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Estimation of Greenhouse Gas Reduction Potentials by Introducing Smart Energy Systems: Empirical Evidence in Korea's Building Energy Management System

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ABSTRACT

Interest in smart energy systems as a means to reduce greenhouse gas (GHG) emissions and mitigate climate change has been increasing. In particular, much attention is focused on the building sector, which has the highest potential for GHG reduction. Yet, there have been few studies that have thoroughly and quantitatively analyzed the potential amount of greenhouse gas reduction through introduction of building energy management systems (BEMS). This study focuses on empirical evidence generated by BEMS in Korea and analyzes the benefit to cost ratio of such installations for various types of buildings using individual building-level microdata from large buildings in the 2017 Energy Consumption Survey to quantitatively derive the potential for GHG reduction. According to the main research findings, the BEMS dissemination rate could increase by as much as 21 percent, which induces 3.3 percent of energy saving and 3.4 percent of GHG emission reduction. Among 9 sub-sectors, the telecommunications sub-sector has the largest dissemination rate (87.5 percent), and the department stores sub-sector has the lowest rate (1 percent).

Key words: *Climate Change Mitigation, Smart Energy System, Greenhouse Gas Reduction Potential, Building Energy Management System (BEMS)*

1. Introduction

In the New Climate Regime established by the Paris Agreement in 2015, both developed and developing countries are required to participate in responding to climate change through mitigation and adaptation efforts. Under the existing Kyoto Protocol, only developed countries were obligated to reduce greenhouse gases, but now all parties must submit Nationally Determined Contributions (NDCs) to the United Nations Framework Convention on Climate Change (UNFCCC).

The Republic of Korea submitted an NDC in 2015 and proposed a reduction target of 37 percent from business as usual (BAU) by 2030. In 2018, the GHG reduction roadmap was revised and supplemented to maintain the 37 percent from BAU reduction target by 2030, but reductions in the domestic sector increased from 219 million tons carbon dioxide equivalent (CO_2eq) to 276.6 million tons CO_2eq. Korea intends to deal with the remaining 38.3 million tons CO_2eq through overseas reductions and carbon offsets (Joint Association of Related Ministries, 2018).

To further reduce greenhouse gas emissions worldwide, energy efficiency improvements must be strengthened and

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the supply of renewable energy must be further expanded. Reducing final energy consumption by improving energy efficiency or by expanding renewable energy can help replace fossil fuels and contribute to greenhouse gas reductions (IEA, 2017).

The efforts to reduce greenhouse gases to tackle climate change promote the expansion of small-scale distributed resources such as new renewable energy, energy storage systems (ESS) and electric vehicles and induce energy demand management in terms of energy systems.

Responding to this global trend, the Korean government recognized the limitations of supply-oriented energy policy and attempted to shift the energy policy paradigm beginning in the mid-2000s. In the first Basic Plan for Energy in 2008, sustainable development that simultaneously considers energy security, economic growth and the environment was set as the most significant goal of mid- to long-term energy policy (MoTIE, 2014).

The second energy plan in 2014 and the third in 2019 reiterated the importance of energy demand management and the necessity of establishing a distributed power generation system (MoTIE, 2014; MoTIE, 2019). The Renewable Energy 3020 Implementation Plan and the 8th Basic Plan for Power Supply and Demand announced in 2018 also emphasized the importance of expanding the supply of renewable energy, expanding distributed resources and managing energy demand (MoTIE, 2017a).

Even though government policy is well established, a micro-quantitative analysis is necessary in order to predict the precise effects of the introduction of smart energy systems and to also to conduct ex post verification. However, there are few microscopic and quantitative analyses of how much smart energy systems reduce energy consumption and further contribute to the reduction of greenhouse gas emissions.

We should be particularly interested in the potential of the building sector's for reducing greenhouse gas emissions. According to the Intergovernmental Panel on Climate Change (IPCC), the building sector has the highest potential among all sectors for greenhouse gas reduction (mitigation).

Against this backdrop, this study intends to quantitatively analyze the potential for energy savings and greenhouse gas reductions through the introduction and expansion of BEMS targeting commercial and public buildings in a variety of applications.

