Journal of Cleaner Production 201 (2018) 820–829

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Life cycle carbon dioxide emissions for fill dams

Sookack Noh [a], Younghwan Son [b, c, *], Jaesung Park [d]

[a] Civil Design Team, Daelim Industrial Co., Ltd., Seoul, South Korea
[b] Department of Rural Systems Engineering, Seoul National University, Seoul, South Korea
[c] Research Institute for Agriculture & Life Sciences, Seoul National University, Seoul, South Korea
[d] Division of Environmental Science & Technology, Graduate School of Agriculture, Kyoto University, Kyoto, Japan

ARTICLE INFO

Article history:
Received 13 June 2017
Received in revised form
10 August 2018
Accepted 10 August 2018
Available online 13 August 2018

Handling Editor: Yutao Wang

Keywords:
Life cycle assessment
Infrastructure
Fill dam
Survival function
Carbon dioxide emissions

ABSTRACT

The construction industry including infrastructure construction, affects the environment due to the use of a considerable amount of resources and energy. The management of the environmental effect of dams for agricultural reservoirs is especially important in South Korea because of their large scale and nationwide distribution. The objective of this study is to propose an assessment method for evaluating life cycle carbon dioxide emissions associated with fill dams and to characterize carbon dioxide emissions to use in effectively addressing the environmental concerns for infrastructures. A total of four dams were selected for the research, and the material production, use of equipment and transportation were considered as the causes of carbon dioxide emissions at the dams. The effective life cycle of a fill dam was assumed to be 100 years. The results of the research indicated that the total amount of carbon dioxide emissions were different for each dam according to their characteristics, and the results showed that the dam size is the primary cause. In addition, the carbon dioxide emissions increased as the period of use increased, and a rapid increase was indicated in 40–50 years interval of the dams' use periods because the repair activities were concentrated in those years. Materials were the biggest contributor in the amount of total carbon dioxide emissions at all four sites and the ratio of carbon dioxide emissions caused by materials was higher than any other factors in most processes. There was little difference in the proportion of carbon dioxide emissions for each process in the total carbon dioxide emissions for the four sites. Most carbon dioxide was emitted during repair activities at the two largest dams. Activities associated with the construction process was the major source of carbon dioxide emissions at the two other dams. This difference in process carbon dioxide emissions was the result of the difference in the construction scale for the embankment elevation. The assessment method that has been proposed in this study reflects the characteristics of fill dams, and the result of estimating carbon dioxide emissions indicates that we are able to reduce carbon dioxide emissions in the life cycle of fill dams by selecting the construction materials and the repair methods with a low carbon dioxide emissions.

1. Introduction

Concerns about the local and global environment are rising all over the world as a result of environmental problems caused by intensive environmentally harmful human activities such as the burning of fossil fuels, deforestation and land use changes (Buchanan and Honey, 1994; Koomey et al., 2001a, 2001b; Khasreen et al., 2009). Currently, global warming is one the most serious environmental problems, and requires special attention from the government, industry and the people. (Buchanan and Honey, 1994; Bilec, 2007; Khasreen et al., 2009). Green-house gases (GHG) should be considered when assessing environmental impacts because global warming is the consequence of long term formation of GHG in the upper layers of the atmosphere. In addition, many researchers have investigated GHG emissions because they can be more readily quantified than other impacts (Buchanan and Honey, 1994). In addition, the research about carbon dioxide (CO_2) emissions was conducted in many industry fields because CO_2 is a major cause of global warming and accounts for 80% of total greenhouse gas emissions CO_2 emissions (Gustavsson et al., 2010; Noh et al., 2014a).

The construction industry is considered to be one of the greatest

* Corresponding author. Department of Rural Systems Engineering, Seoul National University, Seoul, South Korea.
E-mail address: syh86@snu.ac.kr (Y. Son).

https://doi.org/10.1016/j.jclepro.2018.08.099
0959-6526/

contributors of CO_2 emissions. This is because it consumes substantial amount of natural resources, such as energy, water, land and minerals. (Raynsford, 1999; Bilec, 2007; Fairmairn et al., 2010; Gustavsson et al., 2010). In South Korea, 40% of the total energy is expended by the construction industry, which produces approximately 42% of the total CO_2. (Seo et al., 1998; Kim et al., 2004). Therefore, total CO_2, which is emitted during the entire life cycle of a structure, should be accurately quantified for activities in the construction industry to prevent global warming (Ochoa et al., 2002; Junnila and Harvath, 2003; Noh et al., 2014a, 2014b).

