions. There is also a change in the uses of the income, in which is increasingly used to cover expenses related to education and health care (preferably private rather than public).

Agricultural production is changing in both the Nepal and India cases for several reasons, responding both to demographic changes and changes in needs to invest labour time in different income sources, interlinked with climate changes. Agriculture is increasingly mechanized in all sites (but most prevalent in Ambala), and especially in India there is an increased intensification of crop production. The use of fertilizers is increasing, due to increase in pests and diseases and their resistance to herbicides and weedicides, and to the perception of declining soil fertility and drying. Farming is mainly carried out by smallholders in both Nepal and India. These smallholders use seasonal labourers and machines for some tasks/stages of production. Labour demand has, however, decreased due both to mechanisation and to the increased cost/wage of seasonal labourers. The biggest differences between the Nepal and India findings are in the farming itself. The land sizes differ (0.5-3 ha in India sites, average less than 1 ha in Nepal sites), while especially Ambala (India) is dominated by (relatively) larger scale cereal production. The types of crops also vary, with maize being more prominent in Nepal, though farmers cultivate multiple crops in all sites, including (seasonal grains, annual crops, vegetables, perennial crops, and monsoon rice.

These changes in demographics, income and agricultural production indicate that the importance of agriculture as the main family income, and thereby the dependence on crop yields alone, is declining in most sites. In Ambala, where some households still have large holdings, agriculture is still the primary income for some families.

The other aspect are environmental changes that are noted in both the India and Nepal sites, with increased experiences of extreme weather events such as heat waves and unusual precipitation, and pollution. Changing rainfall patterns, temporal variation in onset and offset as well as erratic monsoon and fluctuation in temperature are observed in both sites, but the events vary in intensity and between areas. The Nepal sites report an increase in damages to crops from hail events, while in India reports of persistent warm weather leading to premature flowering of wheat dominate. In both cases, the events have significant impacts on crop production. Both the Nepal and India sites also noted a rise in air pollution. The level of pollution varies between districts, seasons and times of day. Urban areas and areas near highways are the most polluted in both India and Nepal, while in the India sites, the rural areas are also polluted. However, as reported both in the workshop and as evident from the case study analysis, farmers (and interviewed experts) in both the India and Nepal sites are largely unaware of the connection between air pollution and agriculture.

The environmental events have spurred different types of adaptation measures, though not necessarily to climate change. The level of implementation of adaptation measures depends on the level of awareness of the links between climate change and the impacts on crops production. This awareness varies between India and Nepal. Farmers and experts in the Nepal sites were largely unaware of linkages between climate change and crop productivity, while in the India sites farmers were acutely aware of the possible effects of abnormally warm weather. Local level presence of government agricultural services is relatively stronger in India (especially Ambala), while local level institutional presence in Nepal is mainly limited to NGOs doing participatory research methods to generate new practices among farmers.

Possibly as a response to the lack of government services combined with multiple factors including the observed environmental changes and the changes in households, intensified production, yield changes and soil quality (fertility and moisture) changes, agricultural input shops and climate change adaptation projects are proliferating in all sites. In spite of such a proliferation, farmers are frustrated and feel neglected by the government regarding need for assistance and technical advice.

The potential and perceived importance of adaptation must thus be seen in the context of these rural and agricultural changes. Adaptation takes place as a response to multiple changes, including climate, but also and perhaps especially demographic and income changes. The privatisation of both health- and agricultural services also play a role in rural livelihoods. While income is diversifying in most sites, which may increase resilience to change, shocks and impacts, this diversification trend does not

make adaptation in agriculture and rural areas less urgent. This is also reflected in peoples own sense of contribution of farming to livelihood security. The labour and income relations between urban and rural regions, as well as gender relations in agricultural activities, are also more nuanced than simplifications of “mostly farming” or “people leaving farming entirely” might suggest. Furthermore, the discourse of ‘agriculture needs to be industrialised large-scale’ also feeds into dominant climate change adaptation discourses, influencing the types of climate information services that are provided (and climate change knowledge that is being produced). Adaptations efforts should further be tailored to the scale and implementation options that exist: Industrialisation of wheat may be predominant in just a couple of Indian states, while in other sites wheat production is more small-scale, perhaps more directed to support subsistence.

Our assumptions affect what questions we ask. Understanding the context of wheat production is of key importance in understanding adaptation options and related research needs.