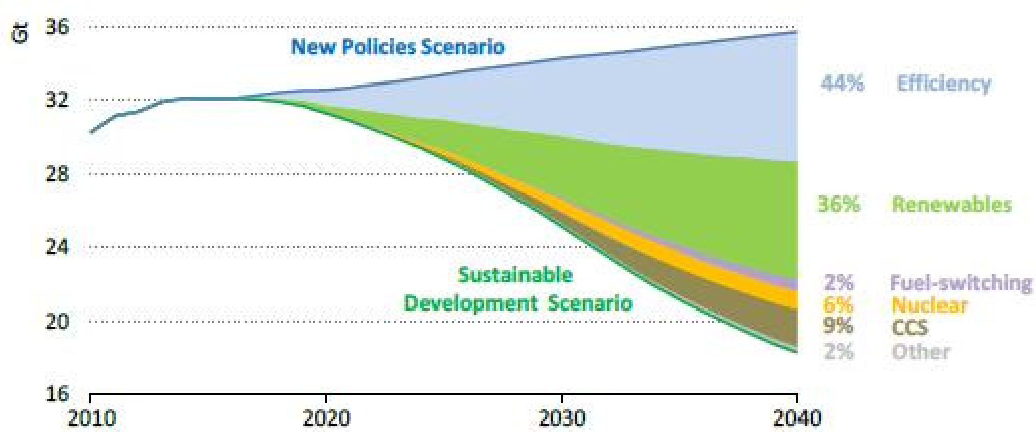

Fig. 1. Effect of reduction measures on global CO_2 reduction

(Source: IEA, 2017)

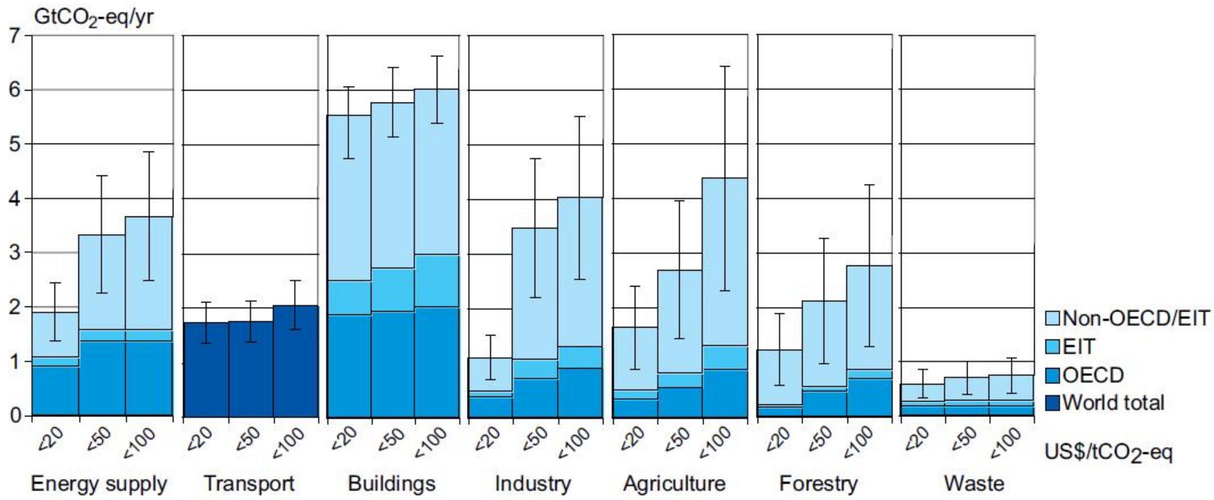

Fig. 2. Potential for greenhouse gas reduction by sector

(Source: IPCC, 2007, p.11)

To this end, this paper consists of five sections. Chapter one introduces background and purpose of the study. Chapter two discusses domestic and foreign market trends in BEMS. Chapters three and four examine the energy savings rates by BEMS function and the reduction potential of greenhouse gases through BEMS, respectively. Chapter five summarizes and concludes.

2. Market Trends and Applications of BEMS

According to the Korean Industrial Standard KS F 1800-1 (2014 Building Energy Management System Part 1), BEMS is the ‘Integrated Control, Management and Operation System that helps maintain a pleasant indoor environment and efficiently use energy of buildings’ (KATS, 2014). The Korea BEMS Association defines BEMS as ‘a system that collects and analyzes various information about buildings using construction technology, information and communication technology, and energy technology to provide optimal environment for buildings and efficiently manages energy.’ The International Energy Agency (IEA) defines BEMS as “the system by which, under a reasonable and efficient utilization of energy, the building manager controls, manages, and maintains a safe, sanitary, comfortable and functional environment for living as well as for business for the sake of tenants.” (IEA, 1991). Combining these definitions, BEMS is a system that effectively manages energy use in buildings by using information and communication technology to implement smart buildings in terms of energy use. It can be interpreted as a concept that incorporates the Fourth Industrial Revolution process in the recent manufacturing industry.

Global Market Insight (2020), a global market research firm, estimated that the market size of BEMS is expected to surpass six billion USD by 2023. In Korea, in order to foster the BEMS industry, the Korean BEMS Association was established in 2013 (Ministry of Land, Infrastructure and Transport establishment permit No. 16). Table 1 compares and summarizes the main functions of BEMS provided by major domestic and foreign companies.

