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Environmental Performance of Peruvian Waste Management Systems under a Life Cycle Approach

Kurt Ziegler-Rodriguez[a,*], María Margallo[b], Rubén Aldaco[b], Angel Irabien[b], Ian Vazque-Rowe[a], Ramzy Kahhat[a]

[a]Peruvian LCA Network, Department of Engineering, Pontificia Universidad Católica del Perú, Avenida Universitaria 1801, San Miguel 15088, Lima, Peru
[b]Department of Chemical and Biomolecular Engineering, University of Cantabria, Avda. Los Castros s/n, Santander, Spain
kziegler@pucp.pe

Peru generated in 2014 a total of 7.5 million metric tons of municipal solid waste (MSW). Of these, 47 % of residues ended up in open dumpsites and only 21 % were sent to controlled landfills. Efforts must be made to conduct a change from open dumpsites to sanitary landfills, reaching an adequate and sustainable waste management system. This study aims at meeting this challenge by means of the Life Cycle Assessment (LCA) methodology. In particular, the objective of this study is to develop a life cycle model that will allow the estimation of environmental impacts linked to waste landfilling in Peru, and to compare in further studies alternatives to determine a more environmentally sustainable solution. The model is flexible in order to be adapted to the three main geo-climatic regions in Peru: the hyper-arid coast, the Andean Highlands and the Amazon Rainforest. The life cycle model was developed with the EASETECH software, taking into account the phases of construction, operation and end-of-life the Peruvian landfills. The main parameters of this model include waste composition and the characteristics and treatment of the leachate and landfill gas, taking into consideration local parameters such as temperature, humidity and precipitation intensity. The model lays the foundation stone to determine the main hotspots in Peruvian sanitary landfills. This information will allow achieving an adequate and sustainable waste management by proposing improvement measures to help stakeholders in the decision-making process.

1. Introduction

Waste management is a sector that, through time, has required increasing attention. However, huge differences regarding waste generation, composition and management are found between developed and developing countries (Laurent et al., 2014). From a global waste production of 1.3 billion metric tons per year, Organization for Economic Co-operation and Development (OECD) nations make up close to half of the world's waste, c.a. 673,200 thousand metric tons in 2016 (OECD, 2017). This is consistent with the premise that the higher income level, the higher waste generation. For waste management, the trend is that while developed countries seek more integrated and sustainable waste management systems (Laurent et al., 2014), emerging nations are still basically fighting to switch from the disposal of residues in open dumpsites to disposing of them in controlled landfills (Guerrero et al., 2013). This is the situation in most Latin American and Caribbean (LAC) countries. In the particular case of Peru, in year 2014 a total of 7.5 million metric tons of municipal solid waste (MSW) were generated. Of these, 47 % of residues ended up in open dumpsites and only 21 % were sent to controlled landfills. Regarding the remaining fraction, 17 % was recycled, 12 % was openly burned, 3 % spilled into any water source and the final 1 % had another unknown destination (MINAM, 2017). As the Peruvian waste management situation is a well-known problem by the government, all along the last decade there has been an intended compromise from it to improve the situation. In this sense, the development of an adequate waste management system will be facilitated by the use of environmental tools, such as Life Cycle Assessment (LCA). LCA quantifies the environmental benefits and impacts of production processes (Laso et al., 2016), helping organizations to perform their activities in the most environmental friendly way along the whole value chain (Margallo et al., 2016) and performing the green economy transition (Mah et al., 2017). This methodology has

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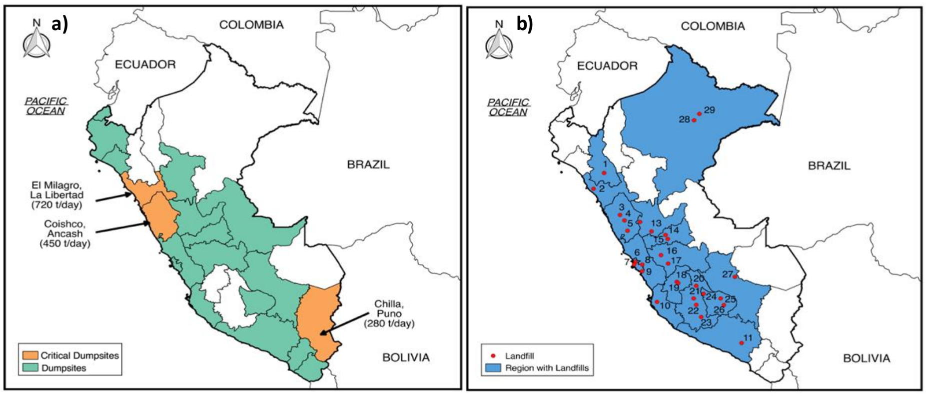
been widely applied to the management of the Municipal Solid Waste (MSW) sector, in particular, in Europe and Asia, mainly in Italy, UK, Germany and China (Margallo et al. 2018). However, there is a lack of studies in LAC and it is important to address that European case studies may not be representative of the LAC scenario due to their technological and geo-climatic conditions (Henriksen et al., 2017). Therefore, this study aims at filling this gap, developing a life cycle model to estimate the environmental impacts of waste landfilling in Peru. The model will be flexible in order to be adapted to the three main geo-climatic regions in Peru: the hyper-arid coast, the Andean Highlands and the Amazon Rainforest.