For this reason, a considerable amount of research regarding life cycle CO_2 emissions has been performed on activities associated with the construction industry but most of the research focused on the materials and some of the processes in construction project (Lippiatt and Norris, 1995; Nicoletti et al., 2002; Horvath, 2004; Flower and Sanjayan, 2007; Tae et al., 2011; Hong et al., 2012), and has targeted construction with relatively well-defined designs such as buildings, bridges and roads (Eaton and Amato, 1998; Citherlet, 2001; Park et al., 2003; Treloar et al., 2004; Sharrard, 2007). Thus, a life cycle CO_2 emissions assessment about various infrastructures, which can include the full duration of a construction project, must be performed to help understand the environmental impacts of the construction.

Dams are one of the oldest structures that humans built for the sake of collecting. They can be mainly divided into fill dams, concrete gravity dams and concrete arch dams. Fill dams are defined to be made of all kinds of earth materials such as soil and rock. These days, a great number of fill dams have been built nationally and globally. This increasing trend are due to the good adaptability to geological and topographical circumstances, the resistance on rigid climate, the ease on materials and goods from exterior region, the economy of construction material quantities, the saving of time on construction process, the freedom from danger in operation and the easier maintenance. Particularly, from 2005 more than 150 fill dams have been constructed or is in process of building in China (HongQi and Cao, 2007). In addition, there are approximately 17,000 agricultural reservoirs in South Korea, most embankments of which are fill dam type (Um et al., 2004). Thus the management of the environmental effects of fill dams is important in South Korea, because of the large scale of fill dams and their distribution nationally. The management of pollutant emissions during infrastructure construction is needed to assure development that includes environmental awareness. The management of pollutant emissions should include the assessment of life cycle CO_2 emissions because infrastructure repairs require considerable resources and emit various pollutants, including CO_2.

Therefore, the objective of this study is to propose an assessment method for evaluating life cycle CO_2 emissions associated with fill dams and characterize the method through the analysis of dams of agricultural reservoirs in South Korea, with an emphasis on fill dams.

2. Methodology

2.1. Study area

Dams of four reservoirs located in South Korea that could provide data about the construction process and the status of embankments were selected to estimate life cycle CO_2 emissions for the earth fill dams. Dams, which were constructed lately and had a lot of relevant information among construction sites of reservoir embankment elevation, were selected in order to analyze the construction statement that is able to describe the construction process of fill dams for this research. At first, the dam, which was established newly, was selected for estimating CO_2 emissions during construction of the fill dam. Additionally, three more dams, which other methods of the reservoir embankment elevation were applied, were selected in order to analyze the characteristics of CO_2 emissions according to the method. The status of each reservoir is presented in Table 1.

2.2. System boundary

An entire life cycle of an earth dam includes the production of materials, construction, operation and demolition (ISO, 2006; Noh et al., 2014b). Fig. 1 explain the method of the life cycle assessment. In this study, the life cycle is limited from the material manufacturing to the construction, the use, maintenance and reinforcement over the entire life cycle of the embankment because the embankment is installed to remain in place indefinitely, without a disposal stage. CO_2 emissions for each of the individual processes were estimated separately based on the construction materials, equipment and transportation. System boundary of this research is shown in Fig. 2.

Moreover, the period of analysis was assumed to be 100 years. The service life of agricultural reservoirs is defined to be 60 years. However, a lot of dams are being still used in South Korea although it has been more than 60 years since the construction through appropriate reinforcements. Therefore, the life cycle of fill dams was defined 100 years based on current situation in this research. The hybrid method is used in the estimation of life cycle CO_2 emissions. The process method is generally considered in the analysis regarding life cycle and the Energy Input-Output (EIO) method is used in the calculation of density of CO_2 emissions for materials.

Electricity consumption was the only activity considered for the use stage because an automatic system operates during this stage, which eliminates the need for other energy and materials to be

Table 1
Description of study area.

Classification		Sindong	Bocheong	Maehwa	Woongyang
Capacity	Total (10,000 ㎥)	1887	–	257	3291
	Effective (10,000 ㎥)	1881	–	255	3185
Embankment	Classification	Fill dam (Zone type)	Fill dam (Zone type)	Fill dam (Zone type)	Fill dam (Zone type)
	Height (m)	19.5 → 25.5	35.5 → 37.8	23.8 → 28.8	47.5 → 50.7
	Length (m)	149	418	154	356
	Width of crest (m)	6	8	7	8
Gradient	Up slope (Vertical:Horizon)	1:2.8	1:3.0	1:2.7	1:3.5
	Down slope (Vertical:Horizon)	1:2.5	1:2.0	1:2.5	1:3.0
Construction type		New establish of the embankment	Raising the crest of the embankment	Extension of the backside of the embankment	Raising the crest of the embankment