According to KICT (2014), having confirmed 28 cases of domestic BEMS applications, each a level based on their BEMS functionality was assigned, but the level of functionality in four domestic cases could not be determined. Out of the remaining 24 cases, we assigned three systems the Level 2 designation, which means that they can provide usage and zonal data (MoLIT, 2014;

KEA, 2018). Twelve cases were assigned the Level 3 designation; these systems are capable of systematic analysis (Kwak Y *et al*., 2013; Lee J *et al*., 2016; Song J. & Kim J., 2015; MoLIT, 2014; KEA, 2015). There were nine systems with Level 4 capabilities: these systems can provide data on energy usage data for individual devices and floors (Byeon J, 2008; MoLIT, 2014; KEA, 2015; KEA, 2018). The energy savings rate due to the introduction of BEMS is measured by different standards in the literature and expressed in different ways, so batch comparison is not easy, but it is thought that the energy savings effect is around 10 percent (KICT, 2014).

Overseas cases of BEMS application were also examined through a literature review. According to KICT (2014), when classified by Level according to BEMS function, three Level 2 cases capable of usage and zone analysis, two Level 3 cases capable of system analysis and nine cases capable of analyzing specific devices and floors and four Level 4 cases were found. There were three cases where the level of the system could not be confirmed (Kim DH *et al*., 2008; Cha Y, 2014; Yuan J *et al*., 2015; Macarulla *et al*., 2017; Choi H *et al*., 2017; Papantoniou S *et al*., 2015; Manjarres D *et al*., 2017). The maximum energy savings rate was 36 percent, for a Greek hospital building, and the minimum energy savings rate was one percent, the electricity savings of a university building in Japan (KICT, 2014).

On the other hand, a few researches related to the effect of reducing energy consumption or improving energy efficiency of BEMS were previously conducted. Lee D. and Cheng C. (2016) statistically analyzed energy saving effects based on a total of 105 BEMS cases from 1976 to 2014, and found that the energy saving effect of BEMS increased from 11.39% to 16.22% per year. Using Austrian and Spanish building data, Roche *et al*. (2015)

Table 1. Current status of major BEMS providers

Classification		Samsung SDS (Smart BEMS)	SK Telecom (Cloud BEMS)	KT (K-BEMS)	Honeywell (HBS)	Johnson Controls (METASYS)	Schneider (EMIS)
Basic Info	Core Business	IT Service Provider with BEMS	Mobile Service Provider	Wired and Wireless Communication Companies	Building Automation Specialist	BMS Specialist	Automation Control Specialist
Main Functions	Energy Monitoring	Supported	Supported	Supported	Supported	Supported	Supported
	Fault Diagnosis	Supported	Supported	Supported	Supported	Supported	Supported
	Energy Consumption Trend Analysis	Supported	Supported	Supported	Supported	Supported	Supported
	Equipment Operation Status	Supported	Supported	Supported	Supported	Supported	Supported
	Optimization / Report	Supported	Supported	Supported	Supported	Supported	Supported
Remarks		Equipment for Automation Control Capabilities Incorporated into BEMS	Solutions for Network Operation Center	Android iOS Based Application Development	Enterprise Buildings Integrator Solutions	Metasys based BAS/BEMS	Solutions across the Enterprise

(Source: KICT (2014))

confirmed that the case of smart BEMS resulted in reducing more energy consumption than the case when traditional BEMS and policy measures were combined. Beucker *et al*. (2015) conducted an environmental impact assessment of BEMS and found significant effects of reducing GHG emissions through the life cycle assessment in cold climates.

3. Energy Savings Rate per BEMS Function

To understand the energy saving rate by BEMS, we need to check four things. First, it is necessary to analyze the detailed functions of BEMS. Korean Industrial Standard KS F1800-1 (Building Energy Management System-Part 1: Functions and Data Processing Procedures, enacted in 2014) classifies specific BEMS functions, while Korean Industrial Standard KS F ISO 16484-3 (Building Automation and Control System-Part 3: Functionality, revised in 2008) describes the necessary functions and engineering services for building automation and control systems (BACS or BAS) (KEA, 2017). In order for BEMS to effectively implement its functions, it is necessary for it to interact with BACS. Operation data of various facilities can be collected from BACS control points and the BEMS algorithm can be executed through BACS field equipment. In order to save energy in a building, it can be implemented through the improvement and management of facilities and systems, or by improving the operation of facilities and systems. Therefore, in the control function, it is difficult to distinguish whether it is a BACS function or a BEMS function for each control item, but doing so is not necessary.

Second, an analysis on the applied effects of BEMS is requested. In Korea, analyses of the quantitative energy savings effects of BEMS are lacking. Since the Korean industry standard for BEMS was established in 2014, there have been few cases of BEMS introductions to date. Only since 2017 have mandatory installations of BEMS in public buildings of over 10,000m2 to assist in analyzing the effects of BEMS applications. There is a dearth of quantitative data, with only a handful of R&D demonstration results, pilot project results and survey results. According to the MoLIT (2014, p.101), as a result of surveys on changes in energy usage before and after BEMS installations, it was recognized that energy savings of as little as one percent to as much as 30 percent were obtained compared to before, and the average energy savings rate for a total of 15 application cases was found to be about 10 percent.

