Waste Management 123 (2021) 15–22

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Urban Municipal Solid Waste management: Modeling air pollution scenarios and health impacts in the case of Accra, Ghana

Gina Kanhai [a,*], Julius N. Fobil [b], Betty A. Nartey [b], Joseph V. Spadaro [c], Pierpaolo Mudu [d]

[a] Institute for Systems Science, Innovation and Sustainability Science, Karl-Franzens University of Graz, Graz, Austria
[b] Department of Biological, Environmental & Occupational Health Sciences (BEOHS), University of Ghana School of Public Health, University of Ghana, Ghana
[c] Spadaro Environmental Research Consultants (SERC), Philadelphia, PA, USA
[d] World Health Organization (WHO), Public Health, Environmental and Social Determinants of Health (PHE), Geneva, Switzerland

ARTICLE INFO

Article history:
Received 19 August 2020
Revised 14 December 2020
Accepted 5 January 2021
Available online 3 February 2021

Keywords:
Solid waste management
Landfills
Waste burning
Air pollution
Short-lived climate pollutants
Health
Accra
SWEET tool
AirQ+

ABSTRACT

Despite the clear link between air pollution and health, research to investigate the relationship between municipal solid waste management and air pollution and health has not been prioritized. Such research may generate scientific information that would help reduce population exposure to air pollutants. This paper examines the case study of Accra in Ghana, a city dealing with serious waste management problems. The paper proposes a methodology to estimate the impact of waste management on urban air pollution and health. The analysis is described in the following four steps: (1) collecting data on the waste sector; (2) modeling the emissions arising from waste management; (3) transforming emissions to concentration values and (4) estimating the burdens on health. The assessment has been conducted using the CCAC SWEET tool and WHO AirQ+. The method presented can be used in different locations, depending on data availability, when analyzing the impact of and potential changes to waste sector policies. The results of this health impact assessment indicate that, based on the emissions of $PM_{2.5}$ from the waste sector in Accra, a change from the business-as-usual to more sustainable options would reduce air pollutants emissions and avert 120 premature deaths in 2030. Levels of air pollution in Accra are significant and interventions to reduce $PM_{2.5}$ exposure should be promoted. The detailed analysis of the current situation provides suggestions for waste management policies in terms of impacts on health and ideas to reconsider the waste policies in Accra.

1. Introduction

Studies on the connection between sound waste management and health have identified a number of potential risks linked to waste management activities (Ziraba et al., 2016). Improper waste management can lead to the contamination of soil and water, thereby spreading microbial agents, cholera, malaria (Dzotsi et al., 2016; Songsore, 2017) and other vector transmitted diseases (Dhar-Chowdhury et al., 2015). Indiscriminate dumping of waste and uncontrolled waste burning have been associated with significant health hazards (Dionisio et al., 2010; Modak, 2011). There is increasing evidence from local studies (Amegah et al., 2012; Munyai & Nunu, 2020) and literature reviews that proximity to untreated waste is associated with congenital anomalies, low birth weight, respiratory diseases and an increased risk of cancer (Mattiello et al., 2013; Ncube et al., 2017). The uncontrolled processing of waste, for example its burning, is associated with air pollution (Wiedinmyer et al., 2014), critical pollutants such as particulate matter, as well as the production of heavy metals and volatile organic compounds (Das et al., 2018; Giusti, 2009; Song & Li, 2014; Wang et al., 2017), which contribute to adverse health outcomes in terms of mortality and morbidity (International Agency for Research on Cancer, 2015; Thurston et al., 2017; WHO, 2016).

Africa is a continent where the challenges associated with waste management are already high and expected to worsen significantly, due to its large population growth and the associated risk of inadequate waste collection and treatment capacity. Accra, the capital of the West African country Ghana, has been selected

Abbreviations: AMA, Accra Metropolitan Area; BAU, business-as-usual; CO_2e, CO_2 equivalent; EPA, Environmental protection agency; GHG, greenhouse gases; HIA, health impact assessment; MSW, municipal solid waste; MSWM, municipal solid waste management; PM, particulate matter; SWEET, Solid Waste Emissions Estimation Tool; SWM, solid waste management; WHO, World Health Organization.

* Corresponding author.
E-mail address: gina.kanhai@gmail.com (G. Kanhai).

https://doi.org/10.1016/j.wasman.2021.01.005
0956-053X/© 2021 Published by Elsevier Ltd.

as a case study due to data availability and several analyses that provide an articulated background for our study. Data from the Ghana Health Service 2010 show that 60% of the most frequent diseases in the country were related to insufficient environmental sanitation. Several studies demonstrate waste management to be a limiting factor of population health in Ghana (Boadi & Kuitunen, 2005; Miezah et al., 2015; Oteng-Ababio et al., 2017; Owusu-Sekyere et al., 2015). Accra is a city dealing with serious health challenges, the most notable being two recent cholera epidemics (Dzotsi et al., 2016), and pollution problems related to the ineffective management of the large quantities of generated solid waste and imported e-waste (Anaman & Nyadzi, 2015; Oduro-Appiah et al., 2017; Oteng-Ababio & Grant, 2019; Oteng-Ababio et al., 2013; Wittsiepe et al., 2015). Further studies demonstrate that waste management is a significant contributor to climate change, which also leads to significant long-term population health impacts through the release of greenhouse gas (GHGs) and short-lived climate pollutants (EPA-Ghana, 2019; Hoornweg & Bhada-Tata, 2012; Premakumara et al., 2018). The waste sector contributed 14% of Ghana's total greenhouse gas emissions in 2010 (UNFCCC, 2015). The population of Accra is exposed to high levels of air pollution. During 2014–2015, the EPA-Ghana measured annual mean $PM_{2.5}$ and PM_{10} levels in residential areas of 78 and 81 μg/m3 respectively, which greatly exceed the WHO recommended guidance-level of 10 and 20 μg/m3. These high levels of PM are related to the emissions from heavy traffic, industry, Harmattan winds, road and wind-blown dust, and open burning of waste. According to Apte et al., 2018 reducing $PM_{2.5}$ to meet the WHO recommendations is equivalent to the global health benefit of eradicating lung and breast cancer which numbered 2.4 million deaths in 2018, a figure that is equivalent to a 60% reduction in the number of air pollution deaths.

