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Incorporating life cycle assessments into building project decision-making: An energy consumption and CO_2 emission perspective

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ABSTRACT

In the past two decades, the globalization of financial markets and multinational trade has intensified internationally, and become increasingly competitive. In the construction industry, critical changes are initiated to reduce operating costs for achieving sustainable operation. Conventional cost pricing for building projects no longer apply as energy shortage and environmental pollution are new challenges faced by construction companies. Many countries have attempted to solve the CO_2 emission problems by levying a carbon tax, which leads to a higher cost for construction companies. Therefore, this study aims to adopt life cycle assessment (LCA) in order to assess CO_2 emission costs and apply a mathematical programming approach to allocate limited resources to maximize profits for construction companies.

1. Introduction

In the past two decades, the globalization of financial markets and multinational trade has intensified internationally, and become increasingly competitive. In the construction industry, critical changes are initiated to eliminate operating costs for achieving sustainable operation. The emission of greenhouse gases (GHGs), particularly CO_2 emission [1], has posed a serious problem on the global climate system. The construction industry is responsible for 40% of the primary energy use, and 36% of energy related CO_2 emissions in industrialized countries [2], because the production of materials and construction process can significantly increase atmospheric concentrations of GHGs [3]. Many countries have attempted to solve the CO_2 emission problems by levying a "Carbon tax" in order to increase the operating cost of high-energy intensive firms.

Zhang and Baranzini [4] argued that a carbon or energy tax produces "winners" and "losers", as the different relative impacts on production costs are imposed on both low- and high-energy intensive firms. Sathre and Gustavsson [5] suggested that environmental taxation may act as an economic incentive to overcome organizational inertia, encouraging firms to adopt innovations that result in both lower environmental impact and increased economic benefits. However, as opposed to other well-examined fields, such as cost pricing of building projects [6], research on the considerations of carbon tax incorporated with project management is minimal. Therefore, this paper takes CO_2 emission costs into consideration in order to help construction companies maximizing their profits.

Many previous studies suggest that the life cycle assessment (LCA) is a powerful and internationally accepted system analysis tool that measures energy efficiency and energy conservation assessments throughout material life cycles [7,8], as acknowledged by a growing number of studies [1,9–11]. Hence, this study applied the LCA method to measure energy consumption and CO_2 emissions, in order to gain a better understanding of energy use during construction process, and determine CO_2 emissions over the life cycle of building projects. Hoinka and Ziebik [12] applied a mathematical approach to assess the energy management of complex buildings, and pointed out that energy management is an essential problem of complex buildings. Very few researches have simultaneously adopted a mathematical programming approach and LCA method for construction companies to maximize profits on building projects. The contribution of this study is that it incorporates CO_2 emission costs into mathematical programming, thus allowing construction companies to evaluate CO_2 emissions of building projects.

The remainder of this paper is organized as follows: Section 2 introduces the background of the carbon tax, CO_2 emissions, and

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the LCA method used in this study. Section 3 presents the proposed model adopted mathematical programming methods. Section 4 discusses a numerical example to demonstrate the proposed model. Finally, the conclusions and future developments are addressed in Section 5.

2. Research background

2.1. Carbon tax and CO_2 emission costs

Energy shortages and environmental pollutions have become major technological, societal, and political challenges around the globe [8,13], and several researches have addressed these problems. Lee et al. [14] proposed that applications of price mechanisms are important instruments for carbon reduction, among which the carbon tax has been frequently advocated as a cost-effective economic tool. They also showed that some European countries, such as the Netherlands, Denmark, Sweden, Finland, and Norway, have implemented carbon taxes for over 10 years, while Italy, Germany, and the UK also began to levy carbon taxes between 1999 and 2001. Herber and Raga [15], and Sathre and Gustavsson [5] proposed that carbon and energy taxation would increase financial incentives to reduce emissions of carbon into the atmosphere, thus, combating global warming.

With increasing concerns about ecological preservation since the late 1980s, building energy efficiency has been under serious considerations [8,16,17]. The construction industry, as one of the fastest growing industry in terms of energy consumption, is responsible for 40% of the primary energy use, and 36% of the energy related CO_2 emissions in industrialized countries [2,18]. Thus, building energy is an important issue, as energy is one of the most critical resources used over the lifetime of a building [19]. For construction companies, higher CO_2 emissions would lead to higher carbon taxes, which would result in higher building costs.