In order to assess the effect of introducing BEMS by detailed function, Korea University *et al*. (2011) reviewed the results of a BEMS initiative in Japan (NEDO, 2008) promoting the installation of high-efficiency energy systems in housing and buildings. NEDO (2008) analyzed the effect of introducing BEMS installations at a total of 258 buildings (offices, sales facilities, hospitals, schools, hotels, complex facilities, computer centers, research centers, and others) from 2002 to 2005, including 32 new buildings and 226 existing buildings across Japan. Lighting controls (scheduled lighting control, illumination controls using daylight sensors), control/indoor number zonal controls, heat source pump oil flow controls, ventilation linked with operation of combustion equipment and room temperature automatic setting controls generated large savings and great effects on investment (Korea University *et al*., 2011).

Third, we need cost information related to installation of BEMS. The investment cost of BEMS varies greatly depending on the use of the building, the size and the applied function of BEMS. According to the MoLIT (2014, p.81, p.96), the deployment of BEMS is valued at 150 million KRW for small buildings and 550 million KRW for large buildings. In addition, the BEMS construction cost for each case surveyed was at least 40 million KRW to 600 million KRW. The average installation cost for 12 cases was calculated to be 228 million KRW.

Fourth, energy savings rates needs to be combined with investment cost by BEMS function. The functional classification is based on KS F 1800-1 standards, and the investment cost is the unique investment amount per function plus the sum of field equipment, BEMS software and hardware, commissioning and consulting costs divided by function. The energy savings rate prediction value is 11 percent of the total energy savings rate, which is the effect observed in the Japanese BEMS promotion support project (Korea University *et al*., 2011). The energy savings rate classification by function depends on expert opinion. The effect of introducing BEMS can be quantitatively analyzed by measuring the energy consumption before and after installation, but the energy savings rate for each detailed function is very difficult to estimate, as most functions merely comprise energy consumption analysis information.

According to IEA (1991), there are four levels of BEMS, classified by function: Level 1 systems, which analyze the total amount of energy used, Level 2 systems, which analyze energy by use and zone, Level 3 systems, which can analyze energy use in specific systems, and Level 4 systems, which can analyze the energy use of specific devices and floors. In order to calculate investment cost and energy savings rates by level for each building, the per-building area installation cost of BEMS is used. Level 1-type systems are in fact installed in most buildings, being a measurement of the energy consumption of the entire building and a rough understanding of the energy consumption of the entire building. It is assumed that Level 1 BEMS does not incur additional cost. Therefore, it is judged that the application examples of Level 1 are not found in the literature. The average energy savings rate of Level 2 systems was 8.4 percent, the average energy savings rate of Level 3 systems was 12.4 percent, and the energy savings rate of Level 4 was calculated to be 13.6 percent (Kwak Y *et al*., 2013; 2004; Lee J *et al*., 2016; ; Song J. & Kim J, 2015; Kim YK *et al*., 2012, MoLIT, 2014; Byeon J, 2008; KEA; 2015).

The costs will be different by building size and BEMS level. Small buildings were classified as those of 10,000m^2 or less total floor area, medium-sized buildings as those with at least 50,000m^2 total area and large buildings as those with at least 100,000m^2 total area. The energy savings rate for each level calculated in the previous section is applied. The simple payback period for Level 2 was calculated from 2.1 to 11.3 years the simple payback period for Level 3 was calculated from 17.5 to 27.1 years, and the simple payback period for Level 4 was calculated from 31.4 to 60.9 years. It can be seen that (save for Level 1 systems), Level 2 BEMS are the most economically efficient. In other words, it is judged that Level 2 measures and analysis of energy consumption per building by zone can effectively save energy. Level 3 and Level 4 systems also demonstrate cost-effective energy-savings at minimal cost without the need for numerous sensors and data. In Level 4, the investment costs to setup the various functions of the BEMS are excessive and the energy savings does not recoup the investment, making it economically infeasible. In order make BEMS viable economically, it is necessary to secure energy savings by disseminating functions from an integrated control center through the cloud and other technologies, with the Level 2 functions physically installed in the building and additional algorithms and complex programs.

