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An Analysis of Problems with Current Indicators for Evaluating Carbon Performance in the Construction Industry

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Abstract

"Low-carbon" is well acknowledged as one of the key factors contributing to sustainable urban development, and also an effective approach for tackling climate change. Since the building sector accounts for a high proportion of carbon emissions, the construction is regarded as one of the most potential industry for reducing carbon emissions. However, there is no standardized indicator to measure carbon performance in the construction industry. As a result, the choice of various indicators may result in significantly different carbon performances which determine whether an industry is considered truly "low carbon". In this paper, the current indicators for assessing carbon performance in the construction industry are reviewed. The pros and cons of the current indicators are also highlighted. The problems of using the current indicators are discussed, and these problems are often related to accuracy of indicator, data availability and definitions of specific terms. Suggestions are made to focus on carbon emissions at building operation stage first as it accounts for a significant amount of carbon emissions during the whole building life-cycle. It should be highlighted that embodied emissions of buildings are also important during the whole building life-cycle. However, due to the challenges in data acquisition for calculating embodied emissions, attention should be paid more to the operational stage first as smart meters can be used to facilitate data collection processes. The findings provide clues for industry practitioners to develop an indicator which is more practical in use to assess carbon performance in the construction industry.

Keywords: carbon emissions, low-carbon performance, indicators, construction industry

1. Introduction

Reducing carbon emissions in all sectors and the planning of low carbon cities have been regarded as a solution to tackle climate change. It is well known that the building sector is responsible for a large proportion of carbon emissions [1]. A number of studies indicated that buildings consume more than 40% of global energy and account for 36% of carbon emissions [2]. In addition, the construction of buildings consumes significant amounts of raw materials (e.g. 40% of stone, sand and gravel, 25% of the timber and 16% of the water in the world) [3]. Given the above figures, the building sector has great potential for significantly reducing carbon emissions. The carbon emissions in the construction industry mainly come from the construction process and its supply chain from emissions embodied in construction materials [4]. The industry produces substantial on-site emissions from electricity and fuel use, transporting workers, materials, deliveries, and waste [5].

The urgency to reduce the current level of carbon emissions through innovative technology in design and use of materials, regulations and setting energy and carbon rating standards has been increasingly advocated. However, a comprehensive and robust development of a set of low-carbon indicators, and in particular, a method for calculating carbon emissions is still lacking a consensus. Thus, it is difficult to determine whether a sub-sector in the construction industry is 'low carbon'. This paper aims to review the current indicators for assessing carbon performance in the construction industry, and provide future directions to develop a low-carbon indicator. The paper first discusses the pros and cons of current indicators. After that, the problems of using these indicators are highlighted. Future directions are also suggested to develop an indicator which is more practical in use to assess carbon performance in the construction industry.

2. Current Indicators

Indicators are defined as a tool for visualizing the current conditions in complex systems by expressing those conditions in numerical form, for example, environmental indicators for environmental systems. Low-carbon indicators play an important role in tracking progress towards meeting the increasingly urgent goal of a low-carbon future. Low-carbon indicators can be used by national, regional and local governments, non-governmental organizations and research institutions to measure the status of low-carbon development and outcomes of climate change policies. The indicators also enables policy makers to benchmark targets, strategies and policies to support policy improvements. In general, the current indicators for assessing carbon performance can be classified into two types, namely, macro-level indicators and micro-level indicators. Table 1 shows the current carbon indicators in the construction industry.

Table 1: Pros and cons analysis of current carbon indicators in the construction industry.

Indicator(s)		Pros	Cons	Observations
Macro-level	Economic-based indicators	Provide a quick comparison among cities, regions, and province	Ignore the differences of economic structure	Commonly used in the international level
	Population-based indicators	Provide a quick comparison among cities, regions, and province	Not consider migrant/transient populations	May lead to over-accounting of energy use per capita
Micro-level	CO_2 emissions in the construction of a single building	Focus on carbon emissions during the construction and demolition stage	Not consider the operation stage	No standard method to calculate carbon emissions at different stages
	Life-cycle CO_2 emissions in a single building	Consider carbon emissions during the operation stage	Involve complicated calculations	No standard method to calculate carbon emissions at different stages
	Average CO_2 emissions per working area per year	Eliminate the impact of different working areas on CO_2 emissions	Difficult to determine the period of construction and operation accurately in advance	Able to compare the level of carbon emissions with different buildings
	Life-cycle carbon efficiency	Provide a linkage between life-cycle carbon emission and value creation of buildings	Difficult to define life-cycle values for various buildings	The concept of life-cycle carbon efficiency is not widely adopted

2.1. *Macro-level indicators*

2.1.1. Macro-level economic-based indicators

For macro-level indicators, it can be further divided into two types of indicators, namely macro-level economic-based indicators and macro-level population-based indicators [4]. Macro level economic-based indicators are the indicator based on CO_2 emissions per unit of GDP. This economic-based indicator comprises two components: (1)

energy intensity, defined as the amount of energy consumed per unit of economic activity; and (2) carbon intensity of energy supply, defined as the amount of carbon emitted per unit of energy [6]. It is worth noting that there is a difference between final energy and primary energy when constructing this indicator. Final energy, or end-use energy, accounts for energy delivered at the end-use sites, but it does not consider energy loss during transmission and distribution (T&D) and electricity generation efficiency. Primary energy is the sum of final energy and energy consumed during the T&D of electricity and the generation.

