https://doi.org/10.1016/j.rser.2016.11.086

Establishment of a base price for the Solar Renewable Energy Credit (SREC) from the perspective of residents and state governments in the United States

Minhyun Lee [1], Taehoon Hong [2], Hyunji Yoo [3], Choongwan Koo [4], Jimin Kim [1], Kwangbok Jeong [1], Jaewook Jeong [1], and Changyoon Ji [5]*

[1] Ph.D. Candidate, Department of Architectural Engineering, Yonsei University, Seoul, 03722, Republic of Korea.

[2] Associate Professor, Department of Architectural Engineering, Yonsei University, Seoul, 03722, Republic of Korea (CORRESPONDING AUTHOR).

[3] Graduate Research Assistant, Department of Architectural Engineering, Yonsei University, Seoul, 03722, Republic of Korea.

[4] Visiting Scholar, Division of Construction Engineering and Management, Purdue University, West Lafayette, IN 47906 & Research Professor, Department of Architectural Engineering, Yonsei University, Seoul, 03722, Republic of Korea.

[5] Ph.D. and Postdoctoral Fellow, Department of Architectural Engineering, Yonsei University, 03722, Republic of Korea.

* 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

Solar Renewable Energy Certificates (SREC) in the United States (U.S.) have become an important driver for promoting the solar photovoltaic (PV) system. However, the SREC price volatility is considered the major barrier for installing the solar PV system due to the uncertainty of the revenue from selling the SREC. To address this challenge, this study aimed to establish a base price for SREC in order to encourage the installation of residential solar PV systems in the U.S. Toward this end, this study conducted the life cycle cost analysis to establish the minimum SREC prices required for reaching the target payback period of the residential solar PV system in the U.S. In addition, this study conducted the comparative analysis from the perspectives of residents and state governments by considering the SREC prices. This study was conducted in four steps: (i) target selection; (ii) data collection; (iii) defining assumptions; and (iv) establishing the minimum SREC prices. The results showed that Massachusetts and New Jersey are the most superior state from the perspective of both residents and state governments. This study can help both residents and state governments to get financial advice for installing solar PV system and improving the SREC-related policies.

Keywords: *Solar Photovoltaic (PV) Systems; Solar Renewable Energy Certificates (SREC); Solar Alternative Compliance Payments (SACP); Payback Period; Financial Analysis.*

1. Introduction

In order to cope with global warming and environment pollution, the world has exerted various efforts to reduce the greenhouse gas (GHG) emissions in the building sector [1-6]. One of the best solutions to reduce the GHG emissions in the building sector is to promote new renewable energies (NRE), and many countries have been established NRE targets as a part of their policy [7-12]. Accordingly, the European Union (EU) have set NRE target of 20% by 2020 [13]. Similarly, a presidential memorandum was issued directing the United States (U.S.) federal government to set NRE target of 20% by 2020 [14]. As a practical policy instrument to achieve such NRE targets, renewable portfolio standards (RPS) mandates electricity suppliers to produce a certain percentage of the electricity from the NRE system [15, 16]. Solar carve-out, which is a part of RPS, is a regulation that mandates electricity suppliers to meet a certain amount of NRE targets with solar energy. As the initial investment cost of the solar PV system is relatively higher than those of other NRE systems, the solar carve-out is being implemented to encourage the implementation of the solar PV system [17]. Electricity suppliers can comply with the solar carve-out by purchasing solar renewable energy certificates (SREC), which are issued to certify the electricity generation of the solar PV system. Electricity suppliers can buy the SREC from NRE generators, including commercial and residential generators, who actually generates electricity from the solar PV system and acquires the SREC [18]. Since SREC is issued separately, regardless of the profits from the sales of the electricity generated by the solar PV system, NRE generators can acquire additional profits through the transactions of SREC [19]. Therefore, such tradable mechanism of SREC is considered a key driver of the implementation of the solar PV system [16, 20].