4. Estimation of BEMS Prevalence and GHG Reduction Potential

4.1 Analysis Method

Here this study will analyze the benefit to cost ratio of BEMS installations for each building using data from the 2017 Energy Consumption Survey (MoTIE, 2017b). The analysis will proceed as follows: First, we will define the benefits and costs of BEMS installations. Second, we will describe energy efficiency improvement policies and describe carbon cost scenarios. Third, we will calculate the benefit to cost ratio for each large building by scenario. Fourth, if the ratio of benefits to costs is greater than 1, it is interpreted that BEMS has been introduced. Fifth, we calculate the BEMS dissemination rate by calculating the number of buildings with BEMS installed. Sixth, we calculate and sum the GHG reduction potential of BEMS for each building. The benefits of installing BEMS are set as following equations (1 to 4)

$$B_i = \Sigma_y[(AFCS_{i,y} + ACCS_{i,y}) \times df_{y,s}] \quad (1)$$

$$df_y = \frac{1}{(1+r)^{y-by+0.5}} \quad (1a)$$

$$AFCS_{i,y} = \Sigma_f(FC_{i,y,f} \times RBEMS_{i,f} \times FP_{y,f}) \quad (1b)$$

$$ACCS_{i,y} = \Sigma_f(FC_{i,y,f} \times RBEMS_{i,f} \times EF_f \times CP_y) \quad (1c)$$

y: year (2018 to 2027)

i: individual buildings

B_i: present value of total benefits over the life of the BEMS when installed (1,000 KRW/year)

$AFCS_{i,y}$: Yearly fuel cost reduction with BEMS installation (1,000 KRW/year)

$ACCS_{i,y}$: Reduction of annual carbon cost with BEMS installation (1,000 KRW/year)

df_y: Discount factor for the base year of the year 'y' (%)

r: discount rate (%)

$FC_{i,y,f}$: Building fuel demand (TOE)

$RBEMS_{i,f}$: Building fuel savings rate with BEMS installation (%)

$FP_{y,f}$: Unit price of fuel per year (1,000 KRW/TOE)

EF_f: Greenhouse gas emission factor of fuel (CO_2 ton/TOE)

CP_y: Annual carbon price (1,000 KRW/CO_2 ton)

Subsequently, the cost of installing BEMS is set as following equation (2).

$$C_i = UC_{hardware} \times BA_i + C_{software} + \Sigma_y(OMC_i \times df_y) \quad (2)$$

C_i: Present value of total cost over the life of the BEMS when installed (1,000 KRW/year)

$UC_{hardware}$: Investment cost related to measuring equipment and construction

BA_i: Building area

$C_{software}$: Software and hardware costs for analysis and control of the equipment and data

OMC_i: Operation and Management Cost

Among the initial investment costs of BEMS, a cost that is proportional to the area and a cost that is not proportional to the area is applied separately. Those costs and the energy savings rate used in the analysis are depicted in Table 2. The operation cost is assumed to be five percent of initial investment costs.

Table 2. Initial investment costs and energy saving rate of BEMS (per 10,000m^2)

Cost Item	Cost (1,000 KRW)	Energy Saving Rate
Equipment for metering and control + Installation work ($UC_{hardware}$)	150,192	11%
Software and hardware for analysis and control of the equipment and data ($C_{software}$)	194,600	
Total	344,792	11%

4.2 Analysis Data and Scenarios

4.2.1 Data Description

In this paper, we analyze a total number of 899 buildings, having excluded 302 of 1201 large buildings in the 2017 Energy Consumption Survey that are primarily residential. The buildings were further classified into the following: First, there are General Buildings; corporate offices or mixed-use complexes (for example, Hyundai Motor Company Yangjae-dong Office, POSCO, Hanwha 63 City). Second, there are Public Buildings: buildings where the main purpose of the building is use by government agencies, national and public institutions, public organizations and cultural institutions (i.e., the Seoul Metropolitan Police Agency, Seoul Central Post Office, Seoul Arts Center). Next, there are Shopping Malls: buildings where the main use of the building is commercial. These include large discount stores such as Lotte Mart, E-Mart and Home Plus. Fourth, there are

Telecommunications Buildings, which are predominantly used in the telecommunications industry and as computer centers (IDC), for example SK Telecom, KT, NACF Distribution and Computing Center and SC First Bank Computer Center. Finally, there Other Buildings: Buildings whose main uses are not included in the categories specified above (i.e., Full Gospel Mission, EXCO, BEXCO, Kintex, Shinsegae Yeoju Logistics Center).

The data items for the building of microdata are as follows: 1) The main and secondary uses of buildings, 2) business hours, *et cetera*, 3) total building area and completion year, 4) matters related to insulation and heating and cooling: use of insulation, window area ratio, heating status, cooling status, average daily heating time, average daily cooling time, 5) heating and cooling systems and facilities, 6) installation of energy-saving and electric chargers: installation status of energy-saving facilities and lighting facilities, energy-saving practices, building energy efficiency rating, certification status, whether the building is subject to greenhouse gas/energy target management, demand resource market recognition/participation status and Electric Vehicle Charger Installations, 7) 2016 monthly consumption by energy source, 8) 2016 consumption by use by energy source and 9) 2016 self-generation and heat production facilities.

