Open burning of municipal solid waste in developing countries: the case of Huejutla, Mexico

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1 Abstract

This research aims to determine the activity level of uncontrolled open burning of waste in a representative municipality of Mexico (Huejutla de Reyes, in the state of Hidalgo), with the objective of better understanding the BC emissions generated from this source at the household level in the country. A survey was conducted to gather information about the waste management practices operating at the household level as well as drivers influencing waste disposal, recycling and burning patterns. Additionally, twenty houses that frequently burned waste were selected for compositional analysis, and household waste samples were collected over a two-week period for characterisation. Finally, interviews were carried to gather information about waste generation and management services provided by the Municipality. Using the information gathered in the field, a waste flow diagram was elaborated for Huejutla de Reyes. This exercise showed that the rates of open burning of waste by households were influenced by the frequency of the waste collection service. Thus, rural households with no collection service burn the majority of the combustible waste fraction compared to urban households that have a reliable twice-weekly service. Overall, 22 % of the waste generated in Huejutla is disposed by burning; however, the rate of burning varies significantly between areas and 91 % of waste generated in rural households is disposed by uncontrolled burning in backyards or unofficial dumping sites. These provisional data emphasis the potential scale and impact of BC emissions on the environment and human health from the uncontrolled burning of MSW by households in developing countries.

2 Introduction

The municipal solid waste (MSW) sector is a major emission source of two important short-lived climate pollutants (SLCPs): methane (CH_4) and black carbon (BC). Black carbon is a by-product of incomplete combustion that contributes to climate change and is a component of particulate matter that has a global warming potential (GWP) up to 5000 times greater than carbon dioxide (CO_2) (Bond et al., 2013). Uncontrolled burning of discarded waste materials in open dumps or backyards is common in developing countries (IPCC, 2006) and releases polluting emissions such as greenhouse gases and BC,.. Short and long-term exposures to BC also have a broad range of public health impacts, including respiratory and cardiovascular diseases, as well as premature death (US EPA, 2012).

Uncontrolled burning of waste is common in small to medium sized cities and particularly in rural areas in Mexico. Therefore, the aim of this research is to determine the extent of uncontrolled open burning of household waste in a representative municipality of Mexico. A waste management profile for the case study area will be constructed to identify the types and quantities of solid waste generated and disposed by burning at a household. This data will help to better understand the extent and impact of BC emissions generated from the uncontrolled burning of waste in Mexico.

3 Literature Review

There is growing recognition that climate change mitigation should not only focus on reducing CO_2 emissions, but also on reducing SLCPs, since they contribute significantly to climate change. The MSW sector is a major emission source of two SLCPs: CH_4 and BC. The contribution of the MSW sector to CH_4 emissions has been studied extensively, however there is a lack of information relating to MSW as a source of BC emissions. This pollutant is formed by the incomplete combustion of fossil fuels, biofuels, and biomass and it has a potent GWP compared to CO_2 because it is the most effective component of particulate matter (PM) at absorbing solar energy (Bond et al., 2013). There is also a strong link identified between the exposure to BC and several adverse and potentially severe health effects, such as premature mortality, increased hospital admissions for cardiovascular and respiratory diseases, and development of chronic respiratory disease (US EPA, 2012).

A potential major release of BC arises from the uncontrolled, open burning of MSW at dumpsites and at the domestic household level, especially in developing countries (Wiedinmyer et al., 2014). Evidence from field measurements performed in central Mexico by Christian et al. (2010) strongly implicate burning waste as an important global source of atmospheric emissions that is currently omitted from national emission inventories worldwide. Moreover, uncontrolled open burning of waste contributes significantly to urban air pollution (Hoornweg and Thomas, 1999). Localised open burning of waste at residential dwellings, businesses and dumpsites, represents a potentially significant source of air pollutants, which has been neglected as an important source of global atmospheric emissions (Li et al., 2012, Wiedinmyer et al., 2014).

Residential open burning of waste is practiced in both developing and developed countries. In developed regions, domestic waste is typically collected, however, burning can still occur in rural areas where collection services are expensive, unavailable, or infrequent (US EPA, 2001). In developing countries, however, waste collection services are typically only available in the most densely populated urban areas and may also be relatively inefficient or infrequent (Buenrostro and Bocco, 2003) so the domestic burning of waste is a common both rural and urban areas. However, the extent of burning activity at residential properties and, therefore, the contribution to BC emissions, remains uncertain. Additionally, in many developing countries, waste that is collected and transported to dumpsites is frequently burnt in open uncontrolled fires to reduce volume (Wiedinmyer et al., 2014).

Global MSW generation is estimated to be equivalent to 1.9 x 10^9 to 2.4 x 10^9 t y^{-1} Wiedinmyer et al. (2014). Wiedinmyer et al. (2014) considered that 0.62 x 10^9 t y^{-1} of generated MSW may be burned by households and 0.35 x 10^9 t y^{-1} was burned in an uncontrolled process at dumpsites. Thus, approximately 1.0 x 10^9 t, of total MSW generated globally may be disposed of by uncontrolled burning. This quantity represents 40-50 % of the overall global amount of MSW generated annually (Christian et al., (2010), Wiedinmyer et al. (2014). Figure 1 presents the global distribution of MSW burning in households and at dumpsites internationally. According to these data, between 5 x 10^6 to 10 x 10^6 t of waste is burned per year in households and between 10 x 10^6 to 25 x 10^6 t of waste is burned annually at dumpsites in Mexico (Wiedinmyer et al., 2014). Uncontrolled open burning of waste by households and at dumpsites is most prevalent in regions with emerging economies such as Asia and Latin America.