However, due to its short history, the SREC market is unstable with price volatility in the U.S. [18, 21-23]. Started in 2009, the SREC market and the associated policies are still in the early stage of development, which makes it difficult to overcome the SREC price volatility. Basically, SREC prices depend on the supply and demand in the SREC market. Thus, when there is less demand for the SREC, SREC prices will fall, which makes it difficult for NRE generators to benefit from the sales of SREC. Although such operating principle can discourage the implementation of the solar PV system, there is lack of policy instrument to protect NRE generators from the SREC price volatility [16, 19].

Furthermore, the SREC price volatility makes it difficult to guarantee the economic feasibility of the solar PV system in terms of residents. Generally, residents decide to install the solar PV system in order to substitute the electricity used at home, and the additional profits from the sales of SREC can further promote such decision [19]. However, the SREC price volatility causes uncertainty of profits from the sales of SREC, discouraging the installation of the solar PV system. In SREC transactions, therefore, it is necessary either (i) to guarantee SREC floor price through regulation or (ii) to provide the minimum SREC price information to residents that can guarantee economic feasibility of the solar PV system. In this way, it is possible to reduce the risk related to the investment on solar PV systems, thus promoting the distribution of solar PV systems. Accordingly, this study aimed to establish a base price for SREC to provide a guidance of the SREC price for both residents and state governments in the U.S.

Regarding this issue, previous studies analyzed various aspects of the solar policies including the SREC. First, some studies assessed the impact of solar policies and incentives on the implementation and cost of the solar PV system [16, 24-34]. Shrimali and Jenner (2013) assessed the impact of solar policies on the implementation and cost of residential and commercial solar PV systems [26]. Cash incentives and property tax incentives played a significant impact on the cost of the residential solar PV system, but their effect on the cost of the commercial solar PV system was not clear. However, these previous studies did not consider SREC in assessing solar policies and incentives. Li and Yi (2014) analyzed the multilevel governance of solar development in the U.S. by considering the state and local solar PV policies [28]. The study showed that cities with local financial incentives demonstrated a higher number of installations of the solar PV system than those without them. Huijben et al. (2016) analyzed the impact of governmental support instruments on the growth of solar PV installation [34]. The results showed that available support instruments offer business opportunities to the solar company and green electricity certificates, serving similar purpose as SREC, have the most significant impact on the growth of the solar PV market.

Second, other studies conducted the financial analysis of the solar PV system considering the SREC [23, 35-41]. Burns and Kang (2012) conducted the financial analysis of solar policies in the U.S. by considering the SREC markets [23]. The results showed that New Jersey, Delaware, and Massachusetts had strong SREC markets and the SREC had stronger impacts on the solar PV market than the other policies. Swift (2013) analyzed and compared the costs and financial returns of the solar PV systems in four states of the U.S. [38]. Based on the solar radiation, incentives, and electricity price of each state, financial returns of the solar PV system were shown to differ considerably. But these previous studies did not consider SREC price volatility in the financial analysis of the solar PV system. Chapman et al. (2015) analyzed the impacts of residential solar PV policies in Australia within five criteria of installation, employment, market maturity, FIT settings, and environmental outcomes [41]. The results showed that the Australian government succeeded in meeting its goal regarding installation and environmental outcomes, but showed limited success in meeting its goal regarding industry development. Furthermore, it was showed that the Feed-in Tariff had more impacts on solar PV installation than the SREC.

Third, other studies estimated the future SREC price by considering the SREC price volatility [20, 42, 43]. Zeng et al. (2015) analyzed the optimal timing to buy back the solar system by considering Renewable Energy Certificates (REC) and Alternative Compliance Payment (ACP) [20]. The results showed that as the ACP value increases, the benefit from buyback option of solar system also increases under the optimal timing. While these previous studies did consider the SREC price volatility, they lacked in analyzing the economic feasibility of the solar PV system systematically. Coulon et al. (2015) developed the stochastic model to describe SREC price behavior of the SREC market in New Jersey [42]. The results showed that SREC prices could be sensitive to the market design and the behavior of market participants. Zhou and Bradley (2012) analyzed the relationships between various factors affecting the SREC price (e.g., the supply and demand of SREC, the cost of energy, and the state obligation policies) and estimated the SREC price using linear optimization method [43]. The results showed that when the SREC price volatility is high, solar markets and regulatory arrangements can have impacts on the benefit from trading the SREC.

