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Calculating Potential Green Area Impact on Land Uses to Estimate Future Green Areas in Land Use Planning

Jiyoung Kim* · Yesuel Kim** · Minseok Oh*** · Haneul Lee**** · Ha Kyeong Lee***** · Mooyeol Oh****** · Youngchul Kim*******

* Ph.D Student, KAIST Urban Design Lab, Dept. of Civil and Environmental Engineering, KAIST, South Korea (kimiji@kaist.ac.kr)
** Coauthor, Ph.D Student, KAIST Urban Design Lab, Dept. of Civil and Environmental Engineering, KAIST, South Korea (yesuel21@kaist.ac.kr)
*** Coauthor, Ph.D Student, KAIST Urban Design Lab, Dept. of Civil and Environmental Engineering, KAIST, South Korea (oms216@kaist.ac.kr)
**** Coauthor, Ph.D Student, KAIST Urban Design Lab, Dept. of Civil and Environmental Engineering, KAIST, South Korea (skythehuman@kaist.ac.kr)
***** Coauthor, Ph.D Student, KAIST Urban Design Lab, Dept. of Civil and Environmental Engineering, KAIST, South Korea (lhkny96@kaist.ac.kr)
****** Coauthor, M.Sc Student, KAIST Urban Design Lab, Dept. of Civil and Environmental Engineering, KAIST, South Korea (mooyeol.oh@kaist.ac.kr)
******* Corresponding author, Associate Professor, KAIST Urban Design Lab, Dept. of Civil and Environmental Engineering, KAIST, South Korea (youngchulkim@kaist.ac.kr)

ABSTRACT

Purpose: Since green space becomes more significant in the greenhouse gas reduction, this study seeks to propose the potential green area impact that mean expected amounts and impacts of green space on land uses in the future in the planning phase. **Method:** To calculate the potential green areas impact, this study analyzes current characteristics of green spaces using land use spatial data and normalized difference vegetation index (NDVI) raster data. Five cities planned and developed in the 1990s and 2000s in Korea were selected, and the values of potential green area impact were calculated for each land use. The spatial unit used in the calculation was a 10 by 10 m unit cell considering the spatial resolution of NDVI raster data and combining spatial and raster data in the cell unit. **Result:** This study proposed 'potential green area impact', a value that quantifies the potential land use ability to increase green areas for carbon absorption in the future. This potential green area impact is expected to be a criterion to develop guidelines of green space and to assess planning schemes of green space in urban land use plans to reduce greenhouse gases.

KEYWORD

도시개발
온실가스
저탄소도시

Urban Development
Green House Gas
Low-Carbon City

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1. Introduction

The climate change convention on efforts to reduce greenhouse gas emissions and discussions are one of the most internationally interested topics in recent years. Since the 1970s, starting with the Kyoto Protocol and ending with the United Nations Framework Convention on Environment and Development in Rio in 1992, efforts to reduce carbon emissions in various ways and directions have become a global trend[1]. Since COVID-19 also added economic crises to each country, Korean government also announced new growth strategies such as the Green New Deal[2]. In addition, the rise in the average temperature of the earth, the continuous emission of greenhouse gases has a direct impact on climate change, such as a rise in average sea level and a decrease in the area of glaciers[3]. Since Korea's urbanization rate reached 81.4% in 2022 according to the 2022 data of the National Statistical Office[4], it became more urgent to consider greenhouse gas issues at a city. In Korea, various studies investigated green gas reduction in developing cities, in particular, residential areas. For example, the Hwaseong Dongtan 2nd New Town was declared as a carbon-neutral city, and were different from other urban development projects because this project sought to secure green areas and open spaces and apply the concept of a smart city[5]. In addition, Low Carbon Cities were an unavoidable way to achieve the goal of sustainable development[3][5], and efforts to reduce greenhouse gases in the planning phase should be considered for Low Carbon Cities in Korea[6][7]. However, since those previous studies usually demonstrated planning strategies, schemes and results of urban development, it is difficult to quantitatively estimate the amount of greenhouse gas reduction in the future depending on land use plan in the planning phase.

Therefore, this study aims to propose the 'potential green space impact', a concept that can induce the additional securing of green spaces in urban spaces during the planning phase. To develop a concept that can infer the possibility of how much green space can be secured for each type of area when planning a new city in the future, this study seeks to propose a method of obtaining a regional 'potential green area impact' rate by analyzing the land area and density of green space.

