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Economic Analysis of Special Rate for Renewable Energy Based on the Design of an Optimized Model for Distributed Energy Resource Capacities in Buildings

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Abstract: Various incentive schemes are being implemented to improve the economic return of distributed energy resources (DERs). Accordingly, research on the optimal capacity design and operations of photovoltaic (PV) power generation and energy storage systems (ESSs) is important to ensure the economic efficiency of DERs. This study presents the models of optimal capacity and facility operation methods based on long-term operational changes of DERs in a building with self-consumption. Key policy variables are derived for a renewable energy system. We first analyzed the operating environments of the DERs according to the basic types of PVs and ESSs, and by examining the detailed benefit structure of a special rate for renewable energy. The optimal capacity of PVs and ESSs with the lowest net cost was estimated using various parameters in consideration of long-term operations (~15 years), and by setting rules for a special rate for renewable energy. It was confirmed that the combined use of peak and rate reductions constituted the most economical operational approach. A case study confirmed the economic sensitivity of cost and benefit analyses based on actual load data. Correspondingly, it is inferred that this study will identify core policy variables that can aid decision-making in the long-term perspective.

Keywords: rate for renewable energy; energy storage system; photovoltaic energy; energy promotion; optimization

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1. Introduction

There is a growing interest in mitigating greenhouse gas emissions worldwide to prevent climatic changes due to global warming. With this interest, numerous countries worldwide are expanding their supplies of renewable energy based on various ecofriendly energy policies. Korea has announced plans to reduce greenhouse gas emissions by 37% (business-as-usual) by 2030. In addition, based on the implementation of the Renewable Energy 3020 Implementation Plan, Korea plan to reduce thermal and nuclear power generation, and to increase the proportion of renewable energy generation from 7% to 20% [1]. As part of the plan, mandatory policies have been implemented, such as the Renewable Energy Portfolio Standard (RPS), an incentive policy established to support subsidies and taxes, and schemes to promote renewable energy, such as special rates for renewable energy systems. After the plan was established, renewable energy facilities with a capacity of 2989 MW were introduced, of which 2027 MW corresponded to photovoltaic (PV) installations. The proportion of installed solar power facilities for buildings increased from 25% to 40% [2]. In addition, the spread of energy storage systems (ESSs) plays a role, as these systems compensate for the intermittency of renewable energy, and act as demand management resources through load leveling to transfer the power load. Thus, the construction of additional power generators for frequency regulation cannot be required in power system, since ESS replaces the role of maintaining the frequency at 60 Hz. If the small-sized ESS supply including home use is activated in the future, the spread of ESS equipment is expected to increase sharply [3].

In current environments, there were several studies tried to deal with the combination of renewable energy technology. Besides, with increasing penetration levels of PV systems, the grid layer utilizing ESSs is transition toward residential or commercial building level. The planning method of the intermittent solar and wind power with a hybrid energy storage system was proposed to supply firm electricity under various demand condition from a bulk level to a residential level [4]. The renewable energy transition models were also developed as the built environment, such as a building and an island system, would be suitable for planning intermittent resources and energy storage systems [5,6]. With increasing interest of prosumers in the residential sectors, a systemic method was presented to compare optimization result between household level and total electricity system level in circumstances where prosumers utilize the DERs [7].

As PV systems and ESSs are being increasingly used as distributed resources, many studies are being conducted to estimate the optimum capacity of PV and ESS based on considerations of stability and economic efficiency. The methods for optimal sizing ESSs were proposed to minimize operating costs of the microgrid system [8,9]. These methods considered the operating schedule and the lifetime of the ESSs for solving the unit commitment problem. Although the operation characteristics of ESSs in these methods should be considered for the reliable system, subsidies or incentives of the ESSs operation would be also considered for the economic operation of the system. Other methods for optimal sizing ESSs considered CO_2 reduction with economic operation of the system [10–12]. The ESSs in these methods contributed to minimizing CO_2-emission with reducing the operation of conventional generators emitting CO_2. The above-mentioned studies proposed the methods for optimizing ESSs in order to minimize the operation cost and CO_2-emission of the power system. In contrast with minimizing the cost and the emission, the methods for maximizing the revenue with utilizing the ESSs connected with a distributed energy resource (DER) were proposed [13–15].

With sizing the optimal ESSs, they considered electricity price and the incentive for the PV supplier under Korean government policy. The methods presented in other studies considered the peak shaving and tariff of demand to analyze customers' economic benefit [16–19]. Customers in these methods could maximize their benefit to reduce peak demand and the total cost by considering the ESS operation with their tariff. Other methods were proposed to describe the strategy of various customers including residential and non-residential customers for maximizing their benefit [20–22]. However, prior research studies have been limited in that they only considered (a) the revenue of a power generation business, (b) a specific season, or (c) a single facility [23,24]. In particular, there is insufficient consideration of the lifetime of a facility and the government's special policy plan [25]. In short, practical applications of optimizing methods, considering subsidies and incentives of DERs and ESSs, have not been presented.

This study estimates the optimal capacities of PV and ESSs to minimize the net cost by considering settlement rules and an incentive plan according to the actual DER policy of Korea. In addition, this study analyzes the optimized cost and revenue of DERs by identifying the most effective operating model. A case study was conducted by examining one year of load data, maximum power data, and charge data of a commercial building in operation. An analysis of policy implications of a special rate for renewable energy systems in the case study would contribute to policy decision-making for related systems in the long-term perspective. Moreover, it can have a positive effect on the expansion of the supply of renewable energy facilities.

The rest of the paper is organized as follows. In Section 2, the operation and benefits of small- and medium-sized dispersed power sources are classified, and the operating environment for distributed power sources in Korea is analyzed based on an explanation of a special rate for renewable energy. In Section 3, a scenario is formulated for the design of the optimization model. The operating model of a DER is illustrated using a structural diagram. The operating modes of the PV and ESS approaches are explained, and a coefficient of variation is set during the operation of the facility. Section 4 defines the objective function and constraints for the mathematical optimization model. In Section 5, the optimal capacity of each DER is obtained using actual data, and the cost and revenue is analyzed by changing the parameter of the special rate for renewable energy. Section 6 summarizes the results of the research and describes policy implications and future research plans. Finally, in Section 7, the limitation of the study and future works are presented.

2. Overview of Distributed Energy Resource Policies and Rules in Korea

2.1. Classification of Photovoltaic Power and Energy Storage System for Operation and Transaction

PV is classified into two types: (a) a grid-connected type that is connected to the commercial power grid; and (b) a standalone type that is used by the solar cell alone for a wireless base station [5]. Out of the two types, we focus on the grid-connected type generally used in Korea. It is important to choose adequate the types of solar power transactions since these types could determine the revenue of PV. These types can be largely divided into price offset transactions, links to new and renewable power projects, and installation of self-consumption power generation facilities that directly consume the power generated by the PV system owner. Price offset transactions refer to transactions in which a facility receives power from the power system if it does not have solar power or if it lacks sufficient power. The facility uses electricity produced by solar power and transmits it back to the power system. In this case, the electricity charges are calculated based on the residual amount of electricity. The excess amount is deducted from the amount of electricity for the subsequent month without the need for any cash adjustments. A linkage of new and renewable power generation businesses using solar power can be established, and power can be sold in the electric power market or based on an electricity contract with a retailer. Here, the amount of electricity sold will be settled by the system marginal price (SMP), and the revenue from the renewable energy certificate (REC) sales can also be obtained. The operator of self-consumption power generation facilities can sell the electricity that is used and/or left over by the PV. Currently, those who have installed facilities other than PV can only sell less than 50% of the annual total output of electricity.

As lithium-ion batteries constitute the main source of power storage in Korea, operating rules for these batteries have been developed based on high capacity and fast response characteristics. In addition, ESS can be used for various purposed according to a report issued by the Department of Energy/Electric Power Research Institute (DOE/EPRI) [26]. The ESS could be used for power distribution networks, emergency power, renewable connections, and peak reduction. The ESS for a power distribution network is used to detect frequency fluctuations in the power system to determine normal and transient conditions, to charge itself if the frequency exceeds a specified value, and to discharge itself to react to charging conditions. The ESS for emergency power is used to prevent a fatal loss of essential facilities by ensuring a stable power supply in the event of power failure. It provides emergency power in the short term and acts as a self-managing power source in the event of a long-term power outage, thus preparing for emergency situations in the power system. The ESS is used for new and renewable connections to compensate for the intermittent nature of renewable energy generation, to buffer rapid power fluctuations, to stabilize the output and improve power quality. The ESS used for peak reduction functions, to store the power during a non-peak period in which the power rate is low, and then to discharge the load at a peak time in order to transfer the load.