2. Waste management in Peru

Landfilling is the most common treatment method in Peru and many LAC countries (MINAN, 2017). However, there are huge differences between sanitary landfills, controlled landfills and open dumpsites. A sanitary landfill comprises spreading and compaction of waste on a waterproof bed, daily coverage and an adequate management of leachate and gases, whereas a controlled landfill does not have the infrastructure of a sanitary landfill, but some control measures. In contrast, in open dumpsites (referred to in the region as “botaderos”) waste is disposed of without any control and protection to the environment and thus, the chemical and biological contaminants in wastes will find their way back to humans to affect health and quality of life (Rushbrook, 1999). Between 2012 and 2013 it was denoted approximately 105 open dumpsites in 177 municipalities of Peru with more than 10,000 inhabitants, excluding the areas of Metropolitan Lima and Callao. Figure 1a shows the location of the 20 most critical open dumpsites. Three of them, located in La Libertad (“El Milagro”), Ancash (“Coishco”) and Puno (“Chilla”), treat 34 % (1450 metric tons) of the total waste disposed in these 20 open dumpsites (OEFA, 2014). Efforts are being made to conduct a change from open dumpsites to sanitary landfills (Figure 1b).



Sanitary Landfills in Perú

1. Cajamarca
2. Chicama
3. Carhuaz
4. Independencia
5. Cajacay
6. Zapallal
7. Modelo del Callao
8. Huaycoloro
9. Portillo Grande
10. Ica
11. Quebrada Honda
12. Llata
13. Ambo
14. Pozuzo
15. Oxapampa
16. Santa Cruz
17. Pampaya
18. Yauli
19. Ccochaccasa
20. Cangallo
21. Coracora
22. Huaya
23. San Miguel
24. Chuquibambilla
25. Anco Huallo
26. Huancarama
27. Anta
28. Nauta
29. El Treinta

Figure 1: (a) Location of critical open dumpsites and (b) sanitary landfills in Peru in 2017

3. Environmental assessment

3.1 Literature review

LCA of a waste management system is divided in the same stages as the LCA of a product. The main difference between the LCA of a product and of waste resides in defining the cradle and grave approach. Whilst it shares the same grave as individual products, the lifecycle of waste does not share the same cradle (Margallo, 2014). Moreover, whereas product-based LCA usually follows a single product from cradle-to-grave, a waste-LCA will assess the handling of several waste fractions from end-of-life to grave or remanufacturing. Generic LCA tools are not designed for the modelling of a reference flow consisting of a mix of materials (Clavreul et al., 2014). To take into account these very heterogeneous reference flows, several “add-on” models have been developed from the 2000s. Among all of them, the Technical University of Denmark (DTU) launched EASETECH, an upgrade of the EASEWASTE model developed in 2004, which provides inventories of waste management technologies to users for LCA modelling (EASETECH, 2017). This software allows modeling a range of different environmental technologies from a systems perspective, using a toolbox of processes. For each flow the user can define the collection system, transport mode and treatment in a defined number of processes (Clavreul et al., 2014). Since 2014, this software has been widely applied in LCA studies summarized in Table 1.