Related research focuses on two areas, namely, the exploration of the reduction of energy consumption in building environments [20–23], and the examination of the effects of carbon taxes on building competitiveness [5,24]. However, as opposed to the above well-examined researches, studies on incorporating CO_2 emission costs with building project costs are minimal. Upon this focus, by taking CO_2 emission costs into consideration in building projects, the findings of this study can serve as a reference to construction companies in decision-making.

2.2. Application of LCA in the building project

Development of modern evaluation methods that apply the LCA method in building energy conservation assessments have become a trend [8,10,25–28]. Many previous studies suggest that LCA is a powerful and internationally accepted system analysis tool, which studies environmental aspects and potential impacts of a product or service system throughout its life cycle [8,29–32]. This study attempts to apply LCA method in evaluating energy use and carbon emissions created during construction processes. Given the complexities of interactions between construction processes and natural environments, LCA represents a comprehensive approach to examine the environmental impacts of an entire building project.

Building projects include the sub-division of phases and terms, all of which cause environmental impacts, such as materials production, transportation, construction wastes, pollutants, and materials consumption [8,11]. Ward and Chapman [33] proposed that a project lifecycle is commonly divided into four phases, namely, conceptualization, planning, execution, and termination, where both the level of resources employed and the rate of expenditures are very different in each phase. In addition, the majority of expenditures occur within the execution phase [33].

Therefore, this study is divided into three phases in order to illustrate the energy consumption and CO_2 emission costs of building projects:

(1) Design and planning phase (conceptualization and planning): this phase causes little energy consumption (e.g., burdens from electricity used for lighting) [8,11].
(2) Construction phase (execution): the phase causes the majority of energy used (e.g., the production and transportation of building materials; diesel fuel used by heavy equipment; burdens from electricity used for power tools and lighting) [9,23].
(3) Delivery and maintenance phase (termination): this phase causes some end-of-life energy consumption (e.g., disposal the waste treatment by burdens from electricity used for power tools and lighting; diesel fuel used by heavy equipment) [1,7].

2.3. Summary

LCA is internationally acknowledged as a science-based, fairly comprehensive, and standardized environmental assessment methodology, which is used in several sectors, including the construction industry, with a wide range of applications [7]. One of the most important extensions of related research is in the area of energy consumption and CO_2 emissions [1,8–11]. The LCA method can acquire a comprehensive view of a project's entire-life environmental cost, which implies that the environmental and social costs (e.g., CO_2 emission costs) of all phases in the building project life cycle are assessed. Therefore, this study applied the LCA method to analyze the energy consumption and CO_2 emission costs in a building project. The calculation processes of building project costs are briefly described as follows.

3. Model formulation − assessing building project costs

Project costs must be determined in a relatively short time by project managers as a reference for evaluating competitive bids [6]. The information regarding all cost items on project bids must be known and assessed in advance in order for managers to make accurate judgments. Conventional construction costs include material costs, labor, and equipment cost, but exclude value added tax [5], which would lead to improper measurement. The reason is that CO_2 emission costs are critical, and have become one of the major cost items in recent years. In order to address related problems and accurately calculate the total costs of a building project, this study classified these cost items into four categories [2,5,22,34], namely (1) materials costs: including the cost of raw materials and goods purchased from other categories of the industry; (2) labor costs: including the personnel expenses and other added costs; (3) machine costs: including equipment for operating and completing building projects; and (4) environmental and social costs: including the costs of environmental pollution, and paying carbon taxes. This study only considered the above costs, while regarded other costs as unchangeable fixed costs.

A flowchart is used to illustrate the costs of a building project, as shown in Fig. 1. This study was divided into two main stages; the first focuses on applying the LCA method to assess CO_2 emission costs, while the second focuses on incorporating the above costs (e.g., direct material costs, direct labor costs, direct machine costs, and CO_2 emission costs) through a mathematical programming approach in order to identify the optimal building project. This study is a pioneer in incorporating CO_2 emission costs into building project costs, and offers construction companies comprehensive considerations in decision-making.