

Article

Scenario Analysis for GHG Emission Reduction Potential of the Building Sector for New City in South Korea

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Abstract: A new government report on climate change shows that global emissions of greenhouse gases have increased to very high levels despite various policies to reduce climate change. Building energy accounts for 40% of the world's energy consumption and accounts for 33% of the world's greenhouse gas emissions. This study applied the LEAP (Long-range energy alternatives planning) model and Bass diffusion method for predicting the total energy consumption and GHG (Greenhouse Gas) emissions from the residential and commercial building sector of Sejong City in South Korea. Then, using the Bass diffusion model, three scenarios were analyzed (REST: Renewable energy supply target, BES: Building energy saving, BEP: Building energy policy) for GHG reduction. The GHG emissions for Sejong City for 2015–2030 were analyzed, and the past and future GHG emissions of the city were predicted in a Business-as-Usual (BAU) scenario. In the REST scenario, the GHG emissions would attain a 24.5% reduction and, in the BES scenario, the GHG emissions would attain 12.81% reduction by 2030. Finally, the BEP scenario shows the potential for a 19.81% GHG reduction. These results could be used to guide the planning and development of the new city.

Keywords: greenhouse gas (GHG); CO₂ emission; long-range energy alternatives planning system (LEAP); renewable energy supply target; building energy saving; building energy policy

1. Introduction

In Kyoto on 11 December 1997, the Kyoto Protocol was adopted at the Third United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP3). This accord defines the obligation of developed countries to reduce GHG (greenhouse gas) emissions [1]. The Kyoto Protocol imposed on Annex 1 countries is an obligation to reduce GHG emissions by an average of 5.2% (compared to the levels of the 1990s) within the first commitment period (2008–2012). Under the Kyoto Protocol system, South Korea is not categorized among the Annex 1 countries obliged to reduce greenhouse gas emissions. However, before a newly derived climate system (Post-2020) scheduled to start in December 2015, a GHG reduction goal was set at 37% (compared with the business-as-usual or BAU scenario) by 2030. This was done in anticipation that South Korea could expand its influence in the international community [2]. For the building sector, a GHG emissions reduction goal was set of 26.9% of BAU by 2020 [3]. To support this goal, the Korean government strengthened building design standards and evaluated the building's energy efficiency and total energy consumption. In addition, many policies [4] have been introduced to manage building energy supply in a way that reduces energy consumption and greenhouse gas emissions in the building sector. To support these policies, research is being conducted on ways to predict and reduce greenhouse gas emissions from existing cities in Korea.

In the study of Jo et al. [5], energy consumption and GHG emissions of residential buildings in Siheung City were analyzed. In the research of Koo et al. [6], a low-carbon scenario was established by 2020 by developing an integrated multi-objective optimization model to achieve the national carbon emission reduction target in the residential building sector in Korea. In addition, research on the prediction of GHG emissions and the possibility and cost analysis of GHG reduction measures were conducted. In addition, studies related to the prediction and reduction of greenhouse gas emissions in existing cities in the world are as follows.

Yasuyo Makido et al. [7] investigated a relationship between urban and CO₂ emissions generated in urban areas in 50 cities in Japan. Tan et al. [8] evaluated the difficulty of achieving CO₂ emission reduction targets ahead of Chongqing CO₂ emission reduction potential and analyzed the low carbon conversion pathway. Wang et al. [9] identified the major factors that increased greenhouse gas emissions in Suzhou, China between 2005 and 2010, and, quantitatively, analyzed using Kaya identity and the logarithmic mean division index method. Chaturvedi et al. [10] analyzed long-term building energy demand in India using an integrated assessment modeling framework. Lin and Liu et al. [11] conducted an empirical study on the determinants of CO₂ emission related to building energy in China and evaluated the possibility of CO₂ reduction during the building operation. Pukšec et al. [12] analyzed long-term forecasts of energy demand in the Croatian residential sector. Promjiraprawat et al. [13] used the AIM/End Use Model to investigate energy savings, reduction potential, and costs in Thailand's residential sectors. Lin et al. [14] evaluated the effects of urban energy reduction and GHG emission measures, developed a LEAP (Long-range Energy Alternatives Planning) model to study energy demand, and future trends in GHG emissions in Xiamen.

The previous studies mentioned above relate only to GHG mitigation and the potential for reduction in the existing city. The GHG emission prediction and reduction scenarios for existing cities have been studied significantly. However, studies that can predict and reduce greenhouse gas emissions in newly constructed cities are lacking. In addition, the analysis of GHG forecasting and reduction scenarios by expanding existing cities or building new cities was insufficient.

Currently, in Korea, the existing specific cities are becoming huge, resulting in problems with population density and regional imbalance. In addition, greenhouse gas emissions are increasing very much in these cities, and, to prevent this, the Korean government has been building innovative cities (new cities) for each region by moving public institutions from 2013. Therefore, it is necessary to analyze various scenarios to reduce greenhouse gases targeting buildings in newly constructed urban development (planning) districts.

For that reason, there is a limit for the reduction of greenhouse gases generated from already constructed buildings. It is necessary to find a methodology for reducing greenhouse gases through linkage with the use of buildings, energy saving factors, application of new and renewable energy, and energy policies before new city construction.

In this study, predictions, energy demand, and greenhouse gas emission models were made for the building sector of innovative cities (new cities) in Korea. In addition, the BAU (Business as usual) was derived by calculating the GHG emissions through the LEAP model using information on the population growth, GDP (Gross domestic product) growth rate, and building (residential, commercial) information of the new city by referring to the government planning data of the new city. This basic greenhouse gas emission was selected as the baseline. In addition, various greenhouse gas reduction scenarios were developed through the Bass diffusion model and the reduction potential was analyzed to differentiate it from previous studies.

For this scenario analysis, Sejong City, a representative city among innovative cities in Korea, was selected as the target city, and the greenhouse gas emission model and reduction scenario of the building sector until 2030 were analyzed using a bottom-up model. This city was founded according to plans for new, low-carbon cities MOLIT [15]. In this study, in order to support the goal set in the Green City-CCP [16], and to analyze the GHG reduction potential based on the emissions calculation and technical foundation of the building sector of the Sejong City, a new scheme was derived that is more

realistically accessible. After analyzing the amount of GHG emissions using these methodologies, this paper tried to assess the applicability and potential of other local government reduction programs in the future, which might result from the application of possible new GHG reduction policies.

2. Methodology

2.1. The LEAP Model

LEAP [17–20] is an econometric model developed by the Stockholm Environment Institute and Boston University in the USA [21]. It can be used as an energy environment modeling tool based on scenario analysis to analyze energy demand, corresponding environmental impacts, and cost/benefit outcomes.

The models are mainly used for national and urban mid-term to long-term energy and environmental planning. In addition, it can be used to predict mid-term to long-term energy supply and demand at a social scale under the influence of various driving factors, and to quantify air pollutants and greenhouse gas emissions related to energy circulation and consumption [22].

