Building and Environment 85 (2015) 173–181

Contents lists available at ScienceDirect

Building and Environment

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

An environmental impact assessment framework and index system for the pre-use phase of buildings based on distance-to-target approach

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ARTICLE INFO

Article history:
Received 29 July 2014
Received in revised form
8 November 2014
Accepted 27 November 2014
Available online 9 December 2014

Keywords:
Building environmental impact
Pre-use phase
Life cycle assessment (LCA)
Distance-to-target
Index system

ABSTRACT

This paper presents an LCA-based environmental impact assessment model and an evaluation index system for the pre-use phase of buildings using distance-to-target as weightings. Environmental impacts are categorized into three broad categories: ecological damage, natural resources depletion and human health damage, and quantified by three corresponding specific indexes (Ecological Damage Index, Resource Depletion Index and Life Damage Index) at three scales of globe, nation and region. Emission standards of pollutants issued by the government authorities, three resources characteristics of available resource supply capacity and resource demand and resource utilization as well as the remaining life expectancies for different age groups are taken as the targets in weighting definition to reflect the environment protection priorities and public concerns. A residential building is used as a case study to test and validate the presented model. Results indicate that the proposed model and index system can effectively quantify the environmental impacts of new construction projects, and can potentially be used as a tool for construction industry to fit environmental priorities and provide clear implications for practice.

1. Introduction

Environmental pollution caused by construction activities has been increasing in China because of the country's fast-paced urban development since the early 1980s. Policymakers are facing a huge challenge to achieve a resource-efficient and environment friendly society. The environmental impact of buildings and construction has become an important issue. Several models and systems were developed for assessing environmental impacts of buildings in China in the last ten years. Most of the models, such as the Evaluation Standards for Green Building (ESGB) [1] and the Evaluation Standard for Green Construction of Buildings (ESGCB) [2], are based on qualitative scoring methods. Although easy to use, their assessment criteria are sometimes subjective, and hence it's difficult for these methods to provide in-depth and comparable results.

On the other hand, a different group of environmental impact assessment tools were proposed. These tools are considered as quantitative tools by using life cycle assessment (LCA) approach because they are based on quantitative environmental-impact and energy-use data of materials during their production and transportation. The Building Environmental Performance Analysis System (BEPAS) is a leading system endorsed by the Ministry of Housing and Rural-Urban Development (MOHRUD). It serves as the foundation of a newly published construction industry standard in China — the Standard for Sustainability Assessment of Building Project [3,4]. In BEPAS, environmental impacts are considered in two categories of ecosystems and natural resources while human health is not included. To incorporate the subject of human health into the environmental impacts assessment (EIA), the authors developed the Building Health Impact Assessment System (BHIAS) with the purpose of establishing a quantitative link between building life cycle emission inventory and health impacts [5]. The two systems use the same weightings based on the social willingness-to-pay (WTP) concept to evaluate the relative severity across different environmental impacts. These methods not only provide a basis for aggregating evaluation results expressed in different units into one single value expressed in monetary terms but also offer an economic perspective of a building's

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http://dx.doi.org/10.1016/j.buildenv.2014.11.035
0360-1323/

environmental impacts. However, WTP results cannot be effectively used for making environmental policies to address environmental protection and green development.

Distance-to-target is a different weighting method which combines an impact assessment with environmental policies. It ranks an impact as being more important when the society is further away from the desired standards. The distance-to-target weighting principle has been widely used in LCA methods, such as the Swiss Ecoscarcity [6] and Denmark EDIP [7] during the 1990s. However, the administrative or sustainable targets used in Ecoscarcity and EDIP were derived from the EU's environmental policies or strategies and are therefore unable to reflect the environmental concerns of Chinese society and policy makers. Lin(2005) [8] used distance-to-target principle to derive weights of five problem-oriented impact categories in ecosystem damage only by excluding other two impact categories of resource depletion and human health damage. Moreover, the policy targets deduced from the environmental policies in Lin's research were issued in the period between 1996 and 2005. These targets have been significantly changed or updated in recent years.

This paper aims at establishing an environmental performance assessment model for building construction from a policy perspective in China. The distance-to−target approach is used to derive weights of three damage categories: ecological damage, resource depletion and health damage, represented by Ecological Damage Index (EDI), Resource Depletion Index (RDI) and Life Damage Index (LDI) respectively. The obtained evaluation results are intended to assist in guiding building design and construction so as to minimize building's environmental impacts. A residential building in Beijing is used as a case study to illustrate how this model works.

