Application of life cycle assessment for hospital solid waste management: a case study

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ABSTRACT

This study was meant to determine environmental aspects of hospital waste management scenarios using life cycle analysis approach. Survey for this study was conducted at the largest hospital in a major city of Pakistan. The hospital was thoroughly analyzed from November, 2014 to January, 2015 to quantify its wastes by category. The functional unit of the study was selected as one tonne of disposable solid hospital waste. System boundaries included transportation of hospital solid waste and its treatment and disposal by landfilling, incineration, composting and material recycling methods. These methods were evaluated based on their greenhouse gas emissions. Landfilling and incineration turned out to be the worst final disposal alternatives whereas composting and material recovery displayed savings in emissions. An integrated system (composting, incineration and material recycling) was found as the best solution among the evaluated scenarios. This study can be used by policymakers for the formulation of an integrated hospital waste management plan.

Key Words

Hospital waste; hazardous waste; greenhouse gas emissions; pollution; public health.

INTRODUCTION

Health care activities can result in different kinds of waste. According to World Health Organization (WHO) around 10-25% of the waste generated across healthcare facilities can be considered as hazardous (Yves Chartier, 2013). This may consist of infectious, radioactive, toxic and genotoxic items. Mismanagement of such wastes can result in environmental and occupational health risks. Different treatment methods can be used for the disposal of hospital wastes. Commonly used methods include microwave irradiation (Ozkan, 2013), autoclaving (Coulter et al., 2001) or incineration (Chen et al., 2012) for infectious wastes and landfilling (Zhao et al., 2008) or recycling (Unger and Landis, 2016) for general/non-infectious waste items. Some of these techniques have been criticized for causing environmental pollution. It would be interesting to compare the environmental impact of different hospital waste disposal methods using a common parameter. Life Cycle Assessment (LCA) (Merrild et al., 2009) is a useful technique that can help evaluate different waste disposal scenarios on the basis of their greenhouse gas (GHG) emissions. GHG emissions from waste management activities form a critical environmental concern. Municipal and hospital wastes in many developing countries are mixed together and dumped in open landfills or burned openly (Patwary et al., 2011). Methane and black carbon from such activities result in environmental pollution. Waste collection and transportation activities consume fossil fuels which in turn contribute towards GHG emissions. LCA can be used to trace the environmental footprint of such activities. There are many studies on LCA of municipal waste (Beylot and Villeneuve, 2013; Habib et al., 2013; Zhao et al., 2012). Studies on LCA of hospital waste are relatively few. Existing studies usually focus on a specific waste type such as infectious waste (Zhao et al., 2008) or specific procedures such as disinfection (Eberle et al., 2006), or services such as infant delivery (Campion et al., 2012), surgical operations (Thiel et al., 2015), etc. or a specific healthcare product such as masks (Eckelman et al., 2012), thermometers (Gavilán-García et al., 2015), sharp containers (Grimmond and Reiner, 2012), bedpans (Sørensen and Wenzel, 2014), etc. Studies modeling an integrated system of hospital waste disposal are limited in scientific literature. This study involves LCA of different hospital waste disposal scenarios at the largest hospital in a major city of Pakistan. The subject of hospital waste management is a niche and most of the studies on hospital waste in Pakistan focus on assessing the knowledge, attitude and awareness of the staff regarding safe management of healthcare wastes (Kumar et al., 2015a; Kumar et al., 2015b), (Ali et al., 2016a) . Studies and surveys on waste quantification and disposal practices of hospital waste in Pakistan are limited. Moreover studies investigating the environmental impact of hospital waste disposal activities in Pakistan are quite scarce. With this study we aim to fill this gap in the existing scientific literature.

METHODOLOGY

Goal & Scope

In this study the goal of the LCA was to determine and compare the environmental burden of hospital waste via different waste treatment scenarios. The study was conducted at District Head Quarter (DHQ) hospital in Gujranwala, a major city of Pakistan. The hospital under study had 449 beds and it was the only large (>100 beds) public hospital providing inexpensive treatment to over 4 million people across the district. The functional unit of the study was defined as '1 tonne of disposable solid hospital waste at DHQ'. For the LCA, three scenarios were developed utilizing different waste treatment techniques. The system boundaries are displayed in Figure 1.