2 Background for the workshop

The world as a whole as well as some particular key regions, such as the Indian IGP, are experiencing a number of environmental crises. While there currently is enhanced attention to air pollution from PM2.5, it is often not realized that ozone pollution forms a substantial part of poor air quality. Ground level ozone is damaging both to health and to agricultural crops. These receptors are also increasingly threatened by climate change, especially by extreme events. It is exactly 40 years ago that the first global meetings on air pollution and climate change took place. However, both mitigation of climate- and air pollution are more urgent than ever before. At this workshop on "Effects of air pollution and climate extremes on agriculture and health in South Asia - Integrating Climate Action with Air Action in Indian Cities", we considered current knowledge of the independent and combined effects of air pollution and extreme climate events on agricultural crops and health. Participants presented research on this topic through focus on 1) CiXPAG results and 2) research results from Indian science institutes, 3) discussed current local air pollution mitigation measures understanding of research, and 3) discussed research, policy and implementation needs, reflecting on knowledge gaps and the way forward.

2.1 CiXPAG (2019) Key findings

WP1: Plant Experiments in Varanasi

- The higher ambient O_3 concentrations coincided with higher temperature and low humidity towards the end of the growing season.
- High temperature and high O_3 concentration during reproductive and grain filling stages played a significant role in influencing the plant physiological processes negatively.
- Both the thermo-tolerant wheat cultivars (e.g. late sown cultivars) show significant yield reductions under elevated O_3, suggesting that tropospheric O_3 will remain a threat to wheat production in the future.
- Yield loss in terms of weight of grain can vary between 20-26% under elevated O_3 compared to ambient in the two cultivars studied (Yadav et al. 2019, Yadav et al. under revision).

WP2/WP4: Regional Climate and Crop Modelling

- Regional climate projections show an increase in mean temperature as well as maximum temperature during the growing season (November-April) including an increase in more frequent and intense heatwaves by 36 %–88 % (Benestad et al. 2018).
- Under rainfed conditions, the direct impact of climate change, via an increase in temperatures and changes in precipitation according to RCP8.5 scenario for mid-21st century, leads to relative wheat yield losses from -0.5 to -8% depending on the site.
- Under best practice conditions (6 irrigations), the relative yield losses are similar, ranging from -1 to -7%, but the total amount of wheat yield is higher than would be without optimal irrigation.
- If the number of irrigations is reduced from 6 to 1 time per day under RCP8.5 mid-21st century climate conditions, wheat yield reductions range between -25 to -35% across sites indicating that the impact of limited irrigation can be even more critical for wheat yield in the IGP than the direct impact from increased temperatures (Daloz et al. submitted).

WP3/WP4: Process-based modelling of ozone and climate effects on wheat yield

- Regional chemistry-climate simulations indicate a strong future increase in near-surface ozone over the IGP during the growing season (December-April). The probability of ozone levels exceeding 80 ppb increases from 2% in the present to 15% in the future (RCP8.5).
- Ozone flux-based impact modelling for the whole of India using the DO3SE model suggest ~12% yield loss due to ozone resulting in 12 Tg of wheat production lost due to ozone (Mills et al., 2018).
- Compared to the current day (2000s), future growing season length is likely to be shorter by ~5 (RCP4.5) and ~7 days (RCP8.4) in the 2050s as modelled using the DO3SE effective temperature sum model for a late sown, medium maturing wheat variety HUW234.
- The DO3SE model estimated ozone induced yield losses of 3-25% for the late sown, medium maturing wheat variety HUW234 for modelled ozone and climate variables conditions of the 2000s, assuming full irrigation, compared to future ozone induced yield losses of 11-32% (RCP4.5) and 10-31% (RCP8.5). Determinants of yield loss between years depend on the interplay of O3 episodes (leading to higher stomatal ozone flux) and heat stress (altering the O3 episodes to which plants are exposed).
- Using supply and demand economic methods, preliminary estimates suggest that O3 induced crop yield and production losses may increase the market-clearing price of wheat by ~30%.

WP1/5: Understanding the socioeconomic and political context of farmers

While adaptation efforts are often centred around securing agricultural production and are predicated on climate risk management, rural livelihoods (example in Nepal) are caught in a wider process of transformation. The number of people involved in farming are declining, and households are experiencing the effects of rising education, abandonment of rural land, increasing wages, burgeoning mechanisation, and high levels of migration into the global labour market (Ensor et al. 2019).