The energy consumption of large buildings is as follows. Average energy consumption per company in 2016 for large buildings is about 2,660 TOE. When looking at the energy consumption per company by building use, buildings such as hotels, hospitals, education and communication facilities consume more than average (2,660 TOE) of energy, while the energy consumption of businesses and commercial buildings is relatively low. Hospitals used the most used energy on average (3,497 TOE), while hotels and communication buildings also consumed a relatively large amount of energy (3,260 TOE). Education buildings at the center of large universities also consumed more than 3,000 TOE per establishment. Communication buildings equipped with computing facilities in the telecommunications industry and Internet data centers (IDC) are rapidly increasing consumption per company, and as of 2016, 92.3 percent of total energy consumption took the form of electricity.

Nest, energy consumption per gross area is as follows. In 2016, the energy consumption per square meter in large buildings was 161.5 Mcal/m^2 and power consumption per square meter was 105.7 kWh/m^2. Energy consumption per square meter is the highest in the telecommunications industry, at 1,125 Mcal/m^2, followed by hospitals, hotels and commercial buildings at 345 Mcal/m^2, 292 Mcal/m^2 and 180 Mcal/m^2, respectively. Hospitals, hotels, and commercial buildings all tend to provide comfortable indoor environments in accordance with the demands of customers due to the long usage time of energy facilities and equipment given the characteristics of their intended use. The telecommunications industry recorded electricity consumption of 1,207kWh/$m^2$0, the highest among all industries, followed by relatively high consumption in hospitals (194kWh/m^2), hotels (158kWh/m^2) and commercial buildings (156kWh/m^2). The high levels of power consumption per square meter in telecommunications buildings is due to increased power consumption for equipment and cooling of telecommunications related IT and computer systems.

4.2.2 Scenarios and Other Assumptions

Subsequently, the analysis scenario is largely set according to the strength of energy efficiency improvement policy and the level of carbon cost as follows: The intensity of the energy efficiency improvement policy was reflected through the discount rate. The standard discount rate is assumed to be 17.5 percent, and the ideal social discount rate is assumed to be five percent. Carbon costs are considered in three levels: 0 KRW, 25,000 KRW, and 50,000 KRW. As of November 2018, carbon costs are between 20,000 and 25,000 KRW per ton.

The next five scenarios are established through the combination of discount rate and carbon cost level as follows: 1) The baseline (BL) scenario assumes a discount rate of 17.5 percent and a carbon cost of zero. 2) The Current Policy (CP) scenario assumes a discount rate of 17.7 percent and a carbon cost of 25,000 KRW per ton, and is the most similar scenario to the current policy situation. 3) The Enhanced Policy 1 (EP1) scenario assumes a discount rate of five percent and a carbon cost of 25,000 KRW per ton. 4) In the Enhanced Policy 2 (EP2) scenario, the discount rate is 17.5 percent, but the carbon cost is assumed to be 50,000 KRW per ton. 5) The Enhanced Policy 3 (EP3) scenario assumes a five percent discount rate and a carbon cost of 50,000 KRW per ton, which is the strongest GHG reduction policy in the short term. Table 3 describes the five scenarios and their combinations of discount rates and carbon prices.

Table 3. Types of scenarios

Scenario	Discount rate (%)	Carbon price (1,000 KRW/tCO_2e)
Baseline (BL)	17.5	0
Current Policy (CP)	17.5	25
Enhanced Policy 1 (EP1)	5	25
Enhanced Policy 2 (EP2)	17.5	50
Enhanced Policy 3 (EP3)	5	50

Next, the strength of the energy efficiency improvement policy was reflected through a decrease in the level of individual building discount rates as follows. Reflecting energy efficiency improvement policy through a decrease in the discount rate (DR) reflects the reality that the discount rate used by consumers when choosing durable goods is higher than the general social discount rate. The discount rate is an indicator of the preference system for returns from investments that occur in the present and over a long period of time after the investment. The higher the discount rate, the higher the preference for the present value, and the lower the discount rate, the higher the utility of future profits. In general, the consumer's discount rate is higher than the social discount rate, and the difference between the consumer's discount rate and the social discount rate is one of the representative factors causing the energy efficiency gap. In this study, the discount rate of consumers is set at 17.5 percent and the ideal social discount rate is five percent in the reference scenario. The 17.5 percent figure is a value set by referring to the basic discount value of the PRIMES model consumer, which is mainly used when estimating the greenhouse gas reduction potential in the European Union. The discount rate reduction policy is a policy that reduces the discount rate of individual consumers to the level of the social discount rate through various policy measures. These policy measures may include energy efficiency labeling systems, investment financing, education and promotional initiatives.

As the main premise of the analysis, the price premise for each fuel and the greenhouse gas emission coefficient for each fuel are applied as shown in the Table 4 below. In addition, the maintenance cost of BEMS accounts for five percent of the initial investment, and the life of BEMS facilities is assumed to be 10 years.

