

# SHORT-LIVED CLIMATE POLLUTANT RESEARCH DIGEST

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**CLIMATE &  
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COALITION**  
TO REDUCE SHORT-LIVED  
CLIMATE POLLUTANTS



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## Multiple Benefits/Impacts & Crosscutting

**Description:** This section includes articles addressing the multiple benefits of action to address SLCPs and implement SLCP measures.

### Climate and air-quality benefits of a realistic phase-out of fossil fuels

The combustion of fossil fuels produces emissions of the long-lived greenhouse gas carbon dioxide and of short-lived pollutants, including sulfur dioxide, that contribute to the formation of atmospheric aerosols. Atmospheric aerosols can cool the climate, masking some of the warming effect that results from the emission of greenhouse gases<sup>1</sup>. However, aerosol particulates are highly toxic when inhaled, leading to millions of premature deaths per year. The phasing out of unabated fossil-fuel combustion will therefore provide health benefits, but will also reduce the extent to which the warming induced by greenhouse gases is masked by aerosols. Because aerosol levels respond much more rapidly to changes in emissions relative to carbon dioxide, large near-term increases in the magnitude and rate of climate warming are predicted in many idealized studies that typically assume an instantaneous removal of all anthropogenic or fossil-fuel-related emissions<sup>1,4,5,6,7,8,9</sup>. Here we show that more realistic modelling scenarios do not produce a substantial near-term increase in either the magnitude or the rate of warming, and in fact can lead to a decrease in warming rates within two decades of the start of the fossil-fuel phase-out. Accounting for the time required to transform power generation, industry and transportation leads to gradually increasing and largely offsetting climate impacts of carbon dioxide and sulfur dioxide, with the rate of warming further slowed by reductions in fossil-methane emissions. Our results indicate that even the most aggressive plausible transition to a clean-energy society provides benefits for climate change mitigation and air quality at essentially all decadal to centennial timescales.

*Shindell, Drew, and Christopher J. Smith. "Climate and air-quality benefits of a realistic phase-out of fossil fuels." Nature 573.7774 (2019): 408-411.*

### A global perspective on national climate mitigation priorities in the context of air pollution and sustainable development

Air pollution and climate change are key global challenges for cities and both have large impacts on human health and economic development. Although there are many long term opportunities to address these issues with integrated policies, the immediate needs of addressing air pollution and climate change mitigation are not the same for all countries in the short run. We examined the relationships between greenhouse gases (GHG) emissions, outdoor air pollution, and levels of socioeconomic development to identify specific near-term mitigation policy responses to climate change and air pollution for countries with different levels of human development. Human development index, as defined by The United Nations Development Programme (UNDP) is a measure of achievement in the basic dimensions of human development across countries, which combines the gross national income index, an education index and a life expectancy index (<http://hdr.undp.org/en/humandev>). Country-level data were collected on indicators of socioeconomic development, emissions of GHG, and outdoor levels of fine particulate matter (PM<sub>2.5</sub>) from the World Bank, the UNDP, and the Task Force on Hemispheric Transport of Air Pollution. Differences in GHG emissions and air pollution concentrations, as well as socioeconomic development indicators, were assessed at national, sub-national, and global scales. Countries were divided into four categories based on CO<sub>2</sub> emissions per capita and an estimation of outdoor PM<sub>2.5</sub>: Group A was characterized by high CO<sub>2</sub> emissions per capita and low PM<sub>2.5</sub> concentrations, Group B by high CO<sub>2</sub> emissions per capita and high PM<sub>2.5</sub> concentrations, Group C by low CO<sub>2</sub> emissions per capita and low PM<sub>2.5</sub> concentrations, and Group D by low CO<sub>2</sub> emissions per capita and high PM<sub>2.5</sub> concentration. Per-capita emissions of CO<sub>2</sub> were strongly correlated with the level of socioeconomic development, while differences in non-CO<sub>2</sub> greenhouse gas emissions per capita across the groups were not correlated. Atmospheric PM<sub>2.5</sub> concentrations were not correlated with either CO<sub>2</sub> emissions per capita or levels of socioeconomic development. Energy and environmental policies focused on CO<sub>2</sub> emission reductions may not inherently lead to development pathways that sufficiently reduce population exposure to air pollution. Countries with low CO<sub>2</sub> and high air pollution levels should pursue short-term policies to reduce air pollution and increase human development, beginning to address GHG emissions after critical human health and development needs are met.

Liu, Qingyang, et al. "A global perspective on national climate mitigation priorities in the context of air pollution and sustainable development." *City and Environment Interactions* (2019): 100003.

## Methane

**Description:** This section includes articles addressing methane source apportionment, emissions factors, impacts and emissions trends.

### Emission factors of fugitive methane from underground coal mines in China: Estimation and uncertainty

Fugitive methane from underground coal mining is the main source of methane emissions in China. Accurate and updateable methane emission factors for underground coal mining are of great significance for the accounting of methane emissions in China. In this paper, 10,951 underground coal mines are investigated for developing an emission factor matrix for national and provincial scales. For national emission factors, 27 types of emission factors are determined according to the classification of the ownership of the enterprise, gas emission rate, and maximum mining depth. For provincial emission factors, three types of emission factors for 25 provinces are determined based on gas emission rates. Based on these metrics, this paper uses bootstrap and Monte Carlo simulations to determine the uncertainty range of different emission factors at the 95% confidence interval (CI). The results show that emission factors at the national scale ranged from 3.005 m<sup>3</sup>/t to 54.487 m<sup>3</sup>/t, with a 95% CI of 2.735 m<sup>3</sup>/t to 76.082 m<sup>3</sup>/t, and that emission factors at the provincial scale ranged from 0.58 m<sup>3</sup>/t to 56.19 m<sup>3</sup>/t, with a 95% CI of 0.347 m<sup>3</sup>/t to 108.115 m<sup>3</sup>/t. By comparison, the emission factors calculated in this paper are more representative than the default values recommended by the Intergovernmental Panel on Climate Change (IPCC). In addition, these results are more specific and updateable than those in previous studies, which lays a foundation for the future study of fugitive methane emissions from underground coal mines at different scales.

Wang, Ke, et al. "Emission factors of fugitive methane from underground coal mines in China: Estimation and uncertainty." *Applied Energy* 250 (2019): 273-282.

## Black Carbon

**Description:** This section includes articles addressing black carbon source apportionment, emissions factors, impacts and emissions trends.

### China's black carbon emission from fossil fuel consumption in 2015, 2020, and 2030

Black carbon (BC) emissions in China have been changing significantly due to rapid evolution of fuel consumption. In this study, BC emissions from fossil fuel consumption in different sectors were estimated in 2015 based on up-to-date activity data and emission factors (EFs). While for the future scenarios in 2020 and 2030, it was estimated according to relative changes in the activity level and EFs. In 2015, total BC emissions were estimated to be 1.48 Tg, mostly from the industrial, residential, and transportation sectors. Emission fluxes were found to have remarkable spatial features, where high fluxes generally located in eastern China. About 25% of the terrestrial area of China showed an annual flux above 0.2 t km<sup>-2</sup>. Total BC emissions will be decreased to 1.33 (2020) and 1.16 Tg (2030). Most reduction will occur in the industrial and residential sectors, while the transportation sector will see an obvious increase. The dramatic reduction of BC emissions in future is a new indication to our current understanding of the emission and its effects as well, and it may provide guidance for future scientific research and policy making in the field of climate change and air quality control.

Lu, Yan, et al. "China's black carbon emission from fossil fuel consumption in 2015, 2020, and 2030." *Atmospheric Environment* 212 (2019): 201-207.

### Integrated assessment of health risk and climate effects of black carbon in the Pearl River Delta region, China

Background: Black carbon (BC) caused by incomplete combustion of fossil and bio-fuel has a dual effect on health

and climate. There is a need for systematic approaches to evaluation of health outcomes and climate impacts relevant to BC exposure.

**Objective:** We propose and illustrate for the first time, to our knowledge, an integrated analysis of a region-specific health model with climate change valuation module to quantify the health and climate consequences of BC exposure.

