https://doi.org/10.1016/j.jclepro.2021.126138

Development of the business feasibility evaluation model for a profitable P2P electricity trading by estimating the optimal trading price

Jongbaek An[1], *Taehoon Hong*[2*] *and Minhyun Lee*[3]

[1] Graduate Research Assistant and Ph.D student, Department of Architecture and Architectural Engineering, Yonsei University, Seoul, 03722, Republic of Korea, ajb2577@yonsei.ac.kr

[2] Underwood Distinguished Professor, Department of Architecture and Architectural Engineering, Yonsei University, Seoul, 03722, Republic of Korea, hong7@yonsei.ac.kr (CORRESPONDING AUTHOR).

[3] Assistant Professor, Department of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong, minhyun.lee@polyu.edu.hk

* Yonsei University

50 Yonsei-ro, Seodaemun-gu, Seoul, 03722, Republic of Korea

82-2-2123-5788 (T); 82-2-365-4668 (F); hong7@yonsei.ac.kr

ABSTRACT

For the market participants (i.e., energy consumers and prosumers) in a microgrid to acquire profits via trading surplus electricity, it is essential to determine an appropriate trading price of electricity. Therefore, this study developed a business feasibility evaluation model to predict the optimal trading price of electricity that maximizes the profits of both the market participants participating in the peer-to-peer (P2P) electricity trading, by reflecting the structure of electricity market in South Korea. The residential areas located in the seven metropolitan cities in South Korea (Seoul, Incheon, Daejeon, Daegu, Ulsan, Busan, and Gwangju) were selected for the model application. The main findings from the model application are as follows. First, the annual electricity generation of the solar photovoltaic (PV) panel was highest in Daegu (5,541 kWh) and lowest in Seoul (3,569 kWh). In addition, the electricity generation was generally shown to be higher in spring (March-May) and relatively lower in summer and winter. Second, the estimated annual maximum profit of the energy prosumer was highest in Daegu (US$995.5) and lowest in Seoul (US$638.1). Furthermore, it was determined to be beneficial to the energy prosumers to reduce their self-use rate to the extent possible. By using the developed business feasibility evaluation model, decision makers, including specialists and non-specialists, can determine the optimal trading price of electricity and whether to participate in the market of P2P electricity trading.

Keywords: Optimal trading price of electricity; Peer-to-Peer electricity trading; Energy prosumer; Levelized cost of electricity; Business feasibility evaluation; Genetic algorithm

1. INTRODUCTION

To address global warming and climate change, the 21st conference of the parties (COP 21) of the United Nations Framework Convention on Climate Change (UNFCCC) held in Paris in 2015 concluded the Paris Agreement called “POST-2020” [1]. Aiming to correspond to this agreement, the South Korean government announced its Basic Roadmap for the Reduction of Greenhouse Gas Emissions in 2016, setting the carbon emission reduction target (CERT) to 37% by 2030, among which the reduction in buildings was set to 35.8 million tons (18.1%) [2,3]. Accordingly, various research has been conducted to improve the energy efficiency, to substitute the fossil fuels used in power plants with renewable energy, and to reduce the carbon emissions by combining carbon capture and storage (CCS) with power plants [4,5].

Most studies in the energy sector consider the improvement of the existing electricity generation systems the most feasible carbon emission reduction method [6–8], and thus argue for the need to substitute the existing electricity generation systems with renewable-energy-source-(RES)-based generation technologies [9–11]. Accordingly, there has been an increase in the installation of renewable energy generation systems like the solar photovoltaic (PV) panel or small wind turbines in buildings. Such methods are called “distributed generation system,” which does not rely on the power supplied from the existing macrogrid but on the self-generated electricity or the power produced nearby. Small-scale power networks, including the distributed generation system, are called “microgrid,” which offers advantages, such as the reduction of power loss in the power transmission and distribution and a more reliable and stable power supply than that from the centralized generation system [12].

As such, energy consumers with a distributed generation system can play the role of an energy producer and that of an energy consumer at the same time, in which case they can be referred to as “energy prosumers.” Energy prosumers can acquire profit not only through lowering their costs of electricity by self-using the electricity that they produce but also through selling the surplus electricity due to the difference between their power generation pattern and power consumption pattern. Generally, distributed generation systems can be installed together with the energy storage system (ESS), but the price of ESS in South Korea is currently too high, which makes it difficult to obtain a return on investment (ROI) from installing ESS [13]. Thus, for energy prosumers to generate profit via electricity after self-use (i.e., surplus electricity), they can either sell the surplus electricity via power-purchase-agreement (PPA) or net metering with Korea Electric Power Corporation (KEPCO), South Korea's sole electric utility, or reduce and optimize the installed distributed generation system capacity. Such method, however, can reduce the profits of energy prosumers and increase the inefficiency of electricity usage.

To address some of these issues, P2P electricity trading was considered to promote the installation of distributed generation systems. P2P electricity trading allows for direct interaction among the market participants [14]. The energy prosumers in P2P electricity trading sell surplus electricity to gain profit while the energy consumers can lower their costs of electricity by purchasing such surplus electricity at a price lower than that from KEPCO [15]. In other words, with P2P electricity trading, electricity consumers can select their electricity supplier as well as the amount of electricity that they will purchase [16]. The P2P electricity trading in South Korea, however, which has been run as a pilot project in 2016, cannot offer huge profits because the method of determining the optimal trading price of electricity has not been established, and also because the price is the same as that from net metering [15,17]. Moreover, the concept of P2P electricity trading is still new, and the related research or policy is still at its infancy.

According to previous studies, various attempts have been made to determine the price for P2P electricity trading. First, many studies determined the trading price of electricity based on auction mechanism. Yaagoubi and Mouftah assumed that the buyers and sellers of surplus electricity were individually connected, and the trading price of electricity was determined through the auction mechanism [18]. Wang et al. assumed that the energy prosumer installed the ESS and maximizes the use of the ESS, and applied a double auction mechanism to determine the trading price of electricity [19]. Long et al. suggested three models for determining the trading price of electricity through bill sharing, mid-market rate, and action based pricing strategy, respectively, and evaluated the feasibility of P2P electricity trading by comparing each model [20]. In the aforementioned auction-based models, energy consumers who participate in the P2P electricity trading market place a bid to purchase surplus electricity, and the energy prosumer sells surplus electricity at the highest bid. In other words, the purpose of this model is to maximize the profits of the energy prosumers. Second, some other studies determined the trading price of electricity based on bilateral contracts. Morstyn et al. presents a bilateral market consisting of distributed generation, flexible loads, intermediaries, consumers, etc., and determines the trading price of electricity through the interaction of energy consumers and prosumers [21]. Lopes et al. designed a multi-agent electricity market based on bilateral contracts and explained the process of deriving trading prices of electricity through a case study [22]. A bilateral contract is a model in which the energy consumer and prosumer derive the trading price of electricity through consensus, but still it tends to maximize the profits of the energy prosumer. Auction-based models and bilateral contracts derive the trading price of electricity through auction or consensus, but they have the disadvantage that they cannot guarantee sufficient profit of energy consumers because it prioritizes the profit of energy prosumers. In addition, it is difficult to generalize a specific model because electricity tariff and policies are different across countries.

To solve the above limitations, this study aimed to develop a business feasibility evaluation model of P2P electricity trading which allows for the market participants to trade surplus electricity at an optimal price in South Korea. To this end, the threshold prices and the optimal trading prices of electricity for the market participants were determined by considering the current situation of electricity market and billing system, as well as the profit structure of market participants in South Korea. Furthermore, based on the determined optimal trading price of electricity and the tradable surplus electricity, the market feasibility of the installation of the solar PV panel was evaluated. The residential buildings with solar PV panels in the metropolitan cities in South Korea were also analyzed, as follows: (i) target region: seven metropolitan cities, high-level local authorities in South Korea; (ii) target generation system: the solar PV panel, which accounts for 42.6% (8,099 MW) of the distributed generation systems in South Korea as of 2018 [23]; and (iii) target building type: the residential building expected to generate high profits via P2P electricity trading due to its progressive tariff [24]. The developed model can be used by decision makers, either specialists or non-specialists who wish to enter into the market of P2P electricity trading, to derive the optimal trading price of electricity depend on various input data (e.g., region, building orientation, solar PV panel capacity, etc.). The proposed optimal trading price of electricity will allow the aforementioned decision makers to evaluate the business feasibility of P2P electricity trading, and to thus decide whether to participate in the market or not.

