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Uncontrolled burning of solid waste by households in Mexico is a significant contributor to climate change in the country

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ABSTRACT

Uncontrolled burning of municipal solid waste (MSW) is an important source of air pollution and is wide spread in many developing countries, but only limited data quantify the extent of domestic open burning of household waste. Here, we present some of the first field data to be reported on the uncontrolled domestic burning of waste. A representative community of Mexico (Huejutla de Reyes Municipality) was investigated and household surveys, interviews with waste operators and a waste characterisation analysis were completed to assess the extent of, and factors controlling, the open burning of waste. Waste collection provision to rural communities was very limited and, consequently 92% of households in rural areas reported that they disposed of waste by uncontrolled burning in backyards or unofficial dumps. Overall, 24% of the total MSW generated in the Municipality was disposed by uncontrolled burning. Urban and periurban areas received twice-weekly collections and the rate of uncontrolled burning was considerably smaller compared to rural households, corresponding to approximately 2% of total waste generation. Carbon equivalency calculations showed that burning waste in backyards represented approximately 6% of the total and 8.5% of fuel related CO_2Eq emissions by the municipality. Moreover, the equivalent carbon dioxide (CO_2Eq) from black carbon (BC) emitted by uncontrolled burning in backyards was over fifteen times larger compared to methane (CH_4) potentially released from equivalent amounts of combustible biodegradable waste disposal at the official dumpsite. An assessment of local respiratory health data showed the incidence of disease was higher in rural than in urban areas, when the opposite trend is typically observed in the international literature; given the high rate of burning activity found in rural areas we suggest that open burning of waste could be a major reason for the apparent poorer respiratory health status of the rural population and requires further investigation. The results emphasise the importance of including BC from uncontrolled burning of waste in international emission inventories of greenhouse gases and in the assessment of the health status of local communities in developing countries where this practice is prevalent.

1. Introduction

1.1. Background and international context

Solid waste disposal is a worldwide issue and represents a serious risk to public health and the environment. Globally, two billion people lack access to municipal solid waste (MSW) collection services and dispose of household waste typically by open burning, burial or dumping on open ground or into watercourses (UNEP and ISWA, 2015). Providing universal access to adequate, safe and affordable MSW collection services and eliminating uncontrolled dumping and burning of waste are strategic international objectives within the United Nations' Sustainable Development Goals (SDGs) (United Nations, 2015).

Open burning of waste is characteristically a form of low temperature combustion with high contaminant emissions, particularly of black carbon (BC), which contributes significantly to air pollution, causing both health and environmental impacts (US EPA, 2012). There is growing recognition of the significant impact of short lived climate pollutants (SLCPs) on climate change (US EPA, 2012). The MSW sector is a major emitter of two important SLCPs, namely methane (CH_4) and BC. The contribution to global CH_4 emissions from the landfill disposal of biodegradable MSW is well established, however, there is a lack of information relating to MSW as a source of BC emissions (Christian et al., 2010; Stockwell et al., 2016; Wiedinmyer et al., 2014; Yokelson et al., 2011).

Black carbon is a by-product of incomplete combustion that contributes to climate change through direct radiative forcing properties caused by absorption and scattering of sunlight, influencing the properties of clouds and froming deposition on to snow and ice. It is a component of particulate matter (PM) that has a global warming

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potential (GWP) up to 5000 times greater than CO_2 and is the most effective component of atmospheric PM at absorbing solar energy (Bond et al., 2013). There is also a strong link between exposure to BC and potentially severe health effects such as cardiovascular disease, chronic respiratory illness and premature mortality (Janssen et al., 2012; US EPA, 2012). A detailed review of literature on the activity levels and atmospheric emissions from open burning of waste can be found in the Supplementary materials (section S1.1-S1.3).

1.2. Open burning of MSW

Global MSW generation is estimated to be in the region of 1.3–2.4 $\times 10^9$ t y^{-1} (Hoornweg and Bhada-Tata, 2012; Wiedinmyer et al., 2014; UNEP and ISWA, 2015). Wiedinmyer et al. (2014) estimated the total amount of waste burned worldwide assuming a burning activity level for each country, following IPCC Guidelines (IPCC, 2006). This analysis suggested that approximately 0.97 $\times 10^9$ t y^{-1} of total MSW generated globally may be disposed of by uncontrolled burning, comprising 0.62 $\times 10^9$ t y^{-1} by households and 0.35 $\times 10^9$ t y^{-1} by burning at dumpsites (Wiedinmyer et al., 2014). Therefore, approximately 40–50% of total global MSW generation may be disposed of by uncontrolled burning in the open (Christian et al., 2010; Wiedinmyer et al., 2014). This equated to 5% of global annual anthropogenic CO_2 emissions in 2010. Kodros et al. (2016) incorporated health data into the model and estimated that 270,000 premature adult mortalities occurred from chronic respiratory exposure to uncontrolled burning of domestic waste per year. As a comparison, malaria infections are responsible for 580,000 deaths globally each year (UNICEF, 2015). The countries with the highest rates of open burning emissions include: China, India, Brazil, Mexico, Pakistan, and Turkey (Wiedinmyer et al., 2014). Nagpure et al. (2015) reported the street burning of waste in the open in three different areas of Delhi, India was equivalent to 2 – 3% of the total MSW generated. This value was considerably smaller than that suggested by Wiedinmyer et al. (2014), but other important types of open burning, such as in backyards, were not considered and the mass of waste burned was only an approximated estimate and could be subjected to significant error.