**Methods:** Based on the data from regional air pollution monitoring stations from 2013 to 2014 in the Pearl River Delta region (PRD), China, we analyzed the carcinogenic and non-carcinogenic effects and the relative risk of cause-specific mortality due to BC exposure in three typical cities of the PRD (i.e. Guangzhou, Jiangmen and Huizhou). The radiative forcing (RF) and heating rate (HR) were calculated by the Fu-Liou-Gu (FLG) plane-parallel radiation model and the conversion of empirical formula. We further connected the health and climate impacts by calculating the excess mortalities attributed to climate warming due to BC.

**Results:** Between 2013 and 2014, carcinogenic risks of adults and children due to BC exposure in the PRD were higher than the recommended limits ( $1 \times 10^{-6}$  to  $1 \times 10^{-4}$ ), resulting in an excess of 4.82 cancer cases per 10,000 adults ( $4.82 \times 10^{-4}$ ) and an excess of 1.97 cancer cases per 10,000 children ( $1.97 \times 10^{-4}$ ). Non-carcinogenic risk caused by BC was not found. The relative risks of BC exposure on mortality were higher in winter and dry season. The atmospheric RFs of BC were 26.31 W m<sup>-2</sup>, 26.41 W m<sup>-2</sup>, and 22.45 W m<sup>-2</sup> for Guangzhou, Jiangmen and Huizhou, leading to a warming of the atmosphere in the PRD. The estimated annual excess mortalities of climate warming due to BC were 5052 (95% CI: 1983, 8139), 5121 (95% CI: 2010, 8249) and 4363 (95% CI: 1712, 7032) for Guangzhou, Jiangmen and Huizhou, respectively.

**Conclusion:** Our estimates suggest that current levels of BC exposure in the PRD region posed a considerable risk to human health and the climate. Reduction of BC emission could lead to substantial health and climate co-benefits.

*Lin, Weiwei, et al. "Integrated assessment of health risk and climate effects of black carbon in the Pearl River Delta region, China." Environmental research (2019).*

## Experimental measurements of black carbon emission factors to estimate the global impact of uncontrolled burning of waste

Open burning is a widely practiced method of solid waste disposal in many regions of the world and represents a significant source of air pollution. Black carbon (BC) is a particularly serious air pollutant emitted from the uncontrolled burning of waste in open fires because it has a global warming potential (GWP) up to 5000 times greater than carbon dioxide (CO<sub>2</sub>) and is also linked to detrimental health impacts. However, few quantitative measurements of BC from open burning have been completed to establish the extent and impacts of this emission source on the environment. Emission factors (EFs) for BC from burning mixed solid waste samples were measured in the laboratory based on waste compositions in a representative developing country (Mexico). Black carbon EFs were also derived for individual waste types, including: green waste, different types of plastics, textiles and paper and cardboard. Individual waste BC EFs were combined using waste composition data from different areas of the world to estimate regional and global BC emissions from this source. The results demonstrated that BC emissions from open burning of waste have a significant climate impact, equivalent to 2–10% of global CO<sub>2</sub>Eq emissions. Global BC CO<sub>2</sub>Eq emissions from burning waste are 2–8 times larger compared to methane (CH<sub>4</sub>) CO<sub>2</sub>Eq emissions arising from the decomposition of equivalent amounts of combustible biodegradable waste disposed at dumpsites. Action to reduce open burning of waste would have a significant and immediate benefit to improving air quality and reducing the potential impact on climate change.

*Reyna-Bensusan, Natalia, et al. "Experimental measurements of black carbon emission factors to estimate the global impact of uncontrolled burning of waste." Atmospheric Environment (2019).*

## Tropospheric Ozone

**Description:** This section includes articles addressing tropospheric ozone impacts and important trends in precursor emissions.

## Historical and projected HFC-410A emission from room air conditioning sector in China

China's room air conditioning (RAC) sector is now undergoing a substitution of HCFC-22 (CHClF<sub>2</sub>) by HFC-410A (a blend of HFC-125 (C<sub>2</sub>H<sub>5</sub>F) and HFC-32 (CH<sub>2</sub>F<sub>2</sub>)) as refrigerant. However, HFC-410A is also one of the strong greenhouse gases (GHGs) and will be regulated under the Kigali Amendment to the Montreal Protocol. In this study, an updated HFC-410A emission inventory for China's RAC sector is established for the period of 2006–2017 with a projection to 2050 based on a bottom-up method. Our estimation indicates that the HFC-410A emissions increased from 0.0092 Gg yr<sup>-1</sup> to 12.0 Gg yr<sup>-1</sup> with an annual increase of 115.7%/yr during 2006–2017. More than 95% of the emissions were from end-of-life process. Under a business-as-usual (BAU) scenario, projected emissions will continuously grow to 89.2 (54.8–126.0) Gg yr<sup>-1</sup> in 2050. However, under a mitigation scenario with implementation of the Kigali Amendment, emissions will peak at 63.8 Gg yr<sup>-1</sup> in 2039 and then decline to 43.1 (26.1–62.0) Gg yr<sup>-1</sup> in 2050, and about 373 Gg of cumulative emission could be curbed during 2018–2050. Additionally, we find that the Beijing-Tianjin-Hebei region, the Yangzi River Delta, the Pearl River Delta and provincial capital cities show greater HFC-410A emission intensities per unit of area than those of the rest of China during 2009–2017.

*Liu, Lisha, et al. "Historical and projected HFC-410A emission from room air conditioning sector in China." Atmospheric Environment 212 (2019): 194-200.*

## Hydrofluorocarbons (HFCs)

**Description: This section includes articles addressing hydrofluorocarbon emissions, relevant new information about use sectors, alternative refrigerants and relevant analysis of energy efficiency.**

### Historical and projected HFC-410A emission from room air conditioning sector in China

China's room air conditioning (RAC) sector is now undergoing a substitution of HCFC-22 (CHClF<sub>2</sub>) by HFC-410A (a blend of HFC-125 (C<sub>2</sub>H<sub>5</sub>F) and HFC-32 (CH<sub>2</sub>F<sub>2</sub>)) as refrigerant. However, HFC-410A is also one of the strong greenhouse gases (GHGs) and will be regulated under the Kigali Amendment to the Montreal Protocol. In this study, an updated HFC-410A emission inventory for China's RAC sector is established for the period of 2006–2017 with a projection to 2050 based on a bottom-up method. Our estimation indicates that the HFC-410A emissions increased from 0.0092 Gg yr<sup>-1</sup> to 12.0 Gg yr<sup>-1</sup> with an annual increase of 115.7%/yr during 2006–2017. More than 95% of the emissions were from end-of-life process. Under a business-as-usual (BAU) scenario, projected emissions will continuously grow to 89.2 (54.8–126.0) Gg yr<sup>-1</sup> in 2050. However, under a mitigation scenario with implementation of the Kigali Amendment, emissions will peak at 63.8 Gg yr<sup>-1</sup> in 2039 and then decline to 43.1 (26.1–62.0) Gg yr<sup>-1</sup> in 2050, and about 373 Gg of cumulative emission could be curbed during 2018–2050. Additionally, we find that the Beijing-Tianjin-Hebei region, the Yangzi River Delta, the Pearl River Delta and provincial capital cities show greater HFC-410A emission intensities per unit of area than those of the rest of China during 2009–2017.

*Liu, Lisha, et al. "Historical and projected HFC-410A emission from room air conditioning sector in China." Atmospheric Environment 212 (2019): 194-200.*

## Socio-Economic impacts

**Description: This section includes articles addressing the socio-economic impacts due to air pollutions and SLCP related climate changes**

### Social cost of methane: Method and estimates for Indian livestock

The quantitative assessment of climate change damage due to an additional unit of greenhouse gases emissions (mainly carbon di-oxide, CO<sub>2</sub>) is termed as the Social Cost of Carbon (SCC). Published literature primarily focused on the SCC of CO<sub>2</sub> emissions, neglecting other greenhouse gases (GHGs). The social cost assessment for other GHGs especially CH<sub>4</sub> is also needed as it is the 2nd highest emitted GHG after CO<sub>2</sub> with high global warming potential. The quantitative assessment of climate change damage per additional unit of CH<sub>4</sub> can be termed as Social Cost of Methane (SCM). In the present study, the SCM (in CO<sub>2</sub>e unit) has been estimated for the Indian

livestock using Integrated Assessment Model (IAM) and system dynamic approach. Different livestock growth scenarios viz. Business as usual (BAU), modified scenarios (MS I, MS II and MS III) have been proposed for SCM calculation (cost per ton CO<sub>2</sub>e CH<sub>4</sub>) through 2017 to 2032. The SCM for 2017 is \$62–\$1150 and is projected to be \$77–\$1438 in 2032. The highest SCM is in BAU (\$1150 in 2017 and \$1438 in 2032) and the lowest in MS I (\$62 in 2017 and \$77 in 2032). The differences in SCM values are due to the different population size of livestock and CH<sub>4</sub> emission rate. Results and findings of the study suggest that the CH<sub>4</sub> even emitted in small quantity has a significant impact on climate and hence should not be neglected in climate change mitigation policies. The SCM is a metric tool which helps to design the appropriate policies for reducing CH<sub>4</sub> emission from livestock. The developed tool can also be applicable to estimate the social cost for other GHGs for market-based policy development.