[Insert Figure 1. here]

Scenario A reflects the mandated practice at DHQ in which the medical waste was incinerated and the general waste fraction was dumped in a municipal landfill site. One way distance from the hospital to the municipal dumping ground was 14.4 Km. The hospital did not have an incinerator and a commercial firm collected the medical wastes from the hospital for incineration. The incineration plant was located in another city, namely Kasur, and the distance between the hospital and the incineration plant was around 119 Km. Scenario B involved incineration of mixed hospital waste at a hypothetical incinerator near the municipal landfill site. This scenario was considered as lack of segregation could render all the waste as infectious. According to national regulations, all infectious waste items need to be incinerated or landfilled. Landfilling was not considered as this could result in occupational safety hazards for scavengers at such a site. Other treatment methods such as microwave irradiation, autoclaving and pyrolisis were not considered due to their high capital costs. Scenario C envisions an integrated waste management approach in which the segregated waste components are treated using a combination of different waste management techniques including composting, incineration and material recycling at the landfilling site. These scenarios were evaluated based on their GHG emissions as measured in kg CO2 equivalent per tonne of hospital waste. The scenarios were simulated using a spread sheet tool developed by Institute for Global Environment Strategies (IGES), Japan for developing countries in Asia-Pacific region (Nirmala Menikpura, 2013). The tool helps quantify GHG emissions from individual treatment technologies as well as integrated systems. GHG emissions can be estimated based on weight (in tonnes) as well as on a time scale (per month). Required input data includes monthly percentage wet waste quantities as well as corresponding fuel and electricity consumption. The output includes total and direct GHG emissions as well as net GHG emissions. Here direct emissions refer to GHG emissions due to fossil energy consumption, waste degradation, combustion of waste fractions, etc. Net GHG emissions are calculated on the basis of GHG avoidance/mitigation potential of the selected technologies. The tool also calculates indirect savings which reflect material and energy recovery from waste management activities resulting in emission reduction. Hence an integrated system can result in an overall net climate benefit even though some of the constituent technologies result in an impact. Guidelines of Intergovernmental Panel on Climate Change (IPCC) (Eggleston H.S., 2006) were used while making all the calculations.

Inventory Analysis

A survey to sort and measure hospital waste items was conducted between November, 2014 and January, 2015. Waste management personnel at the hospital aided the survey during waste collection, sorting and measurement. One week was used for a pilot study in which the wastes were weighed and key issues during the waste measurement process were highlighted. The main issue discovered here was a lack of proper segregation of hospital waste as per hospital guidelines. Consequently, the staff were trained and subsequently two weeks were spent on waste measurement with the waste items segregated into their sub-components. We classified hospital waste into its constituents using the terms defined in local national regulations (Ali et al., 2016b). These included general/non-infectious waste and medical waste with the medical waste being further classified into hazardous infectious items and sharps. The wastes were sorted and weighed following guidelines in peer reviewed articles on the subject of hospital waste characterization and measurement (Munir et al., 2014), (Yong et al., 2009). Medical solid wastes were collected from the medical waste storage bins placed in each ward and then sorted and weighed using a digital balance. All wastes were weighed before being transported to the incinerator. The infectious waste usually consisted of items contaminated with blood and other body fluids including empty drips and drip sets, empty blood and urine bags, gloves, cotton swabs, gauzes, etc. Liquid wastes such as hospital waste water, pharmaceutical items, chemicals, etc. were not included in the study. Sharp items were stored in sharp boxes and mostly consisted of syringes and needles. The total medical waste generation rate (WGR) at the hospital came out as 2.63 kg/patient-day which consisted of 4.4% sharps and 95.6% hazardous infectious items. The units of kg/patient-day were used as patient bed occupancy in some of the wards was greater than 100%. Apart from the medical wastes, the general waste from the hospital was also collected, sorted and then weighed from the hospital general waste container placed outside the hospital boundary wall. It contained general waste items such as food/kitchen waste, leaves, office stationery, packaging materials, etc. These waste items mainly came from hospital canteen, hospital shops and different offices within the wards and the administration building. Table 1. shows the general and medical waste items and their constituents. In the table, 'other' items category includes fruit peels, kitchen waste, garden waste, etc. Apart from a few aerosol spray cans, metal items were non-existent in the general waste. The sharp boxes mainly consisted of plastic syringes. The composition of needles in percentage weight terms was negligible.