Although many previous studies analyzed various aspects of the SREC and the other solar policies, there were several limitations as follows: (i) few studies have assessed the impact of solar policies and incentives by considering SREC; (ii) few studies have performed the financial analysis of the solar PV system by considering the SREC price volatility; (iii) few studies have analyzed the SREC price based on the systematic analysis on the economic feasibility of the solar PV system; and (iv) few studies have investigated SREC price and its market considering regional variation of SREC market and relevant regulations.

To address these challenges, this study aimed to establish a base price for SREC in order to encourage the implementation of residential solar photovoltaic systems in the U.S. Toward this end, this study conducted the life cycle cost (LCC) analysis to establish the minimum SREC prices required for reaching the target payback period of the residential solar PV system in the U.S. In addition, this study conducted the comparative analysis from the perspectives of residents and state governments by considering the SREC prices.

2. Solar Renewable Energy Certificate (SREC) Markets in the United States

2.1. Solar renewable energy certificates (SREC)

One of the best ways for electricity suppliers to meet solar carve-out requirements is to buy the SREC from the other NRE generators. SREC is a certificate issued when electricity is generated from the solar PV system, and one SREC is issued when 1MWh of electricity is generated [19].

As shown in Fig. 1, state governments with SREC program impose solar carve-out requirements on electricity suppliers by requiring a certain amount of SREC, and electricity suppliers comply with such requirements by retiring the assigned amount of SREC. However, if they fail to comply with the solar carve-out, they have to pay solar alternative compliance payment (SACP), a penalty of non-compliance [23].

There are two ways in which electricity suppliers comply with the solar carve-out through SREC: (i) electricity suppliers can be issued with SREC by directly installing the solar PV system; and (ii) electricity suppliers can purchase SREC which is issued by other NRE generators [22]. For electricity suppliers or NRE generators to be issued with SREC for the electricity generation from a solar PV system, solar PV system should be certified by the state regulatory agencies [19]. The SREC issued as such should be registered on the SREC tracking system in order to retire the SREC for the purpose of the compliance with the solar carve-out [22]. Although there are various SREC tracking systems, most of the states with SREC markets use the *PJM-GATS* (Pennsylvania-New Jersey-Maryland-Generation Attribute Tracking System) operated by PJM (which is a regional electric power transmission organization in 13 states and the District of Columbia) [44]. The *PJM-GATS* tracks the electricity generation of the qualified solar PV system, issues the SREC, and provides solar weighted average price [19].

2.2. Solar alternative compliance payment (SACP)

The ACP is a system that encourages electricity suppliers to comply with the RPS by levying penalties on them for the non-compliance. Therefore, the ACP not only promotes electricity suppliers to meet the RPS requirements but also functions as a price ceiling of the REC [18, 45, 46]. In particular, a penalty on non-compliance with the solar carve-out is called the SACP (refer to Fig. 1), and all states with SREC markets, except North Carolina, adopted the SACP [46]. The SACP functions as an incentive to promote the compliance with the solar carve-out and as a penalty on non-compliance with the solar carve-out. But if the SACP price is not reasonably determined, its function as the incentive and penalty becomes unsatisfactory. That is, if the SACP price is set too low, electricity suppliers find it more attractive to pay the SACP than to install a solar PV system, and therefore, it cannot work as a penalty. On the other hand, if the SACP price is set too high, electricity suppliers find it too burdensome to pay the SACP, and therefore, it cannot work as an incentive. Accordingly, states that have adopted the SACP restricted the maximum SREC price in the long term by establishing the SACP price schedules for 10 to 20 years in advance to guarantee the stability of the future SREC prices [20, 45].

3. Material and methods

This study aimed to establish a base price for SREC in order to encourage the implementation of residential solar PV systems in the U.S. Toward this end, this study established the minimum SREC prices required for reaching the target payback period of the residential solar PV system and conducted the comparative analysis from the perspectives of residents and state governments by considering the SREC prices. This study was conducted in four steps: (i) step 1: target selection; (ii) step 2: data collection; (iii) step 3: defining assumptions; and (iv) step 4: establishing the minimum SREC prices (refer to Fig. 2).