2.2 CiXPAG identified Knowledge gaps and recommendations

Crop models should be developed to allow estimates of the effect of ozone and climate variables in combination on crop yields (Emberson et al., 2018). Only with these tools will we be able to assess the future influence of these two integrated stresses, along with management practices such as irrigation, on crop yield and productivity to allow effective targeting of mitigation and adaptation efforts. Given that irrigation plays a key role in sustaining high crop yields in the IGP, it is crucial to investigate the optimal timing for irrigation or suppressing irrigation (e.g. during growing season, different growing stages) in order to adapt to changes in water availability and increasing temperatures. Since irrigation affects the uptake of ozone by plants/wheat, it is necessary to investigate when is the best timing for irrigation for enhancing crop yield but limiting ozone damages.

These findings would suggest that it may be advisable to establish an Air Quality Guideline to target emission reductions to protect agriculture from the ozone pollution. This might be particularly important as changes in climate variables with climate change may enhance wheat crop sensitivity to ozone. Management practices (e.g. enhanced irrigation) will be likely to make crops even more susceptible to ozone.

If ozone pollution were removed (i.e. the air was clean), the price for crops that farmers can sell at will fall (but the effect on farmers will be limited by the minimum support price paid to farmers by the Indian government). By contrast, consumers will see a reduced price in food and enhance food access under pollutant free conditions.

Furthermore, it is necessary to premise adaptation on an epistemological approach capable of exploring also the socio-economic and political context in which change occurs by looking at both ‘what are the most significant changes taking place in people's lives?’, and ‘what are the impacts of climate change on their assets?’ Viewing adaptation as occurring between and within these two

perspectives can reveal critical vulnerabilities and new opportunities for adaptation practice (Ensor et al. 2019).

2.3 GAP seminar (2010) conclusions

Global Atmospheric Pollution Forum Seminar on Ground Level Ozone and Food Security in Asia, New Delhi, India, 15th Nov 2010. This seminar was funded by Sida (the Swedish International Development Cooperation Agency) and hosted by the Global Atmospheric Pollution Forum (GAP Forum) in collaboration with the Stockholm Environment Institute (SEI) and the United Nations Environment Programme (UNEP).

Seminar Conclusions

1. There is sufficient peer reviewed scientific evidence, obtained using a variety of experimental methods, to demonstrate that ambient levels of ground level ozone (O3) (frequently reaching 40-50 ppb 8hr growing season means) are high enough to be causing substantial yield losses (often of between 10 to 20% for a number of important staple crops (wheat, rice, pulses) at agriculturally important sites across South Asia (and especially in the important Indo-Gangetic Plain region).
2. However, there is not yet sufficient evidence to assess the scale of the O3 problem in relation to the magnitude and extent of O3 induced yield losses across the entire South Asian region.
3. This is in part due to extremely limited O3 monitoring, and limited monitoring of the precursors of ozone VOCs, NOx), in rural areas (in terms of number of sites, capability of the monitoring methods and quality assurance of the data collected). This limits the ability to validate photochemical modelling of O3 across the South Asian region.
4. In addition, emission inventories that are necessary for photochemical modelling need to be improved both in terms of their description of the quantity of emissions as well as the geographical distribution of the emission sources.
5. Also, currently, there are no dose-response relationships that have been derived under South Asian conditions, this makes estimating yield losses from O3 concentration data extremely uncertain. Ideally, dose-response relationships would be derived that were representative of the wide variety of South Asian crops and cultivars, environmental conditions and agricultural management practices that exist across the region. Such dose-response relationships could then be used to identify critical levels (levels below which impacts would not be expected to occur) which could be used in risk assessment modelling and mapping.
6. There is a need to continue awareness raising of the O3 issue and engage different research groups (in particular those investigating climate change, hydrology, ecology and agronomy). This awareness raising should also emphasise the multiple benefits of reducing O3 concentrations for both human health and regional climate change.
7. It was agreed there is an urgent research need to fill knowledge gaps that limit our ability to assess the extent and magnitude of the yield losses that might be occurring across South Asia so that risk assessments can be performed to make a scientifically robust assessment of the agricultural losses and associated economic costs resulting from ground level O3.
8. Such assessments would enable cost-benefit style analyses to be conducted to indicate whether efforts to mitigate against O3 damage (which would also have benefits for human health and regional climate change) or adapt to elevated O3 concentrations (for example through the identification of O3 resistant crop cultivars for use in regions where O3 concentrations are particularly high) would be cost effective.
9. Were mitigation efforts are deemed desirable such studies would also provide the information necessary to establish an effects-based emission reduction policy programme.