1.3. Open burning and MSW management in Mexico

Mexico has one of the largest rates of residential and open dump burning and, therefore, is potentially amongst the main emitters of BC from MSW disposal (Wiedinmyer et al., 2014). According to Wiedinmyer et al. (2014), between 5.0 and 10.0 $\times 10^6$ t y^{-1} of waste (equivalent to 13 – 27% of the total generated) is burned by households and between 10 and 25 $\times 10^6$ t y^{-1} (equivalent to 27 − 96% of the total generated) is burned at dumpsites in Mexico. Earlier estimates (Commoner et al., 2000) suggested that 50% of MSW generated in Mexico was disposed informally in either community dumpsites or by backyard disposal and burning, and the amount of waste burnt in open fires was equivalent to 14.5 $\times 10^6$ t y^{-1}. Further details and discussion of published literature on the open burning waste in Mexico is presented in the Supplementary material sections S1.1-S1.3.

In Mexico, waste generation statistics are calculated by the Ministry of Social Development (SEDESOL) based on the population size and consumption habits following the protocols established in regulation NMX-AA-61–1985 on MSW generation. The amount of waste generated nationally in Mexico in 2010 was over 112,300 t day^{-1}, equivalent to 0.98 kg $capita^{-1}$ day^{-1}. However, waste generation patterns vary greatly between the different states in the country (SEMARNAT, 2013). Overall, approximately 84% of MSW generated in Mexico is collected either through selective or mixed collection system and 10% is recycled or recovered through an industrial process. Nevertheless, up to 12% of the waste generated in Mexico is not accounted for by formal collection and disposal/recovery systems and it is possible that a significant portion of this fraction is disposed by burning in households or in dumpsites (INECC, 2012).

Municipal authorities are required to provide waste management services including waste collection, transport, treatment and confinement, a responsibility devolved to them by the Mexican Constitution as early as 1917 (Poder Legislativo Federal, 1917). Article 100 of the "General Law for the Prevention and Integrated Management of Waste" (Diario Oficial de la Federación, 2003) specifies that the regulations relating to the generation, management and disposal of waste adopted by State Authorities must prohibit the uncontrolled open burning of waste. Therefore, burning of waste is an illegal practice in Mexico.

1.4. Aims and objectives

Little quantitative, experimental evidence is available to validate the published estimates for either the extent of uncontrolled burning of waste or the factors controlling BC emissions from this source, which is highly dependent on the types and composition of waste burnt. This information is necessary to understand the impact of uncontrolled burning of waste on climate change and human health, to improve BC inventories, and provide the sound technical basis to effective policies and practices for MSW management, health provision services and climate change mitigation. For instance, IPCC (2006) guidelines on emissions from the waste sector assume a default value of 0.6 for the fraction of waste burned in open dumps in developing countries. However, there are no experimental data available to substantiate this, and, as a consequence, this emission source is not considered in the IPCC Fourth (Bogner et al., 2007) or Fifth (IPCC, 2014) Assessment Reports.

Therefore, the aim of the research presented in this paper is to quantify the extent of open burning of waste in a representative community of the developing world where this activity is commonly practiced to: (a) improve understanding of the impact of open burning of waste on the environment and public health, and (b) identify policies and practices to mitigate these impacts. A main objective was to develop a waste management profile of open burning of waste in a typical medium-sized community in Mexico to identify the types and quantities of MSW generated and disposed by burning by households.

2. Materials and methods

2.1. Selection and assessment of study area

Federal waste management authorities in the National Institute of Ecology and Climate Change (INECC), State authorities responsible of waste management, and local specialists in the sector were consulted to assist in selecting a representative candidate study area for investigation in Mexico. Small to medium-sized municipalities (population size < 100,000) with unreliable MSW collection services were considered the most likely to dispose of waste by uncontrolled burning in the open, compared to cities with larger population densities where more rigorous waste management controls may be in place (Encarnación-Aguilar, 2015; Solorzano-Ochoa, 2015). Other aspects that were considered in selecting the study area included: transport accessibility from Mexico City, the willingness of local authorities to participate in the project and health and safety conditions in the region. Using these criteria, the Municipality of Huejutla, was selected as the study area for the research.

Huejutla Municipality is located in the state of Hidalgo, in central Mexico. The capital of the municipality is the largest community and most densely populated area of the region and the metropolitan area has a population of over 40,000. Other communities in the municipality are considerably smaller with < 5,000 inhabitants; approximately half of the population live in communities with < 1,500 inhabitants. For this research, households in the study area were sub-divided into three principal categories corresponding to: urban, periurban and rural, depending on the density of the population and the frequency of waste collection services. Households within the urban area were of higher