Journal of Cleaner Production 47 (2013) 368–376

Contents lists available at SciVerse ScienceDirect

Journal of Cleaner Production

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

Improving the environmental performance of an earthwork project using cleaner production strategies

Juan José Cabello Eras [a,*], Alexis Sagastume Gutiérrez [a], Danny Hernández Capote [b], Luc Hens [c], Carlo Vandecasteele [d]

[a] Universidad de Cienfuegos, Carretera a Rodas, Cienfuegos, Cuba
[b] Unidad Inversionista Expansión Refinería "Camilo Cienfuegos", Cuba
[c] Vlaamse Instelling voor Technologisch Onderzoek (VITO), Boeretang 200, B2400 Mol, Belgium
[d] Department of Chemical Engineering, K.U. Leuven, Belgium

ARTICLE INFO

Article history:
Received 20 April 2012
Received in revised form
13 November 2012
Accepted 20 November 2012
Available online 2 December 2012

Keywords:
Earthwork
Cleaner production
Life cycle analysis
Construction

ABSTRACT

A quantitative assessment of the environmental impact of construction activities is useful to identify the main environmental impacts and to improve their environmental footprint. This study presents the life cycle assessment of an earthwork project. The results show that earthwork activities entail important environmental impacts; mainly energy consumption, global warming and human toxicity. This study proposes and implements cleaner production strategies, based on the hierarchy of waste management, to improve the environmental performance of the earthwork project. The approach allows reducing the amount of soil to be used by the earthwork project. Moreover both the diesel consumption and the greenhouse gas emissions can be reduced by about 41%. This coincides with a saving of about 1.76 million dollars.

1. Introduction

Construction is not an environmentally friendly process (Li et al., 2010; Tam, 2009). As construction increasingly became a pollution source, the pressure on the sector for improving its environmental performance has increased (Shen et al., 2005). The expansion of the construction industry is increasingly associated with sustainable development challenges (Zhao et al., 2012), but it is still lagging behind other sectors (Tsai and Chang, 2012).

The environmental impact of the construction industry is mainly related on the one hand, with high consumption of natural resources and on the other hand, with the large amounts of residues generated (Tchobanoglous et al., 1994). Construction processes also generate large quantities of greenhouse gases (GHG) (Li et al., 2010). Moreover, these emissions are as a rule not properly quantified (Kenley and Harfield, 2011). Kenley and Harfield (2011) state that "… *the methodologies and measures related to* CO_2 *and other greenhouse gas emissions (GHGE) for construction processes are yet to be developed*". Emissions of CO_2, causing climate change, are one of the most serious environmental threads of our time (Benhelal et al., 2012).

Over the last 20 years, the construction industry made important progress on the way to sustainability partly due to the implementation of ISO 14001 and related standards. However, most efforts focused on the sustainability of construction materials, rather than on the construction processes (Ding, 2008).

During the construction process, waste is mainly generated as a result of earthwork, building and demolition of roads (Quebaud, 1996). The main residues are: soil and stones as a result of the excavations and earthwork, concrete, wood, plastics and metals (Amores, 2009).

The earthwork has limited impacts as compared to the construction process as a whole. It involves the manipulation and movement of soil and stones during the execution of a project (Kenley and Harfield, 2011). The generated residues (stones, soil, etc.) are inert materials (Mercante, 2007).

Relocating stones and earth has important environmental impacts and proves sometimes being the most impacting stage of the process. Norgate and Haque (2010) recommended researching the influence on the GHG emissions. Most research in this field focuses on the reduction of the costs and of the execution time of the project, rather than on the reduction of the environmental impacts (Kenley and Harfield, 2011; Gangolells et al., 2009).

* Corresponding author.
E-mail address: jcabello@ucf.edu.cu (J.J. Cabello Eras).

0959-6526/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jclepro.2012.11.026

Optimizing the earthwork allows to reduce the fuel consumption of the automotive fleet. Indicators were established to control and to improve the technical state of the fleet. The results of this research show that diesel consumption represents 88% of the energy consumption of the earthwork activities and nearly 50% of the production costs (Dipotet, 2010).

> "*Earthwork planning is done at both the tender and the contract stages of a project. There are differences between these two stages. At the tender stage, the available data are often incomplete and thus, the planner has to make assumptions. At the contract stage, when more data are available (including data regarding other non-earthworks activities that have been planned at tender stage), the earthwork activities are regenerated in an iterative manner.*" (Askew et al., 2002).

The issues associated with traditional contracting methods of infrastructure projects, that often resulted in problems of cost overruns, project delay and quality issues, have been discussed. As a result, in recent years, approaches changed towards the integration of project design and assessment, construction, operation and maintenance (Arts et al., 2007; Lenferink and Arts, 2009; Arts and Faith-Ell, 2010).