2. MATERIALS AND METHODS

This study aimed to develop a business feasibility evaluation model to derive the optimal trading price of electricity for market participants to engage in P2P electricity trading, and conducted a business feasibility analysis consisting of the following five steps: (i) database establishment; (ii) estimation of electricity generation by the RETScreen software; (iii) economic assessment for calculating the levelized cost of electricity (LCOE); (iv) determination of the maximum and minimum trading prices of electricity; and (v) determination of the optimal trading price of electricity.

2.1 Step 1: Database establishment

The following database was established in this study to derive the optimal trading price of electricity: (i) regional factors; (ii) solar PV panel information; and (iii) market participant information.

First, for the regional factors, data on the meteorological and geographical factors were collected [25]. The data on meteorological factors such as the air temperature, relative humidity (RH), rainfall, daily solar radiation (DSR), atmospheric pressure (ATM), wind speed, earth temperature, heating degree-days (HDD), and cooling degree-days (CDD) as well as the data on geographical factors such as the latitude, longitude, and elevation were collected to predict the amount of electricity generation of the solar PV panel using the RETScreen software. Such regional factors can affect the amount of electricity generated by the solar PV panel. Shown in Table S2 are examples of the collected standard data for predicting the electricity generation of the solar PV panel.

Second, the solar PV panel information was collected. Solar PV panels are generally divided into the following three types by generation: (i) 1st-generation solar PV panel (monocrystalline silicon [mono-si], polycrystalline silicon [poly-si], etc.); (ii) 2nd-generation solar PV panel (amorphous silicon [a-si], cadmium telluride [CdTe], copper indium gallium selenide [CIGS], etc.); and (iii) 3rd-generation solar PV panel (dye-sensitized PV panel [DSSP], organic PV panel [OPV], nano solar cell, perovskite panel, etc.) [26–30]. The solar PV panel technology is continuously developing, but the 3rd-generation solar PV panel is still in the research stage and has not been commercialized [31]. Thus, in this study, data related to the 1st- and 2nd-generation solar PV panels were collected.

Third, market participant information for energy consumer and prosumer was collected. The optimal trading price of electricity was derived based on the energy prosumer's monthly electricity usage and self-use rate as well as the energy consumer's monthly electricity usage and purchase rate of surplus electricity. As such, these data were collected. According to the acceptance distribution by grade of progressive tariff in residential sector provided by KEPCO, about 92.5 percent of households have a monthly electricity usage of less than 500kWh (refer to table 7). Therefore, in this study, a scenario was established by setting monthly electricity usage of energy prosumers and consumers to a maximum of 600 kWh (interval: 50kWh) and self-use rate and electricity purchase rate in units of 10%.

2.2 Step 2: Estimation of Electricity Generation by the RETScreen Software

Based on the regional factors and solar PV panel information mentioned in section 2.1, the electricity generation of the solar PV panel was predicted using the RETScreen. RETScreen is a program developed by CanmetENERGY Research Laboratory in Canada and is frequently used in various research to estimate the electricity generation of the solar PV panel [25,32–35]. Thus, RETScreen was used in this study to predict the total electricity generation of the solar PV panel. Towards this end, the assumptions below were established (refer to Table S1).

- *Regional factors*: Identical solar PV panels may have different amount of electricity generation by region [25]. Thus, this study targeted all the seven metropolitan cities in South Korea, Seoul, Incheon, Daejeon, Daegu, Ulsan, Busan, and Gwangju, which are most highly populated cities, for the analysis [36].
- *Meteorological and geographical factors*: The data of each region provided by RETScreen was used as the input data on meteorological and geographical factors in this study.
- *Building type*: The Ministry of Trade, Industry, and Energy (MOTIE) in South Korea calls for new/renewable energy distribution projects each year, with different government incentives given by target building type [37]. Generally, the target building types are

residential, commercial, and industrial buildings.

- *Installation purpose*: According to the announcement of the new/renewable energy distribution project, different government incentives are offered depending on the installation purpose of the solar PV panel [37]. To receive the government incentives, the electricity generated from the solar PV panel in a residential building should be first used to supply its energy usage and trade surplus electricity after self-use; that is the government encourages self-use of the electricity generated by the solar PV panel by offering various financial support and incentives.
- *Orientation*: This study assumed that the solar PV panel would face south, which would generate the highest amount of electricity. Thus, the orientation of the solar PV panel in RETScreen was set to south (0° in the RETScreen).
- *Solar tracking mode and tilt angle*: As this study targeted the solar PV panel installed on the building rooftops, the solar tracking mode was set to “fixed.” The fixed tilt angle was set to at which would generate the highest amount of electricity from the solar PV panel [38,39].
- *Solar PV panel and inverter capacity*: The condition for receiving government incentives from the new/renewable energy distribution project in South Korea is that the solar PV panel installed capacity per household should be below 3 kW [37].
- *Degradation rate*: According to the previous studies and solar PV panel manufacturers, the performance warranty period (i.e., service life) of solar PV panels is generally 25 years, during which its efficiency decreases by approximately 20% [40–42].

2.3 Step 3: Economic Assessment for calculating the LCOE

This study derived the levelized cost of electricity (LCOE) of the solar PV panel to determine the minimum trading price of electricity that can guarantee profit for the energy prosumers. Also called “levelized cost of energy” or “levelized energy cost”, LCOE is derived by dividing all the costs incurred during the life cycle of the solar PV panel by the total electricity generation of the panel (see Eq. (1)) [43–46]. Thus, for the calculation of LCOE, both the total life cycle cost and the total electricity generation of the solar PV panel must be determined (refer to Eq. (1)).

$$LCOE = \frac{Total\ life\ cycle\ cost}{Total\ electricity\ generation} = \frac{IC + \sum_{y=1}^{Y} \frac{O\&M_y + RC_y}{(1+dr)^y}}{\sum_{y=1}^{Y} \frac{EG_y \times (1-d)^y}{(1+dr)^y}} \quad (1)$$

where *IC* stands for the investment cost, $O\&M_y$ for the operation and maintenance cost in year *y*, RC_y for the replacement cost in year *y*, EG_y stands for the annual electricity generation of the solar PV panel in year *y*, *y* for the service life of the solar PV panel, *d* for the annual degradation rate of the solar PV panel, and *dr* for the real discount rate.

The total life cycle cost includes all the costs to be incurred for the installation, operation, and maintenance of the solar PV panel, such as the investment cost (IC), operation and maintenance cost (O&M), and replacement cost (RC), and as it refers to all the expenses during the entire life cycle of the panel, it should consider the panel’s service life and the real discount rate (refer to Eq. (1)). Additionally, the following main assumptions were established in this study to determine the total LCC of the solar PV panel (refer to Table 1). Solar PV system's life cycle electricity generation was estimated through RETScreen software based on the assumptions set in chapter 2.2.

Table 1. Main assumptions for life cycle cost analysis

Category		Description
Analysis period		25 years from 2020 [40–42]
Significant cost of ownership	Solar PV panel price	US$895.6/kW [47]
	Solar PV panel price with incentive	US$424.2/kW [37]
	Operation and maintenance cost	1% of the investment cost per year [40,41,45]
	Replacement cost	9.5% of the investment cost every 13 years [40,41,45]
Real discount rate	Inflation rate	0.8% [48]
	Electricity price increase rate	3.06% [49]

Note: The exchange rate (KRW/US$) is KRW 1188.00 to a US$ (as of 30 Jan. 2020).