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2. Literature Review

UK's garden city planning demonstrated that green spaces, life, and people's infrastructure were significant in urban planning and development[3][5]. In addition, the evaluation factor for developing an environment-friendly city became important since the demand for carbon neutrality increased[7]. An approach to reduce carbon emission in the urban planning phase were investigate for greenhouse gas reduction[8] and reduction scenarios were developed by dividing carbon emissions into sectors in urban areas[9].

However, those previous studies sought to develop planning strategies and schemes in and analyze existing conditions of greenhouse emission[7-10], To assess land use plans, it is necessary to identify the amount of greenhouse gas reduction in the future and to evaluate planning schemes at the planning phase.

Although it is known that currently in Korea, forests absorb about 7.4% of greenhouse gases in the entire country, studies about the amount of greenhouse gas absorption by green space are not fully investigated enough to verify their impact on greenhouse gas absorption in urban space[11]. Additionally, although installing facilities to generate renewable energy is more efficient to reduce greenhouse gas, securing green space in urban areas is helpful to reduce greenhouse gas and to provide people with good natural environment in cities[2][11]. To secure and add green spaces in urban space, it is important to plan green-space and low-carbon strategies by understanding current status of green space and energy consumption. For example, major cities in Germany, the UK, the UAE, Canada and China have developed the Low Carbon City planning in land use, green space, transportation, renewable energy, energy saving building, etc.[2][12]. Additionally, the development of China's Low Carbon Cities has directly improved green growth and environment of cities[13]. Thus, it is necessary to investigate current status of green space on various land uses as a strategy to reduce greenhouse gas in urban space.

Therefore, this study seeks to propose a new concept of 'potential green area impact' that quantifies the potential spatial ability to increase carbon absorption by additional green space in the future by developing a method to analyze land use data to achieve a low-carbon city.

3. Methods

This study defines the potential green area, and analyzes the 'potential green area impact' in the 1st and 2nd new towns of Korea where spatial and raster data are available to collect and analyze. Thus, this study seeks to develop the ratio to calculate green areas that would be converted from plots of various land uses for greenhouse gas emissions.

3.1. Definition of Potential Green Area Impact

The potential green area impact in this study means additional green space that can be created in the ground space, although it is not a green area according to its land use plan. When buildings are built in residential or commercial uses, some areas around the building in the ground can become green areas including trees and grass, which is the potential green area. Thus, 'potential green area impact' means the amount of potential green space and is calculated with Normalized Difference Vegetation Index (NDVI) and area (㎡) values.

The value of the potential green area impact are calculated for each land use type (residential, commercial, industrial area, etc.) as follows (Eq. 1).

$$x = \frac{NDVI}{LA} \quad \text{(Eq. 1)}$$

Where x $(/m^2)$ = potential green area impact; $NDVI$ = Mean value of $NDVI$ for each land use type; and $LA(m^2)$ = land area for each land use type.

According to the image resolution of 10 by 10 meters in NDIV raster data, the spatial data of land uses are divided into 10 by 10 meter cells with a geographic information system (GIS) program in Fig. 1. The cell unit is designated to include NDVI, land use, and building status. The number of cells in chosen cities are found from around 100,000 to 1 million cell units.

3.2. Research Process

This study follows three steps in Fig. 2.: data collection analysis, cell unit analysis, and cell unit analysis. In the first step, land uses and NDVI data are collected. A spatial data set is established including land uses and NDVI data and constructed on a 10 by 10 meter cell. In the second step, cells with an NDVI value of 0.2 or larger are selected as a green area.

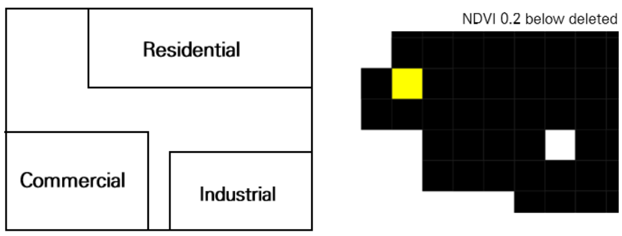

Fig. 1. 10x10 cell module of potential green area impact

Then, the sum, mean, and NDVI values for each land use types are calculated. According to the NDVI values on each land use, the potential green areas are calculated. In the final step, the potential green area impacts are calculated based on 10 by 10 meter cells. After calculating all values of the potential green area impact in chosen cities, the values of each land use are calculated as a reference value for Korean cities.