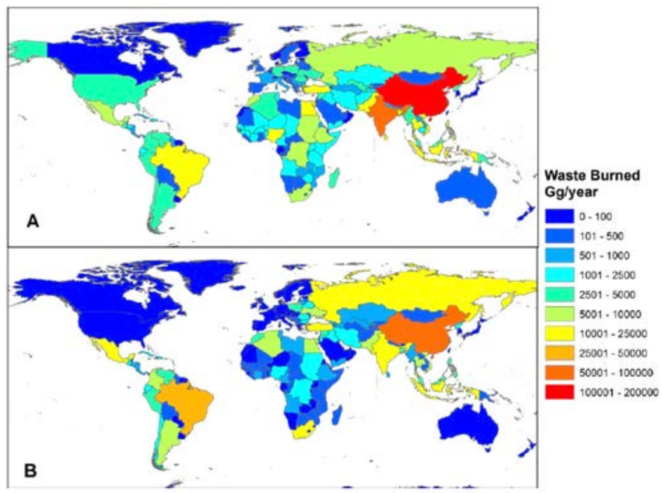

Figure 1 Total estimated annual waste burnt in households (A) and dumpsites (B) (Wiedinmyer et al., 2014)

According to Wiedinmyer et al. (2014), open burning of waste produces organic carbon (OC) emissions of more than 5 x 10^6 t y^{-1}, representing 15 % of all global OC emissions from burning biomass. Those countries with the largest estimates for residential and open dump burning, and therefore with the largest emissions from this source include: China, India, Brazil, Mexico, Pakistan, and Turkey (Wiedinmyer et al., 2014). Hodzic et al. (2012) estimated the impact of burning waste in Mexico City, and developed an emission inventory for this source based on socioeconomic levels and emission factors measured in 2006 (Molina et al., 2010). Based on this analysis, the burning of waste in Mexico City emits approximately 19 t of primary organic carbon (POC) day^{-1}. This quantity can be compared to POA emissions from fossil fuels in Mexico City, and raises the average organic aerosol concentration in the atmosphere up to 2µg m^{-3} in densely populated areas. One of the most important conclusions of this study was that the mitigation of uncontrolled burning of waste in the Mexico City Metropolitan Area could reduce total organic aerosols by 5 % in the centre of the city, and by 15-40 % in the Greater Mexico City area.

Black carbon emissions from the uncontrolled burning of waste can be estimated from the product of an emission factor (EF) (typically mass of BC per mass of waste burned) and the activity level (AL) (such as mass of waste burned per capita). However, few direct field measurements of the AL have been completed. Considerable uncertainty also remains about the specific or appropriate BC emission factors that apply the unmanaged combustion of waste in the open. The EF is influenced by the waste composition and therefore varies depending on the types of waste disposed under local regional conditions. Combustion conditions also have a significant impact on the EF value (Bond et al., 2013). The development of efficient and effective mitigation strategies for BC requires quantitative understanding of the impacts of BC emissions from the open burning of waste in relation to both global warming potential and human health. This will help improve to the quality of BC inventories in Mexico, and provide better information to elaborate effective policies and practices for MSW management, health provision services and climate change mitigation.

4 Materials and methods

4.1 Selection and assessment of case study area

Federal waste management authorities in the National Institute of Ecology and Climate Change (INECC), State authorities responsible of waste management and consultants in the sector were consulted to assist in selecting representative candidate case study regions for investigation in Mexico. This indicated that small to medium-sized municipalities (population size <100,000) with unreliable MSW collection services were most likely to dispose of waste by uncontrolled burning in the open. Other aspects that were considered in selecting the case study area included the 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, in the state of Hidalgo, was chosen as the case study area for the research.

The location of Huejutla municipality within Mexico and Hidalgo State is shown in Figure 2. Huejutla de Reyes is the capital of the municipality and the largest community and most densely populated area of the region. It is considered as the metropolitan area of the municipality and has a population of over 40,000. Other communities in the municipality have less than 5000 inhabitants and approximately half of the population live in communities with <1,500 inhabitants, as shown in Figure 3.