[Insert Table 1. here]

Data regarding the incineration plant was unavailable as the commercial firm refused to provide any information. Hence the medical wet waste was simulated to be incinerated in a semi-continuous stoker type incinerator which could reduce the waste to 75% by mass and 90% by volume without energy recovery. The utilities' requirements for incineration were determined using data from an incinerator at a similar public hospital in the nearby city of Lahore. This incinerator was consistent with the assumptions of the model. Its average electricity and natural gas consumption came out as 0.015 kWh/kg waste and 3.36 Liter/kg waste respectively. Fuel requirement for waste transportation were determined to be 1 Liter diesel/5 Kilometers. For Scenario A the input waste quantities consisted of the medical and general fractions shown in Table 1. Electricity and natural gas consumption for medical waste incinerator came out as 47.13 kWh and 940.24 liters respectively. The general waste was simulated to be dumped in an open landfilling site without gas recovery. Total fuel consumption came out as 415.36 liters. For Scenario B, the total wet waste fractions given in the last row of Table 1 formed the inputs for the incinerator. Electricity and natural gas consumption for the incinerator came out as 91.19 kWh and 1819.32 liters respectively. Total fuel consumption came out as 34.56 liters. For Scenario C, medical waste was simulated to be incinerated and 'Others' category in the general waste category was composted. Paper, plastic and glass items were simulated for material recovery for recycling. Electricity and natural gas consumption were the same as that in Scenario A while fuel requirement was 34.56 liters. Composting can lead to emissions due to anaerobic digestion however it can also lead to GHG mitigation by avoiding chemical fertilizer production. Both of these factors were considered in the calculations. Recycling could lead to GHG emissions through activities such as pre-processing and transportation activities yet it could also lead to GHG mitigation through the avoidance of virgin material production. The software took both these factors into account while making calculations.

RESULTS & DISCUSSION

Impact Assessment

Figure 2. shows the GHG emissions for the three scenarios described above. Scenario A resulted in 1134.00 kg CO2 equivalent/tonne of direct GHG emissions and 737.51 kg CO2 equivalent/tonne of net emissions. Scenario B resulted in 1374.86 kg CO2 equivalent/tonne of direct GHG emissions and 688.46 kg CO2 equivalent/tonne of net emissions. Finally, Scenario C resulted in 1062.59 kg CO2 equivalent/tonne of direct GHG emissions and only 35.98 kg CO2 equivalent/tonne of net emissions due to the savings in lieu of composting and material recovery. Scenario B takes into account the emissions that have been avoided due to landfilling hence its net emissions are relatively lower than those in Scenario A. In scenarios A and B net emissions are lower than direct emissions as the calculations take into account GHG avoidance due to organic waste landfilling. Scenario C results in the least amount of net emissions mainly because of indirect savings due to composting and material recovery technologies.

[Insert Figure 2. here]

Figure 3. displays the individual contributions of the disposal methods in net GHG emissions for each scenario. It can be seen that a reduction in transportation distance results in a reduction in emissions due to transportation. Moreover, incineration and landfilling both result in a high amount of GHG emissions. This suggests that effective waste segregation should be ensured to minimize the amount of waste going to the landfill or to the incinerator.

[Insert Figure 3. here]

Interpretation

The results display a combination of opportunities and challenges. Figure. 3 shows that recycling can lead to indirect savings of 606.40 kg CO2 equivalent/tonne of waste. Therefore safe and responsible material recycling can lead to environmental protection as well as revenue generation. However, it has been reported that unsegregated hospital waste in Pakistan is being recycled illegally into drinking straws and children's toys (Jaffery, 2013). Hence effective segregation needs to be ensured to realize the benefits of material recovery and recycling. At the time of the survey the prices of different recovered articles from municipal waste varied as US$0.07/kg to US$0.08/kg for paper, US$0.30/kg for plastic, US$0.08/kg for glass and US$0.35/kg to US$0.40/kg for metal as per the exchange rate between Pakistani Rupees and US dollars at the time of the survey (Ali et al., 2016b). Hence a yearly profit of approximately US$2901 could be obtained by the hospital just by properly segregating the waste at source. Further recycling of these items and sale of compost could also result in profits and employment opportunities. As an additional benefit, compost applications could help reduce soil salinity which is of substantial importance in a country where majority of the population depends on agriculture for its livelihood. The facilities for material recycling and composting could be scaled up to include inputs from the municipal solid waste of the whole city.

