Ecological Indicators 67 (2016) 68–77

Contents lists available at ScienceDirect

Ecological Indicators

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

Ecological indicators for green building construction

Hongxun Liu[a], Boqiang Lin[b,*]

[a] Collaborative Innovation Center for Energy Economics and Energy Policy, China Institute for Studies in Energy Policy, Xiamen University, Fujian 361005, PR China
[b] Newhuadu Business School, Minjiang University, Fuzhou 350108, PR China

ARTICLE INFO

Article history:
Received 26 October 2015
Received in revised form 27 January 2016
Accepted 5 February 2016
Available online 25 April 2016

Keywords:
Green building construction
Ecological indicators
Meta-frontier technologies
Slack-based efficiency measure
Regional heterogeneities

ABSTRACT

Building construction is one of the largest final consumers of environmental resources as well as one of the largest emitters of greenhouse gas and other pollution. This paper aims to propose ecological indicators for green building construction by applying a slack-based data envelop analysis approach, in which resource conservation and environmental protection are both incorporated. We conduct an empirical analysis of ecological indicators for green building construction using China's regional panel dataset during 1995–2012, and use the analysis to further discuss the technological gaps across the regions. The findings show that: (i) half of China's provinces have a substantial potential increase of more than 60% in ecological performance for green building construction; (ii) the developed areas perform better than the developing areas; (iii) the 11th five-year plan period is a turning point for China's green building construction and development as the policies for green construction have significant effects.

1. Introduction

Building activity is one of the most important human activities, and plays a determining role in the formation of the social environment. But simultaneously, it is also a significant consumer of natural resources and an emitter of greenhouse gas (GHG) as well as other wastes, resulting in irreversible impacts on the natural environment. Statistically, the building sector contributes approximately 50% of final energy consumption in the world and 42% of global GHG emissions during its total life cycle (Guggemos and Horvath, 2005).

In the 1980s, the agenda for green and sustainable development gathered momentum. Under the influence of this movement, the building sector began to attach importance to energy conservation and emission mitigation during its life-cycle, especially in exploration, transportation and processing of building materials, construction, operation, maintenance, renovation, and demolition. In 1992, the concept of "green building" was formally proposed at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, indicating that buildings should meet occupants' needs of comfortable living environment without compromising the ability to save energy and reduce environmental impacts (Wang et al., 2005).

As GHG reduction has become a priority in various industries, buildings are presently designed and constructed to be more energy efficient in their operation. Subsequently, many researchers find that energy conservation and emission reduction in the construction stage is of great importance (Dimoudi and Tompa, 2008; Taylor et al., 2013). More than ever, building construction industry is concerned with improving environmental indicators of sustainability (Ortiz et al., 2009). It is estimated that building construction accounts for 23% of total energy consumption in the whole life-cycle of a building. In some low energy consuming buildings, the rate even reaches 40–60% (Ye, 2012). Building construction is increasingly important to meet energy conservation and climate change mitigation challenges, especially in the context of accelerating urbanization process for many developing countries (Koebel et al., 2015). In 2007, the Chinese Ministry of Construction (CMC) formally proposed a concept called "green construction", referring to a goal of construction activity that maximally saves resources and reduces its environmental impacts without compromising the quality and safety of constructions using scientific management and advanced technologies.

Although the whole world has reached a consensus on sustainable development, the choice for green building construction is in fact a public goods game. On the side of construction enterprises, there are profits to be made by neglecting sustainability and environment. On the other side, for public goods like the environment, they could be lost due to selfish incentives and neglect of cleaner construction. It implies that without governments' well-adjusted plans and polices, green construction cannot

* Corresponding author at: Newhuadu Business School, Minjiang University, Fuzhou, Fujian, 350108, PR China. Tel.: +86 5922186076; fax: +86 5922186075.
E-mail addresses: bqlin@xmu.edu.cn, bqlin2004@vip.sina.com (B. Lin).

http://dx.doi.org/10.1016/j.ecolind.2016.02.024
1470-160X/

be achieved through self-evolution of market mechanisms (Lin and Liu, 2015a).

Policy makers have long been concerned about ecological performance assessment, which is also vitally important for effective green construction plans and policies (Ahlroth et al., 2011). Numerous works have been developed to measure and evaluate how the building sector performs with respect to balancing energy, environment and ecology. In 1990, the Building Research Establishment (BRE) launched the first assessment method for building ecological performance: *Building Research Establishment Environmental Assessment Method* (BREEAM). It includes management, health and wellbeing, energy, transport, water, materials, land use and ecology, waste and pollution assessment of individual building. Following the BREEAM, many other assessment methods are successively launched around the world to promote green building and construction. In 1993, the U.S. released *Guiding Principles of Sustainable Design* (GPSD), listing several environmental indicators for assessment of sustainable building. The indicators mainly aimed at building energy efficiency and waste disposal over its life. In 1995, the U.S. Green Building Council (USGBC) developed the *Leadership in Energy and Environmental Design* (LEED). It is now used as statutory compulsory green building standards in some states in the U.S. as well as in some other countries. In 2004, the *Comprehensive Assessment System for Building Environmental Efficiency* (CASBEE) was launched in Japan, as a co-operative project between government and building industries. CASBEE is based on the concept of closed ecosystems to determine the environmental capacities and the latest version was updated in 2014.