This study aimed to apply LCOE in cases without government incentives while considering that the incentives offered by MOTIE are decreasing every year [37], and considering the uncertainty of sustainable financial support in the future. As a result, the LCOE of the 3kW-capacity solar PV panel can be derived using Eq. (1) (refer to Table 2).

Table 2. Levelized cost of electricity by region

Region	LCOE (US$/kWh)	
	Without incentive	With incentive
Seoul	0.047	0.025
Incheon	0.036	0.019
Daejeon	0.037	0.019
Daegu	0.031	0.016
Ulsan	0.038	0.020
Busan	0.044	0.023
Gwangju	0.038	0.020

Note: The exchange rate (KRW/US$) is KRW 1188.00 to a US$ (as of 30 Jan. 2020).

2.4 Step 4: Determination of the Maximum and Minimum Trading Prices of Electricity

This study determined the threshold trading price of electricity that could guarantee the profits for both the market participants to ultimately determine the optimal trading price of electricity. To this end, the P2P electricity trading market was designed to reflect the relevant pilot study and electricity bill system in South Korea, and the conditions for market participation were determined through comparison with net-metering, the only way to obtain profits through surplus electricity. First, the energy prosumers will sell their surplus electricity via P2P electricity trading if they can acquire higher profits from it than from selling their surplus electricity through the existing electricity selling mechanism. Thus, energy prosumers will opt for P2P electricity trading if the profit that they will obtain from selling their surplus electricity via net metering is lower than the profit that they will obtain via P2P electricity trading, which can be expressed as Eq. (2). The left and right sides of Eq. (2) represent the profit when the energy prosumer sells surplus electricity through P2P electricity trading and net-metering, respectively. $CE(P_1)$ is the electricity bill charged for electricity usage by households without a solar PV system installed. Based on this, in the case of P2P electricity trading, the profit that energy prosumers can obtain through P2P electricity trading can be calculated by subtracting the charge for electricity purchased from KEPCO ($CE(P_2)$) and adding the multiplication of sold surplus electricity ($MEG\text{-}P_3$) and electricity trading price (TP_{min}) (refer to left side of Eq. (2)). In the case of net metering, the electricity sent back to KEPCO is subtracted by the electricity usage of the energy prosumer. In other words, net metering profit can be calculated by subtracting the electricity bill for the amount of electricity excluding surplus electricity ($MEG\text{-}P_3$) from the amount of electricity purchased by the energy prosumer from KEPCO (P_2) (refer to right side of Eq. (2)). Eq. (2) can be then transformed into Eq. (3) to derive the minimum trading price of electricity. The higher value between the LCOE resulting from Eq. (1) and the trading price resulting from Eq. (3) will be determined as the minimum trading price of electricity for the energy prosumer (refer to table 3).

$$CE(P_1) - CE(P_2) + TP_{min} \times (MEG - P_3) \geq CE(P_1) - CE(P_2 - (MEG - P_3)) \tag{2}$$

$$TP_{min} \geq \frac{CE(P_2) - CE(P_2 - (MEG - P_3)}{(MEG - P_3)} \tag{3}$$

where $CE(a)$ stands for the costs of electricity for electricity usage a, P_1 for the energy prosumer's total monthly electricity usage , P_2 for the energy prosumer's monthly electricity usage besides the self-used electricity, P_3 for the energy prosumer's self-used electricity, TP_{min}

for the minimum trading price of electricity, and *MEG* for the monthly electricity generation.

Second, the structure of electricity market in South Korea shows that the affiliate company established by KEPCO produces electricity, which is purchased by KEPCO, who then sells it to the energy consumers [15]. In other words, the energy consumers in South Korea can purchase electricity only from KEPCO. Thus, this study determined the maximum trading price of electricity from the energy consumers' view by comparing the cost of purchasing all their electricity from KEPCO with that of purchasing some electricity from the energy prosumers. As a result, the energy consumers will engage in P2P electricity trading only if their costs of electricity from the purchase of all their electricity from KEPCO is higher than that from the purchase of electricity from both the KEPCO and P2P electricity trading, which can be expressed as Eq. (4). Eq. (4) can be transformed into Eq. (5) to derive the maximum trading price of electricity (refer to table 4).

$$CE(C_1 - EP) + TP_{max} \times EP \leq CE(C_1) \tag{4}$$

$$TP_{max} \leq \frac{CE(C_1) - CE(C_1 - EP)}{EP} \tag{5}$$

where $CE(a)$ stands for the costs of electricity for electricity usage a, C_1 for the energy consumer's total monthly electricity usage, EP for the amount of electricity purchased, and TP_{max} for the maximum trading price of electricity.

Table 3. The calculation result of the minimum trading price of electricity for energy prosumer

MEU_P[a]	SUR_P[b]	Minimum trading prices of electricity (US$/kWh)											
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
50 kWh	10%	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	20%	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	30%	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	40%	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	50%	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	60%	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	70%	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	80%	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	90%	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
…		…		…		…		…		…		…	
150 kWh	10%	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	20%	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	30%	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	40%	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	50%	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	60%	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	70%	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	80%	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	90%	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
…		…		…		…		…		…		…	
250 kWh	10%	0.10	0.09	0.07	0.07	0.07	0.08	0.09	0.08	0.08	0.08	0.11	0.11
	20%	0.07	0.06	0.05	0.05	0.05	0.05	0.07	0.06	0.06	0.05	0.07	0.08
	30%	0.06	0.05	0.05	0.05	0.05	0.05	0.07	0.06	0.05	0.05	0.07	0.08
	40%	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.07	0.08
	50%	0.06	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.06	0.07
	60%	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.07
	70%	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06
	80%	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	90%	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	-[c]
…		…		…		…		…		…		…	
350 kWh	10%	0.16	0.15	0.13	0.12	0.11	0.14	0.12	0.11	0.14	0.14	0.16	0.17
	20%	0.15	0.14	0.12	0.11	0.11	0.13	0.11	0.11	0.14	0.13	0.16	0.16
	30%	0.15	0.14	0.11	0.10	0.10	0.12	0.11	0.11	0.13	0.13	0.15	0.16
	40%	0.14	0.12	0.10	0.09	0.09	0.11	0.12	0.12	0.12	0.12	0.14	0.15
	50%	0.09	0.09	0.07	0.06	0.06	0.08	0.09	0.09	0.09	0.08	0.09	0.09
	60%	0.09	0.09	0.06	0.05	0.05	0.08	0.09	0.09	0.09	0.08	0.09	0.09
	70%	0.09	0.09	0.05	0.05	0.05	0.07	0.09	0.09	0.09	0.08	-	-
	80%	-	0.09	0.05	0.05	0.05	0.06	-	0.09	0.09	0.07	-	-
	90%	-	-	0.05	0.05	0.05	0.05	-	-	-	-	-	-
…		…		…		…		…		…		…	
450 kWh	10%	0.23	0.21	0.19	0.18	0.18	0.19	0.16	0.15	0.20	0.20	0.21	0.21
	20%	0.20	0.18	0.16	0.16	0.16	0.17	0.15	0.14	0.18	0.17	0.18	0.18
	30%	0.21	0.18	0.16	0.15	0.15	0.17	0.14	0.13	0.18	0.17	0.18	0.18
	40%	0.23	0.19	0.15	0.15	0.14	0.17	0.14	0.13	0.18	0.17	0.18	0.18
	50%	0.31	0.19	0.15	0.14	0.13	0.16	0.23	0.15	0.18	0.16	0.18	-
	60%	-	0.09	0.09	0.09	0.09	0.09	-	0.09	0.09	0.09	-	-
	70%	-	-	0.09	0.09	0.09	0.09	-	-	-	-	-	-
	80%	-	-	-	0.09	0.09	-	-	-	-	-	-	-
	90%	-	-	-	-	-	-	-	-	-	-	-	-
…		…		…		…		…		…		…	
550 kWh	10%	0.25	0.24	0.23	0.23	0.23	0.23	0.18	0.17	0.24	0.23	0.25	0.26
	20%	0.24	0.23	0.22	0.22	0.22	0.22	0.18	0.17	0.23	0.22	0.25	0.26
	30%	0.18	0.18	0.18	0.19	0.19	0.18	0.18	0.16	0.18	0.18	0.18	0.18
	40%	0.18	0.18	0.18	0.20	0.19	0.18	0.19	0.14	0.18	0.18	0.18	0.18
	50%	-	0.18	0.18	0.21	0.20	0.18	-	0.09	0.18	0.18	-	-
	60%	-	-	0.18	0.25	0.23	-	-	-	-	-	-	-
	70%	-	-	-	-	-	-	-	-	-	-	-	-
	80%	-	-	-	-	-	-	-	-	-	-	-	-
	90%	-	-	-	-	-	-	-	-	-	-	-	-

Note: The exchange rate (KRW/US$) is KRW 1188.00 to a US$ (as of 30 Jan. 2020). [a]Monthly electricity usage of the energy prosumer. [b]Self-use rate of the energy prosumer. [c]Impossible to trade due to insufficient electricity generation of energy prosumer.