*Kumari, Shilpi, et al. "The social cost of methane: Method and estimates for Indian livestock." Environmental Development (2019): 100462.*

### Health impact and related cost of ambient air pollution in Tehran

Ambient air pollution represents one of the biggest environmental risks to health. In this study, we estimated the avoidable mortality burden attributable to ambient air pollution in Tehran, and derived the economic impact associated with these health effects. Using PM<sub>2.5</sub> data from ground-level air pollution measurements in Tehran, we estimated PM<sub>2.5</sub> exposure for 349 neighborhoods in Tehran, by the Environmental Benefits Mapping and Analysis Program (BenMAP-CE). We considered five scenarios related to PM<sub>2.5</sub> levels: an increase to 35 µg/m<sup>3</sup>; a reduction to 25 µg/m<sup>3</sup>; a reduction to 15 µg/m<sup>3</sup>; a reduction to 10 µg/m<sup>3</sup> (the WHO's air quality guideline value); and a full roll-back, assuming a reduction to 2.4 µg/m<sup>3</sup>. All scenarios used 2017 p.m.2.5 levels as a starting point. Using the concentration response function of the Global Exposure Mortality Model (GEMM), we estimated a total of 7146 (95% CI: 6596–7513) adult (age ≥ 25 years) deaths attributable to PM<sub>2.5</sub> in 2017. The leading causes of death were ischemic heart disease (3437; 95% CI: 3315–3516), stroke (886; 95% CI: 693–1002), lower respiratory infections (531; 95% CI: 414–589), chronic obstructive pulmonary disease (364; 95% CI: 271–420), and lung cancer (274; 95% CI: 236–298). The estimated total annual economic benefit (2017) of reducing PM<sub>2.5</sub> concentration levels to 2.4 µg/m<sup>3</sup> was USD 0.591 (95% CI: 0.447–0.624) billion per year, using the value of a life year (VOLY) approach, and USD 2.894 (95% CI: 2.671–3.043) billion per year, using the value of a statistical life (VSL) approach.

*Bayat, Reza, et al. "Health impact and related cost of ambient air pollution in Tehran." Environmental Research (2019): 108547.*

### Effectiveness of local air pollution and GHG taxes: The case of Chilean industrial sources

In 2017, environmental taxes began to be applied to CO<sub>2</sub>, PM, NO<sub>x</sub> and SO<sub>2</sub> emissions in Chile to reduce the negative environmental effects of fossil fuels burned in industrial and thermoelectric sources with a thermal power greater than or equal to 50 MW. In this context, the present study generates an economic optimization model to simulate how different tax scenarios would modify the behavior of regulated industrial sources considering the alternatives they have to minimize their costs (tax payment, fuel change and/or installation of abatement technologies). The main results show that, under the current tax scenario, CO<sub>2</sub>, PM and SO<sub>2</sub> emissions would decrease by 11%, 48% and 49% respectively, while NO<sub>x</sub> emissions would increase by 5%. By extending the tax to all industrial sources regardless of their thermal power, CO<sub>2</sub>, PM and SO<sub>2</sub> emissions would decrease respectively by 14%, 98% and 66%, while NO<sub>x</sub> emissions would increase by 7.1%. Finally, it is determined that modifying the tax rate of a single pollutant while maintaining the rest of the constant rates generates a low impact on the other pollutants emissions.

*Mardones, Cristian, and Martin Cabello. "Effectiveness of local air pollution and GHG taxes: The case of Chilean industrial sources." Energy Economics 83 (2019): 491-500.*

### Economic losses due to ozone impacts on human health, forest productivity and crop yield across China

China's economic growth has significantly increased emissions of tropospheric ozone (O<sub>3</sub>) precursors, resulting in increased regional O<sub>3</sub> pollution. We analyzed data from >1400 monitoring stations and estimated the

exposure of population and vegetation (crops and forests) to O<sub>3</sub> pollution across China in 2015. Based on WHO metrics for human health protection, the current O<sub>3</sub> level leads to +0.9% premature mortality (59,844 additional cases a year) with 96% of populated areas showing O<sub>3</sub>-induced premature death. For vegetation, O<sub>3</sub> reduces annual forest tree biomass growth by 11–13% and yield of rice and wheat by 8% and 6%, respectively, relative to conditions below the respective AOT40 critical levels (CL). These CLs are exceeded over 98%, 75% and 83% of the areas of forests, rice and wheat, respectively. Using O<sub>3</sub> exposure–response functions, we evaluated the costs of O<sub>3</sub>-induced losses in rice (7.5 billion US\$), wheat (11.1 billion US\$) and forest production (52.2 billion US\$) and SOMO35-based morbidity for respiratory diseases (690.9 billion US\$) and non-accidental mortality (7.5 billion US\$), i.e. a total O<sub>3</sub>-related cost representing 7% of the China Gross Domestic Product in 2015.

*Feng, Zhaozhong, et al. "Economic losses due to ozone impacts on human health, forest productivity and crop yield across China." *Environment international* 131 (2019): 104966.*

## Biomass Burning & Household Energy

**Description:** This section includes articles primarily addressing SLCP measures and innovations related to the household energy initiative, open burning of agricultural residue, and SLCP emissions in relevant sectors. Solid waste burning is covered in the waste section.

### Reducing methane emissions from abandoned oil and gas wells: Strategies and costs

Well plugging, the main strategy for reducing methane emissions from millions of unplugged abandoned oil and gas (AOG) wells in the U.S. and abroad, is expensive and many wells remain unplugged. In addition, plugging does not necessarily reduce methane emissions and some categories of plugged wells are high emitters. We analyze strategies and costs of five options for reducing methane emissions from high-emitting AOG wells - those which are unplugged and plugged/vented gas wells. The five options are: plugging without gas venting, plugging with gas venting and flaring, plugging with gas venting and usage, gas flaring only, and gas capture/usage only. Average plugging costs (\$37,000 per well) can be justified by the social cost of methane, which considers air quality, climate, and human/ecosystem impacts. Savings as measured by natural gas prices and alternative energy credits can offset low plugging costs (<\$15,400 per well) but are not large enough to offset average plugging costs. Nonetheless, reducing methane emissions from AOG wells is a cost-effective strategy for addressing climate change that has comparable costs to some current greenhouse gas mitigation options and can produce co-benefits such as groundwater protection. Therefore, we recommend including the mitigation of AOG wells in climate and energy policies in the U.S., Canada, and other oil-and-gas-producing regions.

*Kang, Mary, et al. "Reducing methane emissions from abandoned oil and gas wells: Strategies and costs." *Energy Policy* 132 (2019): 594-601.*

### A follow-up study after an improved cookstove intervention in rural Mexico: Estimation of household energy use and chronic PM<sub>2.5</sub> exposure

The benefits of improved biomass cookstoves (ICS) depends on their adoption and sustained use. Few studies have documented if and how they are used more than five years after being introduced.

We conducted a 9-year prospective cohort study among young rural women in the highlands of Michoacan, Mexico. Participants had received a Patsari ICS during a community trial either in 2005 or 2006. With retrospective information collected in 2012–13, we studied the households' energy use, ICS survival, and cooking practices during the follow-up period. Using an exposure model constructed with personal PM<sub>2.5</sub> measurements in a subsample of homes at the time of the initial trial in 2005, we estimated the exposure associated with different energy use patterns during the follow-up period.

The ICS had a mean lifespan of 4 years, after which more than half of the stoves were not in use; therefore, the use of open fire increased, particularly among the indigenous communities. ICS use peak was achieved two years after the initial trial, either exclusively or combined with open fire. Yearly household energy use and other variables were used to estimate chronic air pollution exposure. Mean PM<sub>2.5</sub> exposure during the follow-up period ranged from 51 to 319 µg/m<sup>3</sup>; the median was 102 and 146 µg/m<sup>3</sup> for mainly ICS and mainly open fire use, respectively.