According to the 2010 Ghana census, Accra had a population of 1,848,614, while the country's total population was 24,658,823 (Ghana Statistical Service, 2012). In Accra, the development of waste management infrastructure has not kept pace with population growth and the corresponding increase in waste generation. The political turmoil and coups in the 1980s have greatly impacted the current state of waste management. In response, in 1985, the waste management department of the Accra Metropolitan Area (AMA) was established to ensure proper waste collection and treatment (Oteng-Ababio, 2010). During the waste sector privatization in 1999, the Canadian company 'City and Country Waste' was given a monopoly. When the company failed to deliver the expected results, private waste service providers emerged, and now provide 80% of waste-related services in Accra. Informal waste collection, e.g. waste collection on tricycles, is a response to the perceived inefficiencies in privatized waste management (Asibey et al., 2019; Oteng-Ababio, 2011), but cannot provide collection services for all parts of the city (Anaman & Nyadzi, 2015). More than 65% of AMA's revenue is spent on waste collection and treatment and maintaining the landfill site in Tema (UNEP DTIE, 2009). Nevertheless, only 55% of the waste generated is collected formally (Oduro-Appiah et al., 2017), a rate that lags behind typical collection rates observed in low and middle income countries (Oduro-Appiah et al., 2017; Wilson et al., 2015). Waste is mainly sent to the 13 landfills and dumpsites in the proximity of Accra. The majority of Ghana's landfill sites are dumps with limited or no mechanical operations (Kusi et al., 2016). Accra produced approximately 2200 tons of solid waste daily in 2014, and projections based on per capita generation rate and population growth rate indicate that this is expected to double (4419 tons) by 2030 (Oteng-Ababio, 2014). The coronavirus pandemic in 2020 has predictably shifted waste generation away from traditional industrial and commercial sources to the household sector. It is unclear, however, if this temporary trend will have long-term consequences beyond 2020 (IFC-WB, 2020). Low-income settlements, of which there are a large number as in Ghana about 50% of the urban population is estimated to live below the poverty line of one US dollar a day (UN-Habitat, 2015), are usually the last to be serviced or, worse, are neglected altogether (Coffey & Coad, 2010). According to latest census data, only 65.4% of households in the greater Accra region have their solid waste collected, while 17.4% of households dispose through public dumping. Nearly one in seven (14.6%) households burns all of their waste (Ghana Statistical Service, 2019, p. 158). In 2016, the total waste openly burned was 348,000 tons, a figure that includes household refuse, industrial, hazardous, waste oil and clinical waste (EPA-Ghana, 2019, p. 268).

Policy interventions are relevant as they can in turn yield health co-benefits through improvement of air quality. Adequate waste management policies need to consider the impact of air pollution on human health. The aim of our study is to estimate the levels of emissions of $PM_{2.5}$ associated with current urban waste management practice, and to assess the health consequences of these emissions using simple methodologies and publicly available rapid assessment software. We developed alternative near-term scenarios (2030) and assessed the health gains of the interventions compared to a business-as-usual development scenario. We also calculated CO_2 equivalent (CO_2e) emissions using the Excel-based Solid Waste Emissions Estimation Tool (SWEET) and provide data for further studies on climate forcing emissions in Accra. SWEET has been applied in academic research with a focus on estimating the current emissions of a specific waste treatment technology (Mettetal et al., 2019; Yapo et al., 2018). Although a few studies have considered certain stages of waste processing (Das et al., 2018; Nie et al., 2018; Schlosser et al., 2020; Yang et al., 2020), and others the municipal solid waste management (MSWM) lifecycle (Liu et al., 2017; Premakumara et al., 2018); to the best of our knowledge, a study similar to ours on health impact assessment has not been undertaken before in Africa. The general approach in other studies on the waste management impact assessment is either based on life-cycle assessment, or scenario analysis (Allesch & Brunner, 2014). For air pollution emissions, analyses are generally carried out using source apportionment methods or modeling air quality concentrations (Amann et al., 2017).

2. Methods

This section consists of two parts; the first describing the scenario development and the second describing the health impact methodology. For both of these parts we also present the tools utilized to produce MSWM air pollution estimates (SWEET tool) and the related premature population mortality (AirQ+). Both SWEET and AirQ+ are freely available for download (CCAC, 2019; WHO, 2020).

2.1. Development of waste treatment scenarios

In the following paragraphs an overview of the scenarios and scenario development criteria, as well as the data collection process and the SWEET tool is discussed.

Two alternative waste management scenarios were developed and compared against a business-as-usual scenario running to 2030. The scenarios were informed by existing sector policy interventions, and are built in accordance with the Phase Model of Waste Management Development by Klampf-Pernold et al. (2010). Year 2030 was selected to provide input to the Sustainable Development Goals. All scenarios fulfill five criteria: plausibility, internal consistency, comprehensibility and traceability, distinctness, and transparency (Amer et al., 2013; Durance & Godet, 2010; Kosow & Gaßner, 2008).

Under the business-as-usual (BAU) scenario, a steady 2% increase per year in waste collection capacity is assumed relative to year 2020, thereby balancing the expected population growth while maintaining current waste collection, treatment and disposal technology and capacity stable. This is the best outlook one could hope for given past difficulties in coping with waste output in the city (Zainabu, 2014). Without political support no major waste management improvements in technology or processing capacity are expected. We assume the daily waste generation rate to be stable between 2020 and 2030 at the rate of 0.74 kg/person/day (Miezah et al., 2015).

Scenario 1 or 'cease open burning' refers to households and the informal sector ceasing open burning starting in 2021 using a two-step graduated approach. The first reduction of uncollected waste burned would take place in 2021 (reducing from 10–5% outside and 50–35% inside formal collection zones) and the second in 2025 (no waste burning inside or outside formal collection zones). We chose this approach to allow for an initial moratorium on the burning of waste, which is then followed in 2025 by increased enforcement that leads to shifts in population behavior. No other factors of the waste system are changed, and waste collection rates, waste treatment technology and capacity are assumed the same as in the BAU scenario.

Scenario 2 assumes 'increased composting and recycling'. Starting in 2023, the composting capacity is doubled to 60,000 metric tons, and recycling capacity is increased by 60% to about 54,000 metric tons. No additional changes compared to the BAU scenario are made. This scenario reflects the population preference of recycling and composting instead of improving final disposal (Kanhai et al., 2019).