3.3. Selected Sites

Five cities of Bundang, Ilsan, Sanbon, Jungdong, and Pangyo were selected for the potential green area impact, which represent the first and second phase new cities in Korea. When spatial and raster data was missing in cities in the first and second phase new towns in Korea, those cites were excluded in the study. The first phase new towns includes four cities of Bundang (Seongnam-si, Gyeonggi-do, development period: 1989~1996), Ilsan (Goyang-si, Gyeonggi-do, development period: 1990~1995), Sanbon (Gunpo-si, Gyeonggi-do, development period: 1989~1995), Jungdong (Bucheon-si, Gyeonggi-do, development period: 1990~1996) and the second phase new town includes Pangyo (Seongnam-si, Gyeonggi-do, development period: 2003~2017).

3.4. Data Processing

The data of 2021 were used in selected sites. The land characteristics comprehensive spatial data, and NDVI data were used as basic data for potential green area impact analysis. The land spatial data was provided by the National Spatial Information Center of the Ministry of Land. A land characteristic map is a graphic spatial map and data that represents space and land boundary lines. It is a computerized map to identify the land use status by lot number, administrative district code, land category, area, and actual use status such as building data.

Table 1. shows six types of residential land use area according to the regulation in Korea. Depending on the types of residential land use area, floor area ratios and building average ratios vary.

Table 1. Residential land use area (Korea)

Landuse	Objective (Main purpose)	Building Coverage Ratio (Average)	Floor Area Ratio (Average)
Type 1 exclusive residential district	Separate housing	50	50~100
Type 2 exclusive residential district	Public housing	50	100~150
Type 1 general district	Low-rise housing	60	100~200
Type 2 general district	Mid-rise housing	60	150~250
Type 3 general district	Middle and High-rise housing	50	200~300
Semi-residential	Residental with commercial and business function	70	200~500

The NDVI data, which is the basis for the vegetation (greenery)

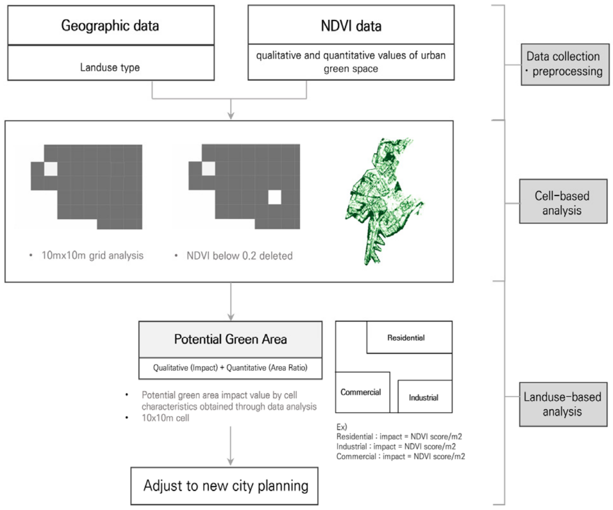

Fig. 2. Research Flow

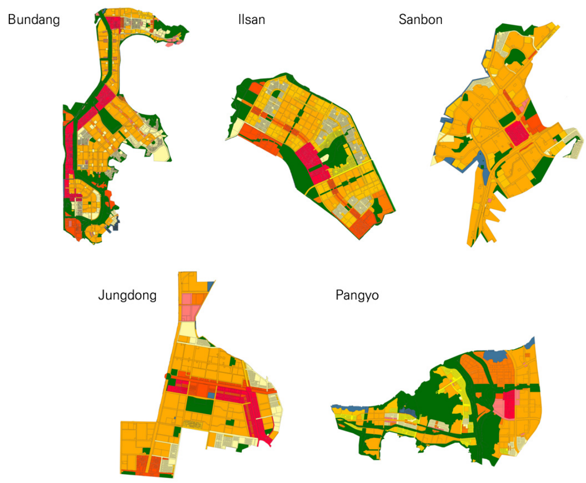

Fig. 3. Landuse data modification

Fig. 4. NDVI data modification

index, used data from May 2019, and Sentinal-2A and MSI L1C were used to gain satellite images. The final organized data has coordinate system EPSG:32652 WGS 84 / UTM zone 52N, and the file format uses GeoTIFF/ Float32 – 32-bit floating point. After the primary processing of the five selected cities, the data was modified as a process of deriving the necessary values according to the calculation process.

The extracted land use data was processed according to the shape of each cities using the QGIS program. Data was established for the five cities: four cities in the 1st phase new towns (Bundang, Ilsan, Sanbon, Jungdong) and one new city in the 2nd phase new towns(Pangyo) in Fig. 3.