The ICS has a useful period after which it needs maintenance, repair, or replacement. Unfortunately, many programs have not afforded a follow-up component. Exposure to biomass smoke air pollutants can be reduced by using an ICS instead of the traditional open fire. Household energy strategies should ensure equitable access to clean energy options adapted to local needs and preferences with culturally appropriate technology implemented on a sustainable perspective.

### Near-term climate impacts of Finnish residential wood combustion

Residential wood combustion (RWC) is a major source of climate-impacting emissions, like short-lived climate forcers (SLCF) and biogenic CO<sub>2</sub>, in Finland. In this paper, we present projections for those emissions from 2015 to 2040. We calculated the climate impact of the emissions using regional temperature potential metrics presented in literature. In our results, the climate impacts are given as global and Arctic temperature responses caused by the studied emissions in a 25 year time span. The results show that SLCF emissions from RWC cause a significant warming impact. Using our selected metrics, SLCF emissions from RWC added to the warming impact of Finland's projected greenhouse gas emissions by 28% in global temperature response and by 170% in Arctic response. When compared with other common heating methods in Finnish detached houses, using a typical Finnish stove (masonry heater) was the least climate-friendly option. Taking biogenic CO<sub>2</sub> emissions into account further highlighted this finding. Finally, we assessed the change in climate impact when implementing various emission reduction measures for RWC. With a time span of 25 years, early action was found to be even more crucial than the eventual reductions in annual emissions in 2040.

*Savolahti, Mikko, et al. "Near-term climate impacts of Finnish residential wood combustion." Energy Policy 133 (2019): 110837.*

### A high-resolution inventory of air pollutant emissions from crop residue burning in China

Crop residue burning is an important source of air pollutants and strongly affects the regional air quality and global climate change. This study presents a detailed emission inventory of major air pollutants from crop residue burning for the year of 2014 in China by the bottom-up method. Activity data were investigated for 296 prefecture-level cities. Emission factors were determined for indoor and in-field burning separately. Regional differences were considered for the proportion of residue burned (PCRB), the ratio between indoor and in-field burning, and the ratio of straw to grain production. The emissions were estimated at prefecture-city level as the first step; then they were redistributed within a city based on 1-km resolution land-use, MODIS fire counts, and rural population. Temporal variation was determined according to farming practices in different regions and MODIS fire counts. Uncertainties were estimated using the Monte Carlo method. The total emissions from crop residue burning in China were estimated to be 0.13 (-47–92%) for BC, 0.71 (-48–92%) for OC, 1.77 (-48–91%) for PM<sub>2.5</sub>, 2.04 (-50–100%) for PM<sub>10</sub>, 0.16 (-59–133%) for SO<sub>2</sub>, 0.53 (-55–105%) for NO<sub>x</sub>, 0.12 (-47–93%) for NH<sub>3</sub>, 1.07 (-55–102%) for CH<sub>4</sub>, 1.85 (-43–74%) for NMVOC, 18.33 (-46–85%) for CO and 305.20 (-45–80%) for CO<sub>2</sub>, in unit of Tg yr<sup>-1</sup>. Our results are remarkably lower than those reported in previous studies, mainly because of the PCRB has decreased significantly in recent years. For most of the pollutants, indoor burning accounted for about 50–70% of the emissions. Rice, wheat and corn contributed more than 85% of the emissions, but their relative contributions varied a lot with region and season. High emissions were mostly located in the eastern China, central China and northeastern China, and temporally peaked in April, June and October, with different intensities in the north and the south. This study provides a useful basis for air quality modeling and the policy making of pollution control strategies.

*Zhang, Xiaohui, et al. "A high-resolution inventory of air pollutant emissions from crop residue burning in China." Atmospheric Environment (2019).*

## Agriculture and Livestock

**Description:** This section includes articles primarily addressing SLCP measures and innovations related to the Agriculture initiative and SLCP emissions in relevant sectors

## Geographic Inventory Framework for estimating spatial pattern of methane and nitrous oxide emissions from agriculture in Alberta, Canada

Agricultural systems are important sources of the global carbon and nitrogen cycle and are also non-point sources of nitrous oxide (N<sub>2</sub>O) and methane (CH<sub>4</sub>) emissions. The objectives of this paper are to develop a Geographic Inventory Framework (GiF) for spatially-explicit estimation and mapping of agricultural N<sub>2</sub>O and CH<sub>4</sub> emissions for the province of Alberta, Canada. The GiF consists of a modelling component, a Geographic Information Systems (GIS) component, and interconnecting Python software to communicate between the model, GIS database and census data. The results show that methane emissions from enteric fermentation (247.04 Gg) prevail over those from manure (20.39 Gg). Nitrous oxide emissions from manure (8.89 Gg) are comparable to those from soil (11.02 Gg). Cattle emit most N<sub>2</sub>O and CH<sub>4</sub>, followed by plant N<sub>2</sub>O emissions and pigs CH<sub>4</sub> emissions. The GIS maps show “hot-spots” and discernible patterns of N<sub>2</sub>O and CH<sub>4</sub> emissions increasing from north and west to central Alberta, then slightly declining to south and east, which could be useful for addressing mitigation strategies. The advantages of this framework keep the IPCC approach simple, open, transparent and comparable. The explicit inventory provides an accounting of complete greenhouse gas (GHG) balance of agricultural ecosystems and their source/sink strengths, affected by soil, water and climate. This provides an easy-to-use tool to integrate national statistical data, GIS and GHGs analysis for decision-making and policy in ecosystem service and sustainable agricultural management.

*Dimitrov, Dimitre D., and Junye Wang. "Geographic Inventory Framework for estimating spatial pattern of methane and nitrous oxide emissions from agriculture in Alberta, Canada." Environmental Development (2019): 100461.*

## Inclusion of *Asparagopsis armata* in lactating dairy cows' diet reduces enteric methane emission by over 50 percent

Livestock production, particularly enteric methane production, contributes to greenhouse gas emissions globally. Various mitigation strategies developed to reduce enteric emissions have limited success. Although in vitro studies have shown a considerable reduction in methane emissions using *Asparagopsis* spp., no studies have been conducted to investigate the effect of any species of *Asparagopsis* in dairy cattle. Our objective was to evaluate quantitatively the response of cows consuming *Asparagopsis armata* on methane production (g/kg), yield (g/kg feed intake) and intensity (g/kg milk yield). Twelve post-peak lactating Holstein cows were randomly assigned to three treatments (control, 0.5% and 1% inclusion levels of *A. armata* on organic matter basis) in a 3 × 3 Latin square design with three 21-day periods. Enteric methane emissions were measured using the GreenFeed system. Methane production by cows decreased significantly by 26.4% at the low (0.5%) level of *A. armata* inclusion and 67.2% at the high (1%) level of inclusion. Feed intake was reduced by 10.8 and 38.0%, in cows fed the low and high level of macroalgae inclusion, respectively. Methane yield decreased significantly by 20.3 and 42.7% in cows fed diet including 0.5% and 1% *A. armata* inclusion levels, respectively ( $P = <0.0001$ ). Methane intensity significantly decreased by 26.8% from cows fed at 0.5% level and 60% at the 1.0% *A. armata* inclusion level. Bromoform concentrations in milk were not significantly different between treatments. Our in vivo results showed that *A. armata* has potential to be used as a feed additive to reduce enteric methane emissions.