Table 4. The calculation result of the maximum trading price of electricity for energy consumer

MEUc[a]	EPRc[b]	Maximum trading prices of electricity (US$/kWh)	
		General season	Summer season
50 kWh	10%	0.09	0.09
	20%	0.05	0.05
	30%	0.04	0.04
	40%	0.03	0.03
	50%	0.02	0.02
	60%	0.02	0.02
	70%	0.01	0.01
	80%	0.01	0.01
	90%	0.01	0.01
…		…	…
150 kWh	10%	0.09	0.09
	20%	0.09	0.09
	30%	0.09	0.09
	40%	0.09	0.09
	50%	0.09	0.09
	60%	0.09	0.09
	70%	0.09	0.09
	80%	0.08	0.08
	90%	0.07	0.07
…		…	…
250 kWh	10%	0.18	0.09
	20%	0.27	0.17
	30%	0.21	0.14
	40%	0.18	0.13
	50%	0.16	0.12
	60%	0.15	0.11
	70%	0.14	0.11
	80%	0.13	0.11
	90%	0.12	0.10
…		…	…
350 kWh	10%	0.18	0.18
	20%	0.18	0.16
	30%	0.18	0.14
	40%	0.18	0.13
	50%	0.19	0.14
	60%	0.17	0.13
	70%	0.16	0.13
	80%	0.15	0.12
	90%	0.14	0.11
…		…	…
450 kWh	10%	0.27	0.18
	20%	0.29	0.18
	30%	0.25	0.18
	40%	0.23	0.17
	50%	0.22	0.15
	60%	0.23	0.16
	70%	0.21	0.15
	80%	0.19	0.14
	90%	0.18	0.13
…		…	…
550 kWh	10%	0.27	0.36
	20%	0.27	0.27
	30%	0.29	0.24
	40%	0.26	0.22
	50%	0.25	0.21
	60%	0.24	0.19
	70%	0.23	0.18
	80%	0.21	0.17
	90%	0.20	0.16

Note: The exchange rate (KRW/US$) is KRW 1188.00 to a US$ (as of 30 Jan. 2020). [a]Monthly electricity usage of the energy consumer. [b]Self-use rate of the energy consumer.

2.5 Step 5: Determination of the Optimal Trading Price of Electricity

Based on the maximum and minimum trading prices of electricity derived from section 2.4, this study determined the optimal trading price of electricity between the energy prosumer and consumer participating in the P2P electricity trading market. Towards this end, this study defined the optimal trading price of electricity as the trading price at which both the market participants, energy prosumer and consumer, can obtain the highest profit through P2P electricity trading. In the P2P electricity trading market designed in this study, however, when one's profit increases, the other's profit decreases, because the profits of the energy prosumer and consumer have a trade-off relationship. Accordingly, it is important to establish an optimal trading price of electricity by balancing the profits between the two market participants. To consider this trade-off relationship between the profits of the energy prosumer and consumer, this study used the concepts of generic algorithm (GA) and Pareto optimality [50–53]. To apply the concept of GA and Pareto optimality, the model for determining the optimal trading price of electricity consists of the following three steps: (i) hyperplane: the Pareto optimal solution involves the definition of the minimum extreme point (Z^-) and the maximum extreme point (Z^+) (refer to Eqs. (S1) and (S2), respectively); (ii) standardization: all the optimization objectives are converted into the standardized value between 0 and 1 (refer to Eqs. (S7) and (S8)); and (iii) fitness function: the fitness function for optimization is defined by using the weighted Euclidean distance (refer to Eqs. (8) and (S9)) [50].

To solve the aforementioned optimization problem, this study determined two optimization objectives: (i) maximizing the energy prosumer's profit, represented by profits from selling his/her surplus electricity (Objective A); (ii) maximizing the energy consumer's profit, represented by savings in electricity costs from purchasing the surplus electricity (Objective B) (refer to Table 5). Objective A stands for profits from selling the surplus electricity and can be obtained by the difference between the left and right sides of Eq. (2)

(refer to Eq. (6)). Objective B stands for savings in electricity costs from purchasing the surplus electricity and can be obtained by the difference between the left and right sides of Eq. (4) (refer to Eq. (7)). In both the objectives A and B, the trading price of electricity (TP) is the optimization variable, while other variables stay the same per scenario. The objectives A and B are calculated based on the monthly electricity usage, as South Korea adopts their electricity bill system on a monthly basis. It has been also assumed that 1,296 cases for energy prosumers and 216 cases for energy consumers are on the market based on the scenarios established in Step 1.

$$Objective\ A = -CE(P_2) + TP \times (MEG - P_3) + CE\big(P_2 - (MEG - P_3)\big) \quad (6)$$

$$Objective\ B = CE(C_1 - EP) + TP \times EP - EC(C_1) \quad (7)$$

where *CE(a)* stands for the costs of electricity for electricity usage a, P_2 for the energy prosumer's monthly electricity usage besides the self-used electricity, P_3 for the energy prosumer's self-used electricity, *MEG* for the monthly electricity generation, C_1 for the energy consumer's total monthly electricity usage, *EP* for the amount of electricity purchased, and TP for the trading price of electricity.

Table 5. Optimization objectives and goals

Classification	Perspectives	Optimization objectives	Optimization goals
Objective A	Energy prosumer	Profits from selling the surplus electricity	Maximization
Objective B	Energy consumer	Savings in electricity costs from purchasing the surplus electricity	Maximization

By standardizing the values of objectives A and B, represented by S_A and S_B, respectively, the fitness function can be defined as shown in Eq. (8). Here, if the standardized value, S_A and S_B, are maximized and become close to 1, it can be said that the trading price of electricity would benefit each of the market participants. When the result of the fitness function derived through Eq. (8) reaches the minimum value, it is determined that the pareto optimal solution is found, and the value of TP at this point becomes the optimal trading price of electricity.

$$Fitness\ function = \sqrt{W_A(1 - S_A)^2 + W_B(1 - S_B)^2} \quad (8)$$

where S_A and S_B stand for the standardization values of optimization objectives A and B, respectively, and W_A and W_B for the weight factors of optimization objectives A and B.

Meanwhile, this study determined the optimal solution by using GA, one of the most widely-used optimization techniques. Generally, GA requires three operators (selection, crossover, and mutation) to find the optimal solution group, which was realized in this study by using the Python v3.7.2 software [54].

The range of optimal trading price of electricity was limited between the maximum and minimum trading price of electricity calculated in step 4. This is because the purpose of determining the optimal trading price of electricity in this study is to maximize the profits of both the energy consumer and prosumer, not just to maximize the profits of only one of the participants. That is, through the optimal trading price of electricity determined in this study, energy consumers and prosumers can be motivated to participate in the P2P electricity trading market.