The NDVI raster data was used based on satellite images to show the growth state of crops was indexed using the near infrared (NIR) band reflectance. Vegetation is quantified by measuring the difference between near-infrared light (strongly reflected by vegetation) and red light (absorbed by vegetation). Each NDVI value was derived as a value between -1 and +1 and was divided into the minimum unit cell (10 by 10 meters) of this study that was pre-determined.

4. Results

4.1. Analysis of Each City

KDE (Kernel Density Plot) Plot was used as one of the methods to confirm that each city has a different potential green space impact depending on the type of the land use. It was expected that the green space for each cities would be represented by a KDE plot, and a green area of 0.2 and more (i.e., a potential green area conversion potential area with a coefficient of potential green area impact) could be extracted.

The KDE plots for each city are shown in Figs. 5. to 9.

Fig. 5. shows that the potential green area impact of type 2 exclusive residential, conservation green, and natural green areas are 0.2 and more in Bundang.

In Ilsan, the potential green area impact of natural green and conservation green areas are 0.2 and more in Fig. 6. Although the potential green area impact of agriculture and forestry area is also above 0.2, it is not important for urban space because those undeveloped and agriculture areas are rarely included in urban space.

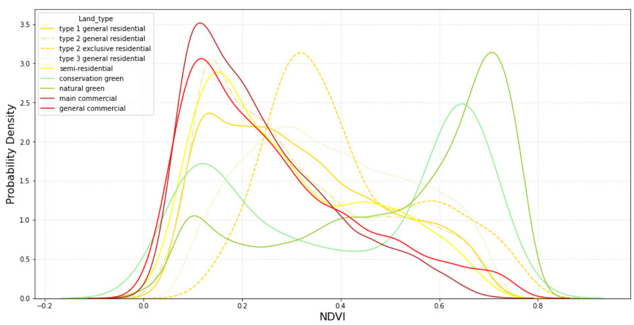

Fig. 5. Bundang potential green area impact KDE Plot

In Sanbon, the potential green area impact of type 1 general residential area, type 2 general residential area, type 3 general residential area, natural green area, general commercial area, and