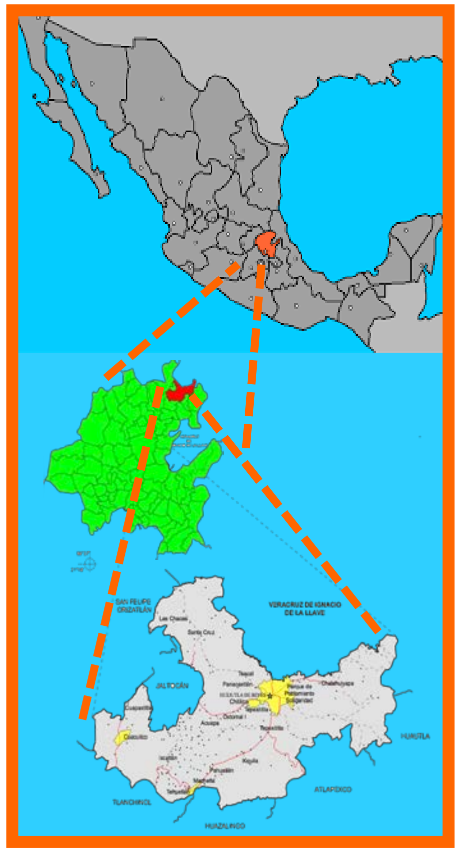

Figure 2 Location of the case study area: Huejutla de Reyes, Hidalgo, Mexico

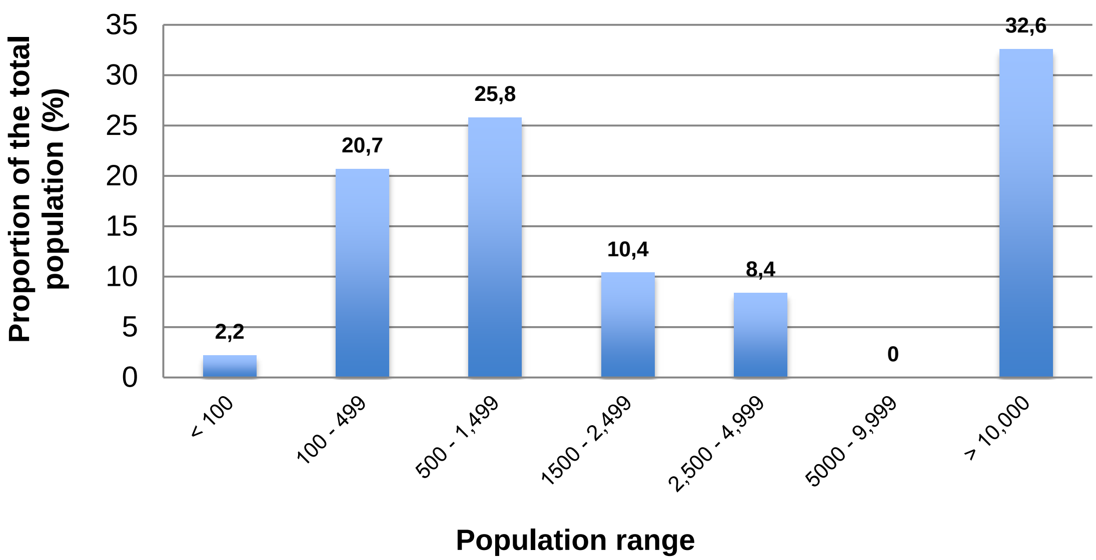

Figure 3 Size of communities in Huejutla de Reyes, Hidalgo, Mexico (INEGI, 2010)

For this research, households in the study area were sub-divided into three principal categories corresponding to: urban, periurban and rural areas, depending on the density of the population, average socioeconomic status and frequency of waste disposal collection service. Correspondingly, households within the urban area were considered of higher socioeconomic status compared to the periurban and rural areas (SEDESOL, 2013), and waste collection services to these communities operated on a frequent daily or twice per week basis. Interviews with local authority personnel indicated that approximately 25 % of the population in the metropolitan area (equivalent to 8 % of the total population of the municipality) were categorised as in urban housing receiving a daily waste collection service. The periurban community is located between the urban and rural areas and, in this case, waste collections occurred at a reduced frequency of once per week. According to local authority data, 75 % of the metropolitan population (equivalent to 24 % of the total population) are provided with this level of waste collection service. The rural area is located outside of the metropolitan area of the municipality and has a lower population density, but larger community size overall (67.5 % of the total population of the municipality). The socioeconomic status of rural homes is generally lower compared to the urban or periurban zones of the municipality (INEGI, 2010). Waste collection services to this section of the community for general household waste were infrequent or were not provided by the Municipal Authority to the rural area.

4.2 Waste management survey

A survey was conducted to determine the waste management practices operating at the household level as well as the drivers influencing waste disposal, recycling and burning patterns in the Huejutla region. A total of 240 properties were randomly selected for assessment within the study area including: 100 urban, 80 periurban and 60 rural households. The survey provided information on the general characteristics of the household members including gender and age. Information on the feeding of food-waste to pets and farm animals was also gathered. Other aspects included waste separation and recycling behaviour, frequency of waste burning activities in the neighbourhood and in the household, identification of other unofficial local sites where open burning of waste was commonly practiced and the frequency of respiratory diseases in children, adults and the elderly. The surveys were completed from May 27 to June 5, 2015.