Local data on waste management were collected. Desktop research, expert interviews and site visits were conducted with the aim to identify the technology employed and capacity of waste management collection and treatment service providers in Accra. Interviews were conducted at the Accra Metropolitan Assembly and at the following companies: Accra Composting & Recycling Plant, Zoomlion Ghana Limited, Sewerage Systems Ghana Limited, Tema Landfill and Zoompark Teshie transfer station, J. Stanley Owusu and Co Limited, Metropolitan Waste and Allied Services, Meskworld Co Limited, Tropical Waste Limited and Jekora Ventures Limited.

To quantify the air pollution generated in the different scenarios we utilized SWEET (version 3), which was developed by the U.S. EPA on behalf of the Climate and Clean Air Coalition MSW Initiative (CCAC, 2019). The SWEET tool conducts a rapid assessment of GHGs and short-lived climate pollutants by employing a life-cycle assessment extending from waste collection and transportation, waste processing and treatment to final disposal. This paper reports on the modeled emissions of $PM_{2.5}$ and CO_2 equivalent (CO_2e).

2.2. Health impact assessment

The health impact assessment (HIA) of air pollution follows the standard quantification protocol discussed in (WHO, 2016). In our study, we used the Robust Uniform World Model (Rabl et al., 2014) for estimating exposure changes relative to the current $PM_{2.5}$ air pollution level in Accra (49.5 μg/m3). For the dilution rate, we used the Accra-specific estimate proposed in Apte et al. (2012). Concentration changes, in turn, were converted into excess deaths by applying the $PM_{2.5}$ concentration-response function in AirQ+ and assuming a baseline mortality rate of 0.55% in the relevant population at risk, i.e., persons aged 25 years and older (Ghana Statistical Service, 2012). The projected population in Accra in 2030 is 2.913 million, of which 50% are assumed older than 25 years. Our study's focus is on inhalation exposure to ambient air pollution from waste management activities of the entire population of Accra. Further method and input data details may be found in the supplementary material.

3. Results

In the following sections an overview of the results of the different scenarios is presented.

3.1. Emission results

The largest contributor to climate forcing is from waste burning (Fig. 1). In addition to households, waste is burned by the informal sector during waste collection or while separating recyclables at landfills.

Table 1 summarizes the CO_2e emissions for the baseline and alternative scenarios. Beginning in year 2025, the aggregate CO_2e emissions for Scenario 1 are half as large as those projected for the baseline scenario, while Scenario 2 emissions are only marginally better than the BAU.

Fig. 2 shows the temporal trend of the $PM_{2.5}$ emission for the baseline and the two alternative scenarios. For the cease open burning scenario, the graph shows the two step reduction in PM emissions, with the first reduction taking place in 2021 and the second reduction in 2025. Thereafter, the $PM_{2.5}$ levels steadily increase due to emissions from other parts of the waste stream, e.g. fossil fuel burning of waste collection. In 2030, the $PM_{2.5}$ emission would increase 26% relative to 2020 in the BAU scenario, whereas after 2025 Scenario 1 emissions would be lower by at least an order of magnitude compared to BAU. The change is primarily linked to reduced emissions from waste burning at formal collection centers. In 2030, $PM_{2.5}$ emissions would be 94% lower than BAU. For Scenario 2, emissions are marginally worse than BAU because of the increased demand for transportation of composted and recycled waste.

3.2. Health impact analysis

Table 2 shows the contribution to the $PM_{2.5}$ air pollution in Accra from waste management in year 2030. Source apportionment indicates that current waste handling contributes around 5.3% to the background $PM_{2.5}$ air concentration. Under the BAU scenario, waste-related activities would contribute 3.25 μg/m3 to the background $PM_{2.5}$ air concentration in 2030 (up from 2.6 μg/m3 in 2020, see supplementary material). This is equivalent to 6.5% of the total concentration in that year. For Scenario 1, on the other hand, the waste contribution would decrease significantly to 0.19 from 3.25 μg/m3, representing a source contribution of only 0.41% to the total $PM_{2.5}$ air concentration. This has implications for the health impacts of air pollution.

The results of the HIA for Accra are presented in Table 2. As can be observed, important health gains in the context of reduced mortality may be achieved. In particular, a reduction of 120 premature deaths in 2030 compared to the BAU projected mortality may be achieved under Scenario 1 (cease open burning).

4. Discussion

First, the emissions scenarios and the related HIA are discussed. Thereafter, some recommendations for the waste sector in Accra, as well as insights into the limitations and indications for further research are provided.

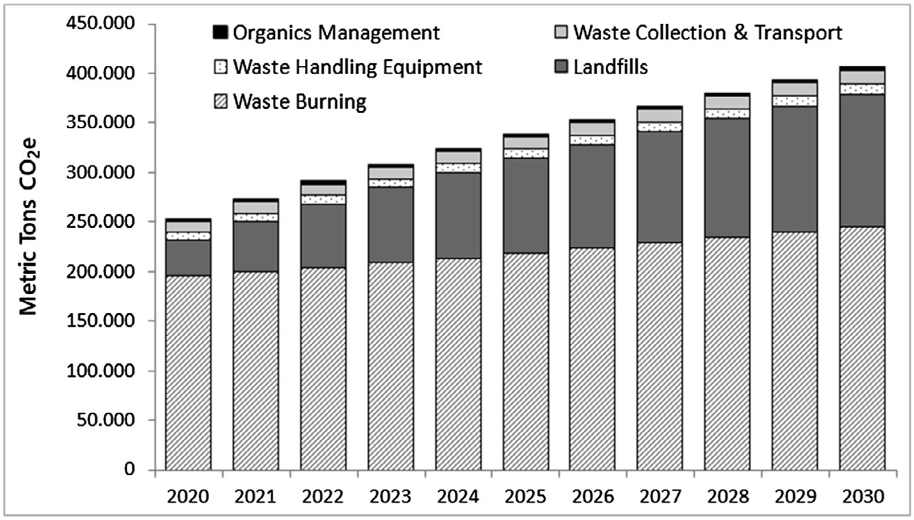

Fig. 1. Business-as-usual sector-specific emissions in metric tons of CO_2e from 2020 to 2030

Table 1
Total emissions in metric tons of CO_2e.