LEAP is a scenario-based energy simulation model that can provide a platform for data structuring, energy balance development, supply and demand scenario planning, related emission estimation, and alternative policy evaluation [23]. This model has powerful accounting functions. This allows you to detail how energy is produced, transformed, and consumed for a specific set of demographic and economic data under alternative assumptions for general energy and demand data, specific environment, fuel, technology, and price conditions.

Moreover, by comparing the predicted outcomes, the potential for reducing energy use and GHG emissions can be obtained under different scenarios for a specific target year or period. With the analysis model of GHG reduction, the amount of emissions in the energy sector is determined by economic activity that consumes energy (i.e., energy intensity per unit and greenhouse gases emissions [carbon intensity] per unit). In this study, the final energy demand [3] required to calculate greenhouse gas emissions was calculated using Equation (1).

$$ED_{b,s,t} = TA_{b,s,t} \times EI_{b,s,t} \quad (1)$$

where ED is energy demand of the building sector and TA is total activity, b is branch (residential, commercial building), EI is energy intensity, s is scenario, and t is year.

This study estimated the availability of urban-scale regional control measures for the new Sejong project. The activity of the building sector was used to make the 2018 statistical data the basis for comparison. The inventory is of energy used in the building sector and the calculated energy intensity. Based on the way this process preserved the basic data, the bottom-up model could take advantage of the LEAP model. Using these, the GHG emissions and energy consumption of Sejong City was projected to 2030. Furthermore, in order to analyze the reduction potential of energy-related policies and optional reductions by the building sector, primary reduction measures were used to evaluate the potential amount of reduction.

In general, we use municipality outlook material to predict the amount of activity. However, for Sejong City, there is no prospect of such material because the city is newly constructed. For this reason, the prospects reference data of Dongtan innovation city, which has the closest characteristic to Sejong City, was used to analyze the predictive value of Sejong City activity. A typical amount of activity of the building sector is related to the population and the number of households. By reference to the Statistics Korea 2005–2030 future population projection data [24], the amount of activity was analyzed.

Variables that affect the energy intensity of Sejong City, efficiency improvement of major equipment, penetration of household appliances, floor area of residences, total floor space of business facilities, number of heating and cooling days depending on the temperature, changes in use time, etc., were analyzed by calculation. Improvement in the efficiency of major equipment was analyzed in reference

to efficiency improvement targets of application-specific representative equipment, and the efficiency to 2030 was calculated using the annual average efficiency of 2018 high-efficiency products when compared to products of similar capacity used in 2016. This was calculated by taking into account the efficiency-improvement targets of major consumer electronics companies. Appliance-specific penetration-rate forecasts of home and office appliances to 2030 were based on 2016 and 2018 data of the Power Exchange [25]. The baseline LEAP comprises two parts: estimation of GHG emissions and energy savings potential. The baseline BAU (business as usual) scenario [26] and REST (renewable energy supply objective) scenarios represent different control actions and policies. The GHG emissions and total energy consumption were calculated through two scenarios. In addition, the potential for energy saving and emission reduction was derived by comparing the results of the two scenarios.

2.2. The Bass Diffusion Model

In this study, we used the Bass diffusion model (a sectoral technology dissemination model) for analysis of the CO₂ reduction potential of Sejong City.

The model proposed in Bass [27] is one of the widely applied diffusion prediction process models. The Bass model has four parameters that indicate nonlinear indices and their behavior. This Bass diffusion model equation is used because it allows smooth change of parameters between time steps. This formula incorporates both internal and external influences based on a differential equation representing the number or market share of innovation adopters over a period of time.

The Bass model calculates the rate of change of adoption as a function of the interpersonal innovation coefficient and the interpersonal imitation coefficient [28]. This Bass diffusion model is used in many industries to predict the market share of new technologies. The equations of the Bass model are (2) and (3) [29,30].

$$\frac{dN(t)}{dt} = \left(p + \frac{q}{m} \cdot N(t) \right) \cdot (M - N(t)) \quad (2)$$

$$F(t) = \frac{1 - e^{-(p+q)t_i}}{1 + \frac{q}{p} e^{-(p+q)t_i}} \quad (3)$$

where: $N(t)$ is the number of customers who have already adopted innovation by time t , M is a parameter representing the total number of customers in the segment that will eventually adopt the product, p is the innovation factor (or external influence factor), and q is the imitation coefficient (or internal influence factor).

The Bass model can be addressed explicitly for $F(t)$, which is part of the infiltrated market, assuming that the number of first adopter is $t = 0$. This is a formula that can be used to estimate cumulative adoption as a function of coefficient of imitation q and coefficient of innovation p .

In this study, the household setting represented in the supply plan by the scale, was reset to multi-residential and single-family households supply area in the building sector, indicated by the Bass model constant M . We projected the number of residential households to 2030 with a model used for predicting the number of households from 2011 to 2020 (using the actual housing supply area), using the Bass model.

In addition, for the ‘dissemination total area prediction’ of commercial buildings to 2030, the building approvals of “happiness city planned area” as issued by the Multifunctional Administrative City change data of the urban construction development plan from the Multifunctional Administrative City Construction Agency of the current situation, planning material of construction business process [31,32], were analyzed with reference to the construction plan of the provincial government office building. For sectoral planning of commercial buildings that were presented in the application-specific categories, the total floor space was analyzed by setting the Bass predictive model to constant m .

In order to build the REST scenario, fuel cells [33], solar cells [34,35], the current spread situation of energy storage, geothermal systems, annual increase, annual demand of annual renewable energy [36], and increase in the amount were predicted using the Bass diffusion model.

In the present study, this diffusion model was used to predict the potential reduction of GHG emissions in Sejong City, South Korea, according to various scenarios. The analytical procedures in the LEAP and Bass models are described in Figure 1, which shows a flowchart of the system analysis calculations implemented in the GHG emission-reduction platform.