2.1.2. Macro-level population-based indicators

Compared with macro-level economic-based indicators, macro-level population-based indicators use population as the denominator instead of GDP. The main propose of using these macro-level indictors is to compare the level of carbon emissions among cities, regions, and provinces.

2.2. *Micro-level indicators*

Unlike macro-level indicators which focus on the level of carbon emissions among cities, regions, and provinces, micro-level indicators emphasize the level of carbon emissions in a single building. In general, there are four types of micro-level indicator for assessing carbon performance in the construction industry.

2.2.1. CO_2 emissions in the construction of a single building

The total amount of CO_2 emissions in the construction of a single building can be used as an indicator to compare carbon performance with different buildings. This indicator only focuses on four major sources of CO_2 emissions in building construction: (1) manufacture and transportation of building materials; (2) energy consumption of construction equipment; (3) energy consumption of processing resources; and (4) disposal of construction waste.

2.2.2. Life-cycle CO_2 emissions in a single building

Unlike the above indicator, a life-cycle CO_2 emission in a single building is an indicator which calculates the CO_2 emissions during the whole building life cycle. Apart from the stage of material production & transportation, construction as well as demolition and waste, this indicator also includes CO_2 emissions at the stage of building operation and maintenance. The findings of existing literature show that the building operation stage accounts for approximately 80-90% of the total CO_2 emissions, whilst the construction stage only constitutes 8-20% [7].

2.2.3. Average CO_2 emissions per working area per year

The main drawback of using total CO_2 emissions as an indicator is that no conclusion can be simply drawn when comparing their total CO_2 emissions with different buildings. This is because the amount of CO_2 emissions for a building not only depends on construction methods and use of construction materials, but also relates to building areas and construction period. Therefore, another carbon indicator, defined as average CO_2 emissions per working area per year, is developed to provide a more practical comparison between different buildings. Peng [8] calculated the average CO_2 emissions per working area per year for different stages of an office building in China, and found that although the operation stage accounts for approximately 85% of the total CO_2 emissions, the average CO_2 emissions per working area per year of construction stage is much higher than that of the operation stage.

2.2.4. Life-cycle carbon efficiency

Life-cycle carbon efficiency is defined as life-cycle values per carbon emissions of building. Li, Chen [2] used this indicator to calculate the life-cycle carbon efficiency of one residential building in Hong Kong. In principle, there can be different definitions for life-cycle values. For example, the value of residential building can be related to its sale price. In the studies of Li et al., the life-cycle value is the product of its service life span and building space in area size (m^2) or by the volume in cubic size (m^3). The main advantage of this indicator is that it provides a linkage between life-cycle carbon emission and value creation of buildings.

3. Problems with current indicators

Since there is no standardized indicator to measure carbon performance in the construction industry, the choice of various indicators may result in different carbon performance for the same building. Other problems of current indicator will be discussed and Table 2 lists the problems of current indicators for evaluating carbon performance in the construction industry.

3.1. *Macro-level indicators*

Price, Zhou [4] discussed the issues with the macro-level indicators and summarized into three aspects. First, the macro-level indicators do not accurately reflect end-use energy or carbon intensities because they are generated using a top-down approach. Second, the official population data often exclude the impact of migrant or transient populations, and this may result in over-estimation of energy use per capita in cities, especially for those cities with large migrant populations. Third, different countries may have their own definitions for end-use energy and use different data sources, making cross-country comparisons inaccurate.

3.2. *Micro-level indicators*

Unlike macro-level indicators, micro-level indicators are used to compare carbon emissions between different single buildings. This type of indicator allows decision makers to analyze carbon emissions at various stages of building life-cycle and benchmark targets on the level of carbon emissions for different types of buildings. However, there are several issues when using the micro-level indicators.

To-date, there is no agreement on the calculation method of carbon emissions at various stages of the whole building life-cycle. For example, there are several methods for calculating carbon emissions at construction stage. Peng [8] adopted the comprehensive method for calculating carbon emissions at construction stage. This method not only includes the CO_2 emissions produced by the operation of construction equipment and office devices, but also by various construction crafts and horizontal transportation. However, this method heavily lies on the energy data which is commonly unavailable in the construction industry. In the Li, Chen [2] calculation method, construction activities are divided more specifically into four major types, including excavation and removal earthwork, grading earthwork, site lighting and crane handling. The advantage of Li et al method is that it is easier to determine the level of those construction activities since they are in the unit of ton, m^3 or m^2.