3 About CiXPAG

Future food production, and consequently food security, is very sensitive to both climate change and air pollution. So far, little is known about how climate extremes and ozone pollution interact to affect agriculture or about the relative effectiveness of climate change adaptation and ozone regulation measures for various crops and regions.

CiXPAG (Interaction of Climate Extremes, Air Pollution and Agro-ecosystems) is a four-year research project (2015-2019) fully funded by the Research Council of Norway (Grant number: 244551)

In CiXPAG (https://www.cicero.oslo.no/en/CiXPAG), state-of-the-art global and regional climate model simulations were combined with statistical downscaling approaches to provide better information on climate extremes relevant to agriculture. We developed a flux-based approach in ozone chemistry and climate models. A novel and more consistent approach to include the ozone effect in statistical crop growth models increased our understanding of the interplay of environmental factors, such as downscaled climate information and air pollution, on agricultural ecosystems.

The development of these models have been informed by field experiments describing the effect of climate and ozone on selected crops. The modelling results were embedded in the particular socio-economic and political context of the study region (Indo-Gangetic-Plain, India) that contributes substantially to regional and global food supply but is threatened by climate extremes and air pollution. A contextualized understanding of potential responses was jointly developed by farmers, researchers and policy makers to support effective climate change adaptation and air pollution regulation measures. Knowledge generated in CiXPAG is relevant also for other significant food producing and exporting countries and regions (e.g., Europe, Brazil).

Primary objective:

The main goal of CiXPAG was to obtain a better contextual understanding of the combined impact of climate extremes and air pollution on agro-ecosystems and to provide knowledge for effective climate change adaptation and air pollution regulation measures.

Secondary objectives include:

- Combine global and regional climate model simulations with statistical downscaling methods to provide improved information on changes in climate extremes on scales relevant for agriculture
- Assess ozone sensitivity of modern crop cultivars bred for adaptation to extreme climate events
- Improve the dry deposition scheme in global and regional atmospheric chemistry models to better account for ozone uptake by plants
- Incorporate the ozone effect on plants in statistical crop models to derive realistic estimate for changes in future crop productivity
- Investigate the impacts of current and projected ozone concentrations on agriculture within the context of climate change
- Integrate local knowledge to develop effective climate change adaptation strategies and air pollution regulation measures

Work package overview and connection:

WP1 Field Studies: Provide baseline agricultural, socio-economic and political context and field experiments/observations on selected crops in the IGP region.

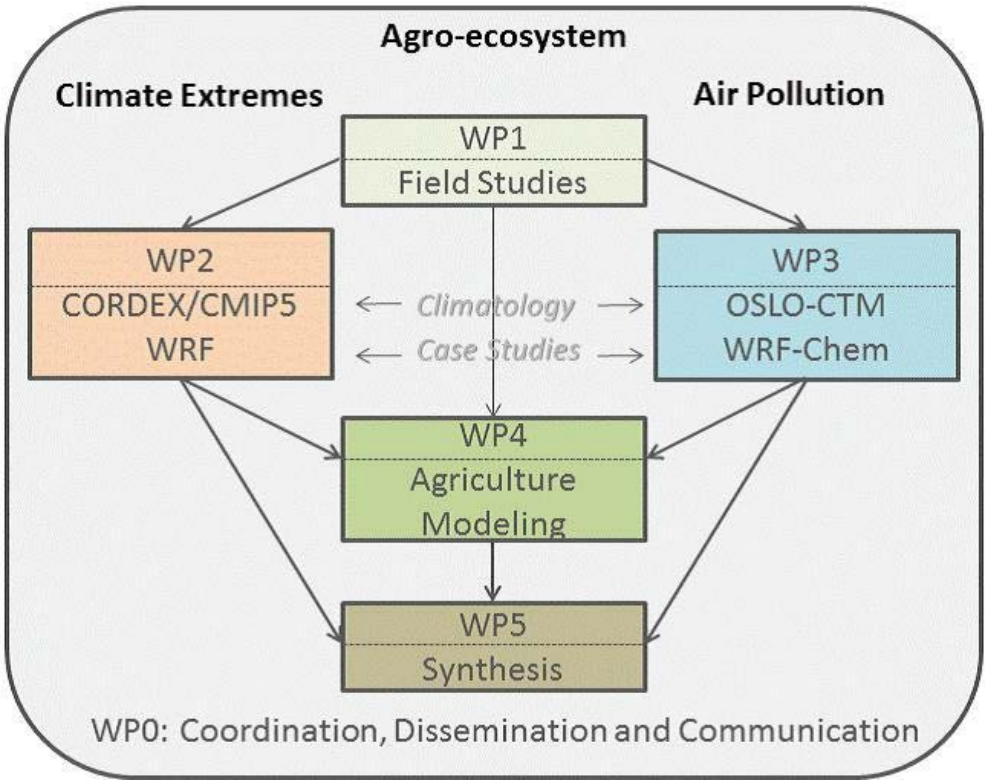
WP2 Regional Modelling of Climate Extremes: Identification of crop-relevant climate extreme events and model evaluation with regard to optimal spatial and temporal representation of climate extremes for the region.