2.6 Systemization of the Calculation Model Using Microsoft Excel-based Visual Basic for Applications (VBA)

It is difficult, for a non-expert (building owner, building manager, residents, etc.) to estimate the electricity generation of the solar PV panel and to evaluate its commercial feasibility by analyzing its economic performance in the preliminary planning stage without experts. To solve this issue, it is important to develop a simplified model with an easy-to-operate, simple graphical user interface (GUI) that can be easily used by non-experts. Thus, this study developed a business feasibility evaluation model for P2P electricity trading using Microsoft Excel-based VBA. The developed model consists of five steps, and Figs. 1-5 show the Microsoft Excel-based GUI of the business feasibility evaluation model for P2P electricity trading.

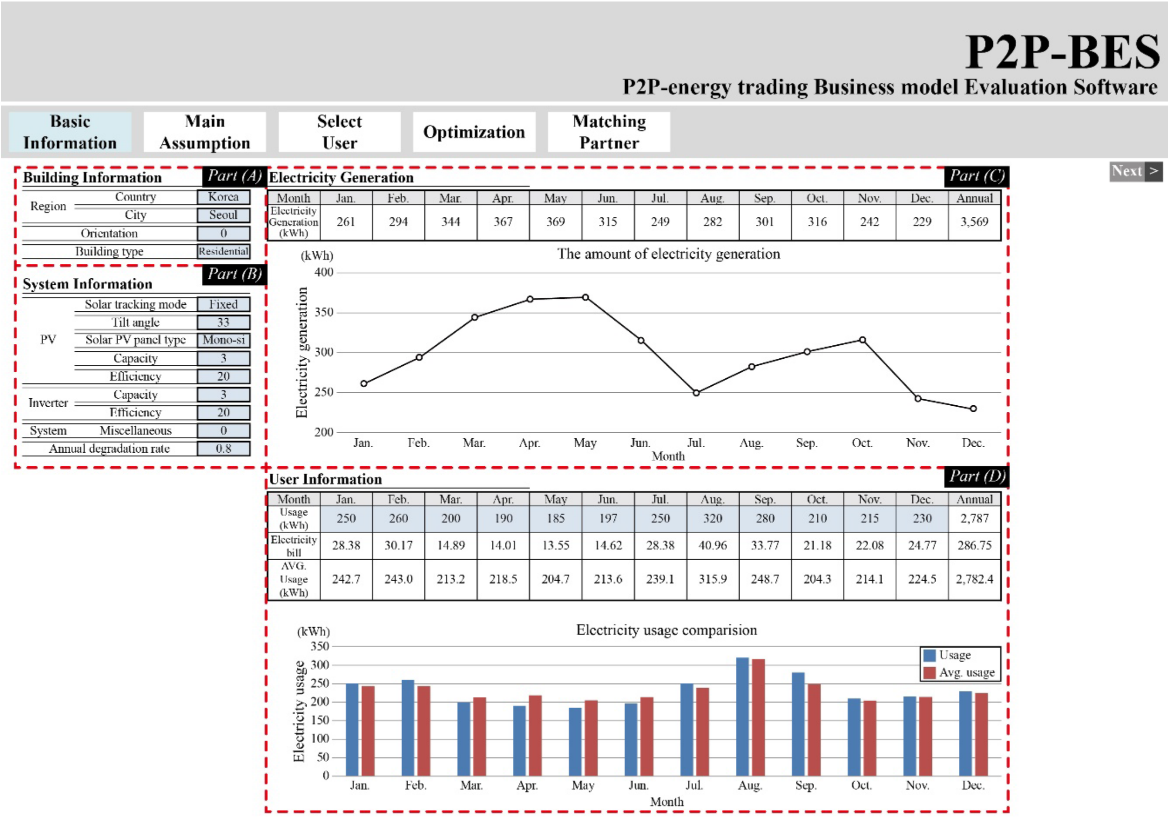

Figure 1. GUI of P2P energy trading business model evaluation software (Part (A) - (D))

- *Part (A) (refer to Fig. 1)*: The market participants can enter the regional factors of the target building and the orientation and building type of the solar PV panel. One of the seven metropolitan cities in South Korea can be selected for the regional factors of the building, and the orientation of the solar PV panel can be selected from among 0° (south), 90° (east), 180° (north), and 270° (west) up to 359°. For the building type, the residential, commercial, or industrial type can be selected.

- *Part (B) (refer to Fig. 1)*: The market participants' solar PV panel information can be entered. The solar PV panel's solar tracking type can be set to one of fixed, 1-axis tracking, 2-axis tracking, and azimuth. For the tilt angle of the solar PV panel, the automatically calculated tilt angle at which the electricity generation is at its maximum is used. For the type of solar PV panel, either the 1st-generation solar panel or the 2nd-generation solar panel can be selected. For the capacity of the solar PV panel, any value up to 3 kW, the maximum capacity for receiving incentives from the current new/renewable energy project, can be entered.

- *Part (C) (refer to Fig. 1)*: Based on the information from Part (A) or (B), electricity generation of the solar PV panel is automatically calculated through RETScreen.
- *Part (D) (refer to Fig. 1)*: The market participants' monthly electricity usage can be entered, based on which the annual costs of electricity can be calculated and compared with the average monthly electricity usage in the region.

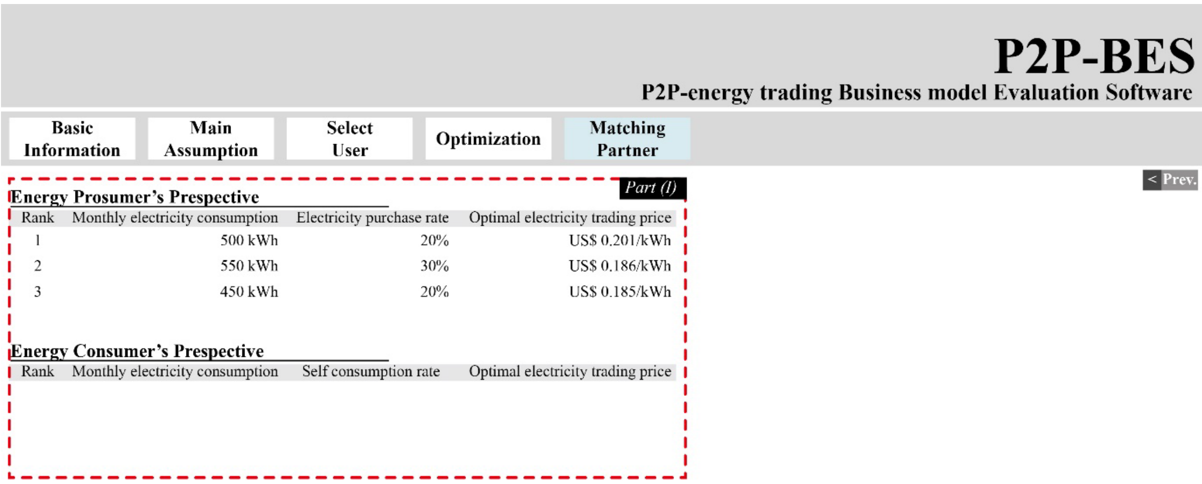

Figure 2. GUI of P2P energy trading business model evaluation software (Part (I))

- *Part (I) (refer to Fig. 2)*: The optimal trading partner is determined based on the optimal trading price of electricity derived from Part (G). Here, the optimal trading partner refers to a partner that can obtain the maximum profit in P2P electricity trading by comparing it with the minimum and maximum trading price database based on user information entered in parts (A) and (B). If "energy prosumer" is selected in Part (F), the electricity trading partner is listed by the order of the highest optimal trading price of electricity, and if "energy consumer" is selected, it is listed by the order of the lowest optimal trading price of electricity. For example, an energy prosumer whose monthly electricity usage is 185 kWh in May can get the most profit when it deals with an energy consumer whose monthly electricity usage is 500 kWh and electricity purchase rate is 20%. The estimated optimal trading price of electricity at this case is US$0.201/kWh.