Table 1: Review of LCA studies on waste management using EASETECH model. MSW: municipal solid waste; BA: bottom ash; FW: food waste; CDR: construction and demolition residues

Authors	Year County	Type of waste	Description
Hadzic et al.	2017 Croatia	MSW	Comparison of landfill combining mechanical separation of recyclable fractions of mixed MSW
Syeda et al.	2017 Pakistan	MSW	Comparison of open dumpsite with a biogasification plant
Bisinella et al.	2017 Denmark	MSW	Quantification of the influence and uncertainty on LCA results associated with selection of waste composition data
Liu et al.	2017 China	MSW	Analysis of five scenarios based on landfilling and incineration
Grzesik and Malinowski	2017 Poland	Mixed MSW	Assessment of mechanical-biological treatment (MBT)
Grzesik and Malinowski	2017 Poland	RDF	Analysis of RDF production from mixed MSW, in a MBT plant
Grzesik	2017 Poland	mixed waste	Comparison of incineration and landfilling
Benavente et al.	2017 Spain	Olive mill wastes	Analysis of hydrothermal carbonization to treat olive mill wastes
Manfredi and Cristobal	2016 Europe	FW	Environmental and economic analysis of management European FW
Di Gianfilippo et al.	2016 Italy	Incineration BA	Evaluation of BA landfilling/ recycling as a filler for road sub bases
Vergara et al.	2016 Colombia	MSW	Analysis of alternative scenarios to formalize the recycling sector
Berge et al.	2015 USA	FW and CDR	Evaluation of hydrothermal carbonization of food wastes
Butera et al.	2015 Denmark	CDR	Modelling of CDR management
Carlsson et al.	2015	FW	Determination of the influence of FW pre-treatment efficiency
Jain et al.	2014 USA	MSW	Assessment of end-use management options for materials deposited and mined from an unlined landfill
Yang et al.	2014 China	MSW	Analysis of construction and operation of MSW sanitary landfills
Starostina et al.	2014 Russia	MSW	Study MSW system landfilling

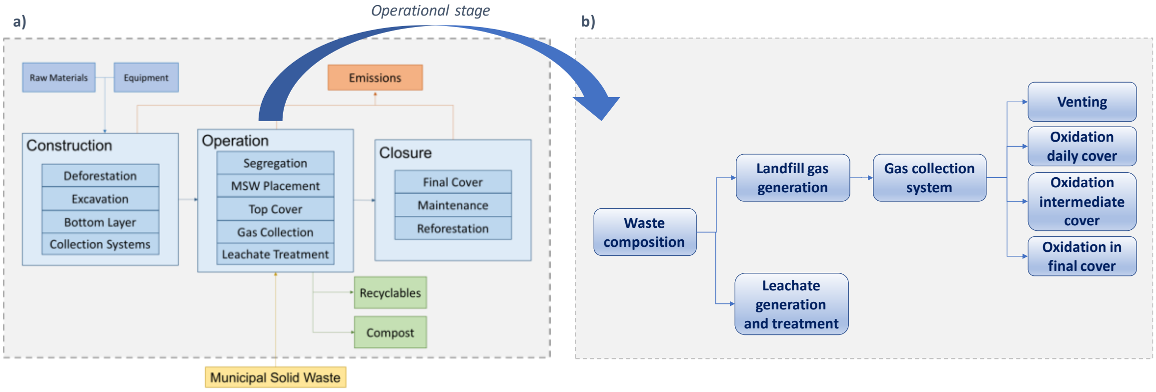


Figure 2: (a) System boundaries and (b) flow diagram of the operational stage

Table 2: Model characteristics

Model variables	Description
Landfill gas (LFG) generation	First order decay model (USEPA, 1998, 2005; IPCC, 2006)
LFG collection, burning	No
Energy generation	No
Leachate treatment	Recirculation
Daily and cell coverage	Clay, geotextiles and geo-membranes of HDPE

3.2 Model description and results

The life cycle model (Table 2) was developed with EASETECH (EASETECH, 2017), which suggests to include construction, operation and end-of-life phases. Based on this assumption, the system boundaries (Figure 2a) included raw material acquisition, landfill construction, transport and supply of materials, energy consumption and the release of pollutants in the three stages. Table 2 shows some technical characteristics of the model. As the main function of the system is to treat MSW, the functional unit (FU) was one metric ton of waste disposed of at the landfill to which all the inputs and outputs will be referred to. Primary data were collected from questionnaires supplied by different sanitary landfills. For secondary data the EASETECH software (EASETECH, 2017), the Ecoinvent database v3.3 (Ecoinvent, 2016) and bibliographic data were used.

3.2.1 Operational stage

Waste composition and the characteristics and treatment of the leachate and landfill gas (LFG) are the main parameters of operational step (Figure 2b), taking into consideration local parameters such as temperature, humidity and precipitation intensity. Table 3 shows the average waste composition in Peru (MINAM, 2017).