WP3 Regional Air Pollution Modelling: Study the impact of extreme meteorological conditions on regional O3 air pollution for present and future climate and emissions.

WP4 Agricultural Impacts of Climate Extremes and Air Pollution: Estimate impacts of climate change and variability as well as O3 pollution on food productivity in the study region.

WP5 Synthesis and Implications for Adaptation Strategies: Synthesize findings from WP1-4 to assess 1) the combined effects of climate change and different levels of CO2 and O3 on yields in the agricultural sector, and 2) explore effective and contextualized adaptation strategies.

Figure 2: Overview of works packages and work package connections in the CiXPAG project.



4 About CAA

Clean Air Asia (CAA) co-hosted the workshop. Clean Air Asia is an international non-governmental organization that leads the regional mission for better air quality and healthier, more liveable cities in Asia. Headquartered in Manila, Philippines, with offices in Beijing China and New Delhi India, CAA aims to reduce air pollution and greenhouse gas emissions in 1000+ cities in Asia through policies and programs that cover air quality, transport and industrial emissions and energy use.

CAA's works with ministries (energy, environment, health and transport), cities in Asia, private sector and development agencies to provide leadership and technical knowledge in the following areas: Air Quality and Climate Change, Low Emissions Urban Development, Clean Fuels and Vehicles and Green Freight and Logistics. As the regional resource hub for air quality management training, CAA is responding to the international call for action on air pollution and is helping to strengthen the capacity of stakeholders to improve air quality through the Air Quality and Climate Change (AQCC) Program. The AQCC Program is supporting cities in the management of air pollution and greenhouse gases, building their capacity in key areas such as air quality standards and monitoring, emissions inventories, air quality communication and clean air action plans

Clean Air Asia's current work in India involves engaging with Indian cities for better air quality management and involves providing scientific input to city governments for better air quality action plans, sustainable transport/mobility programs and education/communication for cleaner air. In India CAA is working with more than 30 cities in India to assess management capacity in preparation for the development of clean air action plans. CAA is also supporting capacity building activities for air quality management. The Clean Air Knowledge Network (CAKN), developed by CAA India is a forum that connects is aimed at promoting knowledge-sharing across cities and issues and sharing best practices. A major component of the work in India is education for better air quality. CAA's Youth Clean Air Network (YCan) operating in multiple cities in India, is a voluntary program in which youth are able to work together on air quality projects, campaigns, surveys, and solutions.

Read more about Clean Air Asia and their work on Air Quality and Climate Change here: https://cleanairasia.org/air-quality-and-climate-change/

5 About SEED and the MOBIUS Foundation

SEED, and in part the MOBIUS Foundation, through Mr. Ram Boojh, co-hosted the workshop.

SEED

Society for Environment Education & Development (SEED) based in India is a voluntary organization advising in the area of climate change and air pollution. SEED is involved in creating awareness about environment and sustainable development issues and works through partnerships and networks utilizing their complementary strengths for synergistic convergence of ideas and goals and builds on strategic opportunities and facilities to address environmental, social and economic dimensions and implications of development. SEED is working in partnership with Clean Air Asia, Ministry of Environment, Forests and Climate Change, Government of India UNESCO, WHO, and Climate Reality Project India.