*Roque, Breanna M., et al. "Inclusion of *Asparagopsis armata* in lactating dairy cows' diet reduces enteric methane emission by over 50 percent." Journal of Cleaner Production (2019).*

## Inventories of methane and nitrous oxide emissions from animal and crop farms of 69 municipalities in Alberta, Canada

Spatially explicit, accurate inventories of greenhouse gas (GHG) emissions are of primary importance when calculating the carbon footprint, identifying sources and sinks, pricing carbon pollution, and creating policy that is effective in reducing emissions. However, there are few reports available on methane and nitrous oxide emissions from each type of livestock and crop in all counties of the province due to a lack of statistical data of sub-categories, such as the different fertilizer quantities used in each crop in the county. Because fertilizer input is the most significant factor for N<sub>2</sub>O emissions from agricultural soils, how to best distribute the total fertilizer mass to a crop-specific fertilizer rate for each county is a major challenge in agricultural management. In this

study, authors developed a crop-specific method correlating the recommended fertilizer rate and planted area of each crop for a reasonable distribution of total fertilizer mass to fertilizer rate. This is based on a balance between the sum of fertilizer used in all crops and the total fertilizer mass used by each municipality. Using this method, our calculations in 69 municipalities in the province of Alberta, Canada showed that the fertilizer rate for each crop was reasonably distributed from the total fertilizer mass of a municipality: less than 170 kg-N ha<sup>-1</sup>. The obtained fertilizer rates for each crop in 69 municipalities were used in GHG inventories using IPCC 2006 tier 1 and 2 methods. The total CH<sub>4</sub> and N<sub>2</sub>O emissions from agriculture in all of Alberta in 2011 were 328 Gg CH<sub>4</sub> yr<sup>-1</sup> and 23.5 Gg N<sub>2</sub>O yr<sup>-1</sup>, respectively. The southeastern municipalities generally emitted more CH<sub>4</sub> and N<sub>2</sub>O than northwestern municipalities. The southern municipality of Lethbridge emitted the largest amount of CH<sub>4</sub> and N<sub>2</sub>O of all municipalities (25.3 Gg CH<sub>4</sub> yr<sup>-1</sup> (7.70% of total CH<sub>4</sub> of entire Alberta) and 1.26 Gg N<sub>2</sub>O yr<sup>-1</sup> (5.40% of total N<sub>2</sub>O of entire Alberta), respectively). This was due to its largest cattle population (414,627 head) and larger synthetic fertilizer input (32,111 ton-N) and planted area (206,077 ha). The second largest CH<sub>4</sub> and N<sub>2</sub>O emission source was also located at the south. The Taber municipality emitted 15.8 Gg CH<sub>4</sub> yr<sup>-1</sup> (4.80% of total CH<sub>4</sub> of entire Alberta) and 1.14 Gg N<sub>2</sub>O yr<sup>-1</sup> (4.80% of total N<sub>2</sub>O of entire Alberta), respectively.

*Shen, Jiacheng, et al. "Inventories of methane and nitrous oxide emissions from animal and crop farms of 69 municipalities in Alberta, Canada." Journal of Cleaner Production (2019).*

### Prediction of effects of dairy selection indexes on methane emissions

Global warming caused by greenhouse gas emissions is a threat to the survival of humans and other organisms living on Earth. The greenhouse gases released from the dairy sector of New Zealand accounted for 18.2 Mt of carbon dioxide equivalent (CO<sub>2</sub>-eq) in 2016, mainly from methane generated by enteric fermentation in the rumen of milking cows and their replacement stock. A productivity commission established by the New Zealand government in 2018 estimated that methane emissions from livestock needed to be reduced from 2016 levels by 10 to 22% by 2050 (i.e., 2.8 to 6.1 million t lower), so as to restrict future increases in global temperature to less than 2°C. In this study, we evaluated genetic effects of 8 traits included in the New Zealand national dairy breeding objective, on 3 types of methane emissions metrics: gross methane emissions per dairy cow per year (E), methane emissions per hectare (EH), and methane emissions intensity per milk protein equivalents (EI), as carbon dioxide equivalents. These effects were then aligned with recent genetic changes in these traits brought about by breeding schemes, so that the overall genetic trend for each metric into the future was estimated. The results showed that EH and EI are currently being reduced at rates of -2.31 kg of CO<sub>2</sub>-eq per hectare per cow per year (current average is 6,915 kg of CO<sub>2</sub>-eq/ha per cow per year) and -0.04 kg of CO<sub>2</sub>-eq per kg of milk protein equivalents per cow per year, respectively (current average is 9.7 kg of CO<sub>2</sub>-eq/milk protein-eq per cow per year). These improvements directly reflect increased production efficiency through selection for farm profitability. If the pastureland area in New Zealand remains the same, at the same productivity and with no increase in supplementation rates from external land sources, in 20 years gross emissions would be reduced by only 0.6%, or 89 Mt. Increased production efficiency will likely result in corresponding changes to the stocking rate, to fully utilize the pasture resource available, and might further encourage a greater rate of intensification via supplementary feeding. Both consequences of current genetic selection could negate any benefits for the national greenhouse gas inventory. New selection criteria for reduced methane production are needed to help achieve New Zealand's national methane reduction targets.

*Zhang, X., et al. "Prediction of effects of dairy selection indexes on methane emissions." Journal of dairy science (2019).*

## Transportation

**Description: This section includes articles primarily addressing SLCP measures and innovations related to the Diesel initiative and SLCP emissions in relevant sectors**

### Air quality and health benefits from fleet electrification in China

China has emerged as a leading electric vehicle (EV) market, accounting for approximately half of the global EV sales volume. We employed an atmospheric chemistry model to evaluate the air quality impacts from multiple scenarios by considering various EV penetration levels in China and assessed the avoided premature mortality

attributed to fine particulate matter and ozone pollution. We find higher fleet electrification ratios can synergistically deliver greater air quality, climate and health benefits. For example, electrifying 27% of private vehicles and a larger proportion of certain commercial fleets can readily reduce the annual concentrations of fine particulate matter, nitrogen dioxide and summer concentrations of ozone by 2030. This scenario can reduce the number of annual premature deaths nationwide by 17,456 (95% confidence interval: 10,656–22,160), with the Beijing–Tianjin–Hebei, Yangtze River Delta and Pearl River Delta regions accounting for ~37% of the total number. The high concentration of health benefits in populous megacities implies that their municipal governments should promote more supportive local incentives. This study further reveals that fleet electrification in China could have more health benefits than net climate benefits in the next decade, which should be realized by policymakers to develop cost-effective strategies for EV development.

*Liang, Xinyu, et al. "Air quality and health benefits from fleet electrification in China." Nature Sustainability 2.10 (2019): 962-971.*

### Environmental and economic assessment of traffic-related air pollution using aggregate spatial information: A case study of Balneário Camboriú, Brazil

**Introduction:** Transportation is one of the main determinants of atmospheric pollutant emissions in urban areas. This externality has direct environmental, economic and public health consequences. This paper aims at investigating the space-time patterns of traffic air pollution in Balneário Camboriú (Brazil) over projected temporal scenarios and at estimating the damage costs of traffic air pollution to support transport policy-making. **Methods:** To estimate the emission rates of pollutants, emission factors and traffic data were jointly used, whereas the pollutant concentrations were estimated using the Gaussian plume dispersion model. To identify the affected areas as well as possible spatial heterogeneity patterns of air pollution within clustered areas, an exploratory spatial analysis was also conducted. To assess the economic impact of air pollution, damage costs were calculated for various pollutants.

**Results:** The modeling results show that oxides of nitrogen (NO<sub>2</sub>) and oxides of sulphur (SO<sub>2</sub>) pollutants exceed the limits of air quality legislation, especially at a distance up to 10 m from the roads, while 60% and 71% of the intersections are found to yield pollutant concentrations above the thresholds, primarily during peak hours. The analysis also confirmed that homogeneous traffic zones with similar emission rates are spatially clustered exhibiting positive autocorrelation patterns. The results of the economic appraisal showed that the estimated costs of traffic-related emissions were \$0.89, \$1.38 and \$1.43 million/year, respectively, for the current, short-term and long-term scenarios.

**Conclusions:** This study serves as the first comprehensive analysis of traffic air pollution for the specific study region, providing implications and modeling tools that can be leveraged in public policies focusing on the elimination of the transportation-generated health burden. The developed analysis framework can also serve as a supporting tool for Public Agencies focusing on the high-level evaluation of traffic-related air pollution using limited and aggregate spatial and traffic data.