Cuba still needs implementing the integration of the different stages of construction projects with the contracting stage. Construction projects are not subject to a bidding process. In general, one just accepts the projects which are proposed by the construction companies. Also, considering that the income of construction companies depends of the volume of the project, usually earthwork projects are over dimensioned, which increases the fuel consumption, the volume of soil to be excavated and the demand for filling material.

The construction industry in Cuba, as in many developing countries, operates without a culture of sustainability and without adequate environmental management (Amores, 2009). The ministry of construction (MICONS) has created a commission for the protection of the environment and the rational use of resources. This commission identified the main environmental impacts of the construction activities in Cuba, but considered mainly those related to production of construction materials, rather than those related to project execution (PNUD, 2003). The GHG emissions are not discussed.

This work aims at reducing the environmental impacts and the economic costs of an earthwork project using environmental tools such as life cycle assessment (LCA) and cleaner production (CP).

2. Materials and methods

Quantitative methods such as LCA allow evaluating the associated environmental impacts. LCA is a well-established method to evaluate the environmental impacts of a product, service, or project "from cradle to grave" (Cheng and Ni-Bin, 2012), contributes to modern environmental management (Huntzinger and Eatmon, 2009) and provides indicators to monitor environmental pollution (Berger and Finkbeiner, 2011). The International Standards Organization (ISO) defined LCA as (ISO, 2006): "A systematic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the functioning of a product or service system throughout its life cycle". The ISO standards outline four steps of the LCA methodology (ISO, 2006):

1. Determination of the assessment scope and boundaries;
2. Selection of inventory of inputs and outputs;
3. Assessment of environmental impact data compiled in the inventory using an environmental impact assessment methodology;
4. Interpretation of results and suggestions for improvement.

LCA allows optimizing the production process by identifying its most significant impacts (Sagastume et al., 2012). The application of LCA in civil engineering, initially as a tool for assessing solid waste management options, has started only in the last decade (Huang et al., 2009). An example of the LCA of an earthwork project is reported by Xiaodong et al. (2007). The authors show that the use of borrow pits entails important environmental impacts and that the earthwork activities adversely impact human health. Also, Angelopoulou et al. (2009) discuss the LCA of the construction and maintenance of a motorway. They show that the earthwork stage is a major contributor to GHG emissions. One aspect of the LCA is that commonly some information relevant for its development is of limited quality or not available. De Benedetto and Klemes (2009) point to important limitations of LCA related to data quality and data collection and indicate that in most LCA studies implicit assumptions are made.

In order to limit the environmental impact of technical facilities an environmental impact assessment (EIA) method has been combined with cleaner production (CP) (Fijal, 2007; Salvador et al., 2000). According to Tukker (2000), the underlying approach to environmental evaluation in both EIA and LCA is based on the same principles. One important difference (Tukker, 2000) is that the impact yardstick used in an EIA depends of the project under scope. While the impact yardstick used in a LCA is defined by the impact assessment method selected for the evaluation of the environmental impact of the data compiled in the inventory. Therefore, considering the similarities of EIA and LCA, CP could be also combined with LCA aiming to reduce the environmental impacts of an earthwork project.

CP was defined by the United Nations Industrial Development Organization (UNIDO) (Kazniierczyk et al., 2002) as a preventive, integrated strategy that is applied to the entire production cycle in order to:

a) Increase productivity by ensuring a more efficient use of raw materials, energy and water;
b) Promote better environmental performance through reduction at source of waste and emissions;
c) Reduce the environmental impact of products through their life cycle by the design of environmentally friendly but cost-effective products.

The environmental impact of a process is linked to its (in)efficiency. CP mainly focuses on the efficient use of materials and energy (Fresner, 1998). An improved use of resources contributes to competitivity and profit, and also the environmental performance of a company (Strazza et al., 2011; Taylor, 2006). Therefore, within the scope of CP, waste generation is considered as process inefficiency. The hierarchy for waste management in CP is (Rigola, 1998; Cagno et al., 2005):

1. Eliminate or reduce the waste generation at its origin;
2. Recycle and reuse (the recycling can be in site or off site);
3. End of pipe treatment;
4. Controlled deposit.

Minimization of waste at the source is not well known in the construction industry and most investigations about residues focus on developing new technologies to recycle and reuse residues. This is a reactive rather than a proactive strategy. This situation can, however, be corrected and reversed implementing cleaner production strategies.

3. Expansion of the Oil Refinery "Camilo Cienfuegos"

The Oil Refinery "Camilo Cienfuegos" is located in the bay of Cienfuegos in the South of central Cuba. Fig. 1 shows the location of