SEED informs the Ministry of Environment, Forests & Climate Change Government of India on air pollution and climate change issues particularly for developing a national communication guidance framework. This feeds into a national information and communication policy process with the objective to make data more development oriented, enhance access to information and communication infrastructures and new technologies, especially in rural areas, and to promote national dialogue on development issues by all citizens. This will facilitate informed participation of people in setting the development agenda and help in its execution. The policy will assist in defining roles of different governments at various levels and other stakeholders besides enhancing the development of cultural and artistic capabilities and institutions, and its initiation would integrate planners, beneficiaries and implementers of development actions. The endeavour of the proposed policy is to make people informed participants in decision making and development planning process. Such a communication approach would also enable policy makers to look at people as part of the solution.

Read more about SEED and their work here:
https://www.facebook.com/seedforchange14/

MOBIUS Foundation

Mobius Foundation, established in 2015, is a non-profit organization working towards environmental sustainability. In a world struggling with scarcity, the foundation believes that environmental conservation is the key to a better future and a greener planet. The Mobius Foundation believes in environmental awareness and eco-friendly practices as a means to build a sustainable future.

The Mobius Foundation is involved in many and diverse environmental sustainability projects.

Read more about the MOBIUS Foundation and their work here:
https://www.mobiusfoundation.in/

6 Attachment 1: Workshop agenda

International Synthesis Workshop

Effects of air pollution and climate extremes on agriculture and health in South Asia

Integrating Climate Action with Air Action in Indian Cities

21st and 22nd November, 2019
Lecture Room 2, India International Centre Annexe, New Delhi

The workshop aims to bring together experts from research and relevant stakeholders to-i) discuss the current state of the art; ii) connect science to policy and practice, iii) co-produce a roadmap in support of climate and clean air science, policy and action.

Detailed agenda day 1: Consolidating key findings and consequences

Day 1:	**Current knowledge on individual and combined effects of air pollution and climate extremes on agriculture and health**
9:00-10:00	**Registration and Tea**
10:05-10:10	*Welcome,* Mr Bob van Oort, Senior Researcher, Centre for International Climate Research (CICERO), Oslo
10:10-10:20	*Introduction on CiXPAG*, Ms Jana Sillmann, Research Director, Centre for International Climate Research (CICERO), Oslo
10:20-10:30	*Introduction on Clean Air Asia*, Ms Prarthana Borah, India Director, Clean Air Asia
10:30:10:40	*Introduction on SEED*, Mr Ram Boojh, Adviser Society for Environment Education & Development (SEED), Lucknow
10:40-10:45	*Technical sessions' Introduction*, CiXPAG, Ms Lisa Emberson, Professor, Dept. of Environment & Geography, University of York
10:45-11:15	*CiXPAG WP2 results: How well are regional and global climate model simulations able to represent observed climate extremes in the IGP*, Ms Jana Sillmann, CiXPAG, Senior researcher CICERO, (on- video)

11:15-11:30	*CiXPAG WP1 results: Physiological, growth and yield responses of crops and cultivars to a range of O3 x CO2*, Ms Madhoolika Agrawal, CiXPAG, Banaras Hindu University, Varanasi
11:30 - 11:45 Tea break	
11:45:12:00	*CiXPAG WP3 results: Impact of extreme meteorological conditions on regional O3 air pollution for present and future climate and emissions*, Prof Lisa Emberson, Dept. of Environment & Geography, University of York
12:00-12:10	*Effects of climate extremes and air pollution on agriculture and vice versa in India*, Mr S. Naresh Kumar, Professor, Centre For Environment Science and Climate Resilient Agriculture, Indian Agricultural Research Institute (ICAR), New Delhi.
12:10-12:20	*Climate change and agriculture in the Hill and mountain regions of north east India*, Ms Chubamenla Jamir, Assistant Professor, The Energy and Resources Institute (TERI), Delhi
12:20:12:30	*Climate change and human health: An Indian Perspective*, Mr Sagnik Dey, Associate Professor, Centre for Atmospheric Sciences, Indian Institute of Technology (IIT), Delhi
12:30:12:40	*Nexus between climate extremes and health/agricultural in India*, Mr Sachin Ghude, Dr., Indian Institute of Tropical Meteorology (IITM), Pune
12:40-13:15	**Discussion**
13:15-14:00	**Lunch**
14:00-15:30	**Group work: Working on key science messages to support air quality guidelines/roadmap**
14:00-15:30	Guiding questions for session: • Do the participants agree that the framing of CiXPAGs key findings is useful for different stakeholders? • Can the participants add additional key findings? • What are the knowledge gaps for science, and what are the knowledge gaps for policymakers? *Are we producing the science that is needed? For whom is it useful?* • Are there other stakeholders (e.g. agronomists, economists, social scientists) that we should connect with and what would be the best 'entry points' for such a connection? • Do the findings have different consequences depending on context, vulnerability, resilience of farmers/consumers? • Do we have enough science evidence to support formulation of air quality guidelines for ozone for vegetation (crops) in India, not only for human health? • What should those guidelines/limits be? • Do we have enough evidence to support development of mitigation and adaptation options? • What should these mitigation & adaptation options be? • *Consolidate key findings for brief presentation in plenum*
15:30-16:00	**Tea**
16:00-16:30	Presentation of conclusions from each group and wrap of Day 1
19:30-	**Workshop dinner at Hotel Ambassador/Yellow Brick Road restaurant**