4.3 Characterisation of waste collected from individual households

Twenty households that frequently burnt waste were identified and selected from those surveyed (5 in the urban and periurban areas and 10 in the rural area) for further detailed investigation of the household waste composition. Four waste samples were collected from the households over a two-week period (8-22 June 2015) for compositional analysis. The methodology followed during this process was adapted from the Mexican regulation for waste characterisation in households (Diario Oficial de la Federación, 1992) and from UK guidance (WastesWork and AEA, 2010). Participants were provided with a waste bag to collect all the household waste generated during the assessment period, including waste that they may normally dispose of by uncontrolled burning. Waste samples for all 20 households were collected on the same day on two occasions per week (Tuesday and Friday) and were transferred to the nearby municipal dumpsite to complete the composition assessment. The samples were weighed on an electronic platform scale to determine the total mass of waste collected per household. Waste samples were initially processed by passing over a 10mm screen to separate the fine material fraction (<10 mm), which was collected and weighed. The main residual portion received preliminary manual sorting into major material categories including: plastics, metals, textiles, glass, paper and cardboard, food and garden waste. The samples were further sub-divided by hand-sorting into 25 separate waste category types, which are listed in Table 1 according to their combustible properties (Diario Oficial de la Federación, 1992), and the mass of each waste material type was measured.

Table 1 Major combustible and non-combustible waste categories

Combustible	Non combustible
Cardboard	Aluminium cans
Tetra pack	Glass
Garden waste	Metals and metallic cans
Nylon bags and plastic wrapping / packaging material	Construction waste
Rubber	Foil
Paper and paperboard	Fine residue
Disposable plastic items (plastic cups, plates, cutlery)	Food waste
Sanitary waste (nappies, toilet paper, sanitary towels, etc.)	
Textiles	
Wood	
Polystyrene	
Electrical appliances / electrical materials / cables	
Toxic waste	
Synthetic fibres	
Others (including cotton and leather)	
Polyethylene terephthalate (PET)	
High density polyethylene (HDPE)	
Hard plastic	

4.4 Interviews with key stakeholders in the waste sector

Information about the generation and management of waste in Huejutla was collected from face-to-face interviews arranged with principal stakeholders with central environmental service and quality responsibilities and those engaged in waste collection, recycling or disposal activities within the Municipality. The stakeholders interviewed and the information and resources provided are described in Table 2.

Table 2 Stakeholder interviews in Huejutla, Mexico

Stakeholder	Information/resources provided
Director of the Ecology Department in the Municipality of Huejutla	The Director of Ecology provided a letter approving the project by the Municipal Authority, to facilitate contact with private householders and other waste stakeholders and health authorities. The Ecology Department provided a vehicle for the waste collection and characterisation assessment. Contacts and access were provided to the Waste and Cleaning Services Manager and to the recycling centres operating in Huejutla.
Waste and Cleaning Services Manager in the Municipality of Huejutla	The Waste Manager provided information about the amount of waste collected from households and from commercial sites, waste collection routes and their frequency, the capacity and number of waste trucks, the number of waste truck drivers contracted by the municipality, and number of informal waste pickers working at the dumpsite. Information was also gathered on the waste management practices operating at the municipal dumpsite.
Waste truck drivers contracted by the Municipality	Waste truck drivers provided and confirmed information about waste collection routes and the amount of waste collected per day. Data was also collected on the types and amounts of waste separated informally by truck drivers and their assistants for sale to private recycling transfer businesses operating in the city of Huejutla.
Waste pickers at the dumpsite (informal workers)	Interviews with waste pickers confirmed the number of individuals picking waste at the municipal dumpsite, and provided information about the type and amount of waste recovered, the local market value, and contact details of the commercial recycling centres that purchase collected recyclable materials.
Managers at recycling collection centres	Interviews with recycling centre personnel provided information about the total amount and type of waste processed by each collection centre in Huejutla Municipality per month. The destinations of the recovered materials for final recycling were also obtained.
Independent waste collectors (recyclables)	Independent waste collectors provided information about the type and amount of material collected, the collection routes and the waste recycling centres that buy collected recyclables.

Table 3 Assumptions and calculations applied to estimate the waste material flow in the Municipality of Huejutla, Mexico

Waste component	Quantity (t day^{-1})	Explanation of calculation
Total waste generation	104	**Generation = Waste generated in households + Commercial waste** • **Waste generated in households** was calculated considering the amount of waste generated in households in urban, periurban and rural areas (from the characterisation analysis) and the population in each area: **Waste generated in households = Number of households in each area * mean waste generated by household type** • **Commercial waste:** This information was provided by the Municipal Authority.
Municipal waste collection	70	Information provided by the Municipal Authority. The amount of collected household waste was verified using the following calculation based on the survey and waste characterisation data: **Household waste collected = Waste generated in households – (burned waste + waste fed to animals + buried waste)** Together, the estimated amount of collected household and commercial waste was equivalent to 65.6 $tday^{-1}$ (data provided by the Municipal Authority).
Final Disposal	67.5	**Final disposal = Municipal waste collection – Recovery from recycling collection centres**
Recovery from recycling collection centres	2.5	Information obtained through interviews with managers at recycling centres.
Scavenging at dumpsites	1.2	Obtained through interviews with waste pickers at dumpsites.
Scavenging during collection	0.3	Obtained through interviews with municipal waste truck drivers and their assistants.
Private collection for recycling	1.0	Obtained through interviews with independent waste truck drivers and their assistants collecting recyclable materials.