*Tischer, Vinicius, et al. "Environmental and economic assessment of traffic-related air pollution using aggregate spatial information: A case study of Balneário Camboriú, Brazil." Journal of Transport & Health 14 (2019): 100592.*

## Waste and Waste Management

**Description:** This section includes articles primarily addressing SLCP measures and innovations related to the solid waste initiative and SLCP emissions in relevant sectors

### Mitigation of ammonia, nitrous oxide and methane emissions during solid waste composting with different additives: A meta-analysis

Composting of solid waste can be associated with a loss of the agronomic value (nutrient loss), as well as a source of environmental impact through the emission of the greenhouse gases (GHG) nitrous oxide (N<sub>2</sub>O) and methane (CH<sub>4</sub>) and volatilization of ammonia (NH<sub>3</sub>). Additives have been considered as a useful option to mitigate these environmental emissions, but the wider effects of using different additives on multiple gas



emissions is still uncertain. Here, a global meta-analysis was conducted using 105 studies with 303 paired comparisons, to quantify the impact of different additives on NH<sub>3</sub> and GHG emissions, considering different composting feedstock properties. On average, additives reduced the total nitrogen (TN) loss (46.4%), NH<sub>3</sub> (44.5%), N<sub>2</sub>O (44.6%) and CH<sub>4</sub> (68.5%) emissions, and total GHG emissions expressed as global warming potential (GWP) (54.2%) during composting. Chemical, physical and microbial additives all significantly reduced TN loss and NH<sub>3</sub> emission; however, the strongest effect was observed for chemical additives under the condition of low moisture content ( $\leq 65\%$ ), low C/N ratios ( $\leq 20$ ) or alkalinity (pH > 7.5). Specifically, PO<sub>4</sub><sup>3-</sup> and Mg<sup>2+</sup> salt had the greatest mean mitigation for TN loss (68.0%) and NH<sub>3</sub> emission (62.0%). In contrast, physical additives (e.g. biochar and zeolite) were more effective at reducing the total GHG emissions (67.2%) compared with chemical additives because of the greater mitigation of N<sub>2</sub>O emission. Low moisture content ( $\leq 65\%$ ) or low C/N ratios ( $\leq 20$ ) enhanced the effectiveness of chemical additives in reducing TN loss and NH<sub>3</sub> emission. Physical additives were suggested to be more effective in reducing N<sub>2</sub>O emission at low moisture content ( $\leq 65\%$ ) or high C/N ratios (>20 to  $\leq 30$ ). The magnitude of the mitigation of TN loss and NH<sub>3</sub> emission increased as the dosage rate of PO<sub>4</sub><sup>3-</sup> and Mg<sup>2+</sup> salt/superphosphate increased between 0 and 20%. This meta-analysis suggests that an optimized combination of chemical and physical additives tailored to feedstock characteristics and application dosage may be a promising approach for the synergistic mitigation of NH<sub>3</sub> and GHG emissions.

*Cao, Yubo, et al. "Mitigation of ammonia, nitrous oxide and methane emissions during solid waste composting with different additives: A meta-analysis." Journal of Cleaner Production (2019).*

## Air pollution & Health Impacts

**Description:** This section includes articles primarily addressing linkages between air pollution exposure and health impacts

### National and sub-national exposure to ambient fine particulate matter (PM<sub>2.5</sub>) and its attributable burden of disease in Iran from 1990 to 2016

Ambient particulate matter is a public health concern. We aimed (1) to estimate national and provincial long-term exposure of Iranians to ambient particulate matter (PM) < 2.5  $\mu\text{m}$  (PM<sub>2.5</sub>) from 1990 to 2016, and (2) to estimate the national and provincial burden of disease attributable to PM<sub>2.5</sub> in Iran. We used all available ground measurements of PM < 10  $\mu\text{m}$  (PM<sub>10</sub>) (used to estimate PM<sub>2.5</sub>) from 91 monitoring stations. We estimated the annual mean exposure to PM<sub>2.5</sub> for all Iranian population from 1990 to 2016 through a multi-stage modeling process. By applying comparative risk assessment methodology and using life table for years of life lost (YLL), we estimated the mortality and YLL attributable to PM<sub>2.5</sub> for five outcomes. The predicted provincial annual mean PM<sub>2.5</sub> concentrations range was between 21.7  $\mu\text{g}/\text{m}^3$  (UI: 19.03–24.9) and 35.4  $\mu\text{g}/\text{m}^3$  (UI: 31.4–39.4) from 1990 to 2016. We estimated in 2016, about 41,000 deaths (95% uncertainty interval [UI] 35634, 47014) and about 3,000,000 YLL (95% UI: 2632101, 3389342) attributable to the long-term exposure to PM<sub>2.5</sub> in Iran. Ischemic heart disease was the leading cause of mortality by 31,363 deaths (95% UI: 27520, 35258), followed by stroke (7012 (5999, 8062) deaths), lower respiratory infection (1210 (912, 1519) deaths), chronic obstructive pulmonary disease (1019 (715, 1328) deaths), and lung cancer (668 (489, 848) deaths). In 2016, about 43% of all PM<sub>2.5</sub> related mortality in Iran was, respectively, in the following provinces: Tehran (12.6%), Isfahan (9.3%), Khorasan Razavi (8.0%), Fars (6.5%), and Khuzestan (6.4%). In summary, we found that the majority of Iranians were exposed to the levels of ambient particulate matter exceeding the WHO guidelines from 1990 to 2016. Further, we found that there was an increasing trend of total mortality attributed to PM<sub>2.5</sub> in Iran from 1990 to 2016 where the slope was higher in western provinces.

*Shamsipour, Mansour, et al. "National and sub-national exposure to ambient fine particulate matter (PM<sub>2.5</sub>) and its attributable burden of disease in Iran from 1990 to 2016." Environmental Pollution 255 (2019): 113173.*

### Short-term associations between daily mortality and ambient particulate matter, nitrogen dioxide, and the air quality index in a Middle Eastern megacity

There is limited evidence for short-term association between mortality and ambient air pollution in the Middle East and no study has evaluated exposure windows of about a month prior to death. We investigated all-cause

non-accidental daily mortality and its association with fine particulate matter (PM<sub>2.5</sub>), nitrogen dioxide (NO<sub>2</sub>), and the Air Quality Index (AQI) from March 2011 through March 2014 in the megacity of Tehran, Iran. Generalized additive quasi-Poisson models were used within a distributed lag linear modeling framework to estimate the cumulative effects of PM<sub>2.5</sub>, NO<sub>2</sub>, and the AQI up to a lag of 45 days. We further conducted multi-pollutant models and also stratified the analyses by sex, age group, and season. The relative risk (95% confidence interval (CI)) for all seasons, both sexes and all ages at lag 0 for PM<sub>2.5</sub>, NO<sub>2</sub>, and AQI were 1.004 (1.001, 1.007), 1.003 (0.999, 1.007), and 1.004 (1.001, 1.007), respectively, per inter-quartile range (IQR) increment (18.8 µg/m<sup>3</sup> for PM<sub>2.5</sub>, 12.6 ppb for NO<sub>2</sub>, and 31.5 for AQI). In multi-pollutant models, the PM<sub>2.5</sub> associations were almost independent from NO<sub>2</sub>. However, the RRs for NO<sub>2</sub> were slightly attenuated after adjustment for PM<sub>2.5</sub> but they were still largely independent from PM<sub>2.5</sub>. The cumulative relative risks (95% CI) per IQR increment reached maximum during the cooler months, including: 1.13 (1.06, 1.20) for PM<sub>2.5</sub> at lag 0–31 (for females, all ages); 1.17 (1.10, 1.25) for NO<sub>2</sub> at lag 0–45 (for males, all ages); and 1.13 (1.07, 1.20) for the AQI at lag 0–30 (for females, all ages). Generally, the RRs were slightly larger for NO<sub>2</sub> than PM<sub>2.5</sub> and AQI. We found somewhat larger RRs in females, age group >65 years of age, and in cooler months. In summary, positive associations were found in most models. This is the first study to report short-term associations between all-cause non-accidental mortality and ambient PM<sub>2.5</sub> and NO<sub>2</sub> in Iran.