Detailed agenda day 2: Need for integration in air action plans in Indian cities

Day 2:	**Climate and pollution policy, and a roadmap to change**
10:00-11:00	Setting the context: Air Pollution and Climate Nexus • Ms Prarthan Borah, India Director, Clean Air Asia City Narratives • Air Action Plan: Ms. Hema Deshpande, Sub-regional officer, Nagpur, Maharashtra Pollution Control Board • Climate Action Plan: Mr. Lokendra Thakkar, Sr. Scientific Officer, EPCO Bhopal
11:10-11:15	**Tea Break**
11:15-12:30	Aligning Climate Change in Air Quality Management • Presentation by Ms Riya Rahiman, India Program Manager, Clean Air Asia • Feedback and Comments from participants
12:30-1:30 pm	**Lunch**
1:30-3:30 pm	Strategies to synergize climate change and air pollution-Moderated Discussion • Moderators: Ms Prarthana Borah,India Director, CAA and Mr Ram Boojh, Adviser, SEED • Remarks by city representative on: o Implementation on Air Action in Cities o Capitalizing synergies between climate change and air pollution.
3:30- 4:00 pm	Concluding remarks and way forward, Professor Lisa Emberson, Dept. of Environment & Geography, University of York
4:00 pm	**Tea**

7 Attachment 2: List of participants

SI No	Name	Affiliation
1	Ms Jana Sillmann	CiXPAG coordinator, Research Director, CICERO Centre for international climate research, Oslo
2	Ms Prarthana Boorah	India director, Clean Air Asia India Office, New Delhi
3	Ms Riya Rahiman	India Program Manager Clean Air Asia India Office, New Delhi
4	Mr Ram Boojh	Adviser SEED - Society for Environment Education & Development, Lucknow
5	Mr Bob van Oort	CiXPAG, Senior researcher CICERO Centre for international climate research, Oslo
6	Ms Lisa Emberson	CiXPAG, Professor Dept. of Environment & Geography, University of York
7	Ms Madhoolika Agrawal	CiXPAG, Professor Banaras Hindu University, Varanasi
8	Mr SB Agrawal	Co-PI of CiXPAG project, Professor Banaras Hindu University, Varanasi
9	Mr Durgesh Singh Yadav	CiXPAG, Research Scholar Banaras Hindu University, Varanasi
10	Mr Soora Naresh Kumar	Professor, Centre For Environment Science and Climate Resilient Agriculture, ICAR-Indian agricultural research institute, New Delhi.
11	Ms Chubamenla Jamir	Assistant Professor, TERI - The Energy and Resources Institute, Delhi
12	Ms Usha Mina	Dr., Jawaharlal Nehru University, New Delhi
13	Mr Sachin D. Ghude	Dr., IITM - Indian Institute of Tropical Meteorology, Pune
14	Mr Sagnik Dey	Associate Professor, Centre for Atmospheric Sciences, Indian Institute of Technology, Delhi
15	Ms Kavya Singh Yadav	MSc., Environmentalist at Mobius Foundation, prev. Guru Gobind Singh Indraprastha University
16	Mr Lokendra Thakkar	Sr. Scientific Officer, EPCO Bhopal
17	Ms Hema Deshpande	Sub Regional Officer - Nagpur
18	Mr Syed Asif Ali	Consulting Engineer, Aurangabad Municipal Corporation
19	Dr Ankur Khansal	Environment Engineer, EPPCB - Dehradun
20	Mr Sushil Dogra	Scientific Officer, Chandigarh Pollution Control Committee
21	Dr Rajan Chedambath	Director, Centre for Heritage Environment and Development, Kochi Municipal Corporation
22	Mr Amit Kumar	Additional CEO, Lucknow Smart City
23	Ms. Kamna Sachdeva	Associate Professor – TERI - Delhi
24	Mr Vibhor Sood	Technical Expert – GIZ Delhi
25	Mr SK Tyagi	Dr., IAPC - Indian Association for Air Pollution Control, Former Addl Director, Central Pollution Control Board
26	Mr A Arumachalam	Dr., ICAR - Indian Council of Agricultural Research
27	Ms Archana Kushwaha	Assistant Manager Environment & Sustainability, Mobius Foundation, Delhi