Table 3 continued

Waste burned	21.2 - 23.4	**Waste burned = Households that burn waste * combustible waste * estimated burning frequency** • The proportion (%) of **households that burn waste** was obtained from the surveys in the different areas and was estimated as 22, 37,and 92 % of households in urban, periurban and rural areas, respectively. • The amount of **combustible waste** was estimated using information from the waste characterisation analysis. • The **burning frequency** in urban and periurban areas was adjusted in a sensitivity analysis to test the impact on the potential amount of waste burned. This was carried out by assuming the frequency of burning waste varied between one to three days per week, respectively, in urban and periurban areas, where waste collection services are provided once or twice per week. Rural households were assumed to burn waste daily, since they do not receive a waste collection service, or waste is collected infrequently at a rate of once per month or every three months. Waste collection services provided by the Municipal Authority to rural areas is generally only for bulky and non-compactable items and materials including furniture and glass.
Waste fed to animals	12.9	**Waste fed to animals = Households with animals fed with food waste * food waste** • The number of households with **animals fed with food waste** was calculated using the information from the survey. • **Food waste** was estimated from the waste characterisation analysis.
Waste buried	2.1	**Waste buried = Houses that bury waste * non-combustible waste** • Houses that bury waste were considered to be 60 % of the rural households: o 31 % of the rural population had no collection service and therefore buried all their non-combustible waste; o 29 % of rural households had a waste collection service, but also buried all their non-combustible waste because the frequency was once a month or less and general household waste was not collected (only bulky items such as tires, bed mattresses, etc.). • **Non-combustible waste** was estimated from the waste characterisation analysis.

5 Results and discussion

5.1 General description of waste management practices in the Municipality of Huejutla

The Waste and Cleaning Services Department of the Municipality operates a waste collection service (the frequency depending on the area served) and one main dumpsite, and all collected waste is disposed at this site. Burning at the municipal dumpsite ceased in 2013 and waste is currently consolidated by a mechanical compacting machine and covered with a layer of soil at intervals of 4-6 weeks. Consequently, the Municipal Authority does not consider it is responsible for burning waste in the municipality.

There are 9 trucks (5 compacter trucks, 1 mini compacter and 3 carrier trucks) and 14 drivers contracted by the Municipality to provide waste collection services. Truck drivers also undertake informal recycling activities. Other independent operators (approximately 15) provide a service for collection of recyclable materials (mainly metals from discarded furniture or appliances) and this activity is also mainly focussed on the more densely populated urban area. Independent waste collectors stated that it was not a common practice in the Municipality to sell recyclables such as PET and aluminium cans. There were 20 informal pickers licensed by the Municipality to collect waste at the dumpsite for recycling. Recyclable materials collected by these different groups were taken and sold to private recycling transfer centres and five such centres operate in the city that prepare, bale and transport recycled materials for reprocessing. However, there are no recyclate processing industries operating in the Municipality of Huejutla.

Information collected from interviews with stakeholders, household surveys, and the waste characterisation assessment was used to calculate, among other parameters, the amount of waste generated per capita per day, the percentages of households that burn waste, the frequency of the waste collection service and the combustible, non-combustible and food waste fraction in urban, periurban and rural households of Huejutla Municipality. The estimated amount of waste generated per capita was 0.80, 0.69 and 0.43 kg day^{-1} in urban, periurban and rural areas, respectively (Table 4). The survey results showed that the proportion of households burning waste decreased where regular and reliable collection services for general household waste were provided. In rural areas of Huejutla, 69 % of households had access to a waste collection service for bulky and non-compactable materials, such as bed mattresses or glass, but general household waste was not collected. As very limited or no collection services occurred in rural communities, approximately 91 – 95 % of the total waste generated in these areas was burned in open fires in Huejutla. Thus, the provision of a frequent and reliable waste collection service is a primary factor influencing the extent of burning combustible fractions of MSW in developing countries such as Mexico.

Burning of waste also occurred to a significant extent in areas served with frequent, twice-weekly collections (37 % of the households). A possible reason for the practice of burning waste continuing in these communities is that collections were introduced comparatively recently and have been operating for approximately three years whereas burning has been an accepted and familiar long-term disposal method. This suggests that other controls, incentives and education strategies are required to change behaviour. For example, households have no bins for waste collection, and without a facility to securely store waste between collections, burning may be undertaken as a more convenient or acceptable disposal method.

Table 4 Generation rate, general properties, collection and burning of household waste in different socioeconomic community types in Huejutla, Mexico

	Waste generated (kg capita^{-1} day^{-1})	Proportion of total waste burned (%)	Frequency of service	Combustible fraction (% FW)	Non-combustible fraction (% FW)	Food waste fraction (% FW)
Urban	0.80	22	Daily	66.4	1.2	32.4
Periurban	0.69	37	Once or twice per week	58.2	2.9	38.9
Rural*	0.43	92	31 % has no service 69 % once a month or less	71.6	3.8	24.5
Average	0.64	50	-	65.4	2.6	31.9

*Waste collection services provided by the Municipal Authority to rural areas is generally only for bulky and non-compactable items and materials including furniture and glass. FW; fresh weight.

