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Benchmarks as a tool for free allocation through comparison with similar projects: Focused on multi-family housing complex

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HIGHLIGHTS

- We propose the model for establishing benchmarks for free allowance allocation.
- The model can preliminarily estimate the amount of allowances in construction site.
- The prediction performance of the proposed model is superior in all classification.
- For the concrete, prediction accuracy and standard deviation are 93.45% and 6.01.
- For the steel bar (94.20%; 4.34) and for the formwork (94.28%; 4.67), respectively.

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ABSTRACT

A multilateral effort to reduce greenhouse gas (GHG) emissions has been implemented around the world. In particular, the Emissions Trading Scheme (ETS) emerged as a market-based approach used to control GHG emissions by providing carbon credits (or allowances). One of the most controversial issues in the ETS is the question of how the allowances will be distributed. Therefore, this research aimed to develop a decision support model for establishing benchmarks as a tool for free allocation in the construction industry. It can be used in the pre-design phase to estimate the amount of allowances in a given construction site. In this study, a total of 147 types of data on the reinforced concrete frame in multi-family housing projects in South Korea were collected and used to develop the advanced Case-Based Reasoning (CBR), which can be used to establish benchmarks as a tool for free allocation.

Results showed that the prediction performance of the advanced CBR model was superior (prediction accuracy; standard deviation) in all classifications: concrete (93.45%; 6.01), steel bar (94.20%; 4.34), and formwork (94.28%; 4.67). In the case study, a total of 60 possible combinations were evaluated in terms of the economic and environmental impact simultaneously with the retrieved cases. The results of this study could be expanded into other areas including new renewable energy, rehabilitation projects, and demolition projects.

1. Introduction

The rapid growth of cities and subsequent industrialization has led to the rise of various environmental issues, such as global warming and depletion of resources. With the Kyoto Protocol in 1997, however, a multilateral effort to reduce greenhouse gas (GHG) emissions has been implemented around the world [1,2]. Under the treaty, Annex I Parties (which consist of 37 industrialized countries and the European Community) commit themselves to binding targets for GHG emissions. Toward this end, the protocol defines three flexibility mechanisms that can be used by Annex I Parties [3]. The three flexibility mechanisms are Emissions Trading Scheme (ETS), Clean Development Mechanism (CDM), and Joint Implementation (JI). Among these, the ETS (or cap-and-trade) is a market-based approach used to control GHG emissions by providing carbon credits (or allowances) as economic incentives for achieving the emissions reduction target. That is to say, nations that emit less than their quota will be able to sell the emission credits to nations whose emissions exceed their quota [4,5].

One of the most controversial issues in the ETS is the question of how the allowances will be distributed. Since the ETS creates a significant value, decisions about the allocation of allowances in essence result in arguable issues. It involves whether or not to freely allocate the allowances, whether or not to auction the allowances, or whether or not to use a combination of free allocation and auctioning [6]. Emerging programs have changed in the transition from free allocation to auction over time. A combination of both free allocation and partial auction offers flexibility in order to achieve environmental and economic objectives [7,8]. For example,

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in the first and second trading periods of the European Union Emissions Trading Scheme (EU-ETS), the majority of emission allowances have been freely given to entities covered under the program, according to historical emissions. In the third trading period of the EU-ETS, free allocation of emission allowances will be progressively replaced by auctioning of the allowances by 2020. Yet, free allocation will surely continue to play a significant role up to 2020. The proposal is being negotiated in the European Parliament [9].

Within a free allocation, there may be a variety of acceptable ways to distribute allowances: (i) "grandfathering", allowances based on historical emissions; and (ii) "benchmarking", allowances based on energy input or product output [9]. When allowances are freely given to entities, the following requirements should be met. They should be allocated in a manner that is fair, transparent, and ambitious. In other words, the allocation approach needs to allow entities getting a strong incentive for the achieving GHG emissions reduction target. In this regard, free allocation based on historical emissions called "grandfathering" is potentially problematic. Under the free allocation method of grandfathering, most allowances are assigned to the entities that have emitted most. To make the ETS more efficient and effective, however, free allocation should levy penalty on those who have emitted most. This can be achieved through free allocation based on energy input or product output called "benchmarking". Theoretically, this can find the optimal solution for allowance allocation that is fair, transparent, and ambitious. Yet there remain considerable challenges in designing an allocation scheme and in determining concrete values as the actual benchmarks [9,10].