The main purposes of the ESS are to reduce the base charge, which is a fixed rate charged based on the peak load of the year rather than the amount of power consumption, owing to the peak-load reduction and to reduce the usage charge rate through the energy difference transaction. According to Table 1, the power of small and medium-sized DERs of 1 MW or less can be traded through the electricity market [27]. It is also possible to deal with the retailer through a separate contract. In both cases, it is important to note that while self-consumption and power generation are possible, an operator's transaction with the ESS is only possible through the electricity market.

Table 1. Small and mid-sized renewable energy transactions.

	In Electricity Market			With Retailer	
Transaction Classification	**Self-Consumption Facility**	**Business Facility**	**General Facility**	**Self-Consumption Facility**	**Business Facility**
Participation Capacity Standard	Over 10 kW	Over 1 kW	Under 10 kW	Over 10 kW and Under 1000 kW	Over 1 kW
Tradable Capacity	Sales of surplus power after self-consumption	Power Generation	Self-Consumption	Sales of Surplus Power After Self-Consumption	Power Generation
Settlement Unit Price	Real-time system marginal price (SMP)	Real-time SMP + renewable energy certificate (REC)	Offset for electric charges (1:1)	Monthly Weighted Average SMP	Monthly Weighted Average SMP + REC
Transaction fee	Transaction Fee	Transaction Fee	No Transaction Fee	No Transaction Fee	No Transaction Fee
Check Method	Remote Check	Remote Check	Visiting Check	Visiting Check	Visiting Check

The main revenue of a self-consumption facility is from the differences in time-of-day charges. Correspondingly, it is possible to obtain electricity sales revenue and REC revenue through sales of surplus electricity after self-consumption. However, this is difficult to confirm.

The purpose of this study is to estimate the optimum capacity of DERs and to maximize the reduction of facility operation costs by suggesting solar PV power/ESS special rate plans and market settlement rules. Therefore, the model is based on a scenario in which a utility operator seeks profit by considering various benefit factors. In this case, it is assumed that there is no power surplus after self-consumption. Figure 1 shows the DER revenue structure according to the transaction type.

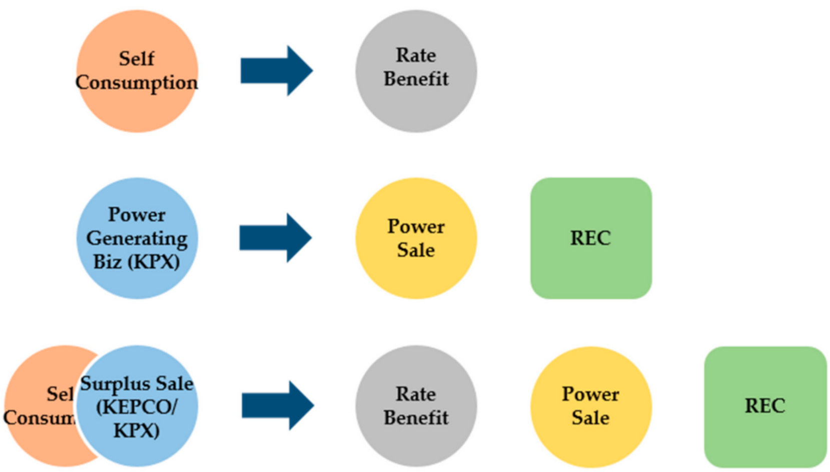

Figure 1. Distributed energy resource (DER) revenue structure according to the type of transactions.

2.2. *Rate for Small and Mid-Sized Distributed Energy Resources*

2.2.1. Electricity Charge Basic Structure for Customer with DERs

An understanding of the electricity rate system should be acquired as a prerequisite for operating DERs efficiently. Currently, the electricity rate system consists of a two-part system comprising the basic charges based on the number of facilities and the usage charge based on the amount of electricity used [28]. The total electricity rate called by electricity bill is defined as follows.

- Electricity bill (KRW) = base charge (KRW) + usage charge (KRW)

The base charge is calculated by multiplying the base unit price by the power of the applied charge. It is charged to recover fixed costs, such as depreciation, maintenance, and sales management costs associated with the power supply facilities. It is calculated as the average maximum demand (kW) for the year. The base charge is defined as follows.

- Base charge (KRW) = base unit price (KRW/kW) × charge applied power (kW)

The usage charge varies with the usage unit price and the amount of power used. The usage unit price is classified as the level of the total electricity demand and the season. The demand level is composed of the peak, mid-peak, and non-peak according to the system usage. The season is also a key factor of determining electricity rate from the usage of air-conditioning and heating facilities. That season is composed of Spring/Fall, Summer, and Winter. The usage charge is defined as follows.

- Usage charges (KRW) = usage unit price (KRW/kWh) × amount of power used (kWh)

The above-mentioned base unit price and usage unit price are listed in Table 2.

Table 2. Electricity rate in Korea.

Base Charge (KRW/kW)	Usage Charges (KRW/kWh)			
	Time	Summer	Spring/Fall	Winter
8320	Non-peak	56.1	56.1	63.1
	Mid-peak	109.0	78.6	109.2
	Peak	191.1	109.3	166.7

A time-of-use (TOU) rate plan separates summer, spring, and winter based on the season, and sets a unit price by dividing the peak, mid-peak, and non-peak load, and is calculated by multiplying the amount of power used by the usage unit price. A TOU rate plan is designed to apply a high rate for seasons and times during which the power consumption rapidly increases, and to apply a low rate for seasons and times during which the power consumption is relatively low. This has the effect of reducing the investment cost through demand management and rationalizing resource utilization. The TOU rate plan used in this study is provided in Table 3 [29].

Table 3. Electric rate table for TOU price in Korea.

Time	Summer (June–August)	Spring (Mar–May), Fall (Sep–Oct)	Winter (Nov–Dec)
Non-Peak	23:00–09:00	23:00–09:00	23:00–09:00
Mid-Peak	09:00–10:00 12:00–13:00 17:00–23:00	09:00–10:00 12:00–13:00 17:00–23:00	09:00–10:00 12:00–17:00 20:00–22:00
Peak	10:00–12:00 13:00–17:00	10:00–12:00 13:00–17:00	10:00–12:00 17:00–20:00 22:00–23:00

2.2.2. Special Rates for Renewable Energy

In Korea, there has been the special rate scheme for renewable energy to promote the ESSs connected with the renewable energy. The electricity rate discount plan in this scheme applies to customers who are self-consuming electricity with renewable energy [30]. Customers who own renewable energy facilities are guaranteed a 50% discounted rate on the amount of power consumption received from power system after their own consumption. Moreover, if additional ESS facilities are installed and operated, additional benefits would be provided. As Table 4 shows, it is a system intended for the spread of renewable energy and ESSs. It is excluded if it is installed in a national institution, a local government body, a public institution, or other similar locations, wherein: (a) renewable energy installations are obligatory according to relevant laws, and (b) renewable energy self-consumption is not to be quantified to obtain incentives. The government predicts that the recovery period for facility investment could be reduced by approximately two years owing to an increase in user profits from reduced electricity bill charges [31].

Table 4. Electricity rate discount plan for renewable energy users [30].

Electricity Rate Discount Plan	
01.05.2017–31.12.2020	Savings of 50% of electricity bill
Discount weight by the installation of ESS	Battery capacity/contract power: less than 5% (80% weight) Battery capacity/contract power: between 5% and 10% (100% weight) Battery capacity/contract power: more than 10% (120% weight)
Consumer	General use and industrial use
Others	Surplus power can be sold after self-consumption (SMP + 1REC)

The ESS electricity charge discount plan is designed for customers who install ESSs for electricity consumption, and who supply electric power from retailer to reduce maximum demand power. The plan applies to all cases except the cases associated with power generation, transmission/distribution, and power-distribution facilities, such as stabilization of reduction and an electricity charging discount. Relevant details are listed in Table 5 below.

Table 5. ESS electricity charge discount plan [30].

Period	Base Discount	Charging Discount
01.05.2017–31.12.2020	300% discount on maximum demand power reduction	50% discount on charging rate for non-peak time
01.01.2021–31.03.2026	100% discount on maximum demand power reduction	None

In the case of discharging only in the peak-load time for the discount of the aforementioned ESS electric charge discounting system, the management of the maximum electric power demand may be performed only during a specific time. The ESS requires significant charge/discharge scheduling to reduce peak demand power and manage the base charge rate so as to reduce the investment payback period and increase the economic efficiency.