3. MODEL APPLICATION

Using the business feasibility evaluation model developed in this study, a model application was performed to verify its applicability and to estimate the profits that energy consumers and prosumers can obtain when P2P electricity trading is introduced in South Korea. As described in Step 2, the amount of electricity generated from solar PV panels varies depending on the region. Therefore, regional factors, orientation, and building type were determined for the model application as follows.

- *Regional factors:* The electricity generation of the solar PV panel is determined by the DSR, which is affected by the building's latitude, longitude, and elevation [25,55]. Thus, this study targeted Seoul, Incheon, Daejeon, Daegu, Ulsan, Busan, and Gwangju, the seven metropolitan cities in South Korea.
- *Orientation:* As South Korea is located in the northern hemisphere, the electricity generation is highest with the solar PV panel facing south. Thus, this study assumed that the solar PV panel was installed toward the south.
- *Building type:* In South Korea, residential building is the only building type with a progressive tariff, and as the resident's electricity usage increases, the costs of electricity increases exponentially [15]. Therefore, if P2P electricity trading is come into effect, the

potential profit from the reduction of the progressive tariff will be significant. Thus, this study selected residential building as the building type.

In this study, the design parameters of the solar PV panel for the model application were defined as shown below.

- *Tracking option:* Generally, the solar PV panel on the of a building is fixed; thus, the tracking option was set to fixed.
- *Tilt angle:* The optimal tilt angle of the solar PV panel differs by region; thus, the angle at which the electricity generation of the solar PV panel is at its maximum was set to the optimal tilt angle (32-39° by region).
- *Solar PV panel type:* The 1^{st}-generation solar PV panel market in South Korea has grown significantly due to the government incentives and the decrease in the unit price of the solar PV panel, whereas the 2^{nd}-generation solar PV panel was not commercialized due to its low efficiency, instability, and higher price range [56]. Thus, this study used the mono-si solar PV panel from among the 1^{st}-generation solar PV panels, which offers high efficiency per area and a relatively lower price.
- *Solar PV panel capacity:* Based on the incentive support criteria for residential solar PV panels in South Korea, a 3kW-capacity solar PV panel is usually installed, but if the monthly electricity usage of the household is 600 kWh or over, and up-to-6kW-capacity solar PV panel can be installed [47]. According to the KEPCO's statistics, however, only 1.1% of the households in South Korea have monthly electricity usage of 600 kWh or over [15]. Thus, this study used 3 kW as the capacity of the solar PV panel.

4. RESULTS AND DISCUSSION

4.1 Estimation Results of Electricity Generation from the Solar PV Panel

The annual electricity generation of the solar PV panel was estimated based on the seven target metropolitan cities in South Korea. Daegu showed the highest electricity generation (i.e., 5,541 kWh), whereas Seoul showed the lowest (i.e., 3,569 kWh) (refer to Table 6).

Also, the electricity generation was generally higher in spring (i.e., March-May) than in summer or winter. As has been discussed, the differences in the regional factors (i.e., meteorological and geographical factors) affect the electricity generation of the solar PV panel. South Korea, in particular, has hot and humid climate characteristics in summer due to the southeastern monsoons, a low DSR due to the rainy season, and a large amount of clouds. In winter, the northwestern monsoons result in cold and dry weather, with Taebaek Mountains, which run northwest, causing different weather characteristics between the east and the west.

Table 6. Standard database of electricity generation

Region			Seoul	Incheon	Daejeon	Daegu	Ulsan	Busan	Gwangju
Tilt angle			33°	37°	36°	39°	34°	33°	32°
Electricity generation (kWh)	Winter	Jan.	256	422	410	618	400	303	318
		Feb.	290	411	406	514	374	303	359
	Spring	Mar.	344	463	451	501	414	344	437
		Apr.	370	447	446	459	432	371	444
		May	374	425	425	438	427	378	426
	Summer	June	320	360	353	382	361	325	368
		July	253	314	309	368	327	303	355
		Aug.	284	353	326	386	336	332	384
	Fall	Sep.	302	360	336	417	313	290	364
		Oct.	314	387	378	461	369	333	385
		Nov.	238	347	347	454	343	300	315
	Winter	Dec.	224	378	382	543	378	301	296
	Total		3,568	4,667	4,570	5,541	4,473	3,884	4,451

4.2 Determination of the Optimal Trading Price of Electricity and Estimation of the Maximum Profit by Region

According to the KEPCO's progressive tariff by household, the households whose monthly electricity usage is between 201-300 kWh have the largest percentage (30.3%), followed by the households with an monthly electricity usage of 301-400 kWh (22.6%) (refer to Table 7). If the monthly electricity usage, however, is between 201 and 300 kWh, the monthly electricity usage is low, and the profit from the solar PV panel will be insignificant. On the other hand, if the monthly electricity usage is between 301 and 400 kWh, the electricity usage (34.7%) and the costs of electricity (36.6%) will be highest in all the zones. Thus, this study selected the energy prosumers whose monthly electricity usage is 350 kWh as the target market participants for deriving the monthly optimal trading price of electricity and the potential profit by region (refer to Table 8 and Table S3).

Table 7. Acceptance distribution by grade of progressive tariff

Grade of progressive tariff	Monthly electricity usage	No. of households		Electricity usage		Costs of electricity	
		Thousand (N)	%	Million (kWh)	%	Million (US$)	%
1	≤100	4,364	18.8	182	3.5	13.7	2.5
	101-200	5,232	22.6	798	15.5	57.9	10.8
2	201-300	7,009	30.3	1,768	34.3	161.2	30.0
	301-400	5,247	22.6	1,792	34.7	196.5	36.6
3	401-500	1,047	2.4	457	8.8	67.7	12.6
	501-1000	262	1.1	153	3.0	37.0	6.9
Super user	1000<	8	0.1	11	0.2	3.45	0.6
Total		23,169	100	5,161	100	537.46	100

Note: The exchange rate (KRW/US$) is KRW 1188.00 to a US$ (as of 30 Jan. 2020).

Table 8. Monthly optimal trading price of electricity and estimated maximum profit by region

Region	Month	Energy prosumer		Energy consumer		Optimal trading price of electricity (US$/kWh)	Estimated maximum profit (US$)
		Monthly electricity usage	Self-use rate	Monthly electricity usage	Purchase rate of surplus electricity		
Seoul	Jan.	350 kWh	10%	550 kWh	30%	0.224	49.5
	Feb.		10%		30%	0.220	56.0
	Mar.		10%		30%	0.209	64.6
	Apr.		10%		30%	0.204	68.4
	May		10%		30%	0.204	69.0
	June		10%		30%	0.214	61.1
	July		40%		10%	0.240	27.2
	Aug.		40%		10%	0.237	34.1
	Sep.		10%		30%	0.218	58.3
	Oct.		10%		30%	0.216	60.2
	Nov.		10%		30%	0.227	46.1
	Dec.		10%		30%	0.230	43.4
	Subtotal						638.1

Note: The exchange rate (KRW/US$) is KRW 1188.00 to a US$ (as of 30 Jan. 2020).

First, the estimated annual maximum profit of the energy prosumer by region was highest in Daegu (i.e., US$995.5) and lowest in Seoul (i.e., US$638.1). This is because the higher the annual electricity generation of the solar PV panel is, the higher the surplus electricity available for sale. Despite the fact, however, that Daejeon has the third highest annual solar PV panel electricity generation, however, its estimated maximum profit was the fifth, lower than that of Ulsan or Gwangju, because 40% of the electricity therein is self-used, and there is lower surplus electricity compared to Ulsan and Gwangju.

Second, for the energy prosumer, lowering the self-use rate to the extent possible was shown to be advantageous to acquire the maximum profit. This is because the energy prosumer whose monthly electricity usage is 350 kWh belongs to the 2nd-grade of progressive tariff, and as such, the costs of electricity savings from self-use will be higher than the profit from selling surplus electricity.