South Korea's National Assembly passed legislation, "The Act on Allocation and Trading of Greenhouse Gas Emissions Allowances", which would set the GHG emissions reduction target starting in 2015. It applies both to entities that emit more than 125,000 tCO_2-eq./yr and to factories or buildings that produce more than 25,000 tCO_2eq./yr. About 95% of allowances will be allocated for free to companies, factories, or buildings for the first period (2015–2017) and the second period (2018–2020) [11]. To keep pace with the current trend, the construction industry has taken various actions to reduce GHG emissions in buildings. The South Korean government has conducted a variety of research to establish the allocation methods that are appropriate for the characteristics of the construction industry. In particular, due to the uniqueness of the construction site, which is substantially different from the characteristics of the manufacturing industry, both policymakers and construction entities are becoming more interested in the "benchmarking" approach for allowance allocation.

Therefore, this research aimed to develop a decision support model for establishing benchmarks as a tool for free allocation in the construction industry. It can be used in the pre-design phase to estimate the amount of allowances for each product (e.g., concrete, steel bar, or formwork) that is produced, transported, and constructed in a given construction site. Along with this, it can preliminarily estimate the construction cost that is required to achieve the level of benchmark for allowance allocated to a given construction site. Using the model developed in this study, both policymakers and construction entities can establish in advance the level of benchmark for allowance allocation specified to a given construction site and negotiate it with each other. Also, construction entities can assess eco-friendly technologies under budget constraints.

The scope of this study is limited to conduct the economic and environmental impact assessment at the sites of construction projects, especially the collection of materials, which are assembled into a reinforced concrete frame in multi-family housing complex projects. Toward this end, the "*product-level LCA method*" was adopted to conduct environmental impact assessment. The "*product-level LCA method*" is one of the four-level methods (i.e., material-level, product-level, building-level, and industry-level) to conduct an LCA, and is calculated as a collection of materials, which are assembled into a final product. After a quantity takeoff of the product is completed, the amount of the emissions from each component of the product is determined. The detailed information on the "*product-level LCA method*" can be founded in [12]. It has a limitation in analyzing all materials, and, thus, the main materials that occupy a considerable amount of the total environmental load should be determined. As proposed by [13], the environmental load evaluation of a standard apartment unit in Korea shows that the total ratio of CO_2 emissions by concrete, steel bar, and formwork accounts for 70.12% of total CO_2 emissions generated during the construction phase of a reinforced concrete frame in a multi-family housing complex. As provided by [12], the *ATHENA® Impact Estimator* covers around 1200 assemblies, consisting mainly of concrete, steel, and wood products used in foundations and structural assemblies. Accordingly, this study selected concrete, steel bar, and formwork as the main materials for the reinforced concrete frame of a multi-family housing project. Also, the "*process-based LCA method*" was implemented as "*a cradle-to-gate approach*" for assessing the environmental load from the material manufacturing through the on-site construction of the building project. The "*process-based LCA method*" is one of the two methods to conduct an LCA, and focuses on a specific product rather than a sector. Accordingly, the major advantage of this method is the ability to compare two products that have the same function. The detailed information on the "*process-based LCA method*" can be founded in [12]. Since collection of the detailed design information for performing energy simulation is limited in the pre-design phase, an analysis of the operational environmental load during the operation and maintenance phases was excluded from this study.

Meanwhile, Case-Based Reasoning (CBR), one of the data-mining methods, was adopted to establish the level of benchmark for allowance allocation specified to a given construction site. CBR has a powerful advantage because it cannot only present the predicted value, but also historical data as references. Based on this feature, policymakers or construction entities can estimate the level of benchmark for a given project by comparison with similar projects that are retrieved through the CBR algorithm. In other words, the CBR is characterized by suggesting the prediction results with a high explanatory power based on historical data. Despite such advantages of CBR, its prediction accuracy is inferior to that of the other methodologies, such as Multiple Regression Analysis (MRA) and Artificial Neural Network (ANN). To improve prediction accuracy, MRA and ANN were integrated to filtering the prediction results generated by CBR. Also, Genetic Algorithm (GA) was used to apply the concept of optimization. The research team names a series of processes in "the advanced CBR model". Additional information on the advanced CBR model can be found in previous studies conducted by the research team [14,15].

In this study, a total of 147 project characteristics and quantity data were collected on the reinforced concrete frame in multi-family housing projects in South Korea. This study was carried out in three steps: (i) the collected data were analyzed at the level of the main materials (i.e., concrete, steel bar, and formwork) to establish the case base; then, by using the advanced CBR model, the quantity of the main materials is estimated; (ii) using the estimated quantity, the construction costs and CO_2 emissions in the material manufacturing through on-site construction were estimated; and (iii) based on the estimated construction costs and CO_2 emissions, the study proposed possible combinations on which the economic and environmental impact assessment was performed. The detailed input data can be found in Table S1 of the supplementary data.