4.3. Analysis Results

According to the method described in the previous section, this study calculated a BC ratio for each building. Table 4 shows the average BC ratios for each building type and in total. The overall average BC ratio is 0.43 in the baseline scenario, while it increase to 1.12 in the EP3

Table 4. Price and CO_2 emission factor by fuel

(Unit: 1,000 KRW/TOE, CO_2 ton/TOE)

Fuel	Kerosene	Diesel	Heavy oil A	Heavy oil C	Propane	Butane	City gas	Electricity	Heat
Price	1,145	1,406	596	596	1,189	1,276	588	713	588
CO_2 Emissions Factor	3.03*	3.06*	3.14*	3.33*	2.69*	2.77*	2.33*	5.34**	2.50**

(Source: *GIR (2019), **Ministry of Environment (2018)) scenario. The number of buildings with a BC ratio greater than 1 is as follows. In the BL scenario, the B/C ratio was higher than 1 in 69 establishments in total: 36 in the telecommunications industry alone, followed by 17 in other industries, 12 educational establishments, and the rest in general buildings, public buildings, hotels and hospitals. In the CP scenario, the number of dissemination sites has increased to 110 in total: 54 establishments in the telecommunications industry, 23 in other sectors, and 20 educational establishments. These were in addition to were eight general buildings, three hotels and one hospital. Compared to the BL scenario, the relative increase in general buildings and educational sites is noticeable. In the EP1 scenario, the total number of dissemination sites increased to 152: the number of general buildings, hotels, hospitals with a BC ratio greater than one increased significantly compared to the CP scenario. In the EP2 scenario, the total number of disseminated buildings is 117, an insignificant increase compared to the EP1 scenario. In the strongest EP3 scenario, dissemination of BEMS reaches 189 locations. At this time, almost 88 percent of the telecom sector was analyzed to be suitable for installation of BEMS.

Table 6 shows BEMS penetration rate, which means the share of the buildings with BC ratio greater than 1. In the BL scenario, the overall penetration rate would reach around 7.7 percent, with industries such as telecommunications and others posting relatively higher rates. The overall penetration rate is analyzed to be 12.2 percent in the CP scenario, 16.9 percent in the EP1 scenario, 13 percent in the EP2 scenario and 21% percent in the EP3 scenario.

For buildings with a B/C ratio higher than 1, the energy savings rate of BEMS is applied by 11 percent to calculate the energy savings amount for each building type as follows. As of 2016, the total energy consumption of all large buildings (excluding apartments) is approximately 2.35 million TOE. In the BL scenario, energy consumption falls by 33,463 TOE. Under the CP scenario that figure increases to about 42,324 TOE, and further yet to 65,177 TOE under the EP1 scenario. Under the EP2 scenario energy consumption plummets by 45,574

Table 5. Average BC ratios by scenario

Scenario	General Buildings	Public Buildings	Department Stores	Stores	Schools	Hotel	Hospitals	Telecommunications	Etc	Total
BL	0.27	0.26	0.27	0.23	0.32	0.41	0.44	1.22	0.75	0.43
CP	0.38	0.35	0.35	0.31	0.48	0.53	0.57	2.27	2.05	0.69
EP1	0.54	0.49	0.50	0.44	0.68	0.76	0.81	3.20	2.91	0.98
EP2	0.44	0.40	0.41	0.35	0.55	0.60	0.64	2.63	2.34	0.79
EP3	0.62	0.56	0.58	0.50	0.77	0.85	0.91	3.71	3.32	1.12

Table 6. BEMS penetration rate by scenario

Scenario	General Buildings	Public Buildings	Department Stores	Stores	Schools	Hotel	Hospitals	Telecommunications	Etc	Total
BL	0.6%	2.0%	0.0%	0.0%	6.5%	1.4%	1.1%	56.3%	23.3%	7.7%
CP	4.9%	2.0%	0.0%	0.0%	10.8%	4.2%	1.1%	84.4%	31.5%	12.2%
EP1	8.6%	8.0%	1.0%	1.9%	15.1%	11.3%	14.6%	87.5%	35.6%	16.9%
EP2	4.9%	2.0%	1.0%	0.0%	12.4%	4.2%	1.1%	85.9%	34.2%	13.0%
EP3	13.0%	8.0%	1.0%	1.9%	18.8%	25.4%	27.0%	87.5%	38.4%	21.0%

Table 7. Energy savings rate by scenario

Scenario	General Buildings	Public Buildings	Department Stores	Stores	Schools	Hotels	Hospitals	Telecommu nications	Etc	Total
BL	0.1%	0.7%	0.0%	0.0%	1.3%	0.3%	0.2%	7.6%	3.2%	1.4%
CP	0.7%	0.7%	0.0%	0.0%	1.6%	0.7%	0.2%	9.3%	3.6%	1.8%
EP1	1.8%	1.1%	0.1%	0.2%	2.2%	1.2%	2.3%	9.6%	6.4%	2.8%
EP2	0.7%	0.7%	0.1%	0.0%	1.9%	0.7%	0.2%	9.4%	4.0%	1.9%
EP3	2.2%	1.1%	0.1%	0.2%	3.1%	2.2%	3.4%	9.6%	6.5%	3.3%