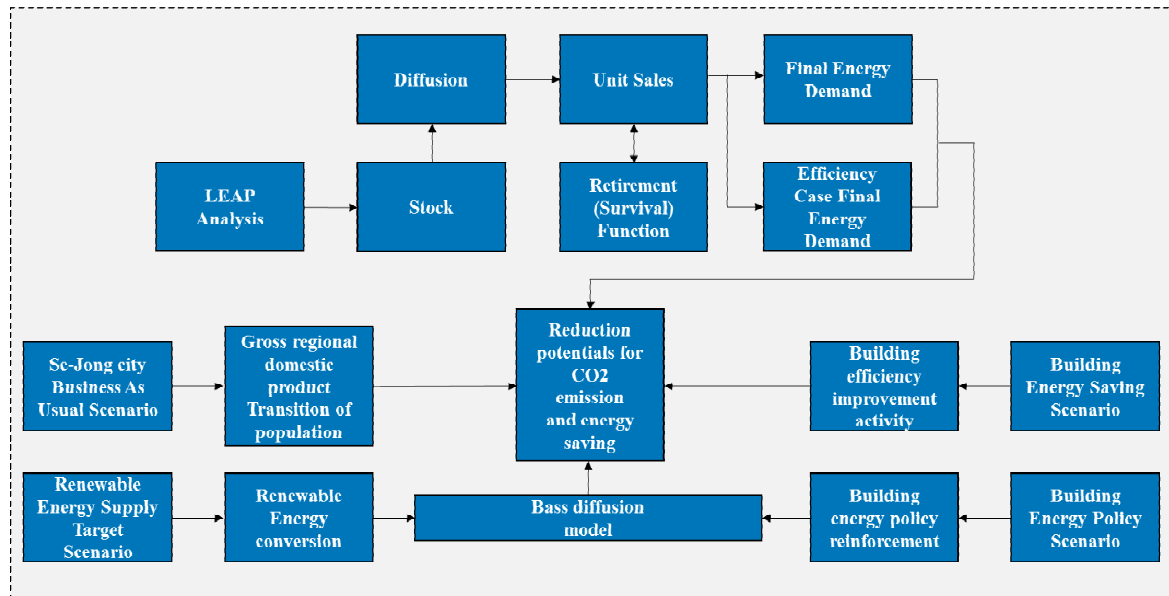


Figure 1. The study processes based on the long-range energy alternatives planning (LEAP) model and Bass diffusion model.

Figure 1 shows the process from the final result to data inputs. Some of this paper's process is implemented in LEAP with user-defined calculations, while others are calculated as platform functions. In general, LEAP calculates energy savings at the national level, taking into account the inventory or sale of each type of equipment combined with the time series of marginal final energy intensity (i.e., the annual energy consumption of new devices entering inventory). GHG emissions are calculated through final energy demand calculations. The activity modeling has been implemented through custom calculations that are not directly driven by a series of product sales.

3. Case Study

3.1. Study Area and Data Use

The government of the Republic of Korea enacted a Special Act on 18 March 2005 to develop Sejong City. Subsequently, construction of the Multifunctional Administrative City began in the City of Sejong in 2010. The innovation city (new city) plan aims to:

1. eliminate urban sprawl in the capital region,
2. strengthen national competitiveness, and
3. balance national development.

Sejong City is located in Northeast South Chungcheong Province, and adjoins Cheongwon-gun in North Chungcheong Province to the east, Gongju City to the west, Daejeon City to the south, and Seoul City to the north (127°16'54" E, 36°29'15" N) (see Figure 2). The new city covers an area of 73 km² and had a total population of 342,000 people in 2020. The data used in this study are from three references: the district unit planning of Sejong City main data and building basic planning data, and the urban development data. The development of Sejong City, unlike for other domestic cities and in response to national measures intended to reduce GHG, is planned to provide a higher-level result than for the Green City designs being implemented worldwide.

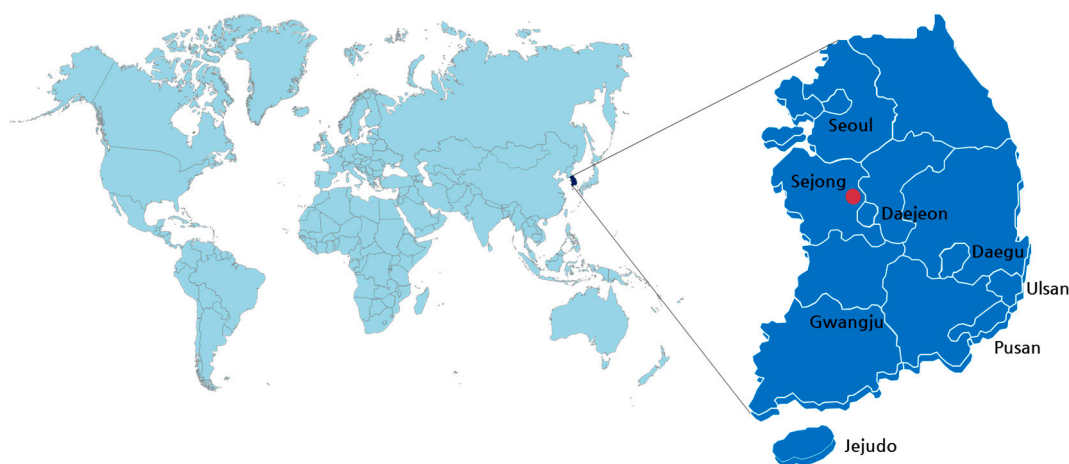


Figure 2. Location of Sejong City in South Korea.

3.2. Scenario Design

The LEAP model was used to analyze GHG emissions and energy consumption from the residential and commercial building sectors of Sejong City. The scenario planning is useful for designing alternative energy infrastructures and long-term planning and explanation of uncertain future greenhouse gas emissions. Due to increasing energy demand and economic growth, it is necessary to analyze scenarios for reducing GHG emissions from the residential and commercial building sectors of Sejong City. The present study examines four scenarios for GHG emission, considering BAU and emission options. The time range for the scenario analysis is 2018–2030 with 2018 as the baseline year. The BAU scenario was set as the first reference point, and the REST scenario was developed to represent the growth rate of renewable energy resources in electricity production. The Bass diffusion model was used to assess the utilization of fuel switching, energy policy, and the introduction of renewable energy over time among consumers. It was applied to GHG mitigation in the REST scenario, by applying the diffusion model, to estimate the adoption rates of new energy technologies, such as those involved in building-energy-efficiency ratings. The BES (Building Energy Saving) scenarios were analyzed to reduce the amount of greenhouse gases by improving the efficiency of home appliances and office electronics. In addition to housing, LED lighting increased the efficiency of commercial buildings. The use of LED lighting, and efficiency improvements in air conditioning and heating facilities, was used to construct a scenario to reduce GHG. Finally, current energy policy scenarios were created that reflect positively the building energy efficiency ratings that are carried out in South Korea. We also strengthened the thermal insulation performance of the step-by-step, energy-saving design criteria of a building scenario that reflects the country's institutions.

4. Results and Discussion

4.1. Business as Usual (BAU) Scenario

The BAU scenario predicts energy flow based on present energy policies as well as supply and demand trends in Sejong City. The modeling of energy demand and greenhouse gas emissions involves some quantitative assumptions about population growth, number of floor area, households, and GDP. This information was obtained from the report of the Sejong City Construction Agency until 2030. Economic indicators for Korea in 2030 are predictions by the Department of Statistics and the Korea Energy Economics Institute, and are estimated via regression and statistical methods. The economic conditions indicated in the quantitative assumptions are presented in Table 1. The Sejong City population is expected to continue growth until it reaches about 500,000 people and becomes stable in 2030. Residential floor area is estimated to increase by an average of 9.2% annually, reaching 16,372 million m² in 2030, whereas commercial floor area is expected to increase by 11.5% annually,

to 8.912 million m². Based on survey data for 2015–2020, GDP is projected to increase by 3.45% per annum from 2015 to 2030 [37].

Table 1. The Quantitative Assumptions and Estimates of Economic Indicators for 2020–2030.