Third, in the case where the energy prosumer whose monthly electricity usage was 350 kWh sold his/her surplus electricity, the monthly electricity usage of the energy consumer with the maximized profit was identical to 550 kWh, but the purchase rate of surplus electricity was 10% in summer (i.e., Jul. and Aug.) and 30% in the normal periods (i.e., Jan.-Jun. and Sep.-Dec.). This is because the 3rd-grade of progressive tariff is imposed from the monthly electricity usage of 400 kWh in the normal periods whereas in summer, it is imposed from the monthly electricity of 500 kWh.

5. CONCLUSION

This study aimed to develop a business feasibility evaluation model that assesses the business feasibility of engaging in P2P electricity trading from the perspectives of both the market participants, such as energy consumer and prosumer. Towards this end, the electricity generation of the solar PV panel was predicted, LCC analysis was performed, and the scope of the trading prices of electricity at which the market participants could guarantee the profit from P2P electricity trading was determined. At the same time, the optimal trading price of electricity which could maximize the profits for both the market participants within the scope of the maximum and minimum trading prices was determined, and based on the result, the estimated maximum profit that could be obtained by the energy prosumers from selling surplus electricity and energy consumer from purchasing surplus electricity were derived.

A case study of the developed business feasibility evaluation model was conducted on the residential buildings in the seven metropolitan cities in South Korea. Overall, the estimated maximum profit of the energy prosumer was affected by the electricity generation of the solar PV panel. Below are the main findings of this study.

- *Estimation of electricity generation*: The estimated annual electricity generation of the solar PV panel in the metropolitan cities in South Korea using the RETScreen software was highest in Daegu (i.e., 5,541 kWh) and lowest in Seoul (i.e., 3,569 kWh).
- *Optimal trading price of electricity and estimated maximum profit by region:* The estimated maximum profit of the energy prosumer by region was highest in Daegu (i.e., US$995.5) and lowest in Seoul (i.e., US$638.1). In addition, the region with a higher annual electricity generation from the solar PV panel generally has a higher estimated maximum profit that the energy prosumer can gain.

The specific calculation that was used in this study reflects the current situation of the South Korean electricity market, and as such, it is believed to be a localized model. In other words, for it to be used in other countries, the data on the electricity tariff system, the solar PV panel price, and the government incentives in the said country should be considered.

This study contributes to the academic and scientific society in terms of consideration of different market participants. Relevant existing research approaches, represented by an auction-based model and bilateral contract, have mainly aimed at maximizing the profits of energy prosumers. In this type of electricity market, however, if one side's profit is maximized, the other side's market participation motivation can become insufficient, making it difficult to facilitate the market. In this regard, the model developed in this study considers profits of both the energy prosumers and consumers, which makes it more realistic and reasonable than other models in terms of market applicability.

The business feasibility evaluation model developed in this study can be applied and used by various stakeholders, as follows: (i) The government can apply this model to evaluate the potential amount of solar electricity generation and establishing a target for spreading mid- to long-term distributed electricity generation; (ii) Energy prosumers and consumers can reduce energy consumption and energy bills through the optimal trading price of electricity derived through the business feasibility evaluation model; (iii) In the case of a business operator, it is possible to predict the profits that can be generated through the P2P electricity trading business, which can help to set an appropriate fee

The future research aims to derive the optimal trading price of electricity in the case of the actual enactment of P2P electricity trading that further reflects the reality. Here, it is believed that the energy consumers and prosumers, P2P electricity trading brokers, and KEPCO will participate in the market of P2P electricity trading, and other issues concerning P2P electricity trading (e.g., grid usage fees, trading fees, installation expenses, etc.) should also be considered. In addition, the physical effects on the electricity grid due to the diffusion of distributed generation and P2P electricity trading are also important issues. If these factors are considered, the optimal trading price of electricity derived in this study may change; thus, it is expected that the estimated maximum profit and estimated costs of electricity savings for the energy consumer and prosumer will decrease. In addition, according to the results of this study, it was found that it is advantageous for energy prosumers to reduce self-use electricity as much as possible. However, in terms of social interests, it is beneficial to increase the self-use rate of the energy prosumer to reduce the energy load on the centralized generation. Therefore, in future studies, the optimal trading price of electricity should be presented considering all market participants, not limited to energy consumers and prosumers, considering not only the monetary value (i.e., economic profit) considered in this study but also the non-monetary value (i.e., environmental profit, social profit).

ACKNOWLEDGEMENTS

This research was supported by a grant (20CTAP-C15188002) from Technology Advancement Research Program (TARP) funded by Ministry of Land, Infrastructure and Transport of Korean government.

REFERENCES

[1] Paris agreement, 2015.

[2] Ministry of Environment. The Paris agreement guideline. 2016.

[3] Ji C, Hong T, Park HS. Comparative analysis of decision-making methods for integrating cost and CO2 emission - Focus on building structural design - Focus o. Energy Build 2014;72:186–94. https://doi.org/10.1016/j.enbuild.2013.12.045.

[4] Budzianowski WM. Target for national carbon intensity of energy by 2050: A case study of Poland’s energy system. Energy 2012;46:575–81. https://doi.org/10.1016/j.energy.2012.07.051.

[5] Van den Broek M, Veenendaal P, Koutstaal P, Turkenburg W, Faaij A. Impact of international climate policies on CO2 capture and storage deployment. Illustrated in the Dutch energy system. Energy Policy 2011;39:2000–19. https://doi.org/10.1016/j.enpol.2011.01.036.

[6] Gambhir A, Napp TA, Emmott CJM, Anandarajah G. India's CO2 emissions pathways to 2050: Energy system, economic and fossil fuel impacts with and without carbon permit trading. Energy 2014;77:791–801. https://doi.org/10.1016/j.energy.2014.09.055.

[7] Alderson H, Cranston GR, Hammond GP. Carbon and environmental footprinting of low carbon UK electricity futures to 2050. Energy 2012;48:96–107. https://doi.org/10.1016/j.energy.2012.04.011.

[8] Wang N, Chang YC. The evolution of low-carbon development strategies in China. Energy 2014;68:61–70. https://doi.org/10.1016/j.energy.2014.01.060.

[9] Dedinec A, Markovska N, Taseska V, Kanevce G, Bosevski T, Pop-Jordanov J. The potential of renewable energy sources for greenhouse gases emissions reduction in Macedonia. Therm Sci 2012;16:717–28. https://doi.org/10.2298/TSCI120202128D.

[10] Anandarajah G, Strachan N. Interactions and implications of renewable and climate change policy on UK energy scenarios. Energy Policy 2010;38:6724–35. https://doi.org/10.1016/j.enpol.2010.06.042.

[11] Ćosić B, Markovska N, Krajačić G, Taseska V, Duić N. Environmental and economic aspects of higher RES penetration into Macedonian power system. Appl Therm Eng 2012;43:158–62. https://doi.org/10.1016/j.applthermaleng.2011.10.042.

[12] Lee M, Hong T, Jeong K, Kim J. A bottom-up approach for estimating the economic potential of the rooftop solar photovoltaic system considering the spatial and temporal diversity. Appl Energy 2018;232:640–56. https://doi.org/10.1016/j.apenergy.2018.09.176.

[13] Soun Y. Enhancement of energy storage system (ESS) use cases and institutions in the energy prosumer market. 2017.

[14] Liu T, Tan X, Sun B, Wu Y, Guan X, Tsang DHK. Energy management of cooperative

microgrids with P2P energy sharing in distribution networks. 2015 IEEE Int. Conf. Smart Grid Commun. SmartGridComm 2015, IEEE; 2016, p. 410–5. https://doi.org/10.1109/SmartGridComm.2015.7436335.

[15] Korea Electric Power Corporation. http://home.kepco.co.kr/kepco/EN/main.do (accessed May 23, 2019).

[16] Lüth A, Zepter JM, Crespo del Granado P, Egging R. Local electricity market designs for peer-to-peer trading: The role of battery flexibility. Appl Energy 2018;229:1233–43. https://doi.org/10.1016/j.apenergy.2018.08.004.

[17] Lee Y su, Kim J hyo. Study on the improvement plan of energy prosumer activation. 2016.