Table 8. Ratio of greenhouse gas reduction potential by scenario

Scenario	General Buildings	Public Buildings	Department Stores	Stores	Schools	Hotels	Hospitals	Telecommu nications	Etc	Total
BL	0.1%	0.8%	0.0%	0.0%	1.4%	0.3%	0.2%	7.6%	3.1%	1.5%
CP	0.7%	0.8%	0.0%	0.0%	1.7%	0.7%	0.2%	9.3%	3.5%	1.9%
EP1	1.8%	1.2%	0.1%	0.1%	2.3%	1.2%	2.3%	9.7%	6.3%	2.9%
EP2	0.7%	0.8%	0.1%	0.0%	2.0%	0.7%	0.2%	9.4%	3.8%	2.1%
EP3	2.2%	1.2%	0.1%	0.1%	3.1%	2.2%	3.4%	9.7%	6.4%	3.4%

TOE, and reductions under the EP3 scenario are the largest yet, it is analyzed that it is possible to save about 77,134 TOE. Energy savings is expressed as a ratio in Table 7. In the baseline scenario, a reduction of about 1.4 percent can be expected, with decreases of 1.8 percent, 2.8 percent, 1.9 percent and maximum savings of 3.3 percent under the CP, EP1, EP2 and EP3 scenarios, respectively.

The amount of greenhouse gas emissions mitigated can be calculated by multiplying the energy savings amount by the greenhouse gas emissions factor as follows. The total greenhouse gas emissions of the target large buildings are estimated to be about 11 million tons of CO_2, derived by summing direct and indirect emissions. Among industries, education produces the most emissions at about 2.7 million tons of CO_2. The remaining industries produce one million tons of CO_2, excluding the 52 million tons generated in the public sector. Under the baseline scenario, CO_2 emissions would fall by 158,051 tons. For the alternate scenarios, those figures are approximately 200,513 tons, 296,816 tons, 213,891 tons, and approximately 347,502 tons for the CP, EP1, EP2 and EP3 scenarios, respectively.

The ratios for GHG reduction potential are calculated and shown in Table 8. A reduction rate of 1.5 percent is calculated for the baseline scenario. At this time, the reduction rate is estimated at 7.6 percent for the telecom industry and 1.4 percent for education; declines calculated for other sectors were insignificant. Under the CP emissions could be cut by 1.9 percent. Under the EP1 scenario, the reduction rate rebound to 2.9 percent. Under EP2 scenario emissions fall by 2.1 percent and by 3.4 percent in the EP3 scenario. If the baseline scenario is interpreted as the current state, it can be interpreted that the EP1, EP2 and EP3 scenarios additionally carry additional reduction potential of 1.4, 0.6, and 1.9 percent points , respectively. If the CP scenario is interpreted as it is, the EP1, EP2 and EP3 scenarios are estimated to have additional reduction potential of 1.0, 0.2 and 1.5 percent points, respectively.

5. Concluding Remarks

As discussed above, this study on the introduction of smart energy systems as a means to reduce greenhouse gases is very important as a piece of basic empirical evidence to be used in effectively implementing related policies. In particular, it is urgent to quantitatively analyze energy management systems in the building sector, which has the greatest potential for GHG reduction. Against this backdrop, this study conducted a quantitative analysis of the benefit to cost ratio of BEMS installations for various types of buildings using building-level data large buildings in the 2017 Energy Consumption Survey.

The results of the analysis of BEMS penetration rates, energy savings and GHG reduction potential under each scenario were consistent with common sense. The dissemination rate of BEMS could reach 21.0 percent, and it was found that if the current state is interpreted as the baseline scenario, additional dissemination at a rate of 13.3 percent point is possible. If the current state is instead seen as a CP scenario, additional dissemination of 8.8 percent point is possible. The telecommunications industry (at almost 88 percent) had the largest expected dissemination rate, and department stores (one percent) had the lowest. It is possible to cut emissions by up to 3.4 percent. If the current state is interpreted as the baseline scenario or a CP scenario, there is additional reduction potential of 1.9 and 1.5 percent points, respectively. This study, which is the first analysis of potential energy and greenhouse gas savings of BEMS using microdata, carries the following implications.

First, the approach of determining the penetration rate by calculating the B/C ratio for each type of building using microdata shows that there is no need to use excessive assumptions and complicated models if there is good detailed data. The computational power of computers continues to grow rapidly, suggesting that good data and intuitive and concise computational principles are important. This implication suggests a form of model analysis that is desirable in the era of big data.

Second, this approach can be further enhanced if additional data and analysis results show how much energy consumption can be reduced for each use of BEMS technology. In the current analysis, the results of the previous study implying BEMS' reduction rate of 11 percent for the entire building were applied. If the reduction rate can be applied differently for each use of BEMS, more detailed analysis is possible, such as specialized analysis for individual buildings.

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