3. Conceptual Model for Analysis of the Distributed Energy Resource Policy

3.1. Overview of Transaction between Retailer and Customer Integrated with PV and ESSs

This study examined a coordinated model of a building with PV and ESSs. The building customer was connected to the bulk grid operated by retailer as shown in Figure 2.

In this study, it is assumed that the PV system and ESS will be implemented in buildings. These facilities will be utilized for self-consumption. The power is represented by two directions. One way is toward the building, where the power is used to supply electricity load in building. The power in this way includes the power generated by the PV system (P_t^{PV}), the discharging power of the ESS ($P_t^{ESS,ch}$) and the supplied power from the bulk grid (P_t^{Load}). The other way is away from the building, where the power is released from the perspective of buildings. The released power includes the charging power of the ESS ($P_t^{ESS,ch}$), the surplus power transmitted to the bulk grid ($P_t^{PV,surplus}$) and the electricity demand of the building (P_t^{Demand}). By utilizing the above-mentioned power, the building customer should balance its electricity load with supply from bulk grid, PV, and discharging power. If the PV generates enough to cover the electricity demand or generates beyond the electricity demand, the building can not only be self-sufficient without the supply from the bulk grid, but also sell the surplus power. The sufficient power from the PV can also charge the ESSs. In that case, the customer can earn credits of the discount weight by selling the power or reducing their consumption. In contrast, if the PV generates less to cover the electricity demand or generates less than the expected power, the electricity of the building should be supplied from bulk grid or the discharge of the ESS. In that case, the customer should pay the bill based its consumption.

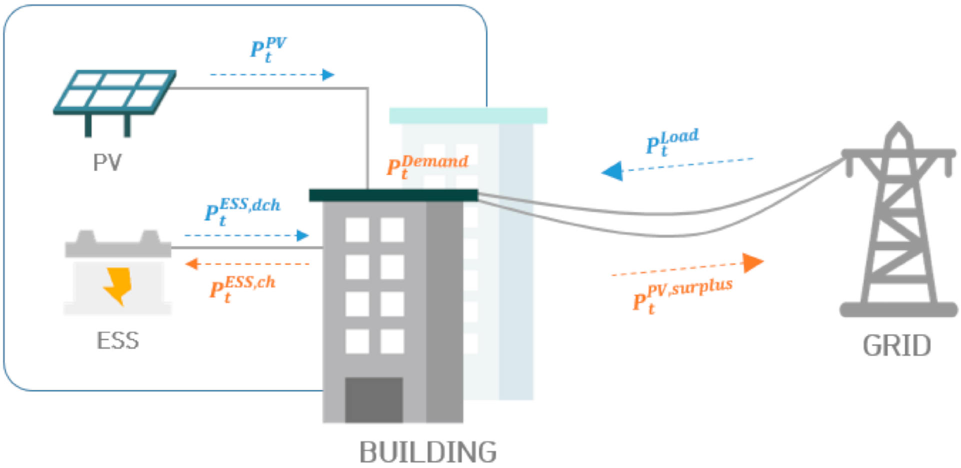

Figure 2. DER structural diagram for buildings considered in this study.

3.2. Operation Schemes for Photovoltaic System and Energy Storage System

3.2.1. Operation Scheme of Photovoltaic System

The amount of PV power generation is calculated based on an irradiance angle according to the reference position data (latitude and longitude). The generated power is utilized for the consumption of the building occupant [32]. We assumed a Weibull distribution that is extensively used in meteorological data prediction for characterizing the degradation of efficiency owing to cloud accumulation [33].

3.2.2. Operation Scheme of Energy Storage System

The ESS performs peak and charge reduction operations to reduce electric power charges. A peak shaving operation is an operation that aims to lower the peak used in the base charge calculation by managing the ESS so that it does not exceed the set peak, as shown in Figure 3. By setting the management peak value, the peak power can be managed, and the power charge can be saved. The largest part of the saved electricity cost is attributed to the reduction of the base charge that is settled differentially according to the contracted capacity. Peak management implemented through an ESS can be assisted by PV power generation when the peak time management threshold is during the solar daytime. If the peak management threshold is excessively high, the installation costs will be low, but the cost savings will be underestimated. In contrast, if the peak management threshold is set too low, the burden of the facility installation cost becomes large, and the facility principal cannot be recovered within the operation period of the facility.

The operation mode for reducing electricity rate is a method that uses the electric power of a TOU plan to save electric power at a time when electric power is cheap, and discharges it at a relatively expensive time. In this mode, the benefit of the difference in power charge between the non-peak load time and peak load time can be obtained by applying the above discount plan. A discount of 50% of the non-peak load time charge can also be obtained. The usage charge difference and the ESS charging discount come together to become the revenue denoted as 'performance revenue'. It is also possible to receive a discount of the base rate following a discharge at the peak time. Correspondingly, this is the method that can obtain the most effective profit among the benefits of the special rate for the renewable energy plan. However, it is impossible to reduce the base charge of a peak reduction operation because the peak is controlled irregularly. In the optimization modeling of this study, we will apply the method for maximizing the economic benefit at a specific time. The operation schemes of the peak and charge reduction are based on the capacity of the ESS. Besides, the charge and discharge scheduling will be set up to maximize revenue. Both operating modes will be applied according to the optimized capacity.

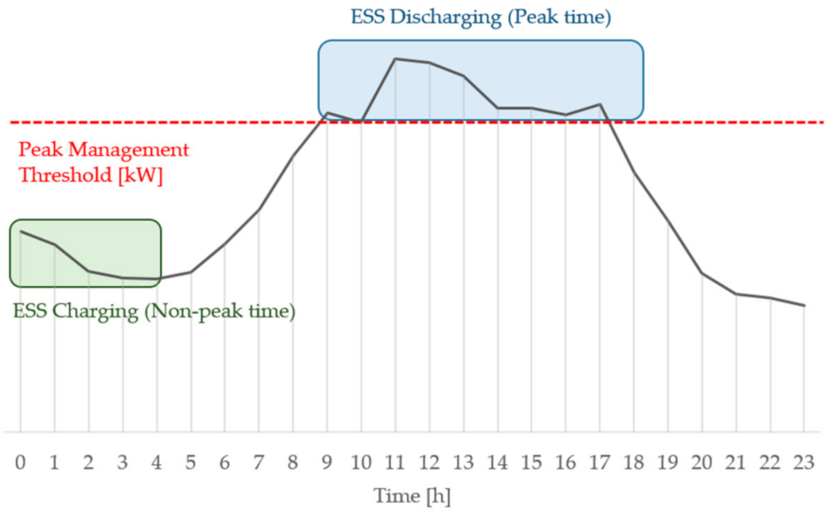

Figure 3. Outline of ESS peak reduction operation.

3.2.3. Coefficient for Variation Rate

The coefficient for variation of rate applied during the operating period is assumed to be the special rate for a renewable energy system. This value can increase or decrease within the operating period. The benefit period expiration and benefit variables of the special rate for renewable energy is applied as of 2019. The peak and load electricity rates are based on the eighth basic plan for long-term supply and demand [34]. The reduction in the facility efficiency of PV and ESS was established on the basis of long-term operation [35]. The details are shown in Table 6.

Table 6. Coefficient for variation of rate applicable to distributed energy resources.