Indicators ^a	Assumptions	2020	2030
Population	Surveyed data (2015–2020)		
	Annual average	341,895	698,213
Residential area (m ²)	4.5% p.a. increase (2020–2030)		
	Surveyed data (2015–2020)		
	Annual average	6,326,689	16,372,027
	9.2% p.a. increase (2020–2030)		
Commercial area (m ²)	Surveyed data (2015–2020)		
	Annual average	3,721,529	8,912,270
Gross domestic product (GDP) (billion USD)	11.5% p.a. increase (2020–2030)		
	Surveyed data (2015–2020)		
	Annual average	1919.39	2,245.65
	3.45% p.a. increase (2020–2030)		

Note: ^a Indicators are based on Trading Economics, 2020, South Korea Indicators.

The Sejong city of this study was a city where it was very difficult to predict greenhouse gas emissions with the BAU scenario calculated by the characteristics of the city. For this study, the GHG BAU emissions of Sejong City were calculated using the LEAP model by referring to the standards of materials used in Dongtan New City, which have similar characteristics to Sejong City.

In general, the heating used in the residential sector and commercial buildings requires oil (kerosene), natural gas, or electricity. Currently, in the case of liquid fossil fuels such as oil, the higher prices of previous times have become lower, but this is expected to pass and the price is expected to continue to increase. Therefore, the analysis indicated the use of natural gas and electricity will be relatively increased. The total amount of fuel associated with urban development is expected to gradually show a declining trend. To calculate the BAU ratio of CO₂ emissions, changes in the increase or decrease of the fuel consumption of the matters discussed above were considered and determined.

In this paper, an increase in the prediction of the fuel consumption during the transition from 2015 to 2030 was calculated by extrapolating the CO₂ emissions per capita. Table 2 shows the results of analysis of the changes in an increase and decrease in the amount of fuels used from 2015 to 2030 in the residential and commercial building sectors.

Table 2. The rate of increase in fuel consumption (Building sector, Sejong City prediction criteria) ^a.

Year	Petroleum (%)	LNG (%)	Electricity (%)	Thermal Energy (%)
15–20	−4.445	1.093	1.715	1.004
20–25	−4.074	0.549	1.548	0.611
25–30	−3.385	0.223	1.105	0.333

Note: ^a the rate of increase in fuel consumption is based on MACCA, 2015.

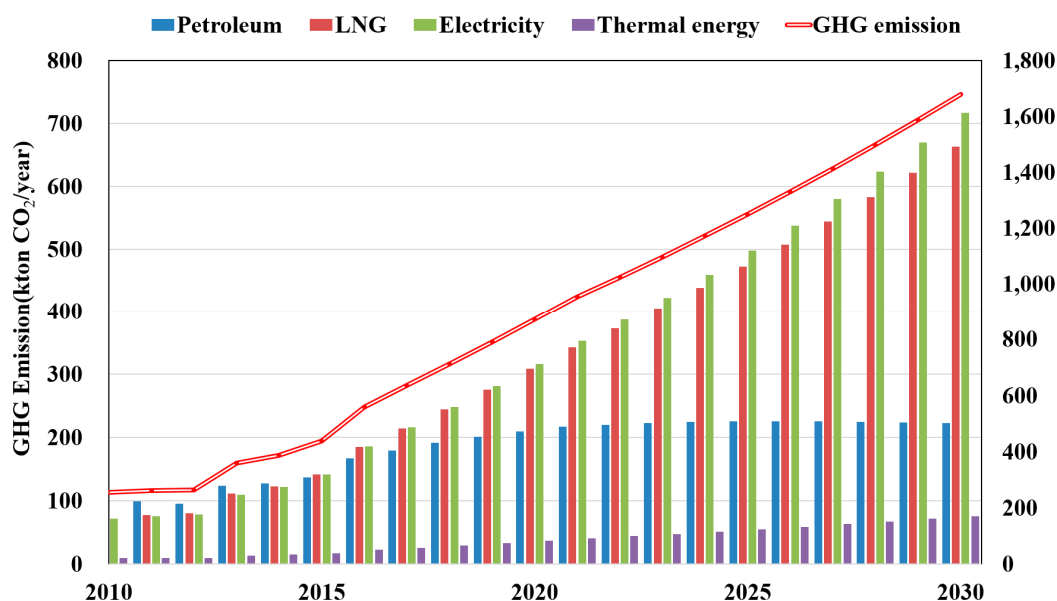
In this study, there were three stages of population planning in 2030, taking into account the rate of change in the per capita fuel use, and the per capita CO₂ emissions in the 2015 standard (BAU), as shown in Table 3. This section predict the household and commercial sector of CO₂ emissions.

The BAU scenario shows the most basic estimate of GHG emissions, based on present national and sectoral policies (see Table 3, Figure 3). As a result, if control is not carried out in Sejong City, annual CO₂ emissions from housing and commercial sectors are expected to be 1.67 million, 587 tons by 2030.

Table 3. The CO₂ Emissions Prediction of 2015–2030 (CO₂ Emissions Per Capita)^a.

Fuel	Petroleum	LNG	Electricity	Thermal Energy	
Unit	tCO ₂ /person				
Year	2015–2030	1.383	0.813	0.778	0.102
Population	501,600	222,652	662,924	717,309	75,702
Total	1,678,587 tCO ₂ /yr				

Note: ^a The CO₂ emissions prediction of 2015–2030 is based on MACCA, 2013. (MACCA, 2013).

**Figure 3.** CO₂ emissions of Sejong City building sector in the business-as-usual (BAU) scenario.

4.2. Renewable Energy Supply Target Scenario (REST-S)

The REST scenario incorporates renewable energy technologies into the entire energy mix. These renewable energy sources substitute for thermal electricity production, which currently predominates, and are based on the estimated existing potential of renewable energy sources in Korea. Moreover, the Bass diffusion model was used to suggest the application of renewables for Sejong City under the REST scenario, incorporating: (1) solar thermal, (2) fuel cell, (3) energy storage, (4) photovoltaic, and (5) geothermal technologies. The REST scenario was analyzed using the supplies of total renewable energy from 2015 to 2030, year by year, based on the energy source composition of the Green City comprehensive plan.

First, solar systems were categorized as a single-family house, apartment house, and general building types to represent the solar supply scenario. To estimate the supply, we entered the parameters required for the Bass model and applied solar house performance data of the Green Home 1 Million supply project. We set a supply trend of approximately 10% of the ‘happy urban population,’ which resulted from considering the population of Sejong City (1% of the national population), and established a supply scenario of solar houses from 2015–2030. The analysis result of the incremental supply transition was 284,846 m² of combined solar collecting area for photovoltaic energy, and potential reduction of 34,257 tCO₂/year until 2030.

The fuel cell system strategy was 300 kW MCFC (Molten Carbonate Fuel) of fuel cell power generation on the basis of the Green City construction comprehensive plan, which was used to predict the overall supply of renewable energy. To provide the predicted amount of fuel cell energy supply (3 × 36,545 toe), it will be necessary to build a facility to increase the supply to 2.7% of total energy.