*Amini, Heresh, et al. "Short-term associations between daily mortality and ambient particulate matter, nitrogen dioxide, and the air quality index in a Middle Eastern megacity." *Environmental Pollution* 254 (2019): 113121.*

### Associations of black carbon and PM<sub>2.5</sub> with daily cardiovascular mortality in Beijing, China

Due to its twofold effects on climate change and air quality, black carbon (BC) is of wide concern in the atmospheric sciences. Considerable uncertainty exists as to the health effects of atmospheric BC for the limited epidemiological and toxicological studies. As combustion-derived BC is one important component of PM<sub>2.5</sub> (particles with aerodynamic diameters less than 2.5 µm), the question remains of whether or not BC may play an important role in PM<sub>2.5</sub>-related health risks. To quantitatively analyze the short-term health effects of BC and PM<sub>2.5</sub>, a confounder-adjusted semi-parametric generalized additive model (GAM) of a time series study was used to calculate the concentration-response relationship between BC and PM<sub>2.5</sub> and daily cardiovascular disease (CVD) mortality from 2006 to 2011 in Beijing. During the study period, the mean daily concentrations of BC and PM<sub>2.5</sub> were 6.8 µg/m<sup>3</sup> and 75.9 µg/m<sup>3</sup>, respectively. The results showed that BC was significantly associated with CVD mortality, and an interquartile range (IQR) increase in BC (5.7 µg/m<sup>3</sup>) and PM<sub>2.5</sub> (64.5 µg/m<sup>3</sup>) were associated with 2.70% (95% CI: 2.20, 3.21) and 4.06% (95% CI: 3.47, 4.65) increase in CVD mortality. The health risk associated with BC may less than that of PM<sub>2.5</sub>. When adjusted for nitrogen dioxide (NO<sub>2</sub>) and sulfur dioxide (SO<sub>2</sub>), the effects of BC remained statistically significant. It showed the relatively difference between BC and PM<sub>2.5</sub> when it comes to the modification effects of age, gender and educational attainment. These findings provide valuable evidence to the rare studies of the concentration-response relationship of BC with human health in developing countries.

*Gong, Tianyi, et al. "Associations of black carbon and PM<sub>2.5</sub> with daily cardiovascular mortality in Beijing, China." *Atmospheric Environment* 214 (2019): 116876.*

### Particulate air pollution in Ho Chi Minh city and risk of hospital admission for acute lower respiratory infection (ALRI) among young children

High levels of air pollutants in Vietnam, especially particulate matters including PM<sub>2.5</sub>, can be important risk factors for respiratory diseases among children of the country. However, few studies on the effects of ambient air pollution on human health have been conducted in Vietnam so far. The aim of this study is to examine the association between PM<sub>2.5</sub> and hospital admission due to acute lower respiratory infection (ALRI) among children aged < 5 years old in Ho Chi Minh city, the largest city of Vietnam. Data relating PM<sub>2.5</sub> and hospital admission were collected from February 2016–December 2017 and a time series regression analysis was performed to examine the relationship between PM<sub>2.5</sub> and hospital admission including the delayed effect up to three days prior to the admission. We found that each 10 µg/m<sup>3</sup> increase in PM<sub>2.5</sub> was associated with an increase of 3.51 (95%CI: 0.96–6.12) risk of ALRI admission among children. According to the analysis, male children are more sensitive to exposure to PM<sub>2.5</sub> than females, while children exposed to PM<sub>2.5</sub> are more likely to be infected with acute bronchiolitis than with pneumonia. The study demonstrated that young children in

HCMC are at increased risk of ALRI admissions due to the high level of PM<sub>2.5</sub> concentration in the city's ambient air.

*Luong, Ly Thi Mai, et al. "Particulate air pollution in Ho Chi Minh city and risk of hospital admission for acute lower respiratory infection (ALRI) among young children." Environmental Pollution (2019): 113424.*

## Long-term exposure to PM<sub>2.5</sub> and ozone and hospital admissions of Medicare participants in the Southeast USA

We examined the association between average annual fine particulate matter (PM<sub>2.5</sub>) and ozone and first hospital admissions of Medicare participants for stroke, chronic obstructive pulmonary disease (COPD), pneumonia, myocardial infarction (MI), lung cancer, and heart failure (HF). Annual average PM<sub>2.5</sub> and ozone levels were estimated using high-resolution spatio-temporal models. We fit a marginal structural Cox proportional hazards model, using stabilized inverse probability weights (IPWs) to account for the competing risk of death and confounding. Analyses were then repeated after restricting to exposure levels below the current U.S. standards. The results showed that PM<sub>2.5</sub> was significantly associated with an increased hazard of admissions for all studied outcomes; the highest observed being a 6.1% (95% CI: 5.9%–6.2%) increase in the hazard of admissions with pneumonia for each µg/m<sup>3</sup> increase in particulate levels. Ozone was also significantly associated with an increase in the risk of first hospital admissions of all outcomes. The hazard of pneumonia increased by 3.0% (95% CI: 2.9%–3.1%) for each ppb increase in the ozone level. Our results reveal a need to regulate long-term ozone exposure, and that associations persist below current PM<sub>2.5</sub> standards.

*Yazdi, Mahdieh Danesh, et al. "Long-term exposure to PM<sub>2.5</sub> and ozone and hospital admissions of Medicare participants in the Southeast USA." Environment international 130 (2019): 104879.*

## Comparison of health and economic impacts of PM<sub>2.5</sub> and ozone pollution in China

Many studies have reported associations between air pollution and health impacts, but few studies have explicitly differentiated the economic effects of PM<sub>2.5</sub> and ozone at China's regional level. This study compares the PM<sub>2.5</sub> and ozone pollution-related health impacts based on an integrated approach. The research framework combines an air pollutant emission projection model (GAINS), an air quality model (GEOS-Chem), a health model using the latest exposure-response functions, medical prices and value of statistical life (VSL), and a general equilibrium model (CGE). Results show that eastern provinces in China encounter severer loss from PM<sub>2.5</sub> and more benefit from mitigation policy, whereas the lower income western provinces encounter severer health impacts and economic burdens due to ozone pollution, and the impact in southern and central provinces is relatively lower. In 2030, without control policies, PM<sub>2.5</sub> pollution could lead to losses of 2.0% in Gross Domestic Production (GDP), 210 billion Chinese Yuan (CNY) in health expenditure and a life loss of around 10,000 billion, while ozone pollution could contribute to GDP loss by 0.09% (equivalent to 78 billion CNY), 310 billion CNY in health expenditure, and a life loss of 2300 billion CNY (equivalent to 2.7% of GDP). By contrast, with control policies, the GDP and VSLs loss in 2030 attributable to ambient air pollution could be reduced significantly. We also find that the health and economic impacts of ozone pollution are significantly lower than PM<sub>2.5</sub>, but are much more difficult to mitigate. The Chinese government should promote air pollution control policies that could jointly reduce PM<sub>2.5</sub> and ozone pollution.

*Xie, Yang, et al. "Comparison of health and economic impacts of PM<sub>2.5</sub> and ozone pollution in China." Environment international 130 (2019): 104881.*

# PM<sub>2.5</sub> and Air Pollution

**Description:** This section includes articles addressing PM<sub>2.5</sub> and air pollution source apportionment, impacts and emissions trends.

## Impact of harbour activities on local air quality: A review

Several harbour activities cause negative environmental impacts in the harbours' surrounding areas, namely the degradation of air quality. This paper intends to comprehensively review the status of the air quality measured in harbour areas. The published studies show a limited number of available air quality monitoring data in

harbours areas, mostly located in Europe (71%). Measured concentrations of the main air pollutants were compiled and intercompared, for different countries worldwide allowing a large spatial representativeness. The higher NO<sub>2</sub> and PM<sub>10</sub> concentrations were found in Europe - ranging between 12 and 107 µg/m<sup>3</sup> and 2–50 µg/m<sup>3</sup>, respectively, while the higher concentrations of PM<sub>2.5</sub> were found in Asia (25–70 µg/m<sup>3</sup>). In addition, the lower levels of SO<sub>2</sub> monitored in recent years suggest that current mitigation strategies adopted across Europe were very efficient in promoting the reduction of SO<sub>2</sub> concentrations.

Part of the reviewed studies also estimated the contributions from ship emissions to PM concentration through the application of source apportionment methods, with an average of 5–15%. In some specific harbour areas in Asia, ships can contribute up to 7–26% to the local fine particulate matter concentrations. This review confirms that emissions from the maritime transport sector should be considered as a significant source of particulate matter in harbour areas, since this pollutant concentrations are frequently exceeding the established standard legal limit values. Therefore, the results from this review boost the implementation of mitigation measures, aiming to reduce, in particular, particulate matter emissions.

*Sorte, Sandra, et al. "Impact of harbour activities on local air quality: A review." Environmental Pollution (2019): 113542.*

### Proximate determinants of particulate matter (PM<sub>2.5</sub>) emission, mortality and life expectancy in Europe, Central Asia, Australia, Canada and the US

**Background:** The growing concern with environmental related impacts on mortality and morbidity means that the conceptual framework of environment-health-economic policy nexus is salient in the global debate on air pollution.