Variation	Coefficient Assumption
Renewable energy utilization discount	Rebate 50% of the electricity charge corresponding to the amount of self-consumption (2019–2020)
Promotion #1 for ESS	300% discount on basic electricity rate (2019–2021) 100 discount on basic electricity rate (2022–2026) No discount on basic electricity rate (2027–)
Promotion #2 for ESS	50% discount on charging cost (2019–20) No discount on charging cost (2021–)
Annual peak demand increase	1.0%/year
Annual load increase	1.3%/year
Annual electricity rate increase	1.3%/year

4. Optimization Model

4.1. Objective Function

The net cost of users of PV and ESS installations could be calculated from the difference between the total cost and the total revenue. The revenue consists of the profit of self-consumption of PV power generation, ESS discharging and the profit obtained by applying the special rate for the renewable energy system. It can be divided into base charge and performance revenues. This study aimed to minimize the net cost through the self-consumption of PV and ESS from the viewpoint of the building's owner. The objective function is described in Equation (1).

$$Minimize\ \pi = cost - revenue \tag{1}$$

The cost consists of the installation, operation and maintenance(O&M), and the electricity costs, which can be expressed by Equation (2). The installation cost is the product of PV and ESS capacity multiplied by the unit installation cost and depicted in Equation (3). The O&M cost is the specific portion of the installation cost, as shown in Equation (4). It is assumed to be applied equally in whole years. Electricity charges can be divided into base and usage charges. The power charges denote the sum of the building demand and ESS charge minus the power generation through PV and ESS discharge, as expressed by Equation (5).

$$cost = cost^{e} + \sum_{y}\left(cost^{o} + cost^{c}_{y}\right) \tag{2}$$

$$cost^{e} = C^{PV} \cdot p^{PV,Equip} + C^{ESS} \cdot p^{PV,Equip} \tag{3}$$

$$cost^{o} = cost^{e} \cdot \eta^{O\&M} \tag{4}$$

$$\begin{aligned} cost^{c}_{y} = {} & \eta^{elec,charge}_{y} \cdot \eta^{elec,demand}_{y} \\ & \cdot \Bigg[\sum_{m} p^{elec,charge,base}_{m} \\ & + \sum_{d}\sum_{t}\left(P^{demand}_{d,t} + \frac{P^{ESS,ch}_{d,t}}{\eta^{ESS,ch}} - P^{PV}_{d,t} - P^{ESS,dch}_{d,t}\right) \cdot P^{elec,charge}_{d,t}\Bigg] \end{aligned} \tag{5}$$

Revenue comprises base charge and performance revenue. This is formatted in Equation (6). The base charge revenues comprise the benefits according to peak reduction and the base charge discounts of the special rate for the renewable energy system, as expressed by Equation (7).

$$revenue = \sum_{y}\left(revenue^{b}_{y} + revenue^{p}_{y}\right) \tag{6}$$

$$revenue^{b}_{y} = revenue^{b,elec}_{y} + revenue^{b,ESS}_{y} \tag{7}$$

The base charge reduction attributed to the peak reduction consists of the difference from the new base charge that used the peak management value from the existing base charge, as shown in Equation (8). The base charge revenue based on the ESS operation is calculated by multiplying the difference between the ESS discharge amount and the charge amount of the weekday peak times by the base unit price, and by applying a coefficient reflecting long-term operation, which is expressed by Equation (9).

$$revenue^{b,elec}_{y} = \sum_{m} p^{elec,charge,base}_{m} - p^{elec,contr,base} \cdot C^{limit} \cdot \eta^{peak}_{y} \cdot n^{month} \tag{8}$$

$$revenue^{b,ESS}_{y} = \frac{\sum_{d}\sum_{t}\left(P^{ESS,dch}_{d,t} - \frac{P^{ESS,ch}_{d,t}}{\eta^{ESS,ch}}\right) \cdot X^{peak}_{d,t}}{n^{workingdays} \cdot n^{hours}} \cdot p^{elec,contr,base} \cdot \eta^{ESS,base} \cdot \eta^{renewable,ESS} \cdot \eta^{ESS,depr} \tag{9}$$

The amount of performance revenue is composed of the revenue of PV power generation and the revenue of the ESS discharge, as shown in Equation (10). The revenue of PV generation can be expressed by multiplying the volume of PV power and the transaction price, as shown in Equation (11). The revenue of ESS is represented by applying a number of variables representing long-term operations, as expressed in Equation (12).

$$revenue_y^p = revenue_y^{p,PV} + revenue_y^{p,ESS} \tag{10}$$

$$revenue_y^{p,PV} = \sum_m \sum_d \sum_t P_{d,t}^{PV} \cdot p^{renewable} \cdot \eta^{PV,self} \cdot \eta^{renewable} \cdot \eta^{PV,depr} \tag{11}$$

$$revneue_y^{p,ESS} = \sum_m \sum_d \sum_t \frac{P_{d,t}^{ESS,ch}}{\eta^{ESS,ch}} \cdot X_{d,t}^{nonpeak} \cdot p_{d,t}^{elec,charge} \cdot \eta_y^{ESS,ch} \cdot \eta^{ESS,depr} \tag{12}$$

4.2. Constraints

4.2.1. PV Generation Capacity

Based on Equations (13) and (14), PV generation limits power generation by the capacity of the limits of the maximum power generated.

$$0 \leq C^{PV} \leq C^{PV,max} \tag{13}$$

$$P_{d,t}^{PV} = C^{PV} \cdot \eta_{d,t}^{PV} \tag{14}$$

4.2.2. ESS Operation Management

Equations (15)–(17) show that the battery's state-of-charge (SOC) is maintained within the range of economy and quality. The SOC of the ESS are always limited by their minimum and maximum amounts [36].

$$SOC^{min} \leq SOC_{d,t} \leq SOC^{max} \tag{15}$$

$$SOC^{min} = C^{ESS} \cdot 0.2 \tag{16}$$

$$SOC^{max} = C^{ESS} \cdot 0.8 \tag{17}$$

Based on the constraints in Equations (18)–(22), the charging and discharging speed and efficiency of ESS corresponds to constants at each time interval. The unit time interval is set to 60 min, and the minimum charging and discharging time is set to a minute. Charging and discharging are conducted continually at least once every minute and not simultaneously.

$$0 \leq \tau_{d,t}^{ESS,ch} + \tau_{d,t}^{ESS,dch} \leq 60 \tag{18}$$

$$0 \leq \tau_{d,t}^{ESS,ch} \leq 60 \tag{19}$$

$$0 \leq \tau_{d,t}^{ESS,ch} \leq 60 \tag{20}$$

$$P_{d,t}^{ESS,ch} = V^{ESS,ch} \cdot \tau_{d,t}^{ESS,ch} \cdot \eta^{ESS,ch} \tag{21}$$

$$P_{d,t}^{ESS,dch} = V^{ESS,dch} \cdot \tau_{d,t}^{ESS,dch} \cdot \eta^{ESS,dch} \tag{22}$$

In Equations (23) and (24), SOC is related to their status, including the previous SOC elements. The state of the previous SOC determines the SOC of the current time. The first SOC on the next day should match the last SOC of the previous day.

$$SOC_{d,t} = SOC_{d,t-1} - \frac{P_{d,t}^{ESS,dch}}{\eta^{ESS,dch}} + P_{d,t}^{ESS,ch} \tag{23}$$

$$SOC_{d,1} = SOC_{d-1,24} - \frac{P_{d,1}^{ESS,dch}}{\eta^{ESS,dch}} + P_{d,1}^{ESS,ch} \tag{24}$$

4.2.3. Power Balance

Equation (25) shows that the sum of the total load owing to the use of the building and the power required to charge the ESS is equal to the amount of power supplied to the building, the discharge of the ESS, and the power generation of the PV. The amount of power supplied from the grid to the building has an upper limit.

$$P_{d,t}^{demand} + \frac{P_{d,t}^{ESS,ch}}{\eta^{ESS,ch}} = P_{d,t}^{load} + P_{d,t}^{ESS,dch} + P_{d,t}^{PV} \quad (25)$$

Based on Equation (26), the peak of the power used by the building during peak reduction operations is managed to below the management peak.

$$P_{d,t}^{peak} + \frac{P_{d,t}^{ESS,ch}}{\eta^{ESS,ch}} - P_{d,t}^{ESS,dch} + P_{d,t}^{PV} \leq C^{limit} \quad (26)$$

5. Case Study

5.1. Setup for Case Study

5.1.1. Data Overview

This case study is for a commercial building attached to an apartment-type factory located in Gyeonggi-do, South Korea. The seasonal load of the building is shown in Figure 4, and all seasons show a maximum peak pattern from 12:00 to 13:00. The total annual electricity consumption was 872,000 kWh. Figure 4 shows that the load pattern of the building is concentrated in the daytime and dispersed at night.

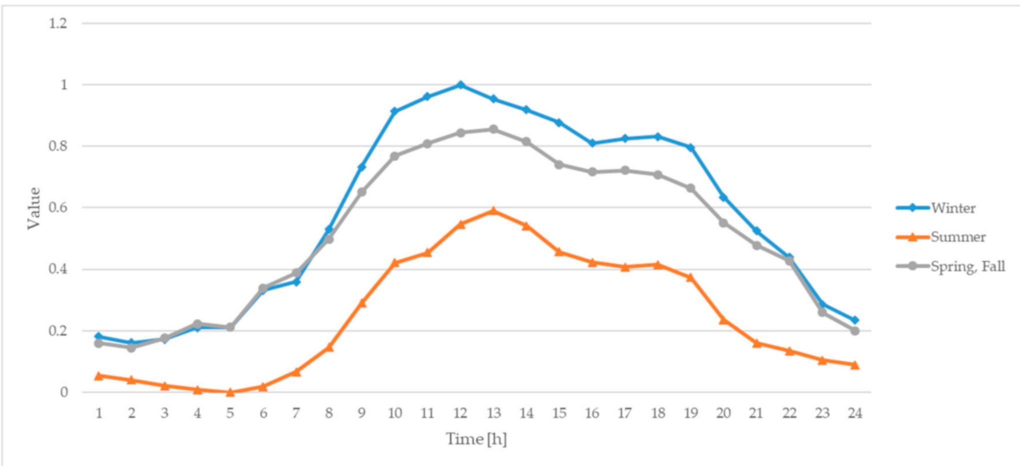

Figure 4. Normalized building load pattern in 2017.