Data availability and quality are also the issue for calculating carbon emissions at specific stages. For example, assumptions are usually made to evaluate carbon emissions at demolition stage due to lack of actual data. The typical approach is to use the data from other countries to estimate the amount of diesel oil per m2 during the demolition stage. Apart from that, it is often assumed that the end-of-life materials will be landfilled at the end. However, there are other alternatives to disposal those materials, such as incineration and recycling. Therefore, those assumptions may result in inaccurate results of carbon emissions for buildings. In addition, Peng [8] indicated that not all the data is classified as high quality data since the development of life-cycle assessment database in construction processes involves many different data sources, underpinning the accuracy of results.

For life-cycle carbon efficiency indicators, difficulties are found in defining life-cycle values. Ideally, life-cycle values should be related to monetary terms which make the indicator easily comparable. However, it is found that the sale price of buildings may not be a suitable factor to determine life-cycle values since the sale price is easily influenced by outside factors such as inflation, market speculation and currency policy. Although Li, Chen [2] defined the life-cycle value for residential buildings, there is still lacking a consensus on the definition of life-cycle values for other types of building such as hotels and office buildings.

Table 2: Problems with current indicators for evaluating carbon performance in the construction industry

Indicator(s)	Problems
Macro-level indicators	Not accurately reflect end-use energy or carbon intensities
	Exclude the impact of migrant or transient populations in the official database
	Have their own definitions for end-use energy in different countries
	Use different data sources
Micro-level indicators	No agreement on the calculation method of carbon emissions at various stages of the whole building life-cycle
	Lack of data to calculate carbon emissions
	Poor quality of empirical data
	Difficult to define life-cycle values for other types of building

4. Future directions

4.1. *Development of low carbon indicator for construction industry*

As discussed in Section 3, there are several problems in the current indicators (both macro-level and micro-level indicators). It is concluded that the problems are related to accuracy of indicator, data availability and definitions of specific terms. Therefore, there is a need to develop an indicator which is more practical in use to assess carbon performance in the construction industry. Since the main purpose of using indicators in the construction industry is to compare carbon performance between different buildings, instead of different cities or regions, the micro-level indicators are more suitable than the macro-level indicators. Due to data availability, the indicator may not be accurate enough to calculate carbon emissions at each stage of the building life-cycle in details. However, the indicator can provide a general picture for construction practitioners to determine whether the proposed building is a low-carbon building or not. For Hong Kong construction industry, it is suggested that the micro-level indicator "average CO2 emissions per working area per year" will be more suitable for use since it can make a simple comparison between buildings based on the value of indicator. To ensure that this indicator can be further adopted in the construction industry, the calculation method should be standardized and relevant organizations should develop their own life-cycle assessment database.

4.2. *Focus on operation stage*

A number of studies indicated that building operation stage accounts for a significant amount of carbon emissions to meet various energy needs such as heating, ventilation, and air conditioning (HVAC), water heating, lighting, office equipment and telecommunications [8]. Islam, Jollands [9] highlighted that the ratio of carbon emissions of construction to operation stages is over 50%. Ramesh, Prakash [10] found that up to 30 % of the embodied energy is attributed from construction in commercial buildings. Although the actual carbon emissions at the operational stage vary from different building types, climatic conditions and thermal comfort requirements, considerable agreement is still observed that attention should be paid on the operational stage to reduce carbon emissions due to the large potential in carbon reduction in existing buildings [11]. The common examples of improving building energy performance include installation of higher insulation on external walls and roofs, optimization of HVAC systems, as well as using high thermal performance windows [12].

With the considerations of the above situation, a carbon indicator which focuses on the operational stage should be first developed. Due to the technological advancement (e.g. adoption of smart meters in buildings), the data acquisition for calculating embodied emissions at the operational stage becomes more convenient and reliable. A carbon audit report regarding the central building services systems can be generated automatically if the sufficient smart meters are installed in buildings. It should be noted that this study does not suggest fully neglecting the embodied emissions of buildings. However, tremendous efforts are needed in order to collect all necessary data for calculating embodied emissions of buildings at the construction stage. In addition, no standardised method to conduct a life-cycle assessment for buildings is yet developed. Without the standardisation of calculation method, it is difficult to develop an effective carbon indicator which can be used for comparisons with different types of buildings.

5. Conclusions

In this paper, a review of the current indicators for assessing carbon performance in the construction industry is conducted. It is found that there is no standardized indicator to measure carbon performance in the construction industry. As a result, the choice of various indicators may result in significantly different carbon performances for the same building. In addition, the problems of using the current indicators are often related to accuracy of indicator, data availability and definitions of specific terms. Therefore, there is a need to develop an indicator which is more practical in use to assess carbon performance in the construction industry. Suggestions are made to focus on carbon emissions at the building operation stage first as it accounts for a significant amount of carbon emissions during the whole building life-cycle. It should be noted that embodied emissions of buildings are also important. However, due to the challenges in data acquisition for calculating embodied emissions, attention should be paid more to the operational stage first as smart meters can be used to facilitate data collection processes. The findings provide clues for industry practitioners to develop a more practical indicator, and thereby improve overall carbon efficiency in the construction industry.

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