Year	BAU	Scenario 1 Cease open burning	Scenario 2 Increase composting & recycling
2020	253,109	253,109	253,109
2021	272,923	232,440	232,440
2022	291,170	249,755	249,755
2023	308,126	265,759	315,101
2024	324,024	280,682	326,209
2025	339,061	146,380	337,106
2026	353,403	156,291	347,851
2027	367,191	165,545	358,493
2028	380,544	174.261	369,078
2029	393,564	182,536	379,642
2030	406,337	190,455	390,220

4.1. Emissions scenarios

In order to implement Scenario 1 (cease open burning), incentives targeting behavioral change of households and the informal waste sector, as well as alternate means for waste disposal are needed. Strong political leadership and awareness campaigns informing citizens about the adverse health risks associated with improper waste management, including uncontrolled waste burning could be a first step. In parallel, waste collection capacity in Accra needs to be substantially increased. Currently, formal waste collection services are privatized. Privatization can improve efficiency and lower operating costs, but fails in most developing countries, including Ghana, due to weak governance, limited political will and moderate capacity in both the private and public sectors, as well as rigid financing and budgeting systems (Oduro-Appiah et al., 2019). Privatization can also lead to displacement of the poor and thereby to significant increases of the social costs of inequality and poverty in cities (Millington & Lawhon, 2018). While the contribution of formal service providers to waste collection coverage has dropped from 60% in 2011 to 55% in 2016, informal sector providers have contributed to an overall collection coverage of 75% by 2016, and currently informal waste collection shows significant growth (Oduro-Appiah et al., 2017). In some low-income areas of Accra waste is collected on foot by the informal sector, due to high population density and narrow and uneven roads (Kanhai et al., 2019). It is therefore unlikely that formal sector collection can provide adequate service in these areas. Results from a survey done in Accra suggest that the informal sector collects waste more reliably than the formal sector (Kanhai et al., 2019), therefore integrating the informal sector into formal collection services could increase the reliability of waste collection.

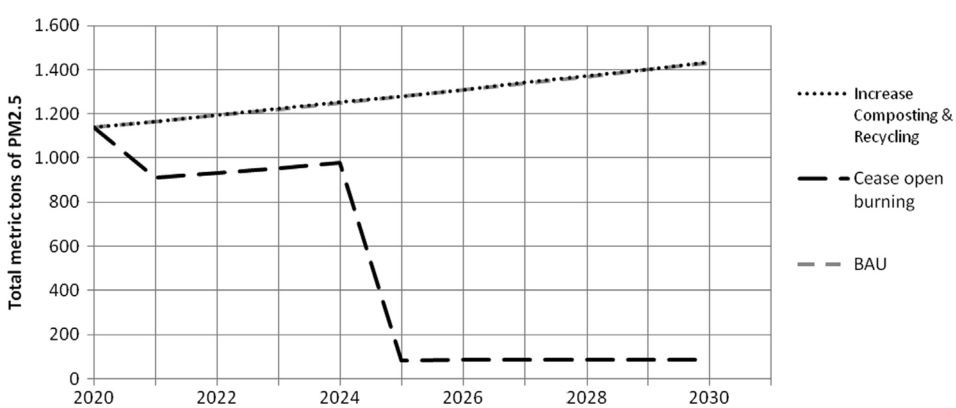

Fig. 2. Scenario comparison of $PM_{2.5}$ emissions over time (overlapping BAU & increase composting and recycling)

Table 2
Modeled results on the contribution of waste-related emissions to background $PM_{2.5}$ concentration (μg/m3) in Accra for various scenarios in 2030.

	Emissions (metric tons/year)	$PM_{2.5}$ Concentration (μg/m3)	Premature deaths (95% CI)
BAU	1432	3.25	127 (90–157)
Cease open burning	86	0.19	7 (5–9)
Increase Composting & Recycling	1435	3.25	128 (90–157)

CI: confidence interval considering only the health risk factor uncertainty

Aparcana (2017) provides an overview of approaches for informal sector integration, ranging from a mapping of the informal waste collection sector to research on incentivizing informal sector workers to collaborate with the formal waste sector. This process could be applied to Accra in order to reduce indiscriminate dumping and burning of collected waste by the informal sector. Nevertheless, these measures require public policy support that leads to grassroots development, is humane, as well as makes social, economic, and environmental sense (Medina, 2010). A challenge faced when increasing the capacity of waste collection in Accra is financing. The Accra Metropolitan Assembly is currently spending more than 65% of its budget on waste management (UNEP DTIE, 2009). Hence, implementing a high level of waste collection bears some challenges in terms of the needed investment. Increasing household payment is unlikely in developing countries due to the large percentage of low-income households (Marshall & Farahbakhsh, 2013).

It is worthwhile noting that the emissions for the cease waste burning scenario are underestimated in the case in which household waste generation increases more than waste collection and treatment capacity. Accra Composting & Recycling Plant was closed three times between 2012 and early 2014, due to three main challenges: high plant operation costs due to unsegregated waste, a lack of funding from the government and power instability due to Ghana's energy crises (Owusu-Sekyere et al., 2015). These challenges still apply in Accra; therefore, an underestimation is possible due to unforeseen waste treatment plant closures.

The main challenge in implementing Scenario 2 (increased composting and recycling) is that both composting and recycling rely on well-functioning collection logistics, including separate waste collection and manual sorting in order to obtain high efficiencies. Separate collection logistics do not yet exist in Accra, and manual sorting is not widely implemented. Therefore, increasing these more advanced waste treatment technologies leads to both logistical and economic challenges. A study on how to set priorities for waste management strategies in developing countries suggests that applying advanced technology is not economically sensible in regions spending large proportions of their budget on waste management; instead a focus should be placed on the improvement of disposal systems (Brunner & Fellner, 2007). If recycling and composting is to be increased, further research and new business models would be needed in order to ensure efficiency. A study in Kumasi (Ghana) on the economic potential of plastic waste collection and recycling concluded that recycling is a profitable venture (Owusu-Sekyere et al., 2013). Decentralized composting might be a viable option for garden waste in high-income areas in Accra (Kanhai et al., 2019). Technologies such as vermicomposting or biogas production might be viable options to conventional composting (Komakech et al., 2016; Mwirigi et al., 2014).

The comparison of the BAU and the two scenarios is based on the likelihood of scenario implementation in Accra, the alignment of the scenarios to the Phase Model of Waste Management Development, and the emissions generated. Based on these criteria the cease open burning scenario is the scenario suggested for implementation. While it could be achieved by 2030, it will be a stretch for the implementers due to the need to significantly increase collection capacity through the potential integration of formal and informal sectors, and the need to improve regulatory enforcement. This scenario has the lowest overall climate forcing effect as well as the lowest $PM_{2.5}$ emissions. While there is significant interest in Scenario 2 (increasing composting and recycling), due to the public falsely seeing it as the cleanest waste treatment option (Kanhai et al., 2019), it needs large investments in terms of capital, skilled labor, planning capacity and mindset change and education regarding waste separation. The BAU scenario can be achieved with only limited effort by keeping treatment and collection capacities stable, but has higher environmental impact and health risks in comparison to the cease open burning scenario.