We simulated the capacities and operation methods of DERs with the lowest net cost when buildings associated with the cost and benefit would be operated for 15 years based on the current special rate for a renewable energy system. The application costs, equipment details, and user conditions are based on Table 7, which is actually applied to the aforementioned commercial building. An optimization tool was used in MATLAB (R2020a, MathWorks, Natick, MA, USA), and a solver was applied by importing Gurobi-CPLEX.

Table 7. Basic application factors for case study.

Cost				
PV Installation (KRW/kW)	**ESS Installation (KRW/kW)**	**O&M**	**Discount Rate (%)**	
1,750,000	600,000	(Installation cost)·0.5%/year	5	
ESS				
Type of battery	**Charging and discharging speed (kWh/min)**	**Charging efficiency (%)**	**Discharging efficiency (%)**	**DoD (%)**
Li-ion	2	90	95	60
User				
Base rate (KRW)	**Usage plan**	**Contract power (KW)**	**Applied data**	**Data coverage period**
8320	Standard, HP(A), C II	8000	Actual building load	01.01.2017–31.12.2017

5.1.2. Decision of Peak Management Threshold Based on a Normal Distribution

In peak reduction operations, a threshold should be identified wherein a peak load management reference threshold can be efficiently applied to the peak load of the target building. It is possible to manage peaks below the reference threshold without the ESS since the peak exceeding the reference point could be managed through the ESS. If the amount of peak exceeding would be normally distributed as shown in Figure 5, the peak management range would be decided by outside confidence interval. This was calculated based on a value that does not generally occur, and is set to be utilized for base charge reduction through peak management.

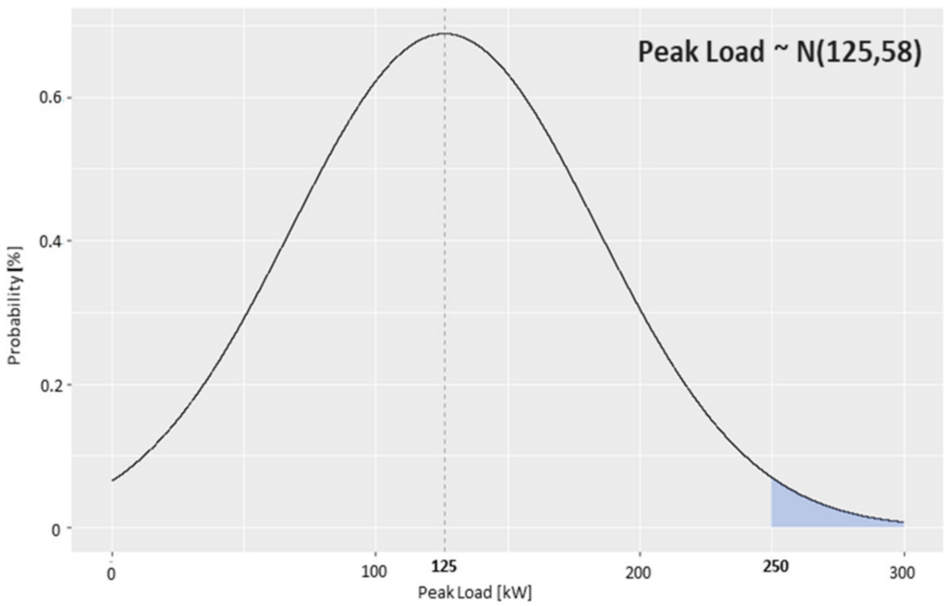

Figure 5. Peak management range decision.

5.2. Optimization Result for Capacity of Photovoltaic System and Energy Storage System

5.2.1. PV Capacity

As a result of the simulations, it was confirmed that the installation amount of PV power sources increased infinitely to maximize the profit of renewable energy promotion. However, as the PV power has a limited installation area, it is fixed at 35 kW, which is technically the maximum value of power that can be installed.

5.2.2. ESS Capacity

The operating modes of the ESS were simulated by simultaneously dividing them to a peak, rate, and peak/rate reduction operations. The operating mode with the smallest net cost is the model that simultaneously performs peak and rate reduction operations. The net cost for the 15-year period was 1,898,441,629 KRW. As shown in Table 8, with the optimal operation schedule of ESS charging and discharging, the most beneficial operation mode is a mode in which the remaining SOC of the peak-time ESS is discharged after the reduction of the peak of the building load. In this mode, it is confirmed that the peak reduction effect could be obtained by reducing the peak value, and the benefit can thus be increased by receiving the base charge reduction through the peak time period discharge. In the above mode, it was found that the facility was operated on a single cycle every single day according to the settlement rules of the special rate system.

Table 8. Optimal capacity and net cost comparison.

	Peak Reduction	Rate Reduction	Peak and Rate Reduction
PV Capacity (kW)	35	35	35
ESS Capacity (kWh)	214	540	540
Peak Management Threshold (kW)	250	-	250
Total Operation Cost (KRW)	2,258,521,542 (98.3%)	2,296,309,917 (99.9%)	2,296,602,275 (100%)
Total Revenue (KRW)	145,411,880 (36.5%)	270,403,078 (67.9%)	398,160,646 (100%)
Net Operation Cost (KRW)	2,113,109,662 (111.3%)	2,025,906,839 (106.7%)	1,898,441,629 (100%)

Figure 6 shows the operating results for one day following the application of the optimal capacity and operating method of the PV and ESS elements in the building. Even though the charging time is not limited to the light load time, the result is the charging of the ESS at the minimum cost. The ESS was discharged so that its value could be kept below the peak management threshold point, and the remaining SOC was operated to obtain the minimum net cost by discharging before reaching the maximum load time.

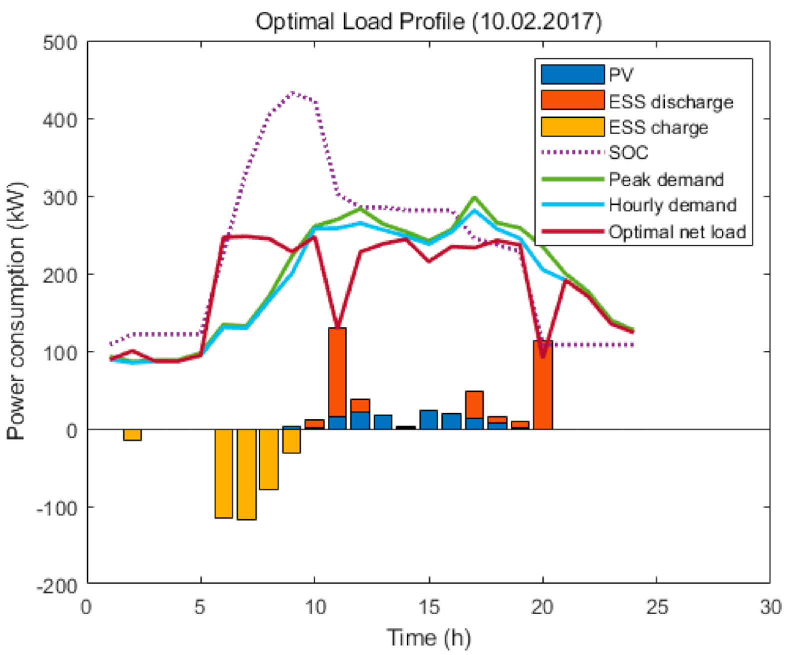

Figure 6. Optimal load profile on 10 February 2017.