3.1. Step 1: Target selection

3.1.1. Target states and cities

In the U.S., nine states, the District of Columbia, Delaware, Illinois, Massachusetts, Maryland, North Carolina, New Jersey, Ohio, Pennsylvania, have the SREC program [47, 48]. Except for Illinois, the other eight states have their own SREC markets with different SREC traded prices [49]. Thus, this study selected eight states, except Illinois, as the target states.

Unlike SREC programs, which are run by state level, other solar incentives can vary by regions and cities within a state. Therefore this study selected the city with the largest population (a metropolitan city) in each state as the target city. Fig. 3 shows the selected target states and cities.

3.1.2. Target capital budgeting method

To determine a reasonable SREC price, it is necessary to set a goal that needs to be achieved through the sales of SREC. In order to do so, this study established the target capital budgeting method and its adequate level for determining the reasonable SREC price.

Among the various capital budgeting methods that analyze the economic performance of the solar PV system, net present value, profitability index, and payback period are some of the most widely used methods. Net present value is the difference between the present value of total system costs and total energy savings. Profitability index is the ratio of the present value of total energy savings to total system costs. Payback period is the time required to recover the initial investment cost [50, 51]. This study used the payback period, the financial index that residents consider the most important among various capital budgeting methods, as the target capital budgeting method [52, 53]. Payback period, usually expressed in years, is widely used in the decision making on investment of energy efficiency technologies and easy to understand the economic value of such investment.

According to [53], the payback period in which residents consider the installation of the solar PV system positively was between 7 and 10 years, but such duration can differ by the preferences of residents and state governments. Therefore, this study did not use a single target value for the payback period, but rather analyzed the minimum SREC prices for every year during the useful life of the solar PV system. In this way, residents and state governments can select the target payback period based on their preferences and can get the minimum SREC price information that can satisfy their preferences.

3.2. Step 2: Data collection

Data collection was conducted to establish the minimum SREC prices required for reaching the target payback period of the residential solar PV system in the eight states of the U.S. with SREC markets. The data collection was conducted in terms of two aspects: (i) data collection by target state (i.e. electricity prices, SREC prices, and SACP prices) and (ii) data collection by target city (i.e. solar radiation and solar incentives). First, as data such as electricity prices, SREC prices, and SACP prices can differ by state, these data were collected by target state. Since electricity and SREC markets are operated at the state level, the electricity prices and SREC prices were determined based on the target state [48, 54]. Second, as data such as solar radiation and solar incentives can differ by city within a same state, these data were collected by target city. Since solar radiation and solar incentives depend on the region and city, they were determined based on the target city [47].

3.2.1. Data collection by target state

3.2.1.1 Electricity prices

U.S. Energy Information Administration (EIA) provides electricity price data by state, which includes the average retail price of electricity by various sectors (i.e., residential, commercial, industrial, and transportation sectors) [54]. Among these data, this study collected and used the residential average retail price of electricity in 2013 in the eight states of the U.S. (refer to Table 1).

Among the eight states of the U.S. with SREC markets, Massachusetts and New Jersey showed the highest residential average retail price of electricity (i.e., US$0.1589/kWh and US$0.1556/kWh). It indicates that the benefits from the electricity generation of the residential solar PV system in Massachusetts and New Jersey would be expected to be high. Meanwhile, the residential average retail price of electricity in North Carolina was US$0.1088/kWh, which was lower than the average price in the U.S. (US$0.12/kWh). It demonstrates that the benefits from the electricity generation of the residential solar PV system in North Carolina would be expected to be low.

3.2.1.2 SREC prices

The SREC tracking system, such as the *PJM-GATS* and SREC transaction companies such as the *SRECTrade* and *Flett Exchange*, provide the SREC prices. The *PJM-GATS* reports the solar weighted average prices that include both the spot prices and long- or mid-term contract prices in the *PJM* market. However, the *SRECTrade* and *Flett Exchange* only report the spot prices from monthly auction and online exchange, respectively, which may bring discrepancy in the SREC price data [55]. Thus, in order to maintain the consistency in SREC price data for the eight states of the U.S., this study used the monthly solar weighted average prices from the *PJM-GATS*. In the case of Massachusetts where the monthly solar weighted average prices from the *PJM-GATS* are not available, the monthly spot prices from *SRECTrade* were used.