The GHG reduction from such use of fuel cells would be 89,566 tCO₂/year, according to the REST scenario for 2015 to 2030.

If energy storage systems (ESS) were included in the strategy for Sejong City Regional Energy Statistics [38], it would be possible to save 5% of the power generated by two groups of facilities (with a total of 515 MW) in 2030. In this paper, we analyzed an additional supply scenario with ESS installed in the PV (photovoltaic system) for combined heat and power plants and for energy storage systems with a capacity of 6180 MWh. The resulting CO₂ reduction would be 142,152 tCO₂/year.

The supply scenario of the PV sector included analysis of three parts: detached houses, apartment houses, and commercial buildings. Based on the domestic residential solar supply capacity influenced by the hundred thousand solar house supply project, we analyzed supplies using the BASS Model. The PV system supply capacity of domestic residences was analyzed. The dissemination capacity of the household building PV systems utilized in this model was analyzed using a national ratio of 10%. Moreover, the PV scenario of public facilities, compared to calculate the capacitance ratio based on the spread-plan domestic RPS (Renewable Portfolio Standard) was used as data. In other words, by utilizing the RPS supply plan [39,40] in the PV sector, we estimated the supply model in Sejong City in 2030 and calculated the prediction rate. This model was divided into three stages with the final supply capacity to be applied in 2030. Then, in order to achieve the target value at each stage, the scenario was analyzed. Then it moved to the next step. In conclusion, for 2030, a scenario was built in which a total PV collecting area of 314,788 m² existed, and for which the CO₂ mitigation potential expected was 106,737 tCO₂/year.

Finally, in the scenarios for the Sejong City residential sector geothermal systems, the BASS model was used to calculate the potential supply. The resulting supply included about 58,000 households or 10%. For commercial buildings, an estimate was made using 2011 geothermal system statistics. To create a scenario that provided a capacity equivalent to 3.65 times the Green Home geothermal housing estimated dissemination capacity every year, it was necessary to analyze the amount of CO₂ reduction. The CO₂ reductions were analyzed separately for the heating and cooling sectors. Heating had a CO₂ emission target that excluded the geothermal heat pump CO₂ emissions from among the CO₂ emissions of district heating. Cooling was analyzed by placing the reduction of CO₂ emissions for geothermal heat pump consumption within the air conditioning power consumption. The geothermal field analysis result included a scenario in which 304,524 kW of equipment was supplied to detached houses, apartment buildings, and general buildings through 2030. In this case, the CO₂ reduction would be 38,487 tCO₂/year. According to the Bass diffusion model, the coefficient of innovation and conversion factor, coefficient of utilization, market potential, heat production, and the CO₂ emission reduction for the supply of renewable-energy-source estimates are shown in Table 4. Figure 4 shows total CO₂ emissions mitigation for the REST scenario during the period of 2015–2030, accounting for the effects of fuel switching in Sejong City, and for various parameters in the LEAP and Bass diffusion models. On the whole, there would be a steady increase in the reduction of GHG emissions under each scenario up to 2030, but with different growth rates. Under the REST scenario, CO₂ emissions will reach 1,267,388 tCO₂/year in 2030 and will grow at an average annual rate of 7.36%. The REST scenario is characterized by a greenhouse gas control policy as the ratio of renewable energy sources to power generation increases. By 2030, it can achieve an emission reduction of 411,199 t CO₂/year. This indicates that increasing the proportion of renewable energy sources in electricity production contributes to reducing CO₂ emissions.

Table 4. Results from the Renewable Energy Supply Target (REST) Scenario: Used in the Bass Diffusion Model.

Renewable Energy Source Type	Coefficient of Innovation (p)	Coefficient of Imitation (q)	Conversion Factor	Coefficient of Utilization ^a (%)	Market Potential ^a (M)	Heat Production (kWh)	CO ₂ Emission Reduction (tCO ₂ /yr)
1. Solar thermal (2015–2030) 1.1 Single-family house supply (Green home project) 1.2 Residential building (Multi-family house) supply 1.3 Commercial building supply	1.003 × 10 ^{−4}	0.535	1.60 × 10 ^{−4}	75	284,846 (Collecting area, m ²)	224,876,784	34,257
2. Fuel Cell (2015–2030)	1.10 × 10 ^{−3}	0.413	4.71 × 10 ^{−4}	50	72 (Supply rate, ea)	518,400	89,566
3. Energy Storage System (2015–2030)	0.843 × 10 ^{−4}	0.627	-	50	6,180,000 (Energy storage, kWh)	6,180,000	142,152
4. Photovoltaic (2015–2030) 4.1 Single-family house supply 4.2 Residential building (Multi-family house) supply 4.3 Public facility supply	1.37 × 10 ^{−4}	0.323	4.71 × 10 ^{−4}	75	314,788 (Collecting area, m ²)	226,858,158	106,737
5. Geothermal system (2015–2030) 5.1 Single-family house supply 5.2 Residential building (Multi-family house) supply 5.2 Commercial building supply	0.48 × 10 ^{−4}	0.268	4.71 × 10 ^{−4} 1.60 × 10 ^{−4} (District heating)	50	304,524 (Installed capacity, kWh)	404,407,827	38,487

Note: ^a The Bass diffusion model of the coefficient of utilization and market potential is based on MACCA, 2015. (MACCA, 2015).

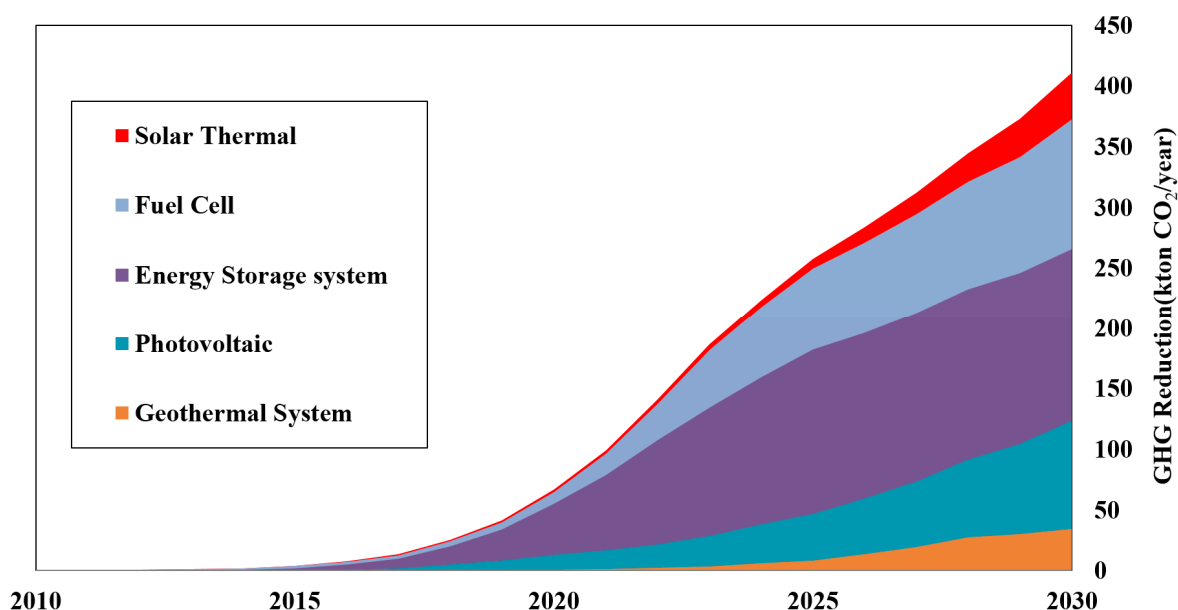


Figure 4. CO₂ emissions reduction potential of the Renewable Energy Supply Target (REST) scenario.