5.3. Economic Analysis

5.3.1. Parameter Definition and Simulations

To analyze the sensitivity of the special rate for the renewable energy plan, parameters were set and simulated for the cost and revenue items based on the optimum capacity and operation mode. We assume that the PV systems and ESS were both associated with a 5% decrease in installment cost that accounted for the largest part of the cost by fixing the benefits. This is the extent to which the reduction in the number of renewable energy facilities—which have been declining during the past decade—is reflected in the relevant policy. We also extended the coverage period for the special rate for the renewable energy plan (which is scheduled to be closed by 2020), and analyzed the results. The results were analyzed when the base charge revenue and performance revenue factors were extended at 1, 3, and 5 year intervals, respectively, during the special rate plan. The deadline for the special rate of a renewable energy system in 2017 was extended from 2019 to 2020 to expand the number of renewable energy facilities. Additionally, there are ample possibilities for further extensions in the future. An analysis of the extension of the application period for the special rate of the renewable energy plan based on the analysis of the cost and level parameters can be used as a basis for policy decision making.

5.3.2. Sensitivity to Changes in Installation Cost

As observed in Figure 7, we analyzed the change in the benefit/cost (B/C) ratio (which is generally used in economic evaluations) based on the assumption that the value of the benefit was fixed as simulated in Section 5.2. with the baseline B/C ration of 9.6, and that the price of PV and ESS equipment decreased or increased by 5%. The simulation results showed that the price sensitivity of the ESS was greater than that of a PV when the 5% equipment cost drop affected the B/C ratio of the plant operation. This is because the installation unit cost of PV is more expensive, but the installation environment constraints do not allow a sufficient amount to be installed. An ESS with integrated installation leads to a more sensitive parameter.

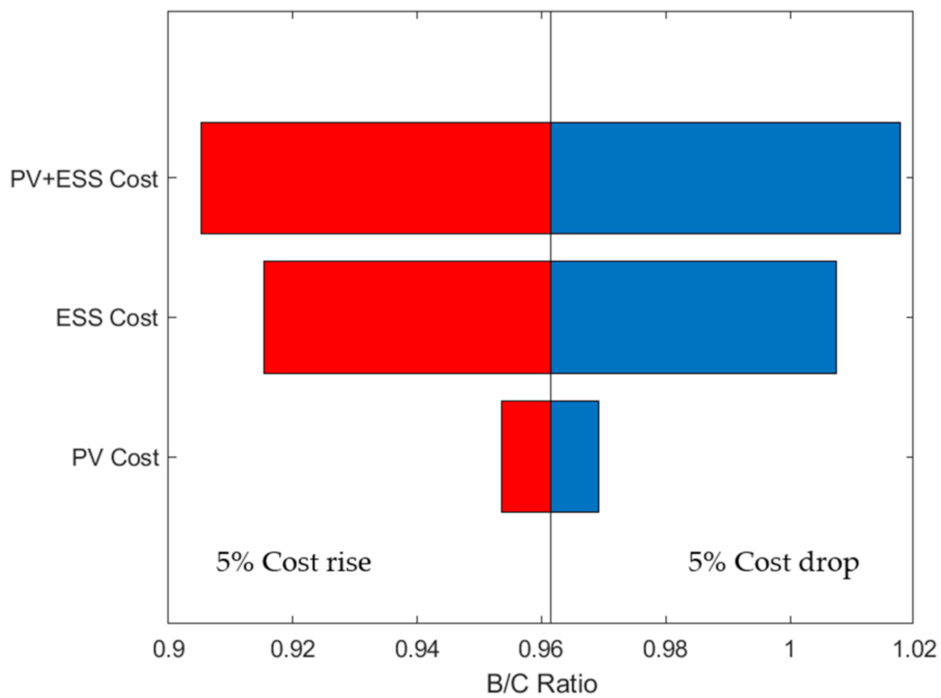

Figure 7. B/C ratio sensitivity owing to the cost rise/drop.

In Figure 7, the decline in the price of PV equipment does not affect considerably the economic efficiency of new and renewable facilities. In contrast, the ESS has a B/C ratio of 1.0, which is economical, owing to the 5% price drop of the facilities with optimized capacities and operation methods, as shown in Figure 8.

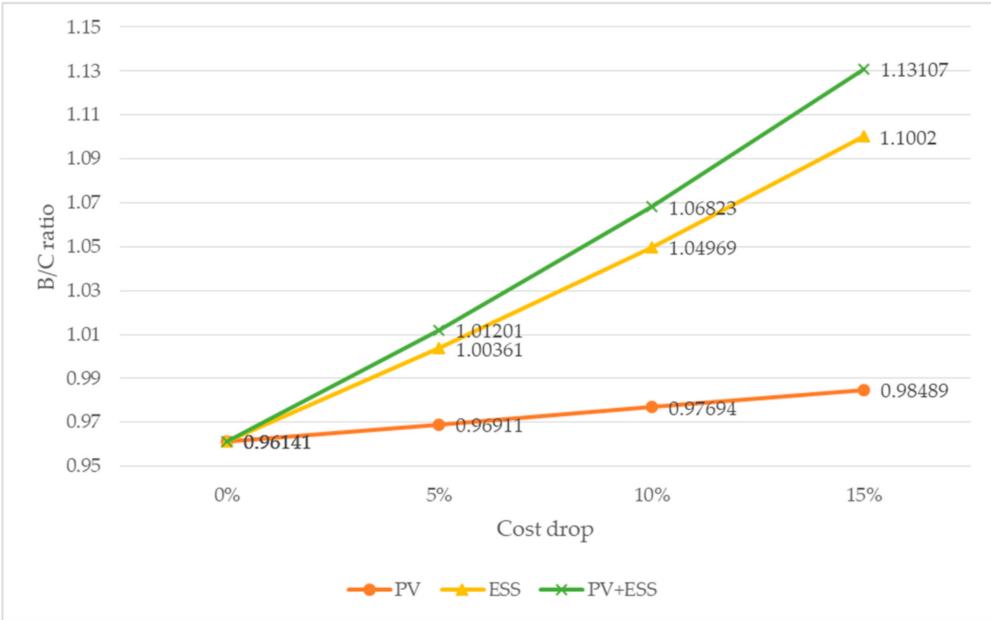

Figure 8. B/C changes owing to the equipment cost drop.

5.3.3. Sensitivity to Changes of Expiration

We analyzed the effects of base charge revenue and electric performance revenue on economic efficiency when (a) the cost was fixed, and when (b) the expiry date of the special rate for the renewable energy system was extended to 1, 3, and 5 years. As a result of the simulation, the effect of the B/C ratio on the extension of the system expiry date by one year was determined to be 3.9 times larger than the benefit of the electric performance revenue, as shown in Figure 9.

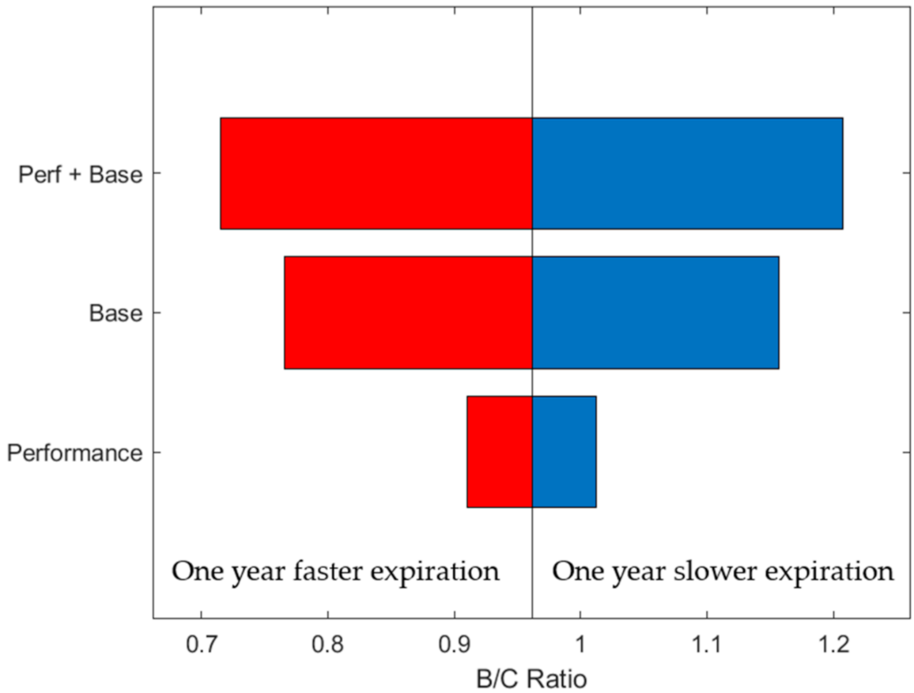

Figure 9. B/C ratio sensitivity owing to modification of benefit period expiration.