8 Acknowledgements

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Thus, at the risk of forgetting anyone, besides those already mentioned above a great thanks goes out to Jana Sillmann, Jon Ensor, Milton E. Pereira, Flavio Justino, Madhoolika Agrawal, Durgesh Singh Yadav, S.B. Agrawal, Maheswar Rupakheti, Frode Stordal, Johanne Rydsaa, Abdelkader Mezghani, Patrick Bueker, Rasmus Benestad, Øivind Hodnebrog, Marianne Tronstad Lund, Kristin Aunan, Amund Søvde Haslerud, Borgar Aamaas, Iulia Marginean, Ragnhild Bieltvedt Skeie, Christian Wilhelm Mohr, Anne Sophie Daloz, Clemens Schwingshackl, Marit Sandstad, Miriam Stackpole Dahl, Suzanne Tærud Day, Eilif Ursin Reed, Monica Bjermeland, Erik Tollefsen, Frode Rørvik and Paolo Zupin.

The workshop also builds on the key findings from the Global Atmospheric Pollution Forum Seminar on Ground Level Ozone and Food Security in Asia, New Delhi, India, 15th Nov 2010. This seminar was funded by Sida (the Swedish International Development Cooperation Agency) and hosted by the Global Atmospheric Pollution Forum (GAP Forum) in collaboration with the Stockholm Environment Institute (SEI) and the United Nations Environment Programme (UNEP). A great thanks to all participants involved for forming a basis for comparison to this workshop.

Finally, without the presence and valuable inputs from all workshop participants we would not have had a workshop or report. Therefore, a great thanks to all participants in addition of those mentioned above: Soora Naresh Kumar, Chubamenla Jamir, Usha Mina, Sachin D. Ghude, Sagnik Dey, Kavya Singh Yadav, Lokendra Thakkar, Hema Deshpande, Syed Asif Ali, Ankur Khansal, Sushil Dogra, Rajan Chedambath, Amit Kumar, Kamna Sachdeva, Vibhor Sood, SK Tyagi, A Arumachalam and Archana Kushwaha.

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CICERO is Norway's foremost institute for interdisciplinary climate research. We help to solve the climate problem and strengthen international climate cooperation by predicting and responding to society's climate challenges through research and dissemination of a high international standard.

CICERO has garnered attention for its research on the effects of manmade emissions on the climate, society's response to climate change, and the formulation of international agreements. We have played an active role in the IPCC since 1995 and eleven of our scientists contributed the IPCC's Fifth Assessment Report.

- We deliver important contributions to the design of international agreements, most notably under the UNFCCC, on topics such as burden sharing, and on how different climate gases affect the climate and emissions trading.
- We help design effective climate policies and study how different measures should be designed to reach climate goals.
- We house some of the world's foremost researchers in atmospheric chemistry and we are at the forefront in understanding how greenhouse gas emissions alter Earth's temperature.
- We help local communities and municipalities in Norway and abroad adapt to climate change and in making the green transition to a low carbon society.
- We help key stakeholders understand how they can reduce the climate footprint of food production and food waste, and the socioeconomic benefits of reducing deforestation and forest degradation.
- We have long experience in studying effective measures and strategies for sustainable energy production, feasible renewable policies and the power sector in Europe, and how a changing climate affects global energy production.
- We are the world's largest provider of second opinions on green bonds, and help international development banks, municipalities, export organisations and private companies throughout the world make green investments.
- We are an internationally recognised driving force for innovative climate communication, and are in constant dialogue about the responses to climate change with governments, civil society and private companies.

CICERO was founded by Prime Minister Syse in 1990 after initiative from his predecessor, Gro Harlem Brundtland. CICERO's Director is Kristin Halvorsen, former Finance Minister (2005-2009) and Education Minister (2009-2013). Jens Ulltveit-Moe, CEO of the industrial investment company UMOE is the chair of CICERO's Board of Directors. We are located in the Oslo Science Park, adjacent to the campus of the University of Oslo.

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