4.2. Health impact assessment

The estimate of premature deaths in 2030 for the cease open burning scenario indicates a 94% reduction in the $PM_{2.5}$ health burden compared to the number of deaths projected under BAU. In other words, in 2030, 120 premature deaths could be postponed. The annual impact increases thereafter since the $PM_{2.5}$ emissions of the BAU keep growing, while the cease open burning scenario emissions have flattened out (compare Figure 2). The health assessment carried out offers the opportunity to consider estimates related to specific interventions and policies that could be implemented in the case of Accra. These interventions must be framed within the context of local conditions. The concentrations indicated in Table 2 reflect the urban background, and would certainly underestimate the direct exposure experienced by individuals who are living in the proximity of the waste that is burnt, or occupational hazards. Since the population awareness in Accra of the adverse health risks related to waste management, and in particular contaminant exposure from waste burning, is low, it is unlikely that households that burn their waste are going to take any serious precautions (e.g. by closing windows) to lower their exposure. The health risks are expected to be highest for informal sector workers who burn waste in order to retrieve components for recycling or to dispose of the waste collected from households. The majority of these informal workers likely live in low-income areas. Inhabitants of households burning waste are exposed to the next highest health risk. Burning waste is most common in high- and middle-income areas (Kanhai et al., 2019). All other factors being equal, the high-income population is likely to have lower exposure levels than the middle-income, because their house plots are larger, and, therefore, the distance to source is greater. Educational measures on the connection between waste and health could lead to a reduction of exposure, as finances are not the main limiting factor in the case of high-income households. As demonstrated the equity issues of socioeconomic disparity and occupational hazard exacerbate health risks. Better waste management is needed to improve societal equity.

4.3. Limitations

The main limitation of this study is the limited amount of data available on waste management in Accra. It is difficult to get data related to specific years. Many data are obtained through surveys and/or published reports generated to provide information on issues other than waste. For example, official statistical surveys do not provide information on whether the waste is collected by the formal or informal sector. This is a challenge as part of the waste that is collected by the informal sector is also burned in order to dispose of it. For these reasons, it is worth presuming that the waste burning rate of households is likely higher than 14.6% indicated by the census data (Kanhai et al., 2019). Other local studies show burning rates of 18% (Thompson, 2010) and 19.2% (Adzawla et al., 2019) in 2010, and 11% in 2015 of respondents only burning waste, with an additional 50% of respondents either burning or dumping at least some of their solid wastes (Anaman & Nyadzi, 2015).

While the SWEET tool is an easy to use software to calculate emissions from waste, some of the input assumptions, especially those regarding waste burning, should be further explored. Emissions from uncollected waste are only estimated in the SWEET calculations when this waste is openly burned, while if waste is illegally dumped and left to biodegrade, these emissions are not considered. Consequently, the emissions and related health impacts of all of the scenarios are conservative lower bound estimates. While the waste transport contribution to emissions is small, it should be noted that the data are based on US conditions, and therefore likely underestimated as Ghana has less regulation on fuel content and regulations on emissions from mobile sources. We have used the emission factors and default values provided by SWEET which are based on the IPCC (2014), but the use of local data, whenever available, should take priority. We do not provide a breakdown of CO_2e emissions by gas or provide a discussion on climate change mitigation, although we do recommend that further research address this.

The HIA has some limitations due to the approximated figures for total mortality and the lack of data for cause-specific mortality, which would have potentially provided more precise information for public health interventions. Nevertheless, our estimates can provide an idea of the relevance of the health impacts of the emissions generated by the waste system. A comprehensive HIA looking at a range of health risks, not limited to $PM_{2.5}$ is needed for a clear understanding of the health risks from waste management. The additional burdens and impacts (mortality and morbidity) of MSW should consider other pollutants, such as SO_2, NO_X and heavy metals. Further research could also identify different levels of exposure to $PM_{2.5}$ within the population of Accra and provide recommendations on lowering exposure by population group.

4.4. Policy suggestions

Given the previous analysis, though theoretical, there are some implications that can be considered in order to frame the possible scenarios for the SWM in Accra. The SWM sector in Ghana faces numerous problems due to implementation conflicts in current institutional arrangements as well as weaknesses in existing laws. Table 3 depicts an overview of identified issues as well as policy suggestions to tackle these challenges and enable alternate scenarios implementation. The majority of the challenges and suggestions are related to good governance. Prerequisites of good governance in SWM are accountability, transparency, efficiency, and effective institutions. The quality of SWM governance is strongly connected to the overall national governance structures. An effective legal and regulatory framework must be in place that clearly defines the roles and responsibilities of various stakeholders as well as procedures required to implement laws governing the management of solid waste.

In waste management the rapid changes due to national policies and local circumstances require a new generation of tools to facilitate decision-making. SWEET has demonstrated value when defining a framework for the rapid assessment of solid waste scenarios.

Table 3
Challenges of MSWM and suggestions for improvement.

Current challenges of MSWM	Suggestion
Legal provisions on waste management and environmental protection are scattered in various policy and institutional documents and are often weak and/or outdated.	• Invest in good governance • Build capacity on how to develop and implement context-specific strong policies • Develop policies for mainstreaming alternative uses of solid waste through appropriate incentives, for regulating urban land-use and land ownership. • Clear legal provisions regarding waste burning are needed.
Lack of monitoring and enforcement of environmental laws. Lack of political will and commitment to address solid waste sector problems.	• Invest in enforcement and measures counteracting corruption by utilizing already existing institutions in order to be able to enforce the implementation of the scenarios. Public policy research institutions, such as the Institute of Economic Affairs, aim to fight political corruption (IEA Ghana, 2017; Oduro-Appiah et al., 2017). • Develop monitoring systems for indiscriminate waste dumping and waste burning. • Provide transparency on sanctions for non-compliant service provision of waste collection providers.
Lack of coordination of actors leading to program duplication.	Provide clarity on roles & responsibilities as well as regulations that provide incentives for the harmonization of multiple activities.
Insufficient technically skilled personnel to analyze, plan and implement effective solid waste management. A poor maintenance culture leads to a frequent breakdown of SWM equipment.	• Invest in capacity building, potentially on basis of collaborations, e.g. city partnerships with and participation in international waste networks. Potential formats include workshops, webinars, and access to online resources, such as free expert advisory services. • Build capacity on appropriate technology investments. Frequent breakdowns of equipment, such as trucks, due to the road inaccessibility during raining seasons or the missing clarity about waste composition, suggest inappropriate technology investment (Kusi et al., 2016).
Lack of cooperation and participation of the general public in environmental management.	Good governance, including public participation. • Provide transparency (financials, aims, priorities, challenges of SWM) • Implement public education measures on the health risks of uncollected or burned waste
Lack of reliable waste data, leading to challenges in monitoring inhibit good policy-making.	Literature provides many suggestions on collecting essential data in developing countries, which would enable informed decision-making (Asase et al., 2009; UN-Habitat, 2010; Oteng-Ababio et al., 2013) and improve the ability to build scenarios with tools such as SWEET.
Insufficient financial funding of the SWM sector and fund mismanagement	Build knowledge on how to raise funds and effectively plan budgets and development measures (GIZ, 2017 a)
Limited city infrastructure and planning, leading to inaccessible roads for waste collection trucks.	• Improve the road network, especially in middle income areas (Kanhai et al., 2019) • Informal sector integration for waste collection, especially where road network is limited