Combustible material represented a significant fraction of the total waste generated (65.4 % on average) in Huejutla, and the survey indicated that approximately 25 % of the overall combustible waste was burned in the Municipality. Up to 25 % of the combustible waste was composed of nappies, toilet paper and sanitary towels (17.8 %), paper and card (3.9 %) and nylon bags and packaging (3.9 %). Combustible recyclable materials such as paper and cardboard (3.9 %), tetra packs (2.2 %), PET (2.0 %), HDPE (1.7 %), and non-combustible recyclables, including glass (1.2 %), aluminium (1.0 %) and metals (1.0 %) collectively represented almost 15 % of the total waste generated.

5.2 Household waste composition and statistical analysis

A further detailed breakdown and statistical analysis of the results from the waste characterisation analysis is shown in Table 5. No statistically significant effect ($P>0.05$) of community type (urban, periurban and rural) was detected by ANOVA on the number of occupants per house, or on garden, sanitary, metal, paper and card, or plastic waste generation. There was no statistically significant difference ($P>0.05$) between the waste generation or properties between urban and periurban households. However, the total amount of waste generated, and food, foil and polystyrene waste generation were significantly ($P<0.05$) larger in urban and periurban areas compared to rural households. One reason why food generation was lower in rural compared to urban/periurban areas maybe explained due to the increased feeding of food waste to domestic animals by rural households (see Table 6).

Table 5 Composition of solid waste disposed by households in Huejutla, Mexico (kg fresh weight day^{-1}, unless otherwise stated)

Parameter	Mean (+/- standard deviation)			*P*	LSD 1	LSD 2	ETA (%)
	Urban (n=5)	Periurban (n=5)	Rural (n=10)				
Number of occupants per house	5.80 (±1.48)	5.00 (±1.58)	5.00 (±1.63)	0.629	NS	NS	5
Waste generated per house	64.7 (±15.2)	48.3 (±21.8)	29.8 (±14.8)	0.005	27.5	31.7	47
Waste generated per capita	0.83 (±0.25)	0.79 (±0.63)	0.43 (±0.18)	0.088	0.58	0.67	25
Food waste	21.0 (±3.6)	18.8 (±6.2)	7.30 (±4.12)	<0.001	7.50	8.66	16
Garden waste	15.4 (±8.7)	5.85 (±4.58)	8.53 (±9.90)	0.221	NS	NS	69
Sanitary waste	11.5 (±11.7)	12.1 (±22.2)	3.62 (±2.09)	0.354	NS	NS	12
Metals	0.29 (±0.22)	0.57 (±0.44)	0.38 (±0.34)	0.418	NS	NS	10
Polystyrene	0.30 (±0.09)	0.29 (±0.10)	0.13 (±0.08)	0.002	0.14	0.17	51
Paper and card	2.77 (±2.30)	0.92 (±0.76)	1.55 (±1.63)	0.230	NS	NS	16
Plastic waste	0.90 (±0.58)	0.68 (±0.42)	0.43 (±0.38)	0.171	NS	NS	19
Foil	0.29 (±0.13)	0.30 (±0.10)	0.15 (±0.08)	0.015	0.16	0.18	39
Bags and packaging	2.34 (±1.00)	2.31 (±0.77)	1.04 (±0.25)	0.001	1.044	1.21	55

NS = not significant ($P>0.05$); LSD1 = Least significant difference ($P=0.05$) for comparing means with equal numbers of replicates (urban v periurban); LSD2 = Least significant difference ($P=0.05$) for comparing means with unequal replicates (urban or periurban v rural)

5.3 Waste flow analysis

The estimated rate of MSW generation in Huejutla Municipality was 104 t day^{-1}. Based on this research, the Municipal Authority manages 24.6 % of the total household waste generated in Huejutla, and the majority of the remainder (75.4 %) is disposed directly by households and a small fraction is recycled informally (Table 6). Sensitivity analysis indicated that 21-22 % of the total household waste generated in the Municipality was burned in open fires (Figure 6), approximately 12 % (equivalent to over one 30 % of the total food waste generated) was fed to animals and 2 % was buried. Currently, 2.4 % of the waste generated in the Municipality is recovered for recycling and transported to other locations for reprocessing since there are no facilities to support this industry in the region.

Table 6 Municipal solid waste generation and disposal in Huejutla (kg day^{-1})

Type of household	Population	Waste generated	Burned	Buried	Fed to animals	Household waste managed by Municipality	Commercial / schools / hospitals **	Waste recycled	TOTAL
Urban *	10,004	7,972	306	0	1,191	6,474			
Periurban*	30,011	20,687	1,756	0	4,972	13,958	40,000	2,500	
Rural	82,890	35,236	21,201	2,137	6,723	5,175			
Total	**122,905**	**63,894**	**23,263**	**2,137**	**12,887**	**25,607**	**40,000**	**2,500**	**103,894**
Percentages (%)		**61.5**	**22.4**	**2.1**	**12.4**	**24.6**	**38.5**	**2.4**	**100.0**

Notes
*Percentages of urban (25 % of metropolitan population) and periurban populations (75 % of metropolitan population) in the metropolitan area were estimated from information provided by the Municipal Authority
** Reported by the Municipal Authority

Information collected from the interviews with stakeholders, household surveys, and the waste characterisation study was integrated together to calculate a Material Flow Diagram (MFD) representing the different pathways for recycling and disposal of waste in the Municipality of Huejutla (see Figure 4). The assumptions and calculations applied to develop the MFD are presented in Table 3.

