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The effect of new carbon emission reduction targets on an apartment building in South Korea

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ABSTRACT

A heavily industrial nation, South Korea has one of the highest carbon emission production rates in the world. To participate in the global efforts to reduce carbon emissions, the South Korean government has recently proposed four national targets for carbon emission reduction: 14.7%, 19.2%, 25.7%, and 31.3% from the predicted 2030 BAU level. As the embodied environmental impacts of apartment building are becoming increasingly apparent, this study develops a carbon emission reduction policy model using a system dynamics approach to estimate the required amount of carbon emission reduction of apartment building construction. The results of this study indicate that apartment buildings require the reduction of 190 million kg CO_2 for policy one, 248 million kg CO_2 for policy two, 332 million kg CO_2 for policy three, and 404 million kg CO_2 for policy four, respectively, in the year 2030. This study also conducts a sensitivity analysis to investigate the impact of apartment floor demand on the expected total carbon emission amount and the carbon emission reduction amount of an apartment. Based on those results, this study develops a mathematical model for determining the optimal numbers of apartment units.

1. Introduction

As South Korea is the seventh largest source of carbon dioxide (CO_2) emissions in the world [1], the South Korean government has developed policies to reduce greenhouse gas emissions. It aims to reduce 233 million CO_2 equivalent tons (30% of greenhouse gas emissions) from 776 million CO_2 equivalent tons, which is the predicted 2020 business as usual (BAU) level by the year 2020 [2]. To fulfill its goal of reducing the nation's greenhouse gas emissions, the South Korean government has assigned specific carbon emission reduction targets to seven major sectors – 18.5% for the industry sector, 26.7% for the energy sector, 26.9% for the building sector, 34.3% for the transportation sector, 25% for the public sector, 12.3% for the waste management sector, and 5.2% for the agricultural and fishery sector [3]. Since the building sector produces approximately 23% of the nation's total CO_2 emissions [4], the South Korean government has determined that, compared to other sectors, the building sector has the largest potential for CO_2 reduction [5] by focusing on residential buildings, which are a major source of energy consumption and carbon emission production. Due to South Korea's high population density, apartment buildings are the most prevalent type of residence.

The recent slow economic growth has caused the South Korean government to adjust the nation's initial greenhouse gas emission reduction goal of a 30% reduction of total greenhouse gas emissions by the year 2020. Therefore, in June 2015, the South Korean government proposed four new policies addressing carbon emission reduction targets. Based on the expected total carbon emission in the year 2030, 850.6 million CO_2 equivalent tons, the first option's aim is to produce 726 million CO_2 equivalent tons by decreasing 14.7% of greenhouse gas emissions from the predicted 2030 BAU level. The second option's aim is to produce 688 million CO_2 equivalent tons by decreasing 19.2% of greenhouse gas emissions from the predicted 2030 BAU level. The third option's aim is to produce 633 million CO_2 equivalent tons by decreasing 25.7% of greenhouse gas emissions from the predicted 2030 BAU level. The last option's aim is to produce 585 million CO_2 equivalent tons by decreasing 31.3% of greenhouse gas emissions from the predicted 2030 BAU level [6].

Although the South Korean government has selected the third policy as its official carbon emission reduction policy, there is still a possibility of further changing the carbon emission reduction target in response to South Korea's economic condition. Thus, this study investigates the required reduction amount of carbon emissions

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under four reduction targets, ranging from the lower 14.7% reduction to the higher 31.3% reduction by the year 2030, while analyzing total carbon emissions from the construction materials in six types of apartment buildings. Since the total energy consumption and carbon emission are mainly determined by the amount of building materials required in the construction stage [7], the material production stage and the construction stage have recently been recognized as important stages in a building's life cycle. Thus, it is reasonable to consider construction materials as the starting point of life cycle assessment research, and then expand to include the entire life cycle of a building.

In order to estimate the required reduction amount of carbon emissions in the government's proposed four policies, this study utilizes a system dynamic approach that provides a comprehensive overview of industrial, economic, social, and environmental systems based on fundamental principles and dynamic cause-and-effect relationships between system parameters [8]. This study further conducts a sensitivity analysis to estimate the impact of annual apartment demand on the expected total carbon emissions of an apartment building and the carbon emission reduction amount of an apartment building. Finally, this study estimates the optimal numbers of six apartment types, while satisfying the allowed annual carbon emissions in a building sector. The results of this study can serve as reference data for designers and environmental policy makers to determine the amount of carbon emission reduction in the residential sector under the four carbon emission policies, along with the optimal numbers for each apartment type.