5. Conclusion

In this paper we have calculated the health impacts attributed by fine particulate matter air emissions originating from solid waste management activities in the city of Accra using readily available screening tools to estimate the emissions of alternative intervention measures (SWEET tool), estimate concentrations using the methodology RUWM, and to perform a health impact assessment (AirQ+ software). We have estimated the $PM_{2.5}$ and CO_2e emissions for 2020 and future emissions for the BAU out to 2030. Further, we have modeled two alternative scenarios: cease open burning and increased composting and recycling. The lowest $PM_{2.5}$ emissions are predicted in the cease open burning scenario, which is also expected to reduce CO_2e emissions by one-half (200,000 tons) by 2030, thereby substantially reducing both climate forcing and air pollution. Compared to the baseline scenario, the cease open burning alternative is expected to reduce 120 $PM_{2.5}$ premature deaths in 2030.

The main challenges identified in waste management in Accra were the limited waste collection capacity, and the poor enforcement of environmental regulations, which contribute to the open burning and indiscriminate dumping of waste. We, therefore, recommend to strengthen law enforcement, and to increase waste collection through informal sector integration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

SWEET was developed by the U.S. Environmental Protection Agency with support from Abt Associates and SCS Engineers on behalf of the Climate and Clean Air Coalition Municipal Solid Waste Initiative. The authors would like to acknowledge the U.S. Environmental Protection Agency and its team of contractors (particularly Ben Matek, Abt Associates and Alex Stege, SCS Engineers) for their support in using the SWEET tool. Particular thanks go to the University of Ghana. We also want to thank Dr. Ralf Aschemann for his suggestions during the entire research and Michael Hinsch for his support. Part of the research leading to these results has received funding from the Urban Health Initiative of the World Health Organization. P.M is a staff member of the WHO. This paper reflects the authors' views. The authors alone are responsible for the views expressed in this publication, and they do not necessarily represent the views, decisions, or policies of the WHO. This work was supported financially by UN Environment and the Climate and Clean Air Coalition through a grant provided for the Urban Health and SLCP Reduction project in Accra.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.wasman.2021.01.005.

References

Adzawla, W., Tahidu, A., Mustapha, S., Azumah, S., 2019. Do socioeconomic factors influence households' solid waste disposal systems? Evidence from Ghana. Waste Manage. Res.: J. Sustain. Circ. Econ., 51–57

Allesch, A., Brunner, P.H., 2014. Assessment methods for solid waste management: a literature review. Waste Manage. Res. 32 (6), 461–473.

Amann, M., Purohit, P., Bhanarkar, A.D., Bertok, I., Borken-Kleefeld, J., Cofala, J., Majumdar, D., 2017. Managing future air quality in megacities: a case study for Delhi. Atmos. Environ. 161, 99–111.

Amegah, A., Jaakkola, J., Quansah, R., Norgbe, G., Dzodzomenyo, M., 2012. Cooking fuel choices and garbage burning practices as determinants of birth weight: a cross-sectional study in Accra, Ghana. Environ. Health 11 (1).

Amer, M., Daim, T., Jetter, A., 2013. A review of scenario planning. Futures 46, 23–40.

Anaman, K., Nyadzi, W., 2015. Analysis of improper disposal of solid wastes in a low-income area of Accra, Ghana. Appl. Econ. Finance 2 (1), 66–75.

Aparcana, S., 2017. Approaches to formalization of the informal waste sector into municipal solid waste management systems in low- and middle-income countries: review of barriers and success factors. Waste Manage., 593–607

Apte, J., Bombrun, E., Marshall, J., Nazaroff, W., 2012. Global intraurban intake fractions for primary air pollutants from vehicles and other distributed sources. Environ. Sci. Technol. 46, 3415–3423.

Apte, J., Brauer, M., Cohen, A., Ezzati, M., Pope, C., 2018. Ambient PM2.5 reduces global and regional life expectancy. Environ. Sci. Technol. Lett. 5 (9), 546–551.

Asase, M., Yanful, E., Mensah, M., Stanford, J., Amponsah, S., 2009. Comparison of municipal solid waste management systems in Canada and Ghana: a case study of the cities of London, Ontario, and Kumasi, Ghana. Waste Manage. 29 (10), 2779–2786.

Asibey, M., Amponsah, O., Yeboah, V., 2019. Solid waste management in informal urban. Occupational safety and health practices among tricycle operators in Kumasi, Ghana. Int. J. Environ. Health Res. 29 (6), 702–717.

Boadi, K., Kuitunen, M., 2005. Environmental and health impacts of household solid waste handling and disposal practices in third world cities: the case of the accra metropolitan area, Ghana. J. Environ. Health 68 (4), 32–36.

Brunner, P., Fellner, J., 2007. Setting priorities for waste management strategies in developing countries. Waste Manage. Res. 25, 234–240.

CCAC, 2019. CCAC Coalition. Retrieved Jan 05, 2020, from https://www.ccacoalition.org/en/resources/solid-waste-emissions-estimation-tool-sweet-version-30.

Coffey, M., Coad, A., 2010. Collection of Municipal Solid Waste in Developing Countries. UN-HABITAT, Malta.