5.4 Waste per capita and recycling rates comparison for Huejutla and the rest of the world

Figure 5 and Figure 6 compare the per capita waste generation and the recycling rates estimated for Mexico (INECC, 2012) and Huejutla with the rest of the world, divided into regions as suggested by the World Bank (Hoornweg and Bhada-Tata, 2012). Mexico generates more waste per capita than the African and South Asian countries; however, it generates less per capita waste than other regions of the world. The amount of waste per capita generated in Huejutla is similar to the rates found in the African continent. The results of waste generation per capita obtained through this research for Huejutla were consistent with a similar evaluation of household waste generation in Atlapexco, a neighbouring municipality (SanJuan-Marquez and Méndez-Pacheco, 2014). As shown in Figure 6, INECC (2012) has estimated a relatively high recycling rate for Mexico overall, equivalent to 9.6 %, which is smaller compared to OECD countries and East Asia and Pacific regions. However, the local recycling rate determined for Huejutla, equivalent to 2.4 %, was much smaller than the national average for Mexico, and is smaller also compared to those found on average in other regions of the world.

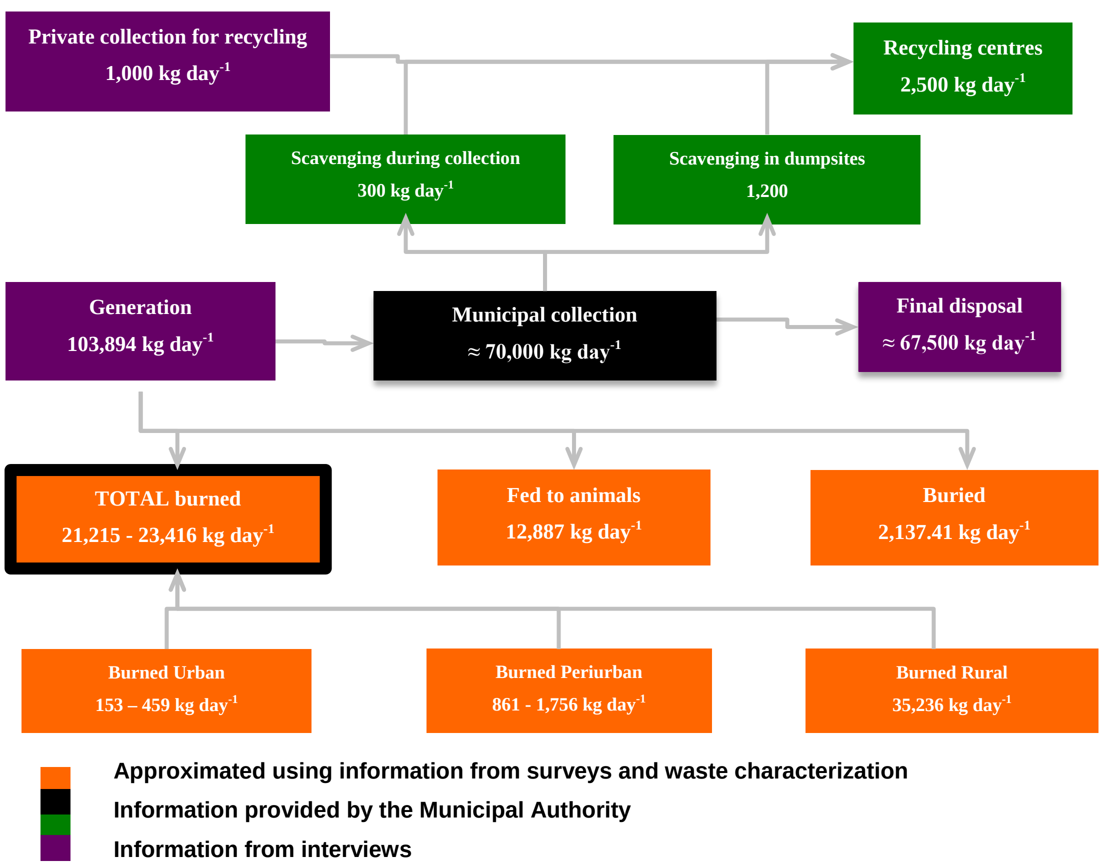

Figure 4 Waste flow diagram for Huejutla, Hidalgo, México (% of total waste generated and kg day^{-1})