2. Literature review

In order to analyze the complex and dynamic systems, it is necessary to understand the interactions among variables and parameters in the simulated system [9]. Various researchers have used a system dynamics approach to represent complex and dynamic systems as feedback structures to obtain a comprehensive understanding of the dynamic behavior of complex systems in the fields of business, ecology, economy, engineering, and, society. However, the system dynamic approach has rarely been applied to the life cycle assessment study in a building sector.

For carbon emission mitigation scenario evaluation, Han and Hayashi represent the inter-city passenger transport system as a system dynamics model in China. Their study indicates that a railway network is the most effective mode to reduce fuel consumption and to mitigate carbon emissions in the inter-city passenger transport system [10]. Using a system dynamics approach, Egilmez and Tatari simulate the U.S. highway system to evaluate three policy options in fuel efficiency, public transportation, and electric vehicles for a carbon emission reduction target for the year 2050. The study suggests that the collaboration of the three policy options would lead to a sustainable highway system [11].

Anand et al. use a system dynamic approach to assess carbon emissions from the cement industry in India. The study indicates that related policies on population growth stabilization, energy efficient production process, and renewable energy have a large impact on carbon emission reduction [12]. Ansari and Seifi analyze energy consumption and carbon emission from the cement industry under various production and export scenarios in Iran. The study demonstrates that blended cement production with waste material as an alternative fuel potentially reduces 25% of average energy consumption and 22% of carbon emissions [13].

Onat et al. investigate greenhouse gas emissions in the U.S. residential sector using a system dynamics approach under 19 policy scenarios in the fields of green building, retrofitting building, and net zero building. The results of the study indicate that policies in retrofitting building are the most effective option for stabilizing and mitigating carbon emissions and that collaborating policies in three fields have the largest impact on carbon emission reduction in the U.S. residential sector [14].

In the conceptual level, Kim et al. develop the system dynamics model for the life cycle assessment of an apartment building in terms of cost and carbon emission. The proposed model consists of five subsystems: a life cycle cost subsystem, a life cycle carbon emission subsystem, a cost-carbon effect subsystem, a life cycle energy subsystem, and a decision-making subsystem. Based on a cost-effective analysis, the model provides the amount of resources, energy consumption, and carbon emissions for apartment construction projects [15].

Marzouk and Azab simulate the construction waste management process in a system dynamics model to compare two alternatives – a recycling method and a disposal method – in terms of energy consumption and emissions. The simulated results of the study indicate that the recycling of construction and demolition waste is the most effective way to reduce energy consumption, emissions, and global warming potential [16].

With the aim of influencing urban air pollution policies, Vafa-Arani et al. simulate an urban transportation system and air pollution industries in Iran through a system dynamics approach. The study considers four sectors – fuel efficiency improvement, public transportation infrastructure development, road construction, and traffic control – to find effective policies to improve urban air quality. The results of the study shows that three sectors, all except traffic control, have an impact on urban air quality improvement [17].

A review of the relevant literature on system dynamics illustrates that most studies do not consider the carbon emission reduction target issue in the building sector. Furthermore, there are few studies analyzing the environmental impact of an apartment building's construction materials using a system dynamics approach. To correct those omissions, the objective of this study is to develop a system dynamics model to estimate the required amount of carbon emissions under four policies at a given expected apartment construction demand, while providing the proper number of six types of an apartment unit based on the allowed annual amount of carbon emissions in a Korean building sector by the year 2030.

3. Methodology

Using a system dynamics approach, this study develops a carbon emission reduction policy model, which is decided based on the amount of carbon dioxide production of an apartment building's construction materials under the projected carbon emission reduction target by the year 2030. To estimate the total amount of carbon emissions produced by an apartment building's construction materials, this study considers the most typical types of apartment units in South Korea in terms of floor area—29.9 m^2 (type A), 46.2 m^2 (type B), 59.6 m^2 (type C), 84.9 m^2 (type D), 102.5 m^2 (type E), and 149.5 m^2 (type F).

3.1. Residence demand

Due to South Korea's high population density, apartment buildings are this country's most typical residence building [18]. As a government-led project, the large sizes of apartment clusters were developed in response to South Korea's rapidly growing urban population in the mid 1970s and 1980s [19]. Although apartment units of less than 60 m^2 were constructed in the 1980s, the national economic growth led to an increase in the size of most apartment units to between 85 m^2 to 100 m^2 constructed in the 1990s [20]. In addition, the rapid national economic growth means the existing