Fig. 4 shows the monthly SREC prices in 2013 by target state that are provided by the *PJM-GATS* and *SRECTrade*. The SREC in the eight states were traded in various prices from

US$30 to US$471. According to the SREC prices by each state, the SREC prices in the District of Columbia were US$315~US$441, which, compared to those of the other states, were higher in general. On the other hand, the SREC prices in Pennsylvania and Delaware were US$42~US$162 and US$59~US$202, respectively, which, compared to those of the other states, were lower. According to the SREC price volatility by each state, the SREC prices in North Carolina were US$30~US$471, showing the highest SREC price volatility among the eight states of the U.S. On the other hand, the SREC prices in Massachusetts were US$182~US$242, showing the lowest price volatility among the eight states of the U.S.

3.2.1.3 SACP prices

The *SRECTrade* provides the SACP prices [48]. Except for North Carolina (which has no SACP regulation) and Pennsylvania (which provide the SACP prices yearly), the states with the SREC markets have established their own SACP price schedules for the next 10 to 20 years. As shown in Fig. 5 (i.e., SACP price schedules from 2013 to 2024 by target state), in all states except Delaware, the SACP prices decline by stages as time goes by. Since the SACP restricts the maximum SREC price, the future SREC prices tent to decrease based on the scheduled SACP prices [45]. Therefore, this study calculated the SREC price degradation rate by using each state's SACP price schedules. In the case of North Carolina and Pennsylvania (which do not provide the SACP price schedules for the next 10 to 20 years), the SREC price degradation rate was assumed as follows: (i) Since North Carolina does not have SACP regulation, the average of the annual SREC price degradation rate in the other seven states was used; and (ii) Since Pennsylvania provide the SACP prices yearly, the SACP prices from 2009 to 2013 were used. In the case of New Jersey (which had intentionally adjusted the SACP price in 2014), the SACP price schedules from 2014 to 2024 were used to calculate the SREC price degradation rate.

3.2.2. Data collection by target city

3.2.2.1 Electricity generation

To collect the data on the electricity generation of the solar PV system for the target cities in the eight states of the U.S. with SREC markets, this study used *RETScreen*, an NRE simulation program. Co-developed by experts from the Department of Natural Resources in Canada and the United Nations Environment Program, *RETScreen* is a globally recognized energy project support program [56-58]. To calculate the electricity generation of the solar PV system for target cities using *RETScreen*, the assumptions for the solar PV system should be established. Referring to [57] and [59], the following assumptions for the solar PV system were established. First, the weather data for each of the target cities were collected from *RETScreen*. Second, the PV panel from Yingli Solar and the inverter from SMA, which have the highest market shares, were used for the energy simulation [60, 61]. Third, the installed capacity of the solar PV system was assumed to be 5 kW, according to the reports on the economic analysis of residential solar PV systems in the U.S. [62-64]. Fourth, the PV panel was assumed to be facing south, where the electricity generated from the solar PV system could be its maximum. Fifth, the PV panel was assumed to be installed at the optimal tilt for each of the target cities, where the electricity generated from the solar PV system could be its maximum. Sixth, the performance of the solar PV system was assumed to degrade by 20% during its useful life of 25 years, according to the previous studies and the actual PV panel data [23, 38, 65].

As shown in Table 2, the electricity generations in the eight target cities were calculated within the range from 6,693kWh to 7,643kWh. Among the eight target cities, Charlotte showed the highest electricity generation (7,643kWh), which indicates that the benefits from the electricity generation of the residential solar PV system would be expected to be high. Meanwhile, the electricity generation in Newark was 6,693kWh, which showed the lowest electricity generation, demonstrating that the benefits from the electricity generation of the residential solar PV system would be expected to be low.