Table 3: Waste composition

Waste streams	Average composition (%)	Lower limit composition (%)	Upper limit composition (%)
Organic mater	52.2 %	50.6 %	61.0 %
Wood and pruning waste	2.30 %	0.30 %	4.80 %
Paper and cardboard	8.10 %	3.90 %	15.0 %
Glass	3.10 %	1.30 %	4.60 %
Plastics	9.80 %	5.35 %	14.1 %
Beverage carton	0.20 %	0.10 %	1.38 %
Metals	2.60 %	0.70 %	3.49 %
Textiles	1.90 %	0.60 %	2.45 %
Others	19.8 %	13.7 %	22.5 %

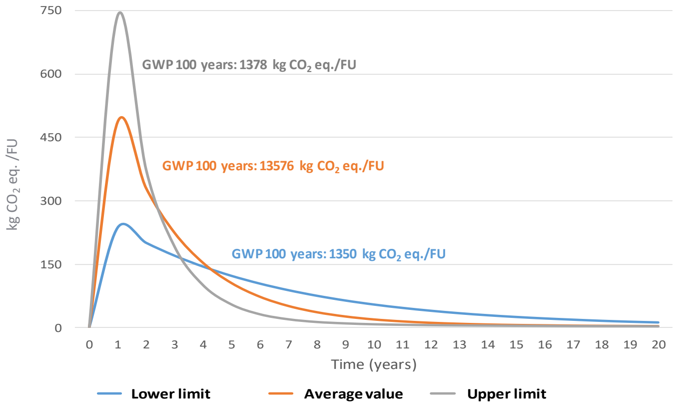


Figure 3: Global Warming Potential (kg of CO_2 eq./ t waste) in landfill gas generation for 20 years

However, waste generation and composition vary according to socioeconomic aspects, climatic, geographical and cultural conditions, the existence of waste planning systems or food habits (Taghipour et al., 2016). Moreover, rural areas and low income countries are likely to have a greater amount of vegetable, fruit and garden waste than inner city areas and high income countries ((White et al. 1997). These variations are visible in the three geo-climatic regions of Peru, which will have influence on both leachate and LFG generation. When speaking of landfilling, the location of the facility is critical in terms of waste degradation (Henriksen et al., 2017). Figure 3 shows global warming impact taking into account the lower, upper and average waste composition and the climatic conditions of the country. Total emissions generated in 100 years varies according to climatic conditions from 1350 to 1378 kg CO_2 eq./ t waste. These results confirm that landfills located in areas with warm tropical weathers and with a high organic matter content will have a higher generation of LFG and leachate, as temperature affects directly the anaerobic decomposition rates of waste, as well as other parameters (Machado, 2009). This happens as the LFG generation follows a first order decay model. The rate used in this equation fluctuated throughout the different modeled scenarios due to variations in geo-climatic conditions. Moreover, Figure 3 denoted that the highest emissions of greenhouse gases are produced in the 5 first years after waste disposal, getting after a steady state that is reached earlier for the upper limit waste composition.

Leachate was modelled having in mind local conditions, such as humidity, temperature and precipitation intensity. However, due to inability of measuring site-specific composition of both leachate and LFG, bibliographic data from the EASETECH software was used (Olesen and Damgaard 2014).

3.2.2 Capital goods of the landfill

Certain studies exclude capital goods because they present a low contribution to environmental impacts (Brogaard et al., 2013). However, in this study capital goods such as infrastructure and machinery were quantified and assigned to the FU according to their lifespan, the landfill's lifetime and the amount of residues intended to perceive during the whole landfill's life. Nevertheless, because of their low contribution to the whole impact (0.17 %), these elements were modelled using the Ecoinvent database v3.3 (Ecoinvent, 2016).

4. Conclusions

The removal of open dumpsites and the improvement of sanitary landfills are some of the challenges that Peru should meet in the not too distant future. This study develops a life cycle model to evaluate the environmental performance of the current sanitary landfills based on the technological and geo-climatic conditions of Peru. The model includes as key parameters waste composition, characteristics and treatment of the leachate and landfill gas, as well as temperature, humidity and precipitation intensity. These parameters can be adapted to the three geo-climatic regions of the country. The model lays the foundation stone to determine the main hot spots of the Peruvian sanitary landfills. Based on these results, further studies will be focusses on the comparison of several waste alternatives. This information will allow achieving an adequate and sustainable waste management strategy by proposing improvement measures to help stakeholders in the decision-making process.

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