Title:	Quantification of open waste burning emissions over the indian subcontinent:
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Abstract:	India struggles with frequent exceedances of the ambient air quality standard for particulate matter and benzene. In the past two decades, India has made considerable progress in tackling indoor air pollution, by phasing out kerosene lamps, and pushing biofuel using households towards Liquefied Petroleum Gas (LPG) usage yet air quality has not improved adequately. Open waste burning is a ubiquitous but often neglected air pollution source which can be observed happening in our surroundings on a daily basis. Waste generation and open burning of waste increases as a result of rapid economic development. Waste disposal and management services typically struggle to keep pace with exponential increase in waste generation when the economy of a nation grows rapidly. At the same time, greater the wealth or prosperity levels leads to more demand for a clean environment from citizens. At a certain point in time when the mismatching between waste generation and waste disposal service quality becomes too large, open burning of any unwanted material becomes socially acceptable. This process happened in the past in several developed nations and is now happening in developing nations. Back yard burning was considering to be biggest source of dioxin in the USA in early 2000s. however, these are now better regulated and the emissions have reduced. Developing nations, on the other hand, still struggle with a mismatch between waste generation and waste management capabilities and consequently suffer from air pollution due to open waste burning. Yet, the official agencies often deny open waste burning exists, and major atmospheric emission inventories such as EDGAR and REAS fail to include this source. Accurate emission inventories serve as critical inputs for air quality and climate models, but are poorly constrained over India. In first part of my thesis work I present a new municipal open waste burning emission inventory from India (OWBEII), at a resolution of 0.1° x 0.1°. Out of the 216 (201-232) Tgy-1 of waste produced in the year 2015, 68 (45-105) Tgy-1 was burned in the open. To determine emissions from waste burning, emission factors of 59 non-methane volatile organic compounds (NMVOCs), CH4, CO2, CO and NOx were measured from garbage fires in a rural and urban site in India. The NMVOC emissions from open waste burning of 1.4-2 Tgy-1 increase India's total anthropogenic NMVOC budget by 8-12%, while Black Carbon (BC) emissions (40-110 Ggy-1) increase the total anthropogenic BC emissions by 8-12%. Open waste burning in India emits 3-7 Tgy-1 of CO and 58-130 Tgy-1 of CO2. Emissions increase the total anthropogenic CO and CO2 in the MIX-Asia inventory by 4-11% and 2-6%, respectively. My study highlights that open waste burning may impact atmospheric OH reactivity and ozone formation rates downwind of urban centers through the emission of other highly reactive compounds such as acetaldehyde (20-320 Ggy-1), propene (50-170 Ggy-1) and ethene (50-190 Ggy-1) and is source of carcinogenic benzene (30-280 Ggy-1). In the second part of my thesis I develop waste generation projections for the 21st century. Waste generation projections for emerging economies like India are highly uncertain. I present waste generation and open waste burning projections for India based on a new approach which considers the projected future income inequality within the country while calculating future waste generation. I evaluated the population and income projections in the shared socio-economic pathways (SSPs) database against recent census data to reduce the uncertainty of projections. I found that for India the SSP3 and SSP2 narrative are no longer consistent with observed fertility trends and limit the projection to the SSP 1, 4 and 5 scenarios. SSP5, the scenario with the fastest economic growth, results in the highest projected waste generation of 272 Tgy-1 and 400 Tgy-1 by 2030 and 2050, respectively. Despite differences in population and income structure the SSP1 and SSP4 narratives result in very similar total waste generation estimates of 252±2 and 333±16 Tgy-1, but different regional trends for the year 2030 and 2050, respectively. I presented assumptions about technological progress, and policies that are broadly in line with the SSP narratives and explore the differences in open waste burning emissions that results from different levels of commitment to a circular economy. I found that a strong commitment to convert biodegradable waste into compressed biogas can bring the country onto a SSP1 trajectory and can reduce open waste burning emissions to one third of what they would be with a business-as-usual approach to waste management. The move will not only help to mitigate open waste burning emissions and landfill fires, it will also help to shift the economy towards low carbon residential fuel choices and a cleaner transport sector. In the third part of the thesis, I calculated past trends in residential fuel consumption and extrapolated them into the future, to explore changes in the contribution of different sectors towards India's largest air pollution problem. I found that residential fuel usage is still the largest air pollution source, and that the <10% households using cow dung as cooking fuel contribute ~50% of the residential sector PM2.5 emissions. I also found that if current trends persist, residential biofuel usage in India is likely to be phased out by 2035. India's renewable energy policies are likely to reduce emissions in the heat and electricity sector, while its recent biogas initiatives are likely to reduce emission from manufacturing industries that currently use solid biomass as fuel. PM2.5 emissions from open waste burning, on the other hand, hardly changed in the decade from 2010 to 2020 and will not reduce unless we significantly invest into upgrading waste management systems. I conclude that without strong policies to promote recycling and upcycling of non-biodegradable waste, and the conversion of biodegradable waste to biogas, open waste burning is likely to become India's largest source of air pollution by 2035. While my study is limited to India, my findings are of relevance for other countries in the global South suffering from similar waste management challenges.
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