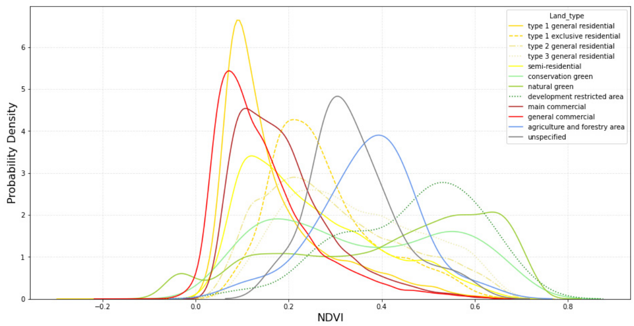

Fig. 6. Ilsan potential green area impact KDE Plot

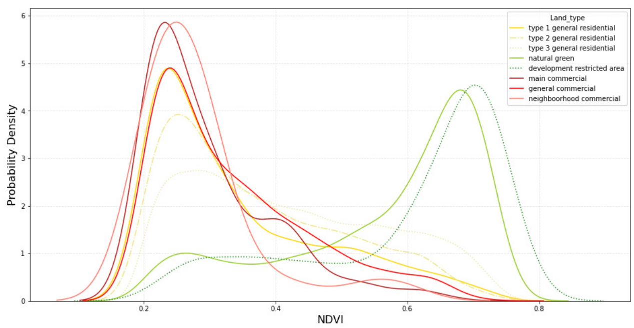

Fig. 7. Sanbon potential green area impact KDE Plot

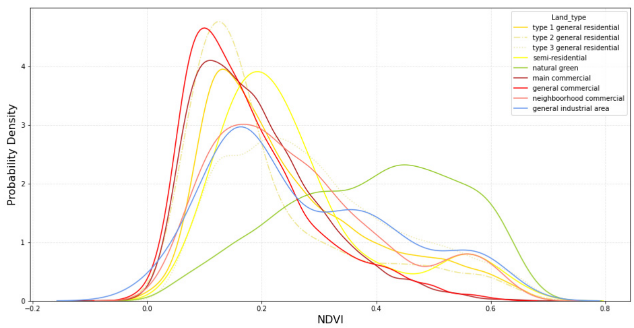

Fig. 8. Jungdong potential green area impact KDE Plot

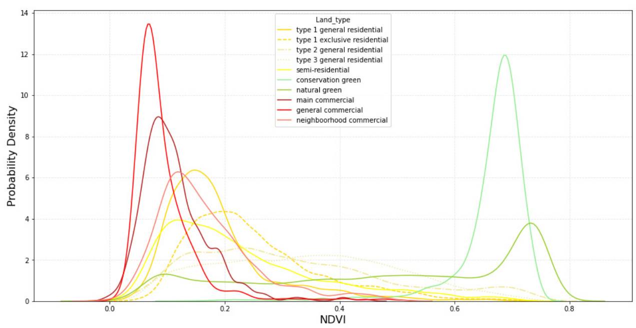

Fig. 9. Pangyo potential green area impact KDE Plot

neighborhood commercial area are above 0.2 in Fig. 7. In particular, the maximum value of type 1 general residential area and general commercial area is similar.

In Jungdong, only the potential green area impact of natural green area is above 0.2. While the value of semi-residential area is almost 0.2, the values of other residential areas show are lower than 0.2.

In Pangyo, the maximum value of natural green and conservation green areas are 0.2 and more. KDE plot patterns that green areas have much higher value compared to other land use areas are similar in Bundang, Sanbon, and Pangyo.

According to those results, the potential green area impact value of the applicable use area is significant. In other words, a significantly larger NDVI value was confirmed in the use of apartment houses (type 2 general residential area, type 3 general residential area), which often plan to lower the building coverage ratio and tries to create green spaces on the ground for its residents. Therefore, according to the result values, the extraction of the separated result value for each land use type of the existing 1st and 2nd phase new town cities is meaningful.

4.2. Potential Green Area Impacts on Land Uses

In addition to the potential green area impact on each city, this section analyzes the value on potential green area impact depending on land uses. Table 2. shows the values of potential green area impact of selected cities in the 1st and 2nd phase new town cities. According to the values of potential green area impact calculated with the land use area and NDVI data, the maximum value of NDVI for each cell based on the entire city was 0.8078, and the minimum value was 0.2. The value of potential green space impact was calculated by the equation of (Eq. 2) as an area ratio by land use type:

$$AR = \frac{NDVICN}{TLCN} \times 100\,(\%) \qquad \text{(Eq. 2)}$$

Where AR = Area ratio per land use; $NDVICN$ = Cell number of $NDVI$ above 0.2 per land use; and $TLCN$ = total cell number per land use type.

Accordingly, the area ratio for each land 1use was calculated excluding areas where land use was not designated. According to Table 3., the area ratio of development restricted and type 2 exclusive residential are are largest. The range of potential green space impact by each land use area confirms that the max-value of the conservation green area is the largest at 0.6999 and the max-value of agricultural area is the lowest at 0.4890 except the value of unspecified area. Since the unspecified ares hardly explain land uses in a city, it is excluded from the results.

Table 2. Combined results of all cities

Land use	Min	Max	Mean	Std	Area ratio
Type 1 general district	0.2000	0.7920	0.3782	0.1583	53.97
Type 2 general district	0.2	0.7627	0.3705	0.1563	69.24
Type 3 general district	0.2	0.7737	0.4065	0.1574	83.23
Type 1 exclusive residential	0.2	0.6455	0.3195	0.1289	71.44
Type 2 exclusive residential	0.2001	0.7902	0.4228	0.1582	95.61
Semi-residential	0.2	0.7262	0.3669	0.1505	56.65
Main commercial	0.2	0.7312	0.3296	0.1516	46.47
General commercial	0.2	0.7778	0.3372	0.1577	23.54
Neighborhood commercial	0.2	0.7590	0.3439	0.1558	58.50
Natural green	0.2	0.8078	0.5401	0.1584	83.65
Conservation green	0.2012	0.7300	0.5489	0.1510	69.08
General industrial	0.2003	0.6143	0.3864	0.1196	54.17
Agriculture and forestry	0.2266	0.5933	0.3828	0.1062	94.74
Development restricted	0.2023	0.7897	0.5932	0.1576	99.87
Conservation management	0.2002	0.7050	0.4395	0.1457	72.92
Unspecified area	0.2120	0.6048	0.3514	0.1139	93.48