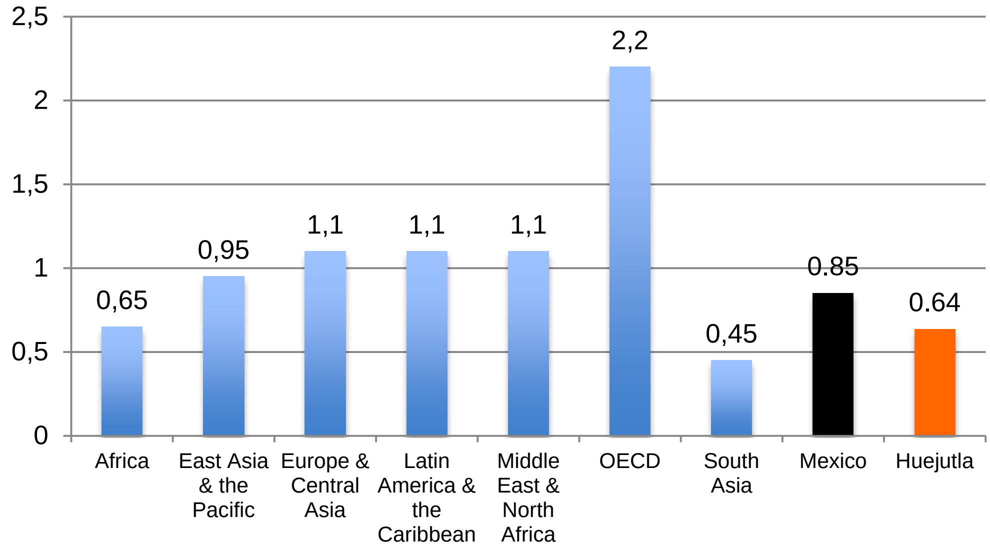

Figure 5 Waste generation per capita (kg day^{-1}) (Hoornweg and Bhada-Tata, 2012) (INECC, 2012)

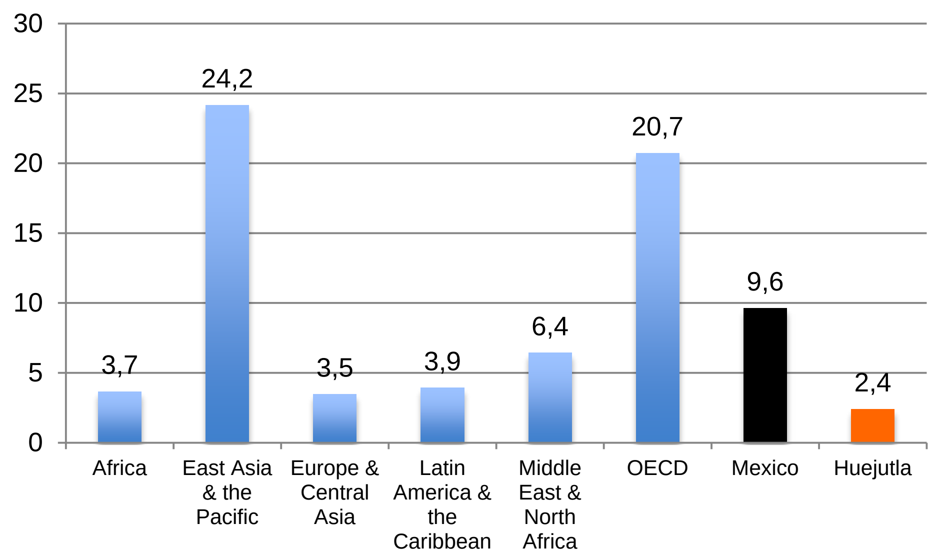

Figure 6 International recycling rates (%) in different regions of the world and Mexico compared to the Municipality of Huejutla (Hoornweg and Bhada-Tata, 2012) (INECC, 2012)

6 Conclusions

Few field measurements are available to quantify the extent of burning waste activity. Therefore the results reported here provide an important contribution to building the evidence based on uncontrolled open burning of waste and, in combination with an appropriate emission factor (EF), this information can be applied to estimate the extent and significance of BC emissions in relation to climate change mitigation from this practice. Future research is planned to conduct further field data gathering exercises on burning waste in another representative region of Mexico and, controlled laboratory experiments will be carried out to develop an EF that is representative of the waste and combustion conditions where open burning of MSW by households within a developing country context is commonly practiced.

Rural and urban/periurban areas on Huejutla Municipality receive different levels of MSW collection service and this is a primary factor controlling the extent of open burning of waste in households. Rural areas, which have numerically the largest overall population compared to the urban city districts have relatively poor or no collection service and therefore burn the majority of combustible waste compared to urban households. Consequently, 91 % of the waste disposed by open burning occurs in rural communities and this represents 22 % of the total MSW generated in Huejutla. Nevertheless, burning is also observed in urban and periurban areas where frequent waste collection is conducted, albeit to a much smaller degree, equivalent to 2 % of the total waste generation, compared to rural areas.

This research has found that households located in areas with access to a reliable waste collection service are less likely to burn waste as a disposal method. Calculating and valuing the health benefits from controlling BC emissions by reducing the open burning of waste is hampered by a lack of quantitative information. However, the available studies undertaking more general assessments of BC emission reductions suggest that mitigating this emission source would have substantial benefits for global public health, potentially avoiding millions of premature deaths each year due to poor air quality and associated respiratory disease (US EPA, 2012). Therefore, reducing the burden of health care potentially associated with open burning of waste in developing countries could justify investment in providing greater access to more effective waste collection services and particularly to rural communities where uncontrolled burning of waste is widely practiced.

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