As mentioned earlier, the hospital waste incineration plant was located around 119 km away in another city. Transportation of the hospital waste at such a long distance led to emissions of 183.20 kg CO2 equivalent/tonne of waste. Hence, there was an urgent need to find an alternate solution to this challenge. At the time of the survey, there was an incineration plant situated at the Combined Military Hospital located in the Military Cantonment area. However, it was found to be non-operational owing to a lack of technical staff for its operation and maintenance. There was a need to either resume activities at that plant or to install a new plant elsewhere in the city.

We used the parameter of GHG emissions to compare different waste disposal scenarios as the results can also be used for Carbon accounting. This means that once an integrated waste management system is in place the emission calculations can also be used for the determination of Carbon credits (Zaher et al., 2013). These credits can then be sold at an appropriate trading floor leading to additional revenue. The United Nation's Clean Development Mechanism (Siebel et al., 2013) promotes the development of environment friendly projects through the sale of such credits. Hence an integrated hospital waste disposal scenario, identified here, can be a beneficiary as well as an instigator of clean and sustainable projects. Such a strategy has earlier been proposed for municipal solid waste management (El Hanandeh and El-Zein, 2009) and it can also be extended to hospital wastes with the aid of LCA.

LCA as a tool is sensitive to local specific conditions for modeling environmental impacts (Laurent et al., 2014). Hence it is quite difficult to compare the results of different studies in the absence of a common methodology to measure the wastes and analyze their impacts. Studies focusing on the LCA may differ from each other in terms of functional unit, system boundaries, waste composition, energy modeling, etc. (Gentil et al., 2010). Studies measuring hospital waste may vary from each other in terms of the definitions of medical waste, duration of the study, the procedure to quantify weights, the season in which wastes are measured and the socio-economic background of the patients (Thakur and Ramesh, 2015). All of these factors cause the waste generation rates to differ from each other. Consequently it is difficult to compare the results of one study with another. Still, many of the studies on LCA of hospital waste also emphasize waste segregation and agree with our findings that incineration without energy recovery is more damaging to the environment than other techniques (Zhao et al., 2008), (Soares et al., 2013).

CONCLUSION

Pakistan is a resource constrained country undergoing a rapid rural to urban migration. This has contributed to challenges such as effective waste management at public hospitals. DHQ serves as a representative example of such hospitals. This study was used to quantify the environmental footprint of different hospital waste disposal scenarios. Hospital waste practices were discovered to be having serious shortcomings. Medical waste was sent to be incinerated in another city resulting in high transportation costs and GHG emissions. LCA results show that waste segregation could help implement environmentally friendly waste disposal technologies such as composting and material recovery. This could lead to emission reduction and pollution prevention. This study showed that an integrated hospital waste management plan could lead to the least amount of emissions. The results of this study can be used by policy makers to highlight the importance of hospital waste minimization, segregation and recycling.

A limitation of this study is that the options of heat/electricity recovery were not taken into account in the model. Additionally this paper focused only on GHG emissions and factors such as acidification potential, human toxicity, photochemical oxidant creation, etc. were not used. A practical difficulty faced during the study involved effective segregation of waste items. Despite providing guidance and training to the sanitary staff there were still some hazardous items found mixed in the general waste. This posed a threat to the health and wellbeing of scavengers and municipal waste haulers. The issues highlighted in this study can be used by the policy makers for a behavioral change geared towards safe management of hospital waste. The present study was conducted at the largest hospital in Gujranwala district. In the future the scope of the study can be expanded to include the remaining hospitals within the district as well as those operating in other cities. Techniques such as life cycle costing (Soares et al., 2013) can also be used depending upon data availability. Once enough evidence is available the government can be called upon for an intervention leading to the application of integrated hospital waste management across the country.

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Figure Legends

Figure 1. System boundaries.

Figure 2. Results of the LCA.

Figure 3. Individual contributions to Net GHG emissions.