Performance revenue can be economically viable if the expiry date of the system is extended for more than three years. In comparison, the base charge revenue can be sufficiently economical if the special rate for the renewable energy plan expiration date is merely extended by one year, as shown in Figure 10. In addition, it can be confirmed that the extension of the expiration date for the base charge revenue is the most important policy variable of the special rate for the renewable energy plan.

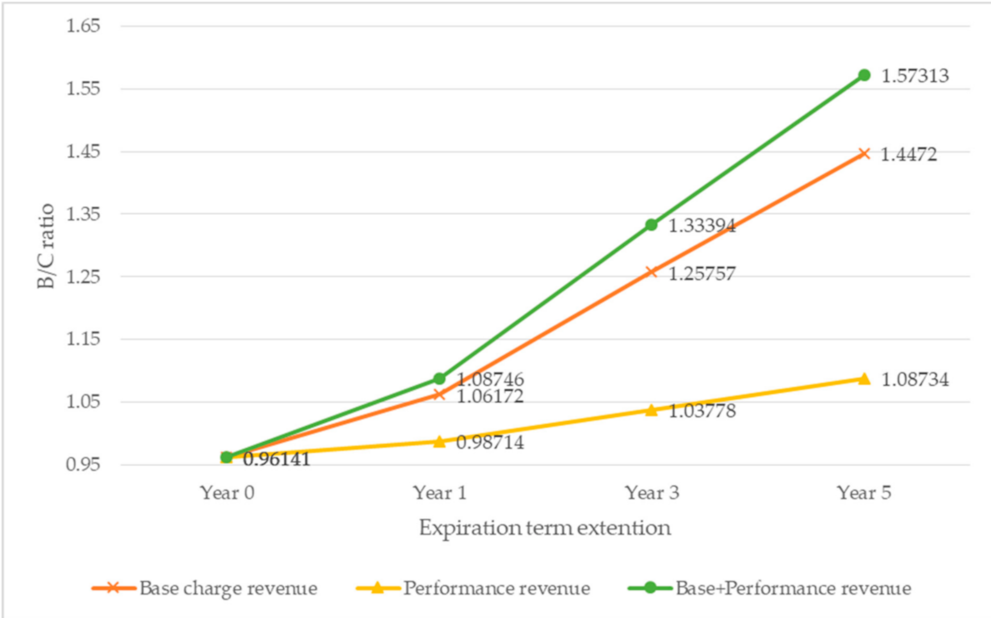

Figure 10. B/C changes owing to benefits from the extension of the expiration period.

6. Conclusions

In this study, we analyzed the long-term policy benefits and technological changes of photovoltaic system and energy storage system from the optimization model based on building customer. The optimization model was proposed to calculate the optimal capacity of PV and ESS, and to establish charge/discharge scheduling so that the net cost was minimized in the operating environment. Previous studies on the capacity estimation of DERs have been limited to the use of power generation for businesses. Besides, they have not considered long-term and/or optimal operations. This study proposed a mathematical model of the optimum facility capacity while concurrently considering the long-term benefits of settlement rules for a self-consuming building with PV and ESS.

Based on case studies and economic analyses, we can predict the increase in users of self-consumption owing to the drop in the price of distributed power equipment in the future. In addition, the greater the drop in ESS equipment prices, the more likely will be the importance of peak reduction and rate reduction operation plans. In addition, the case study determined that if an extension of the period of the special rate plan is considered to balance the benefits with facility operators for power generation for businesses based on revenue from an REC, then the adjustment of the period of the base charge revenues—a key policy variable—should be considered first.

The results of this analysis can be used for the development of regional cooperation projects for domestic power generation companies using nuclear power or fossil fuels, and for resident-driven renewable projects that can help diversify the renewable energy businesses in the long-term perspective.

Additional studies can consider the application of electric vehicles and demand responses which have been actively researched recently as DERs. The results of these studies will be useful for the economic modeling of DER investment models and for national policy decisions regarding long-term energy transitions.

7. Limitation and Future Works

Although all the model and results are consistent with our objectives, there are still limitation and difficulties. First of all, Korea is known to have the properly functioning electricity market under the dominance of Korea Electric Power Corporation (KEPCO). With this environment, the investment of the ESS would be highly dependent on the special rate or subsidy. This dependency might also keep the owner of renewable sources and energy storages from utilizing their resources properly. In short, the analysis in this research might be treated as a temporary relaxation of the tariff rules of renewable energy in Korea. Finally, results for the individual optimization of the ESS would be more effective than those for the proposed optimization. Although this research has limitations of the sub-optimal results, the objective of this research is to be a first step of improving market environment by analyzing the impact of varying rate not mentioned in previous research.

Further studies will focus on aiming to enhance or reform the structure of tariff rules for renewable energy resources and energy storage resources. A novel research will propose an optimized tariff rules to promote investment and operation of energy resources.

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Abbreviations

Indices	
y	Index of year slots
m	Index of month slots
d	Index of date slots
t	Index of time slots
Parameters	
$cost^{e}$	Equipment installation cost
$cost^{o}$	Annual O&M cost
$revenue_{y}^{b,elec}$ argingue from	Revenue from base charge discount of the special rate at year y
$revenue_{y}^{p,PV}$	Revenue from PV self-consumption promotion at year y
C^{PV}/C^{ESS}	PV/ESS capacity
$C^{PV,max}$	Maximum PV capacity
C^{limit}	Threshold demand capacity for peak reduction limit
$p^{PV,Equip}/p^{ESS,Equip}$	Unit price of PV/ESS equipment installation
$p_{m}^{elec,charge,base}$	Monthly base electric charge at month m
$p_{d,t}^{elec,charge}$	Hourly electric charge of usage at day d time t
$p^{elec,contr,base}$	Contractual base electric charge
$p^{renewable}$	Renewable energy transaction price
$\eta^{O\&M}$	Unit O&M price coefficient
$\eta^{renewable,PV}$	Renewable energy promotion contractual coefficient (PV)
$\eta^{renewable,ESS}$	Renewable energy promotion contractual coefficient (ESS)
$\eta^{ESS,base}$	Basic ESS promotion contractual coefficient
$\eta^{PV,depr}$	PV efficiency depreciation coefficient
$\eta^{ESS,depr}$	ESS efficiency depreciation coefficient

$\eta^{ESS,ch}/\eta^{ESS,dch}$	ESS charging/discharging efficiency
$\eta_y^{PV,self}$	PV self-consumption promotion contractual coefficient at year y
$\eta_y^{ESS,\,ch}$	ESS charging promotion contractual coefficient at year y
$\eta_y^{elec,charge}/\eta_y^{elec,demand}$	Electric charge/demand inflation coefficient at year y
η_y^{peak}	Peak load demand inflation coefficient at year y
$\eta_{d,t}^{PV}$	PV generation coefficient at day d time t
$P_{d,t}^{PV}$	PV generation amount at day d time t
$P_{d,t}^{load}$	Actual load consumption of the building at day d time t
$P_{d,t}^{peak}$	Peak demand load of the building at day d time t
SOC^{min}/SOC^{max}	Minimum/Maximum state of charge of ESS
$V^{ESS,ch}/V^{ESS,dch}$	ESS charging/discharging velocity
$X_{d,t}^{peak}/X_{d,t}^{nonpeak}$	Boolean parameter of peak/non-peak time detectionat day d time t
n^{month}/n^{hours}	Number of months/hours
$n^{workingdays}$	Number of working days
Variables	
π	Net cost
$cost$	Total cost
$cost^c$	Total cost from electric usage charge
$revenue$	Total revenue
$revenue_y^b$	Base charge revenue at year y
$revenue_y^p$	Performance revenue at year y
$revenue_y^{b,ESS}$	Annual revenue from ESS base promotion at year y
$revenue_y^{p,ESS}$	Annual revenue from ESS base promotion at year y
$P_{d,t}^{ESS,ch}/P_{d,t}^{ESS,dch}$	ESS charging/discharging amount at day d time y
$P_{d,t}^{elec,demand}$	Net demand load of the building at day d time y
$SOC_{d,t}$	State of charge of ESS
$\tau_{d,t}^{ESS,ch}/\tau_{d,t}^{ESS,dch}$	ESS charging/discharging time in unit hour at day d time y