2. The weighting approaches

The commonly used quantitative weighting approaches in LCA can be summarized into three groups: expert scoring, monetization and distance-to-target [9].

In the expert scoring method, independent experts with specialty in the evaluation field are asked to arrive at conclusions and recommendations through consensus. Delphi method is a widely accepted expert scoring method and has been used successfully in many studies [10]. The expert scoring method is straightforward to use, but is subjective and may be short of theoretical support to some extent [9].

The monetization approach is derived from the idea that the seriousness across categories can be measured by economic values. Characterized by its objectivity and economic perspective, the monetization approach has received significant attention. WTP is a common used monetization method with the principle that anyone who discharges pollutants or exploits natural resources must pay the proprietor for using the environment, and has been used by the Environmental Priority Strategies (EPS) [11]. BEPAS and BHIAS also follow the WTP concept to calculate weighting factors. In BEAPS, green taxes are levied on emissions and natural resources to reflect the social WTP of the environmental damage, while the value of a statistical life year (VSLY) in BHIAS is used as a kind of WTP to weight human health damage.

The monetization approach sounds great in theory, however, with two drawbacks hard to overcome in practical use. First, China, as a developing country, has not established a complete set of green taxation system yet, and is still lack of the green taxes adhere to most of the ecological impact categories. For example, for the absence of carbon tax, previous researches [3,5] had to take the real social loss distributed to each kilogram carbon as an alternative of carbon tax to determine the weighting factor of the global warming caused by greenhouse gases. Similar ways were also used in acidification, ozone layer depletion and eutrophication, etc. However, the social loss in essence is the passive result that the society has to accept rather than its willingness to pay. This drawback to a certain degree diminishes the rationality of the weighing factors. Second, it's controversial to value a human life using the concept of VSLY because a human life is not a commodity and does not have a price [12]. Though VSLY can be estimated based on people's earning capacity, or their potential contributions to society, or what people are willing to pay to avoid certain risks, the results differ considerably. This draws serious criticisms to the reliability of using WTP to weight human health damage.

The distance-to-target approach chooses the ratio of the current environmental burden to the future environmental target value to measure its importance. It focuses on the extent to which society has (so far) failed to achieve the environmental standards [13]. The farther the current level is from the standard level, the higher the weighting value. Distance-to-target is widely used in previous assessment models. In Ecoscarcity [6], ecological factors were calculated with current levels and critical levels, and then integrated into a single value. The EDIP method [7] handled environmental influences, resources consumption, and impacts on work environment as separate categories with distance-to-target approach. Martin Weiss et al. [14] applied distance-to-target to assess non-renewable energy consumption, global warming potential, eutrophication potential and acidification potential in Germany.

Meanwhile, there are critics on the distance-to-target approach. Powell (1997) [13] raised a concern that the emission standards may be politically based rather than scientifically based. Besides, the evaluation results only revealed the inner-seriousness within a category instead of the inter-seriousness across categories. In order to solve this problem, Eco-Indicator 95 [15] took “an extra death in one million people every year”, “health damage caused by smog” and “5% ecosystem damage” as equivalent levels.

Despite criticisms, distance-to-target remains a very popular approach. In environmental protection, government policies play a leading role and policy targets are presumed to be the balanced results of economic conditions, technological conditions and political conditions [7]. Lin (2004) [8] argued that applying distance-to-target is significant in big developing countries like China, because the weights based on policies can best represent the consensus of the public. In addition, there are available up-dated data and mature conditions to use distance-to-target in assessment in China. Specific targets of critical pollutants are set in a very specific manner by formulating particular environmental policies on the base of the advisory panels of experts in every Five-Year Plan period, therefore, providing an authoritative base for employing distance-to-target approach. Consequently, the evaluation results can fit well with environmental priorities and offer clear implications for practice.

3. The assessment framework

According to the International Organization for Standardization (ISO), an LCA study involves four phases: goal and scope definition, inventory analysis, impact assessment and interpretation [16]. The proposed model follows the LCA framework and is developed based on BEPAS and BHIAS, as shown in Fig. 1.

3.1. Scope definition

The scope, including system boundary and level of detail, of LCA depends on the subject and the intended use of the study [16]. The life cycle of a building consists of five phases: raw material