Das, B., Bhave, P., Sapkota, A., Byanju, R., 2018. Estimating emissions from open burning of municipal solid waste in municipalities of Nepal. Waste Manage. 79, 481–490.

Dhar-Chowdhury, P., Haque, C., Driedger, S., 2015. Dengue disease risk mental models in the city of Dhaka, Bangladesh: juxtapositions and gaps between the public and experts. Risk Anal. 36 (5), 874–891.

Dionisio, K., Rooney, M., Arku, R., Friedman, A., Hughes, A., Vallarino, J., Ezzati, M., 2010. Within-neighborhood patterns and sources of particle pollution: mobile monitoring and geographic information system analysis in four communities in Accra, Ghana. Environ. Health Perspect. 118 (5), 607–613.

Durance, P., Godet, M., 2010. Scenario building: uses and abuses. Technol. Forecast. Soc. Chang. 77 (9), 1488–1492.

Dzotsi, E., Odoom, J., Davies-Teye, B., 2016. Outbreak of cholera, Greater Accra region Ghana 2014. J. Sci. Res. Repos. 9 (3), 1–12.

EPA-Ghana, 2019. Ghana's Fourth National Greenhouse Gas Inventory Report. EPA-Ghana, Accra.

Ghana Statistical Service, 2012. 2010 Population & Housing Census: Summary Report of Final Results. Ghana Statistical Service, Accra.

Ghana Statistical Service, 2019. Ghana Living Standards Survey (GLSS). Ghana Statistical Service, Accra, Ghana.

Giusti, L., 2009. A review of waste management practices and their impact on human health. Waste Manage. 29, 2227–2239.

GIZ, 2017a. Unterstützung für Dezentralisierungsreformen. Retrieved 07 24, 2017, from https://www.giz.de/de/weltweit/19434.html.

Hoornweg, D., & Bhada-Tata, P., 2012. What a Waste: A Global Review of Solid Waste Management. Urban development series; knowledge papers no. 15. Washington, DC: World Bank.

IEA Ghana, 2017. Institute for Economic Affairs. Retrieved 07 24, 2017, from http://ieagh.org.

IFC-WB, 2020. COVID-19's Impact on the Waste Sector. https://www.ifc.org/wps/wcm/connect/dfbceda0-847d-4c16-9772-15c6afdc8d85/202006-COVID-19-impact-on-waste-sector.pdf?MOD=AJPERES&CVID=na-eKpI: IFC.

International Agency for Research on Cancer, 2015. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: vol. 109, outdoor air pollution. Lyon, France: IARC.

Kanhai, G., Agyei-Mensah, S., Mudu, P., 2019. Population awareness and attitudes toward waste-related health risks in Accra, Ghana. Int. J. Environ. Health Res,.

Klampf-Pernold, H., Pomberger, R., Schmidt, G., 2010. Das Kapazitätenmodell als Instrument zur Markteinschätzung von Sekundärrohstoffen. 10. DepoTech Konferenz, Leoben, Österreich.

Komakech, A., Zurbrügg, C., Miito, G., Wanyama, J., Vinneras, B., 2016. Environmental impact from vermicomposting of organic waste in Kampala, Uganda. J. Environ. Manage. (181), 395–402

Kosow, H., Gaßner, R., 2008. Methods of Future and Scenario Analysis: Overview, Assessment, and Selection Criteria. Deutsches Institut für Entwicklungspolitik gGmbH, Bonn.

Kusi, E., Kofi Nyarko, A., Boamah, L., Nyamekye, C., 2016. Landfills: investigating its operational practices in Ghana. Int. J. Energy Environ. Sci. 1 (1), 19–28.

Liu, Y., Sun, W., Liu, J., 2017. Greenhouse gas emissions from different municipal solid waste management scenarios in China: based on carbon and energy flow analysis. Waste Manage. 68, 653–661.

Marshall, R., Farahbakhsh, K., 2013. Systems approaches to integrated solid waste management in developing countries. Waste Manage. 33 (4), 988–1003.

Mattiello, A., Chiodini, P., Bianco, E., Forgione, N., Flammia, I., Gallo, C., Panico, S., 2013. Health effects associated with the disposal of solid waste in landfills and incinerators in populations living in surrounding areas: a systematic review. Int. J. Publ. Health 58 (5), 725–735.