4.3. Building Energy Saving (BESS) Scenario

In this study, we analyzed the potential GHG reduction for the BESS (third) scenario. First, there were categories of major measures to save energy at home (HEME: Home Energy Management System). This included energy saved by use of high-efficiency equipment, standby power reducing products, expansion of low-carbon green villages, and green living practices. Then we analyzed the potential for energy savings by applying detailed measures. Next, commercial buildings were added to the system control strategy by introducing energy-saving buildings due to the high proportion of greenhouse gas emissions related to commercial buildings.

Focusing on measures to reduce the energy use of the building, we calculated the greenhouse gas reduction from the introduction of building energy management systems (BEMS), expansion of a low-carbon and high-efficiency building, and building energy measures involving control and management operations [41]. GHG reductions were analyzed using the calculation formula and index, which are given a total of 17 items in the BES scenario in Table 5. From this table, activities case a and b involve buildings with GHG reduction strategies related to energy management by systems, whereas case c to g are commercial buildings in which there are devices that interrupt standby power, high efficiency equipment, high efficiency LED lighting, and air condition applications to reduce GHG.

Table 5. Evaluation indicators and the results of the BES scenario.

Building Energy Reduction Activities ^a	Index	Calculation Formula	CO ₂ Emission Reduction (tCO ₂ /Year)
a. HEMS (Home energy management system) supply ^a	HEMS diffusion rate (%)	-	17,350
b. BEMS (Building energy management system) supply ^a	BEMS diffusion rate (%)	-	58,745
c. Use of standby power reduction product d. The use of high-efficiency equipment e. The use of high-efficiency LED lighting f. The use of commercial high-efficiency air handling unit g. The use of latent heat recovery type hot water boiler	Utilization of standby power 1W equipment (%) Building total area (m ²) LED utilization (%) Utilization of high-efficiency air conditioner (%) Apply the number of latent heat recovery type boilers Utilization of standby power reduction products	Reduction per unit (kg/m ² /year) × building total area (m ²) × diffusion rate (%)	88,465
h. Development of low-carbon Green village model ^b	Current status of the construction of Green village	-	3820
i. Build a roadmap of low-carbon Green village ^b	Practice exercise diffusion	-	4734
j. Practice exercise deployment of Green village ^b	Practice exercise diffusion	-	4734
k. Consultant training and management of climate change ^b	Consultant (climate coordination) training person	-	2708
l. Demonstration home the town designated as the expansion of eco family ^b	Eco-family village test The number of eco-family town	-	3844
m. Social marketing support for the company and exercise deployment of green work ^b	Participation rate of green workplace exercise	-	8754
n. Reasonable limitation proposal of indoor air-conditioning temperature	Enforcement rate (%) Building total area (m ²) Control temperature (°C)	Reduction per unit (kg/m ²) × building total area (m ²) × temperature control (°C) × enforcement rate (%)	10,648
o. Strengthening of green life practice network and campaign deployment	Green living practice rate of citizen	-	14,462
p. Expansion and off practice after work	Building total area (m ²) Off enforcement rate after business (%)	Reduction per unit (kg/m ² /year) × building total area (m ²) × enforcement rate (%)	345
q. Company employee lunch break room off practice building total area (m ²)	Building total area (m ²) Lunch break off enforcement rate (%)		1130

Note: ^a. The building energy saving activities are based on MACCA, 2013. (MACCA, 2013) ^b. The CO₂ reduction activities are based on MOTIE, 2009a. [41].

The utilization rate, application rate, and supply rate were each analyzed and showed the greatest reduction of GHG emission in the BES scenarios.

In the BES scenario, the following resulted from analyzing the amount of reduction of greenhouse gas. In cases h–m (left column, Table 5), the amount of greenhouse gas was calculated that could be shared through the building and roadmap of low-carbon green villages to assist efforts toward the spread and activation of green villages.

In Case ‘o’ (left column, Table 5), human energy saving methods were analyzed to indicate quantitative GHG reduction. Previous studies using models about people’s energy saving practices showed 5–10% potential energy savings. Cases ‘n,’ ‘p,’ and ‘q’ are energy saving scenarios of general buildings for which calculated GHG savings were based on air conditioner temperature settings and on/off lighting controls used according to the presence or absence of people.

The reduction of GHG emissions indicated in cases ‘a’ to ‘q’ of the BES scenario that are presented in Figure 5 and Table 5. The cumulative CO₂ emission reduction between BAU and BES scenarios, from 2015 to 2030, would be 1.4 million tons of CO₂, corresponding to approximately 215,005 tons of CO₂ per year. The total reduction of CO₂ emissions for the BES scenario by 2030 shown in Figure 5 is based on improvements in energy efficiency and low-carbon green life activities in Sejong City as well as the various parameters in the scenarios based on the Bass diffusion model.

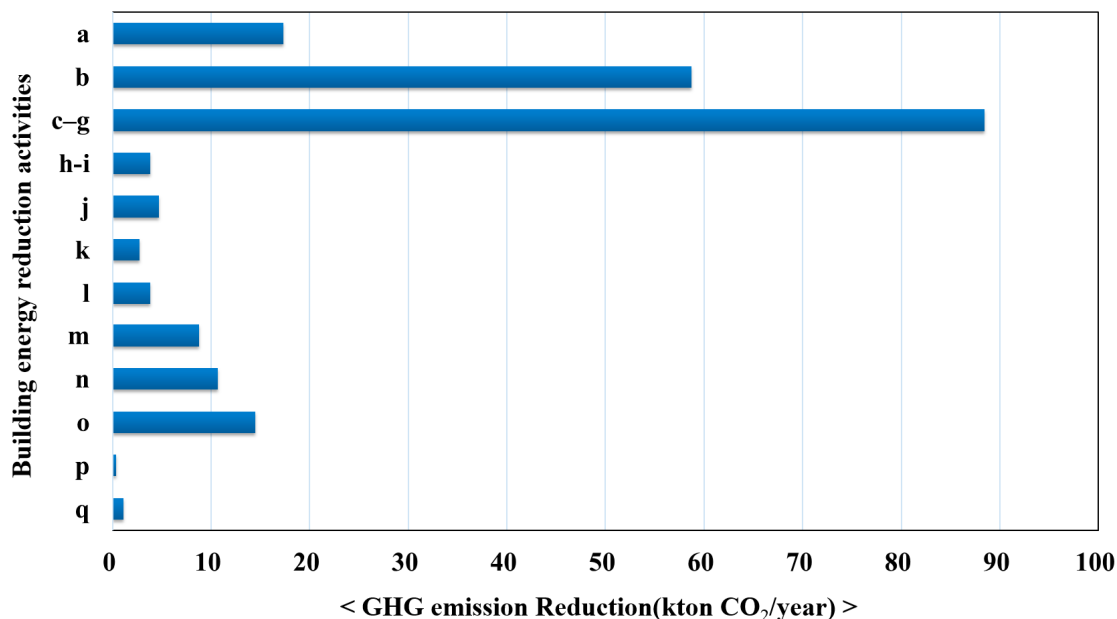


Figure 5. CO₂ emissions reduction potential for the building energy saving (BES) scenario.