*Area Ratio : %

Table 3. Min. and max. values of potential green area impact on each land use

Min.	Landuse	Max.
0.2199	Type 1 general district	0.5365
0.2142	Type 2 general district	0.5268
0.2491	Type 3 general district	0.5639
0.2000	Type 1 exclusive residential district	0.4484
0.2646	Type 2 exclusive residential district	0.5810
0.2164	Semi-residential area	0.5174
0.2000	Main commercial area	0.3912
0.2000	General commercial	0.4949
0.2000	Neighborhood commercial	0.4997
0.2717	Natural green	0.6985
0.3979	Conservation green area	0.6999
0.2668	General industrial area	0.5060
0.2766	Agriculture and forestry area	0.4890
0.4356	Development restricted area	0.7508
0.2938	Conservation management Area	0.5852
0.2375	Unspecified area	0.4653

*Range of the potential green area impact of all cities

Fig. 10. illustrates the distribution of NDVI values in the entire selected cities and the green areas shows large values in all selected cities. Since the value of residential areas are large, landscape areas including planted trees and grass in the residential areas have influenced the value of potential green area impact. Thus, the potential green are impact demonstrate the future green area effect on various land uses that are not green in the plan.

Table 4. shows land use types of which potential green area impact is 0.2 or larger for the five new towns in Korea. Additionally, according to Figs. 5. to 9. excluding natural green area, Bundang shows that residential areas including type 2 exclusive residential and semi-residential areas have the second-largest potential green area impact value after conservation green areas; Ilsan shows that residential areas including type 1 exclusive residential and type 2 general residential areas has a large potential green area impact; Sanbon shows that commercial area including neighborhood commercial area, central commercial area, and general commercial area has a large potential green area impact; Jungdong shows that an industrial area including general industrial area has a large potential green area impact, but the value of industrial area is lower than 0.2; Pangyo shows that commercial areas including general commercial area, central commercial area, neighborhood commercial area have a large potential green area impact.

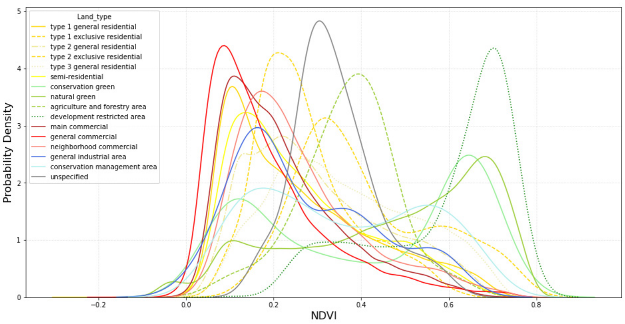

Fig. 10. Potential green area impact KDE Plot of each land use

Table 4. Land uses of potential green area impact 0.2 or larger

City	Total no. of land-use type	No. of land-use NDVI 0.2 or larger	Land uses of potential green area impact 0.2 or larger
Bundang	10	3	Type 2 exclusive residential, Conservation green, Natural green
Ilsan	12	5	Type 1 exclusive residential, Type 2 general residential, Agricultural and forestry, Development restricted, Natural green area
Sanbon	8	6	Type 1 general residential, Type 2 general residential, Type 3 general residential, Natural green, General commercial, Neighborhood commercial
Jungdong	9	1	Natural green
Pangyo	11	2	Natural green, Conservation green

5. Conclusion

This study sought to develop a method to calculate additional green areas on various land uses according to the land use plan in the planning stage for analyzing greenhouse gas and carbon reduction by green area in the future. Accordingly, this study defined the potential green area impact and calculated the values based on Korea's first and second new towns. The amount of potential green area impact was analyzed to determine how much green space each land use is expected to have later.

In addition, this study built a reference data set to evaluate a land use plan in the early planning stage for estimating expected green areas depending on those planned land use. Since land uses except green area hardly demonstrate the amount of green area in the future, the potential green area impact on each land use would be helpful to estimate green areas in the land use plan.

However, in this study, the values of potential green area impact show current conditions and hardly demonstrate changes in green areas chronologically. Since this study uses current zoning in each city, not planned land use in the planning stage, it was difficult how actual land uses in the planning stage influenced green areas after 20 and 30 years. Thus, it is necessary to investigate chronological changes in various land uses based on actual land use plans.

Nevertheless, this study contributed to calculate the amount of potential green area on various land uses excluding green area of land use. Other land uses except green area in the land use plan are confirmed to include green areas after 20 and 30 years. Thus, according to the value of potential green area impact, the carbon reduction by green area would be possible to consider in the planning stage. In the future, it is expected that the potential green space impact will be helpful to assess a land use plan and develop guidelines of land uses for greenhouse gas and carbon reduction in the planning phase. Accordingly, it is also suggest to analyze more cases of changes in the amount of green space on various land uses for generalizing the potential green area impact on land use.

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