Medina, M., 2010. Solid wastes, poverty and the environment in developing country cities: challenges and opportunities. Working Paper//World Institute for Development Economics Research.
Mettetal, E., Matek, B., Donahue, J., Enriquez, S., Sala, R., Frankiewicz, T., 2019. The climate benefits of a proposed anaerobic digester: a US case study from Naucalpan, Mexico. Circular Economy: What are you doing? World Congress ISWA, Bilbao, Spain.
Miezah, K., Obiri-Danso, K., Kádár, Z., Fei-Baffoe, B., Mensah, M., 2015. Municipal solid waste characterization and quantification as a measure towards effective waste management in Ghana. Waste Manage. 46, 15–27.
Millington, N., Lawhon, M., 2018. Geographies of waste: conceptual vectors from the Global South. Prog. Hum. Geogr., 1–20
Modak, P., 2011. Chapter 5 – Municipal Solid Waste Management: Turning Waste into Resources. In: U.-B. Expositions, Shanghai Manual – A Guide for Sustainable Urban Development in the 21st Century (p. Chapter 5). UN.
Munyai, O., Nunu, W.N., 2020. Health effects associated with proximity to waste collection points in Beitbridge Municipality, Zimbabwe. Waste Manage. 105, 501–510.
Mwirigi, J., Balana, B., Mugisha, J., Walekhwa, P., Melamu, R., Nakami, S., Makenzi, P., 2014. Socio-economic hurdles to widespread adoption of small-scale biogas digesters in Sub-Saharan Africa: a review. Biomass Bioenergy 70, 17–25.
Ncube, F., Ncube, E.J., Voyi, K., 2017. A systematic critical review of epidemiological studies on public health concerns of municipal solid waste handling. Perspect. Publ. Health 137 (2), 102–108.
Nie, E., Zheng, G., Shao, Z., Yang, J., Chen, T., 2018. Emission characteristics and health risk assessment of volatile organic compounds produced during municipal solid waste composting. Waste Manage. 79, 188–195.
Oduro-Appiah, K., Afful, A., Kotey, V., de Vries, N., 2019. Working with the informal service chain as a locally appropriate strategy for sustainable modernization of municipal solid waste management systems in lower-middle income cities: lessons from Accra, Ghana. Resources 8, 12.
Oduro-Appiah, K., Scheinberg, A., Mensah, A., Afful, A., Boadu, H., de Vries, N., 2017. Assessment of the municipal solid waste management system in Accra, Ghana: a "Wasteaware" benchmark indicator approach. Waste Manage. Res. 35 (11), 1149–1158.
Oteng-Ababio, M., 2010. Private sector involvement in solid waste management in the Greater Accra Metropolitan Area in Ghana. Waste Manage. Res. 28, 322–329.
Oteng-Ababio, M., 2011. The role of the informal sector in solid waste management in the Gama, Ghana: challenges and opportunities. Tijdschrift voor Economische en Sociale Geografie 103 (4), 412–425.
Oteng-Ababio, M., 2014. Rethinking waste as a resource: insights from a low-income community in Accra, Ghana. City, Territ. Archit. 1 (1), 1–14.
Oteng-Ababio, M., Grant, R., 2019. Ideological traces in Ghana's urban plans: how do traces get worked out in the Agbogbloshie, Accra?. Habitat Int. 83, 1–10.
Oteng-Ababio, M., Arguello, J., Gabbay, O., 2013. Solid waste management in African cities: sorting the facts from the fads in Accra, Ghana. Habitat Int. 39, 96–104.
Oteng-Ababio, M., Owusu-Sekyere, E., Amoah, S.T., 2017. Thinking globally, acting locally: formalizing informal solid waste management practices in Ghana. J. Develop. Soc. 33 (1), 75–98.
Owusu-Sekyere, E., Bagah, D., Quansah, J., 2015. The urban solid waste management conundrum in Ghana: will it ever end?. World Environ. 5 (2), 52–62.
Owusu-Sekyere, E., Osumanu, I., Yahaya, A.-K., 2013. An analysis of plastic waste collection and wealth linkages in Ghana. Int. J. Curr. Res. 5 (1), 205–209.
Premakumara, D., Menikpura, S., Singh, R., Hengesbaugh, M., Magalang, A., Ildefenso, E., Silva, L., 2018. Reduction of greenhouse gases (GHGs) and short-lived climate pollutants (SLCPs) from municipal solid waste management (MSWM) in the Philippines: rapid review and assessment. Waste Manage. 80, 397–405.
Rabl, A., Spadaro, J., Holland, M., 2014. How Much is Clean Air Worth: Calculating the Benefits of Pollution Control. Cambridge University Press.
Schlosser, O., Robert, S., Noyon, N., 2020. Airborne mycotoxins in waste recycling and recovery facilities: occupational exposure and health risk assessment. Waste Manage. 105, 395–404.
Song, Q., Li, J., 2014. Environmental effects of heavy metals derived from the e-waste recycling activities in China: a systematic review. Waste Manage. 34 (12), 2587–2594.
Songsore, J., 2017. The complex interplay between everyday risks and disaster risks: the case of the 2014 cholera pandemic and 2015 flood disaster in Accra, Ghana. Int. J. Disaster Risk Reduct. 26, 43–50.
Thompson, I., 2010. Domestic Waste Management Strategies in Accra, Ghana and Other Urban Cities in Tropical Developing Nations.
Thurston, G.D., Kipen, H., Annesi-Maesano, I., Balmes, J., Brook, R.D., Cromar, K., Grigg, J., 2017. A joint ERS/ATS policy statement: what constitutes an adverse health effect of air pollution? An analytical framework. Eur. Respirat. J. 49 (1).
UNEP DTIE, 2009. Developing Integrated Solid Waste Management Plan: Training Manual – Vol. 4 ISWM Plan. Osaka, Japan: UNEP.
UNFCCC, 2015. Ghana's Third National Communication Report to UNFCCC. United Nations Framework Convention on Climate Change, Bonn.
UN-Habitat, 2010. Solid Waste Management in the World's Cities: Water and Sanitation in the World's Cities 2010. Earthscan, London.
UN-Habitat, 2015. UN-Habitat Global Activities Report 2015: Increasing Synergy for Greater National Ownership. UN-Habitat, Nairobi.
Wang, Y., Cheng, K., Wu, W., Tian, H., Yi, P., Zhi, G., Liu, S., 2017. Atmospheric emissions of typical toxic heavy metals from open burning of municipal solid waste in China. Atmos. Environ. (152), 6–15
WHO, 2016. Health Risk Assessment of Air Pollution – General Principles. WHO Regional Office for Europe, Copenhagen.
WHO, 2020. AirQ+. Retrieved Jan 05, 2020, from https://www.euro.who.int/en/health-topics/environment-and-health/air-quality/activities/airq-software-tool-for-health-risk-assessment-of-air-pollution.
Wiedinmyer, C., Yokelson, R.J., Gullet, B.K., 2014. Global emissions of trace gases, particulate matter, and hazardous air pollutants from open burning of domestic waste. Environ. Sci. Technol. 48 (16), 9523–9530.
Wilson, D., Rodic, L., Cowing, M., Velis, C., Whiteman, A., Scheinberg, A., Oelz, B., 2015. 'Wasteaware' benchmark indicators for integrated sustainable waste management in cities. Waste Manage. 35, 329–342.
Wittsiepe, J., Fobil, J., Till, H., Burchard, G., Wilhelm, M., Feldt, T., 2015. Levels of polychlorinated dibenzo-p-dioxins, dibenzofurans (PCDD/Fs) and biphenyls (PCBs) in blood of informal e-waste recycling workers from Agbogbloshie, Ghana, and controls. Environ. Int. 79, 65–73.
Yang, H., Zhang, S., Ye, W., Qin, W., Xu, M., Han, L., 2020. Emission reduction benefits and efficiency of e-waste recycling in China. Waste Manage. 102, 541–549.
Yapo, S., Kouadio, G., Assamoi, E.-M., Youboue, V., Bahino, J., Keita, S., 2018. Estimation of methane emissions released from a municipal solid waste lanfill site through a modelling aproach: a case study of Akouédo Landfill, Abidjan (Côte d'Ivoire). Int. J. Sci. Res., 1587–1593
Zainabu, I., 2014. Accra Compost & Recycling Plant closed down. Retrieved 09 15, 2017, from https://www.graphic.com.gh/news/general-news/accra-compost-recycling-plant-closed-down.html.
Ziraba, A.K., Haregu, T.N., Mberu, B., 2016. A review and framework for understanding the potential impact of poor solid waste management on health in developing countries. Arch. Publ. Health 74 (1).