The BES scenario shows the predicted reductions in CO₂ emissions from the residential and commercial building sectors for the BASS diffusion model. The results show that the residential building sector would make the largest contribution to energy savings, which was followed by the commercial building sector. In terms of emission reduction, the building sector is expected to make the greatest contribution, and the energy conversion sector is expected to follow.

4.4. Building Energy Policy (BEP) Scenario

Mitigation procedures in both residential and commercial sectors are predominantly based on improved energy efficiency and strengthened requirements for thermal performance. The energy efficiency measures included in the residential and commercial BEP scenario address the following: (1) Expansion and improvement of green home systems, (2) creation of an effective carbon grading system, (3) strengthening of energy design criteria of buildings, (4) implementation of energy target

management systems of buildings, (5) strengthening the building energy efficiency rating system, and (6) implementation of a total energy consumption system [42].

In the proposed BEP scenario, progressive and efficient building energy policies are introduced to achieve energy saving and CO₂ mitigation from 2015–2030, considering the proposed adoption rates of particular policy. Policy measures to reduce GHG emissions in buildings can be summarized as separate consideration of new buildings, existing buildings, and the machines and equipment sector. The GHG emissions and energy efficiency policies in Figure 6 are of institutions related to representative building (construction) subject to government regulation. Analysis was done to strengthen the step-by-step reference to the six types of building energy policy presented through 2030 in each of the five years and four stages of the 2015 criteria. Then, the strategy to achieve energy efficiency of the building sector of Sejong City was analyzed, and the results are shown in Table 6 and Figure 7.

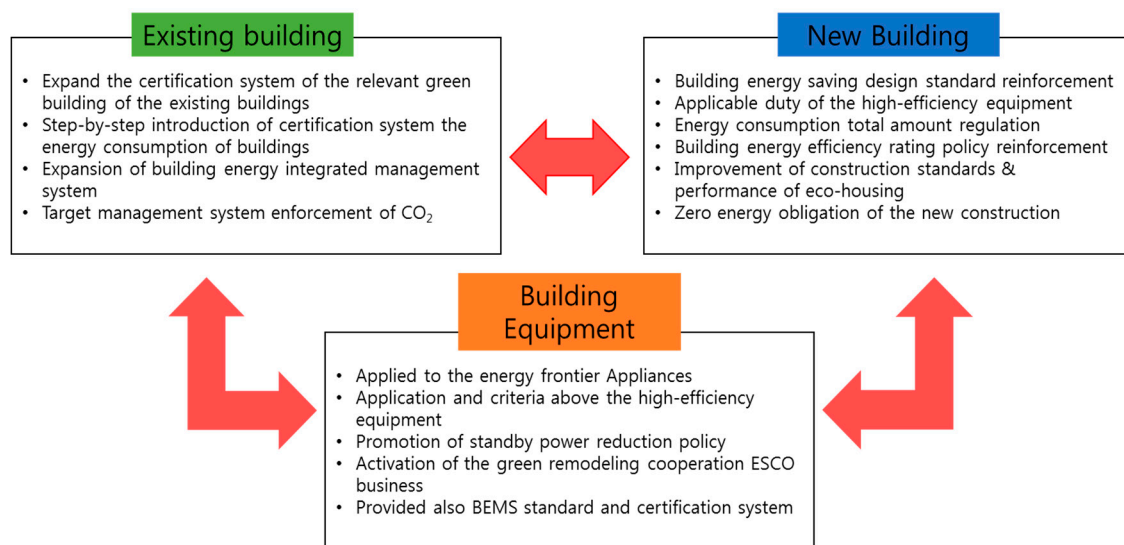


Figure 6. GHG reduction policies and energy reduction policy of building.

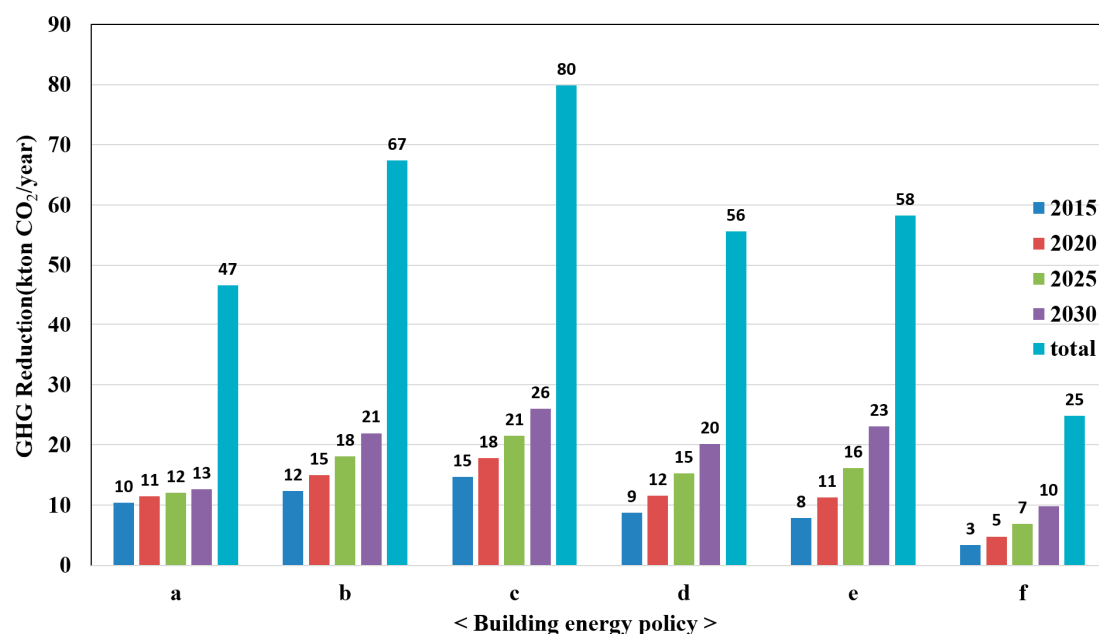


Figure 7. CO₂ emissions reduction potential of the building energy policy (BEP) scenario.

Table 6. The results of the evaluation methods and CO₂ reduction of the step-by-step BEP scenario.

