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Development of a CO_2 emission benchmark for achieving the national CO_2 emission reduction target by 2030

Kwangbok Jeong [a], Taehoon Hong [b,*], Jimin Kim [c]

[a] Department of Architecture & Architectural Engineering, Yonsei University, 50 Yonsei-ro, Seodaemun-gu, Seoul, 03722, Republic of Korea
[b] Department of Architecture & Architectural Engineering, Yonsei University, Seoul, 03722, Republic of Korea
[c] Research Professor, Department of Architecture and Architectural Engineering, Yonsei University, Seoul, 03722, Republic of Korea

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ABSTRACT

To achieve the national CO_2 emission reduction target (CERT) in the building sector established together with the launching of POST-2020, various countries are introducing the emission trading scheme (ETS), which is considered to have a considerable effect on CO_2 emission reduction. Towards this end, it is important to establish a reasonable CO_2 emission benchmark for the effective allocation of CO_2 emission allowances. As the previous CO_2 emission benchmark, however, was focused on the industry sector (e.g., power generation sector, manufacturing sector, etc.), it is difficult to apply to the building sector. To solve this problem, this study aimed to develop a CO_2 emission benchmark for allocating CO_2 emission allowances in multi-family housing complexes (MFHCs). This study was conducted in three steps: (i) establishment of the database; (ii) formation of clusters using a decision tree (DT); and (iii) development of the CO_2 emission benchmark for MFHCs. The nine CO_2 emission benchmarks (i.e., 0.03116-0.06667 tCO_2/m^2 year) for MFHCs were developed using a DT based on the heating type and the elapsed years, and were validated using the Kruskal-Wallis test and *t*-test. It was shown that using the developed CO_2 emission benchmark for MFHCs to calculate the national CO_2 emission reduction in MFHCs satisfied the national CERT (18.1%). On the other hand, when the CO_2 emission benchmarks for MFHCs calculated based on the South Korean ETS and the EU ETS, which were applied to the industry sector, were used, the national CO_2 emission reduction was −5.29 and 45.55%, respectively. The proposed CO_2 emission benchmark for MFHCs may be useful for policymaking for determining the allocation of CO_2 emission allowances for achieving the national CERT.

1. Introduction

To solve the global warming problem caused by careless greenhouse gas (GHG) emissions, the world set the national CO_2 emission reduction target (CERT). For example, European Union (EU) set a 40% CERT based on its 1990 GHG emissions by 2030, and South Korea established a national CERT to reduce its GHG emissions by 37% (building sector: 18.1%) below its business-as-usual level by 2030 [1–6]. To achieve this goal, both the EU and South Korean governments enacted the emission trading scheme (ETS), which allows the allocation and trading of CO_2 emission allowances, targeting the industry sector [7–9].

South Korea's building sector emits 25.5% of the total national CO_2 emissions, requiring the introduction of the ETS, which is considered to have a large effect on the CO_2 emission reduction [10]. To effectively implement the ETS in the building sector, it is important to establish a reasonable categorization system for such sector, and a CO_2 emission benchmark for the allocation of CO_2 emission allowances. Without a reasonable categorization system and CO_2 emission benchmark in the building sector based on the various characteristics (e.g., geographic, physical, utilization, etc.) of the building, errors may occur in the determination of the allocation of CO_2 emission allowances. Accordingly, EU ETS stipulates one CO_2 emission benchmark per product. The previous CO_2 emission benchmark, however, targeted the industry sector (e.g., power generation sector, manufacturing sector, etc.) and could not be easily implemented for the building sector [11,12]. To address this challenge, this study aimed to develop a CO_2 emission benchmark for allocating CO_2 emission allowances in MFHCs.

In the previous relevant studies, the benchmarking approach was adopted for reducing the energy consumption or CO_2 emission.

* Corresponding author.
E-mail addresses: kbjeong7@yonsei.ac.kr (K. Jeong), hong7@yonsei.ac.kr (T. Hong).

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Nomenclature

ANOVA	Analysis of variance
CAGR	Compound annual growth rate
CART	Classification and regression trees
CERT	CO_2 emission reduction target
CHAID	Chi-squared automatic interaction detection
DT	Decision tree
ETS	Emission trading scheme
EU	European union
GEP-HSO model	Gene expression programming – harmony search optimization model
GHG	Greenhouse gas
MFHC	Multi-family housing complex

(i) Energy benchmarking: Jeong et al. [13] developed an energy benchmark with the data mining and statistical methodologies, targeting the MFHCs that use district heating. The developed energy benchmark addressed the irrationality of the original benchmark. Shabunko et al. [14] proposed the building benchmarking scheme based on three housing estates, with a total of 256 samples. The proposed energy use intensity benchmark was estimated to be 2035 kWh/person/year and 56 kWh/m^2 year. Yalcintas [15] developed an energy benchmarking model using the artificial neural network. The weighted energy use index in Hawaii can be determined using such developed energy benchmarking model.