Ding (2008) overviewed several widely used building and construction environmental assessment methods in different countries and concluded that current assessment methods did not adequately consider environmental impacts. Kuzman and Petra Grošelj Ayrilmis (2013) made a comparison of passive house construction types by applying analytic hierarchy process. Hwang and Leong (2013) indentified a set of factors affecting green construction project delay based on various literature reviews and a survey of 30 companies in the Singapore construction industry. Yan et al. (2014) discussed the achievement of green construction by using the controlled low-strength material, which is derived from the recycle of bottom ash and sediment. Whang and Kim (2015) developed an assessment of factors for sustainable construction project in Korea by concentrating on environmental issues as well as economic and social dimensions.

The previous widely used assessment systems have set several lists of ecological indicators for green building construction. They successfully alerted governments and contractors of the importance of ecological performance for building construction. However, most of them aim at setting up ecological performance indicators for individual building and providing rating certification for green buildings. They are not applicable to evaluate ecological performance for building construction industries, which are necessary for effective plans and polices. Moreover, the current assessment methods do not take technology limits or interactions of various input factors in the construction process into consideration.

The objective of this paper is to fill the research gap by establishing a comprehensive ecological indicator for assessment of green building construction from the view of industry, by taking into account both economy and technology aspects of building construction. The rest of the paper is organized as follows. Section 2 introduces how to establish the comprehensive ecological indicator for green building construction. Section 3 conducted an empirical analysis using China as an example. The results are discussed in detail in this section to explore the implications, particularly for green construction policy makers and building contractors in China. Section 4 further measures regional heterogeneities based on two different technological frontiers. Section 5 finally concludes the main findings and policy implications of this paper.

2. Methodologies

2.1. DEA-SBM model

To the public and occupants, green building construction refers to a goal of construction activity that maximally saves resources and reduces its environmental impacts without compromising the quality and safety of constructions. But from the view of construction enterprises, green building construction means balancing resource consumption, economic benefits and environmental impacts. This is equally important for governments, especially in countries such as China where building construction is a pillar industry of the national economy. That is, the best ecological performance for green building construction can be identified as an achievement of the construction industry that maximally saves resource consumption and reduces its environmental impacts without compromising its economic benefits within the existing technological limitations.

Considering resource consumption, economic benefits and environmental impacts as inputs, as well as desirable and undesirable outputs of the construction industry, data envelop analysis (DEA) can be an effective tool to provide quantitative performance assessment indicators for green building construction. This method has an exclusive advantage in assessing performance of any socio-economic systems with multiple inputs and multiple outputs, and has been widely developed and applied to measure energy efficiency and environmental performance since 1978 (Sueyoshi and Goto, 2011; Rogge, 2012; Song et al., 2013; Jin et al., 2014). For instance, Chang et al. (2013) measured environmental performance of China's transport sector under DEA framework. Chen et al. (2015) adopted DEA method to establish assessment indicators for environmental performance in 30 provinces of China. Song et al. (2015) developed a set of network DEA models to study changes in environmental performance among several petroleum enterprises in China.

DEA is in principle an operational research approach based on production theory. It is nonparametric without any specific functional form requirement. DEA identifies the best practice within a set of comparable decision-making units (DMUs) and form an efficient frontier, by building and solving a linear programming mathematical model, as shown by OABCDE in Fig. 1. The efficient frontier is treated as an environmental technology with more desirable outputs and less environmental impacts relative to less input resources (Färe et al., 2007). DMUs located at the efficient frontier have the best performance while the rest DMUs inside the frontier are identified as inefficient.

In fact, some researches have already attempted to measure total-factor energy efficiency of building construction industry

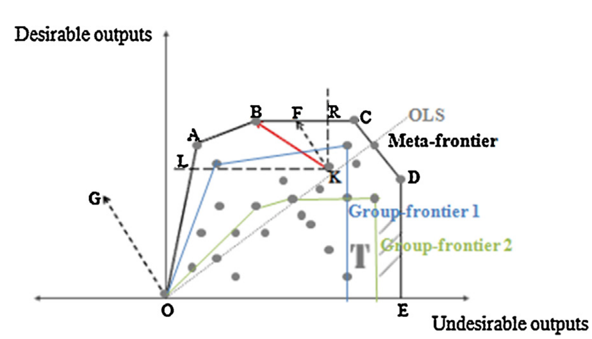

Fig. 1. DEA framework with undesirable outputs.