[18] Yaagoubi N, Mouftah HT. A distributed game theoretic approach to energy trading in the smart grid. 2015 IEEE Electr Power Energy Conf Smarter Resilient Power Syst EPEC 2015 2016:203–8. https://doi.org/10.1109/EPEC.2015.7379950.

[19] Wang Y, Saad W, Han Z, Poor HV, Başar T. A game-theoretic approach to energy trading in the smart grid. IEEE Trans Smart Grid 2014;5:1439–50. https://doi.org/10.1109/TSG.2013.2284664.

[20] Long C, Wu J, Zhang C, Thomas L, Cheng M, Jenkins N. peer to peer energy trading in a community microgrid. 2017 IEEE Power Energy Soc Gen Meet 2017;2017:1–5.

[21] Morstyn T, Teytelboym A, McCulloch MD. Bilateral contract networks for peer-to-peer energy trading. IEEE Trans. Smart Grid, vol. 10, IEEE; 2019, p. 2026–35. https://doi.org/10.1109/TSG.2017.2786668.

[22] Lopes F, Rodrigues T, Sousa J. Negotiating bilateral contracts in a multi-agent electricity market: A case study. Proc. - Int. Work. Database Expert Syst. Appl. DEXA, IEEE; 2012, p. 326–30. https://doi.org/10.1109/DEXA.2012.77.

[23] Korea New & Renewable Energy Center. New & Renewable Energy Statics 2018

(2019 Edition). 2019.

[24] Korea Electric Power Corporation (KEPCO). The electricity price. http://home.kepco.co.kr/kepco/main.do (accessed May 30, 2018).

[25] Koo C, Hong T, Lee M, Park HS. Estimation of the Monthly Average Daily Solar Radiation using Geographic Information System and Advanced Case-Based Reasoning. Environ Sci Technol 2013;47:4829–39. https://doi.org/10.1021/es303774a.

[26] Green MA, Dunlop ED, Levi DH, Hohl-Ebinger J, Yoshita M, Ho-Baillie AWY. Solar cell efficiency tables (version 54). Prog Photovoltaics Res Appl 2019;27:565–75. https://doi.org/10.1002/pip.3171.

[27] Tripathy M, Sadhu PK, Panda SK. A critical review on building integrated photovoltaic products and their applications. Renew Sustain Energy Rev 2016;61:451–65. https://doi.org/10.1016/j.rser.2016.04.008.

[28] Renewable Power Generation Costs in 2017. 2018.

[29] Parida B, Iniyan S, Goic R. A review of solar photovoltaic technologies. Renew Sustain Energy Rev 2011;15:1625–36. https://doi.org/10.1016/j.rser.2010.11.032.

[30] Zhang X, Lau SK, Lau SSY, Zhao Y. Photovoltaic integrated shading devices (PVSDs): A review. Sol Energy 2018;170:947–68. https://doi.org/10.1016/j.solener.2018.05.067.

[31] Ibn-Mohammed T, Koh SCL, Reaney IM, Acquaye A, Schileo G, Mustapha KB, et al. Perovskite solar cells: An integrated hybrid lifecycle assessment and review in comparison with other photovoltaic technologies. Renew Sustain Energy Rev 2017;80:1321–44. https://doi.org/10.1016/j.rser.2017.05.095.

[32] Koo C, Hong T, Kim J, Kim H. An integrated multi-objective optimization model for establishing the low-carbon scenario 2020 to achieve the national carbon emissions reduction target for residential buildings. Renew Sustain Energy Rev 2015;49:410–25.

https://doi.org/10.1016/j.rser.2015.04.120.

[33] Lee M, Hong T, Koo C. An economic impact analysis of state solar incentives for improving financial performance of residential solar photovoltaic systems in the United States. Renew Sustain Energy Rev 2016;58:590–607. https://doi.org/10.1016/j.rser.2015.12.297.

[34] Mirzahosseini AH, Taheri T. Environmental, technical and financial feasibility study of solar power plants by RETScreen, according to the targeting of energy subsidies in Iran. Renew Sustain Energy Rev 2012;16:2806–11. https://doi.org/10.1016/j.rser.2012.01.066.

[35] Natural Resources Canada. RETScreen | Natural Resources Canada. https://www.nrcan.gc.ca/energy/software-tools/7465 (accessed May 23, 2019).

[36] Korean Statistical Information Service. http://kosis.kr/eng/ (accessed May 23, 2019).

[37] Korea New & Renewable Energy Center. https://www.knrec.or.kr/main/main.aspx (accessed May 23, 2019).

[38] Huang Y, Niu JL. Optimal building envelope design based on simulated performance: History, current status and new potentials. Energy Build 2016;117:387–98. https://doi.org/10.1016/j.enbuild.2015.09.025.

[39] Wong NH, Feriadi H, Tham KW, Sekhar C, Cheong KW. The impact of multi storey car parks on wind pressure distribution and air change rates of surrounding high rise residential buildings in singapore 2002;3:30–42.

[40] Burns JE, Kang JS. Comparative economic analysis of supporting policies for residential solar PV in the United States: Solar Renewable Energy Credit (SREC) potential. Energy Policy 2012;44:217–25. https://doi.org/10.1016/j.enpol.2012.01.045.

[41] Swift KD. A comparison of the cost and financial returns for solar photovoltaic systems installed by businesses in different locations across the United States. Renew

Energy 2013;57:137–43. https://doi.org/10.1016/j.renene.2013.01.011.

[42] Yingli Solar. http://www.yinglisolar.com/en/ (accessed May 23, 2019).

[43] Short W, Packey D, Holt T. A manual for the economic evaluation of energy efficiency and renewable energy technologies. Renew Energy 1995;95:73–81. https://doi.org/NREL/TP-462-5173.

[44] Darling SB, You F, Veselka T, Velosa A. Assumptions and the levelized cost of energy for photovoltaics. Energy Environ Sci 2011;4:3133–9. https://doi.org/10.1039/c0ee00698j.

[45] Branker K, Pathak MJM, Pearce JM. A review of solar photovoltaic levelized cost of electricity. Renew Sustain Energy Rev 2011;15:4470–82. https://doi.org/10.1016/j.rser.2011.07.104.

[46] Lai CS, McCulloch MD. Levelized cost of electricity for solar photovoltaic and electrical energy storage. Appl Energy 2017;190:191–203. https://doi.org/10.1016/j.apenergy.2016.12.153.

[47] HAEZOOM. https://www.haezoom.com/ (accessed May 24, 2019).

[48] The Bank of Korea Economic Statistics System. http://ecos.bok.or.kr/ (accessed May 23, 2019).

[49] Korea Power Statistics. http://epsis.kpx.or.kr/epsisnew/selectEkesKepChart.do?menuId=010100&locale=eng (accessed February 17, 2020).

[50] Koo C, Hong T, Kim S. An integrated multi-objective optimization model for solving the construction time-cost trade-off problem. J Civ Eng Manag 2015;21:323–33. https://doi.org/10.3846/13923730.2013.802733.

[51] Caramia M, Dell'Olmo P. Multi-objective management in freight logistics: increasing capacity. In Service Level and Safety with Optimization Algorithms. London: Springer

London; 2008.

[52] Konak A, Coit DW, Smith AE. Multi-objective optimization using genetic algorithms : A tutorial 2006;91:992–1007. https://doi.org/10.1016/j.ress.2005.11.018.

[53] Alabsi F, Naoum R. Fitness Function for Genetic Algorithm used in Intrusion Detection System Firas Alabsi 2012;2:129–34.

[54] Sheppard C. Genetic algorithms with python. 2017.

[55] Lee M, Koo C, Hong T, Park HS. Framework for the mapping of the monthly average daily solar radiation using an advanced case-based reasoning and a geostatistical technique. Environ Sci Technol 2014;48:4604–12. https://doi.org/10.1021/es405293u.

[56] Hoon J. Domestic and overseas PV technology development and market trend. 2016.