(ii) CO_2 emission benchmarking: Huang et al. [16] analyzed the benchmarking of the GHG emissions based on 58 Taiwanese luxury hotels. Using benchmarking, the authors proposed the multiple regression model for establishing the normalized GHG emission intensity. Wu et al. [17] developed a regression-based benchmarking model for the hotel industry in Singapore. Based on the information on a total of 29 hotels, the CO_2 emissions were estimated and normalized based on the gross floor area and the number of room nights. Dai et al. [18] established the general benchmarking framework of Hubei in China, and conducted a comparative analysis of various CO_2 emission benchmarking approaches (e.g., Waxman-Markey benchmark, EU ETS, and Hubei ETS).

The aforementioned studies on the CO_2 emission benchmark, however, had several limitations, as follows: (i) while a CO_2 emission benchmark that uses the total energy resource data of a building should be developed, the previous studies used only some of the various energy resources being utilized by a building; (ii) while the calculation of the CO_2 emission benchmark by building type should consider the characteristics of the building that affect the building's CO_2 emission, most of the previous studies calculated the CO_2 emission benchmark without categorizing the building types; and (iii) while data collection above the regional level is required for the establishment of a CO_2 emission benchmark for the buildings on the national or regional level, the previous studies presented a CO_2 emission benchmark that was established using only part of the sampling data. To address the aforementioned limitations, this study aimed to develop a CO_2 emission benchmark for allocating CO_2 emission allowances in MFHCs.

Meanwhile, the energy consumption in the residential sector accounts for about 58% of the total building energy consumption. Specially, South Korea has a high rate of MFHCs, and the electricity consumption of MFHCs accounts for 68% of the country's total residential electricity consumption [10,19,20]. Thus, the present study aimed to develop a CO_2 emission benchmark for MFHCs.

2. Materials and methods

This study developed a CO_2 emission benchmark for achieving the national CERT by 2030. Using the developed CO_2 emission benchmark, the allocation of CO_2 emission allowances can be determined for the achievement of the national CERT by 2030. As shown in Fig. 1, this study was conducted in three steps: (i) establishment of the database; (ii) establishment of the clusters' formation using a decision tree (DT); (iii) development of a CO_2 emission benchmark for MFHCs.

2.1. Establishment of the database

2.1.1. Definition of variables

To develop a CO_2 emission benchmark for MFHCs for the attainment of the national CERT by 2030, the independent and dependent variables that affect the CO_2 emissions of MFHCs should be defined (refer to Table 1). According to previous studies [13,21–25], information affecting the energy consumption and CO_2 emissions of buildings can largely be divided into two types: (i) geographical information; and (ii) physical information. First, according to Han et al. [23] and Dong et al. [24], the meteorological factors (e.g., solar radiation, temperature, etc.) have been shown to affect the energy consumption and CO_2 emissions of MFHCs. Thus, to analyze the characteristics of the energy consumption and CO_2 emissions of MFHCs, the geographical information (e.g., district, village) that can reflect the meteorological factors were set as independent variables. Second, according to Jeong et al. [13], Hong et al. [21], Hong et al. [22], and Koo et al. [25], the various physical data (e.g., total floor area, number of stories, heating type, etc.) have been shown to affect the energy consumption and CO_2 emissions of MFHCs. The total floor area, number of stories, number of buildings, and number of households are variables that can determine the heating and cooling areas in MFHCs. Due to the differences in the energy source and operation plan, the heating type of the MFHC (e.g., individual, central, or district heating system) affects the MFHC's energy consumption and CO_2 emission. Also, as MFHCs deteriorate, and as their performances are lowered by their use, the elapsed years should be set as an independent variable. Meanwhile, while there may be many other variables (e.g., corridor type, tenure type, etc.) that affect the energy consumption and CO_2 emissions of MFHCs, this study considered the variables (e.g., district, village, total floor area, number of stories, etc.) included in the dataset statistically offered by the South Korean government, among the various variables affecting the energy consumption and CO_2 emissions of MFHCs (refer to Table 1).

2.1.2. Data collection and filtering

To establish a database corresponding to the independent and dependent variables, a total of 1426 MFHCs were collected from the Korea Appraisal Board in South Korea [26]. The collected data are as follows. First, the geographical information (e.g., district, village) and the physical information (e.g., total floor area, number of stories, etc.) were collected. Second, to establish the utilization information (e.g., CO_2 emission per total floor area), energy consumption data were collected. The collected energy consumption data of MFHCs consisted of the data on the electricity consumption of the household electrical appliances and air conditioners and the data on the gas consumption and heat supply for heating the air and water.

To ensure the reliability of the established database, data filtering was conducted based on the following criteria. Among the collected data, the MHFCs with some characteristics omitted or energy consumption data omitted were excluded from the database. Second, the statistical outliers of the collected data were determined using the boxplot outlier method based on quartile.