Energy Policy Category ^a	Target	Application Rate	Implementation Method	Year CO ₂ Emission Reduction (tCO ₂ /yr)				
				2015	2020	2025	2030	Total
a. Expansion and improvement of green home system	New building	70%	2015 year standards, strengthening of 5% added in the five-year unit, up to 20% enhanced	10,413	11,480	12,054	12,657	46,604
b. Carbon grading system is also effective	Existing/New building	40%	2015 year standards, 10% additional applied in the five-year unit, up to 40% of the application	12,384	14,984	18,131	21,939	67,438
c. Strengthening of energy design criteria of the building	New building	70%	2015 year standards, strengthening of 5% added in the five-year unit, up to 20% enhanced	14,670	17,750	21,478	25,988	79,886
d. Implementation of GHG and energy target management system of the building	Existing/New building	60%	Since 2015 year, sustained enforcement	8740	11,536	15,228	20,101	55,605
e. Strengthen the building energy efficiency rating system	Existing/New building	80%	2015 year standards, strengthening of 5% added in the five-year unit, up to 20% enhanced	7873	11,258	16,099	23,022	58,252
f. Implementation of energy consumption total system	Existing/New building	80%	Since 2015 year, sustained enforcement	3348	4787	6846	9790	24,771

Note: ^a The energy policy categories are based on MOTIE, 2009a. (MOTIE, 2009a).

First, the concept of a Green Home was taken from the 'green growth green city composition' and expanded. Then it was continuously applied at the five-year stage of zero carbon dioxide emissions. From this, a strategy was constructed to strengthen the system by 5%. The GHG reduction by this saving method would be 24,771 tCO₂/year. In Case 'b' (left column, Table 6), the reduction of GHG by energy savings were analyzed by applying the carbon rating system from 2015. The GHG reduction from this saving method would be 24,771 tCO₂/year. In case b, the reductions of GHG savings for every five years in new and existing buildings was analyzed by applying the carbon rating system from 2015. We modeled infrastructure for systematic carbon management and reduction, analyzed the quantitative effect of reduction measurements, and then evaluated the quantitative GHG reductions in accordance with the 10% application rate per year. In this study, GHG reduction by energy savings for case b would amount to 46,604 tCO₂/year.

Then, in cases c and d, the scenarios strengthened the criteria for evaluation of building energy design standards and building energy efficiency. In this scenario, the five-year unit of the thermal insulation and facilities of the basic building energy-saving design of existing/new buildings, was strengthened by 5% using performance criteria, such as electricity performance from 2015 to 2030. As a result, the new buildings were housing, matching, and commercial buildings, and the energy demand of the combined construction was predicted.

After forecasting the energy demand based on enhanced standards, we calculated GHG reductions. As a result, case c would have reduced GHG by 67,438 tCO₂/year and case d by 58,252 tCO₂/year. In case e, the 2015 target of the Ministry of Greenhouse Gases and Building Management was used to analyze the GHG reduction in Sejong City. In order to achieve the GHG reduction targets that are currently in force nationally, an application rate of 60% was used for the building sector in Sejong City. The amount of GHG emission reduction would amount to 55,605 tCO₂/year. Finally, in case f, GHG reductions were analyzed considering active enforcement of the total energy-use rate restriction for buildings. A strategy was constructed that included zero-energy buildings in 2030, through a 50% (passive house level) reduction in energy consumption compared to current residential buildings by 2020. Commercial buildings were also subjected to a 30% reduction in energy consumption by 2020, pushing aside the mandated 60% reduction, and the constructed strategy would be imposed by 2030. Finally, case f was found to be capable of reducing greenhouse gas by 79,886 tCO₂/year in 2030.

5. Conclusions

This study was intended to focus on the innovation city (new city) of Sejong in South Korea, and the potential to predict and reduce greenhouse gas emissions was analyzed.

In this study, three GHG emission reduction scenarios were considered, using the LEAP modeling tool and Bass diffusion model to represent different measures to mitigate CO₂ emissions of Sejong City from 2018 to 2030. For the Sejong City building sector, the use of renewable energy and reduction of building energy use, was used to predict the energy demand of buildings in line with energy policy. The potential amount of GHG reduction was calculated. In addition, supply and energy reduction from the inclusion of renewable energy in the building sector was used to predict the energy demand associated with energy policy. The results show that energy efficiency measures adopted by Sejong City, as well as fuel conversion and energy policies, will have significant effects on saving energy and reducing GHG emissions. For the BAU scenario, the GHG emissions in 2030 would be 4.5 times that of 2018. This increase would create huge problems related to the energy supply and GHG mitigation systems, emphasizing the urgent need for energy saving and emission reduction.

For the period of 2018–2030, the BAU scenario was analyzed to determine the baseline emissions of greenhouse gases of the Sejong City building sector. In the BAU scenario, to calculate the amount of greenhouse gas emissions, transition data (including population increases or decreases) and GRDP (Gross Regional Domestic Product) data, were applied to predict the energy consumption. GHG emissions of the Sejong City building sector in 2030 were found to be 1,678,587 tCO₂/year. Such GHG

emissions do not reflect active efforts to reduce greenhouse gas emissions by 2030. We analyzed the potential for reducing GHG emissions in the building sector via the following three scenarios.

In the first scenario, REST was used to analyze the amount of GHG reduced by supplying five renewable energy sources to the Sejong City building sector. After analysis, the results from applying the five renewable energy sources would be a GHG reduction of 411,199 tCO₂/year. The value of the result would be a 24.5% reduction from the BAU emissions.

The second BES scenario was quantitatively analyzed for the Sejong City building sector by considering the potential for reduction by methods capable of reducing the energy use in residential and commercial buildings. In this paper, using 17 types of an energy reduction strategy for buildings could decrease building energy use and the potential for reduction of GHG emissions was analyzed. The results of the analysis indicate that a GHG reduction of 215,005 tCO₂/year might be possible. This shows the potential for a reduction of about 12.81% from the BAU level.

Finally, using the BEP scenario, the potential for reduced GHG was analyzed for the case of step-by-step application of an energy system incorporating various GHG and building policies. After applying the six types of policies and institutions, analysis of the GHG reduction would be 332,556 tCO₂/year, which is a reduction from the BAU level of 19.81%.

This scenario, which combines Bass diffusion models with energy policies, effectively reduces CO₂ emissions, successfully realizing the CO₂ emission reduction conversion. This study also shows that the commercial building sector will make the greatest contribution to energy saving in Sejong City, which is followed by the residential building sector. Therefore, a comprehensive and integrated low-GHG sustainability strategy is needed to achieve reductions in energy consumption and carbon emissions. This study is expected to be applicable to cities that are newly built in other countries. In addition, it is possible to predict the GHG emissions of new cities, and, if a reduction scenario is applied, it can be used as a solution that can flexibly cope with each country's GHG reduction.

Future research plans to analyze scenarios for predicting and reducing GHG emissions in the industrial and transportation sectors of new cities.

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