**Objective:** With time series data spanning 2000–2016, this study explored the proximate determinants of ambient air pollution, mortality, and life expectancy in North America, Europe & Central Asia, and East Asia & Pacific regions.

**Methods:** The study applied historical data on urban population, total pollution, energy consumption, GDP per capita, life expectancy, mortality rate and industrial PM<sub>2.5</sub> emissions to develop six parsimonious models using the generalized least squares (GLS) random-effects model estimation with first-order autoregressive [AR(1)] disturbance across 54 countries.

**Results:** An increase in income level by 1% declined mortality rate by 0.01% and increased longevity by ~0.02% (95% Confidence Interval [CI]) in the long-run. An increase in industrial PM<sub>2.5</sub> emissions per capita by 1% decreased life expectancy by 0.004% and mortality rate by 0.02% (95% CI). Intensification of energy consumption and its related services by 1% were found to increase industrial PM<sub>2.5</sub> emissions by 0.42–0.45% (95% CI). An inverted-U shaped curve between PM<sub>2.5</sub> emissions per capita and income levels was found at a turning point of US\$ 48,061. The validity of an environmental Kuznets curve hypothesis between ambient air pollution and urbanization was confirmed, while a rapid increase in population had a significant positive impact on ambient air pollution.

**Conclusion:** Ambient air pollution contributes significantly in reducing life expectancy and increasing mortality. However, sustained economic development, along with energy efficiency, and sustainable urban settlement planning and management are potential options for reducing ambient air pollution while improving quality of life and environmental sustainability.

*Sarkodie, Samuel Asumadu, et al. "Proximate determinants of particulate matter (PM<sub>2.5</sub>) emission, mortality and life expectancy in Europe, Central Asia, Australia, Canada and the US." Science of The Total Environment 683 (2019): 489-497.*

### A two-pollutant strategy for improving ozone and particulate air quality in China

Fine particulate matter (PM<sub>2.5</sub>) decreased by 30–40% across China during 2013–2017 in response to the governmental Clean Air Action. However, surface ozone pollution worsened over the same period. Model simulations have suggested that the increase in ozone could be driven by the decrease in PM<sub>2.5</sub>, because PM<sub>2.5</sub> scavenges hydroperoxy (HO<sub>2</sub>) and NO<sub>x</sub> radicals that would otherwise produce ozone. Here we show observational evidence for this effect with 2013–2018 summer data of hourly ozone and PM<sub>2.5</sub> concentrations from 106 sites in the North China Plain. The observations show suppression of ozone pollution at high PM<sub>2.5</sub>

concentrations, consistent with a model simulation in which PM<sub>2.5</sub> scavenging of HO<sub>2</sub> and NO<sub>x</sub> depresses ozone concentrations by 25 ppb relative to PM<sub>2.5</sub>-free conditions. PM<sub>2.5</sub> chemistry makes ozone pollution less sensitive to NO<sub>x</sub> emission controls, emphasizing the need for controlling emissions of volatile organic compounds (VOCs), which so far have not decreased in China. The new 2018–2020 Clean Air Action plan calls for a 10% decrease in VOC emissions that should begin to reverse the long-term ozone increase even as PM<sub>2.5</sub> continues to decrease. Aggressive reduction of NO<sub>x</sub> and aromatic VOC emissions should be particularly effective for decreasing both PM<sub>2.5</sub> and ozone.

*Li, Ke, et al. "A two-pollutant strategy for improving ozone and particulate air quality in China." Nature Geoscience (2019): 1-5.*

## SLCPs & Vulnerable Regions

**Description:** This section includes articles addressing SLCP impacts on vulnerable regions or studies discussing the specific vulnerabilities of regions to SLCPs.

### Black carbon aerosol quantification over north-west himalayas: Seasonal heterogeneity, source apportionment and radiative forcing

Continuous measurements of Black Carbon (BC) aerosol mass concentrations were carried at Dehradun (30.33°N, 78.04°E, 700 m amsl), a semi-urban site in the foothills of western Himalayas, India during January 2011–December 2017. We reported both the BC seasonal variations as well as mass concentrations from fossil fuel combustion (BC<sub>ff</sub>) and biomass burning (BC<sub>bb</sub>). Annual mean BC exhibited a strong seasonal variability with maxima during winter ( $4.86 \pm 0.78 \mu\text{g m}^{-3}$ ) followed by autumn ( $4.18 \pm 0.54 \mu\text{g m}^{-3}$ ), spring ( $3.93 \pm 0.75 \mu\text{g m}^{-3}$ ) and minima during summer ( $2.41 \pm 0.66 \mu\text{g m}^{-3}$ ). Annual averaged BC mass concentrations were  $3.85 \pm 1.16 \mu\text{g m}^{-3}$  varying from 3.29 to  $4.37 \mu\text{g m}^{-3}$  whereas BC<sub>ff</sub> and BC<sub>bb</sub> ranged from 0.11 to  $7.12 \mu\text{g m}^{-3}$  and 0.13– $3.6 \mu\text{g m}^{-3}$ . The percentage contributions from BC<sub>ff</sub> and BC<sub>bb</sub> to total BC are 66% and 34% respectively, indicating relatively higher contribution from biomass burning as compared to other locations in India. This is explained using potential source contribution function (PSCF) and concentration weighted trajectories (CWT) analysis which reveals the potential sources of BC originating from the north-west and eastern parts of IGP and the western part of the Himalayas that are mostly crop residue burning and forest fire regions in India. The annual mean ARF at top-of-atmosphere (TOA), at surface (SUR), and within the atmosphere (ATM) were found to be  $-14.84 \text{ Wm}^{-2}$ ,  $-43.41 \text{ Wm}^{-2}$ , and  $+28.57 \text{ Wm}^{-2}$  respectively. To understand the impact of columnar aerosol burden on ARF, the radiative forcing efficiency (ARFE) was estimated and averaged values were  $-31.81$ ,  $-91.63$  and  $59.82 \text{ Wm}^{-2} \tau^{-1}$  for TOA, SUR and ATM respectively. The high ARFE within the atmosphere indicates the dominance of absorbing aerosol (BC and dust) over Northwest Himalayas.

*Kant, Yogesh, et al. "Black carbon aerosol quantification over north-west himalayas: Seasonal heterogeneity, source apportionment and radiative forcing." Environmental Pollution (2019): 113446.*

### Black carbon in a glacier and snow cover on the northeastern Tibetan Plateau: Concentrations, radiative forcing and potential source from local topsoil

Black carbon (BC), which consists of the strongest light-absorbing particles (LAP) in snow/ice, has been regarded as a potential factor accelerating the melting of glaciers and snow cover over the Third Pole. During the winter and summer of 2016, snow, ice and topsoil were sampled from the Laohugou basin located on the northeastern Tibetan Plateau. Concentrations of BC in Laohugou Glacier No. 12 (LG12) and snow cover in this basin (LSC) varied broadly ( $21.7\text{--}2700.1$  and  $89.6$  to  $6326.2 \text{ ng g}^{-1}$ , respectively), indicating large spatiotemporal variability in wet, dry and post-depositional conditions. Further, internally mixed BC in snow grains enhanced the albedo reduction (15.0–26.3%) more than externally mixed BC in LG12 and LSC. Dust played a more important role than BC in accelerating the melting of LG12, whereas these components played comparable roles in accelerating the melting of LSC. In total, externally mixed BC and dust reduced the albedo by 0.075–0.423, with an associated mean radiative forcing (RF) of  $97.5 \pm 41.5 \text{ Wm}^{-2}$  in LSC. This level was lower than those in the ablation zone ( $354.1 \pm 81.2 \text{ Wm}^{-2}$ ) and accumulation zone ( $145.6 \pm 76.7 \text{ Wm}^{-2}$ ) of LG12 because of discrepancies in LAP



concentrations, solar zenith angles and incoming shortwave radiation. Furthermore, we observed that topsoil containing abundant BC was transported along the slope from the debris to the LG12 surface ice, and topsoil in this region could be lifted by strong mountain-valley winds and then deposited on snow/ice surfaces, which affected the LAP concentrations. Therefore, this study is important for understanding the role of BC and dust in the melting of snow/ice in the northeastern Tibetan Plateau.

*Li, Yang, et al. "Black carbon in a glacier and snow cover on the northeastern Tibetan Plateau: Concentrations, radiative forcing and potential source from local topsoil." Science of the total environment 686 (2019): 1030-1038.*