References

1. IEA. Korea Renewable Energy 3020 Plan. Available online: https://www.iea.org/policies/6569-korea-renewable-energy-3020-plan (accessed on 15 December 2020).
2. MOTIE. Annual Solar PV Installed 2GW. Available online: http://www.motie.go.kr/motie/ne/presse/press2/bbs/bbsView.do?bbs_cd_n=81&bbs_seq_n=161337 (accessed on 17 December 2020).
3. MOTIE. Expanding ESS Market by 20 Times in the First Half of this Year with the Expansion of Renewable Energy. Available online: http://www.motie.go.kr/motie/ne/presse/press2/bbs/bbsView.do?bbs_cd_n=81&bbs_seq_n=160662 (accessed on 19 December 2020).
4. Gupta, R.; Soini, M.C.; Patel, M.K.; Parra, D. Levelized cost of solar photovoltaics and wind supported by storage technologies to supply firm electricity. *J. Energy Storage* **2020**, *27*, 101027. [CrossRef]
5. Tronchin, L.; Manfren, M.; Nastasi, B. Energy efficiency, demand side management and energy storage technologies—A critical analysis of possible paths of integration in the build environment. *Renew. Sustain. Energy Rev.* **2018**, *95*, 341–353. [CrossRef]
6. Nastasi, B.; Mazzoni, S.; Groppi, D.; Romagnoli, A.; Garcia, D.A. Solar power-to-gas application to an island energy system. *Renew. Energy* **2021**, *164*, 1005–1016. [CrossRef]
7. Heinisch, V.; Odenberger, M.; Göransson, L.; Johnsson, F. Prosumers in the electricity system–household vs. system optimization of the operationi of residential photovoltaic battery systems. *Front. Energy Res.* **2019**, *6*, 145. [CrossRef]
8. Fossati, J.P.; Galarza, A.; Martín-Villate, A.; Fontan, L. A method for optimal sizing energy storage systems for microgrids. *Renew. Energy* **2015**, *77*, 539–549. [CrossRef]
9. Khorramdel, H.; Aghaei, J.; Khorramdel, B.; Siano, P. Optimal battery sizing in microgrids using probabilistic unit commitment. *IEEE Trans. Ind. Infor.* **2015**, *12*, 834–843. [CrossRef]
10. Lee, W.; Kim, K.; Kim, B. A Research on PV-connected ESS dissemination strategy considering the effects of GHG reduction. *J. Energy Eng.* **2016**, *25*, 94–100. [CrossRef]
11. Hida, Y.; Miyaguchi, Y.; Yokoyama, R.; Iba, K. A study of optimal capacity of BESS to mitigate unstable of solar power generation. In *Proceedings of the International Symposium on Modern Electric Power Systems, Modern Electric Power Systems 2010, Wroclaw Poland, 20–22 September 2010*; Wroclaw University of Technology: Wroclaw, Poland, 2010.

12. Park, H.; Hong, W. Korea's emission trading scheme and policy design issues to achieve market-efficiency and abatement targets. *Energy Policy* **2014**, *75*, 73–83. [CrossRef]
13. Lee, S.; Kim, H.; Shin, H.; Kim, T.; Kim, W. A study on the estimation of optimal ESS capacity considering REC weighting scheme. *Trans. Korean Inst. Electr. Eng.* **2018**, *67*, 1009–1018.
14. Baek, M.; Park, J.; Son, S.; Shin, H.; Park, Y. A study of optimal capacity of battery energy storage system linked PV. *Trans. Korean Inst. Electr. Eng.* **2018**, *67*, 38–45.
15. Oh, S.; Kong, J.; Lee, W.; Jung, J. Development of optimal energy storage system sizing algorithm for photovoltaic supplier in South Korea. *IEEE PES Gen. Meet.* **2018**, 1–5. [CrossRef]
16. Yoon, Y.; Choi, J.; Choi, Y.; Shin, Y.; Kim, J. A study on the economic analysis method of energy storage system. *J. Korea Inst. Inf. Commun. Eng.* **2015**, *19*, 596–606. [CrossRef]
17. Son, J. A study on economic analysis algorithm for energy storage system considering peak reduction and a special tariff. *Trans. Korean Inst. Electr. Eng.* **2018**, *67*, 1278–1285.
18. Hu, X.; Xu, G.; Cheng, H.; Liu, Y.; Cai, Y. Joint planning of BESS and DR for industrial consumers participating in peak-shaving. In Proceedings of the 2018 IEEE Power and Energy Society General Meeting (PESGM), Portland, OR, USA, 5–10 August 2018.
19. Oudalov, A.; Cherkaoui, R.; Beguin, A. Sizing and optimal operation of battery energy storage system for peak shaving application. *IEEE Lausanne Power Tech.* **2007**, 621–625. [CrossRef]
20. Park, Y.; Kwon, K.; Lim, S.; Park, J. Electric bill minimization model and economic assessment of battery energy storage systems installed in a non-residential customer. *Trans. Korean Inst. Electr. Eng.* **2016**, *65*, 1347–1354. [CrossRef]
21. Park, J.; Baek, Y.; Jeong, K.; Park, J. Optimal capacity determination of BESS for customer using investment cost and electric cost. *Trans. Korean Inst. Electr. Eng.* **2015**, *64*, 208–213. [CrossRef]
22. Araneo, R.; Falvo, M. Simulation of a ESS in a prosumer power-plant with a PV system and an EV charging station. *IEEE Int. Conf. Envir. Elec. Eng.* **2016**, 1–5. [CrossRef]
23. Wai, R.; Wang, W.; Lin, C. High-performance stand-alone photovoltaic generation system. *IEEE Trans. Ind. Electr.* **2008**, *55*, 240–250. [CrossRef]
24. Lee, Y.; Kim, S.; Han, S. A study on the energy saving capacity of solar power generation system using economic evaluation. *Trans. Korean Inst. Electr. Eng.* **2018**, *67*, 21–26.
25. Jo, B.; Jung, S.; Jang, G. Feasibility analysis of behind-the-meter energy storage system according to public policy on an electricity charge discount program. *Sustainability* **2019**, *11*, 186. [CrossRef]
26. Akhil, A.; Huff, G.; Currier, A.; Kaun, B.; Rastler, D.; Chen, S.; Cotter, A.; Bradshaw, D.; Gauntlett, W. Electricity storage handbook in collaboration with NRECA. Sandia National Lab. (SNL-NM), Albuquerque, NM (United States). 2013. Available online: https://www.osti.gov/biblio/1661773 (accessed on 21 December 2020).
27. National Law Information Center. The Guideline of Small and Mid-Sized Renewable Energy Transaction. Available online: https://www.law.go.kr (accessed on 27 December 2020).
28. KEPCO. Electric Supply Terms and Conditions of the Cyber Branch of the Korea Electric Power Corporation. Available online: http://cyber.kepco.co.kr/ckepco/front/jsp/CY/D/C/CYDCHP00208.jsp (accessed on 27 December 2020).
29. KEPCO. Electricity Supply Agreement. Available online: http://cyber.kepco.co.kr/kepco/front/jsp/CY/D/C/CYDCHP00101.jsp?menuCd=FN02040201 (accessed on 28 December 2020).
30. KEPCO. Advise on the Revision of the Electricity Price Discount System for Renewable Energy. Available online: http://home.kepco.co.kr/kepco/CU/A/B/CUABPP00102.do?pageIndex=1&boardSeq=21029313&menuCd=FN1201 (accessed on 29 December 2020).
31. MOTIE. Second Meeting of Senior Advisory Panel on Energy Policy. Available online: http://www.motie.go.kr/motie/ne/presse/press2/bbs/bbsView.do?bbs_cd_n=81&bbs_seq_n=159210 (accessed on 30 December 2020).
32. Jeon, J.; Kim, K. An optimal decision model for capacity and inclining angle of residential photovoltaic systems. *Trans. Korean Inst. Electr. Eng.* **2010**, *59*, 1046–1052.
33. Paik, C.; Chung, Y.; Kim, Y. Capacity factor-based approximation approach for calculating capacity credit of solar power in Korea. *Korean Sol. Energy Soc.* **2017**, *37*, 13–26.
34. MOTIE. The Eighth Basic Plan for Long-Term Power Supply and Demand Confirmed Notice. Available online: http://www.motie.go.kr/motie/ne/presse/press2/bbs/bbsView.do?bbs_cd_n=81&bbs_seq_n=159970 (accessed on 3 January 2021).
35. Lai, C.; McCulloch, M. Levelized cost of electricity for solar photovoltaic and electrical energy storage. *Appl. Energy* **2017**, *190*, 191–203. [CrossRef]
36. Yoon, D.; Choo, D.; Ki, B.; Kim, J.; Lee, B.; Chae, W. A study on the methodology of determining proper SOC operation range considering the economic characteristics and the charge and discharge voltage characteristics of BESS. *Trans. Korean Inst. Electr. Eng.* **2015**, *64*, 529–536. [CrossRef]