3.2.2.2 Solar incentives

Solar incentives in the U.S. can be divided into tax incentives and cash incentives [66]. Tax incentives include tax credit and tax exemption, which are offered at federal or state level. Cash incentives include capacity-based incentives and performance-based incentives, which are offered at state or electric utility level [47]. For this reason, solar incentives can be offered at different rates by states and cities. This study collected data on solar incentives in target cities from the *Database of State Incentives for Renewables and Efficiency*, a website providing information on incentives and policies that support NRE in the U.S. (refer to Table 2) [47].

- *Tax credit (i.e. federal tax credit and state tax credit)*: The tax credit is an incentive that exempts a certain percentage of the initial investment cost of the solar PV system, and all the states in the U.S. offer 30% of federal tax credit. Meanwhile, the presence and amount of the state tax credit vary by state, and only Massachusetts and North Carolina offer state tax credits among eight target states [47].
- *Tax exemption (i.e. property tax exemption and sales tax exemption)*: Property tax exemption is an incentive that exempts the property tax imposed on the increased home value due to the installation of the solar PV system, and is offered by only six target states, except Delaware and Pennsylvania. Sales tax exemption is an incentive that exempts the sales tax imposed on the installation cost of the solar PV system, and is offered by only five target states, except the District of Columbia, North Carolina, and Pennsylvania [47, 67].

- *Capacity-based incentives*: Capacity-based incentives are offered as upfront cost based on the installed capacity of the solar PV system, and the presence and the amount vary by regions. As of 2015, only Delaware, Massachusetts, Maryland, and North Carolina offer capacity-based incentives among target states [47].
- *Performance-based incentives*: Performance-based incentives are offered annually based on the electricity generation of the solar PV system, and the SREC is one noted example [47]. Thus, this study used the SREC as the performance-based incentives.

3.3. Step 3: Defining assumptions

To calculate the minimum SREC prices required for reaching the target payback period of the residential solar PV system in the U.S. using the LCC analysis, the following assumptions should be established [11, 57, 59, 68]. This study established the following four assumptions: (i) analysis period; (ii) real discount rate; (iii) significant cost of ownership; and (iv) useful life of the SREC.

First, the analysis period for the solar PV system was determined. Generally, the warranty period of the solar PV system is 20 to 25 years, which is considered to be the useful life of the solar PV system [35, 38, 57, 69]. Therefore, this study set 25 years as the analysis period based on the actual warranty period of solar PV panel from Yingli solar [65].

Second, the real discount rate was calculated. This study calculated the real discount rate using nominal interest rate, inflation rate, electricity price growth rate, and SREC price degradation rate. Nominal interest rate was determined based on the federal funds rate from U.S. Federal Reserve Board (FRB) [70]. Inflation rate was determined based on the inflation rate from USInflation.org [71]. Electricity price growth rate was determined based on the annual residential average retail price of electricity by state from 2001 to 2012 provided from EIA [54]. The SREC price degradation rate was determined based on the SACP by state from the *SRECTrade* [48].

Third, this study considered the significant cost of ownership, including the installation cost of the solar PV system, operation and maintenance cost, solar incentives, and energy benefit.

- *Installation cost of the solar PV system*: From 1998, the U.S. Department of Energy and Lawrence Berkeley Nation Laboratory provide information on the installed price of the solar PV system in the U.S. through a publication named *Tracking the Sun*. This study used US$4,910/kW as the installation cost of the solar PV system, based on *Tracking the Sun VII,* the latest version of the publication [72].
- *Operation and maintenance cost*: Based on the previous studies, annual maintenance and insurance cost is normally 1% of the installation cost of the solar PV system [35]. Meanwhile, inverter replacement cost is normally 9.5% of the installation cost of the solar PV system and it should be replaced once in 13 years [38]. This study used 1% and 9.5% of the installation cost of the solar PV system as the annual maintenance and insurance cost and the inverter replacement cost, respectively.
- *Solar incentives*: This study used the price information on federal tax credit, state tax credit, property tax exemption, sales tax exemption, and capacity-based incentives in each of the target cities (refer to Table 2). Federal tax credit is offered at the same rate (30% of the installation cost of the solar PV system) for every state and city, whereas the other incentives are offered at different rates depending on states and cities. Since this study aimed to establish the minimum SREC prices required for reaching the target payback period of the residential solar PV system, this study did not considered other performance-based incentives. In a state without property tax exemption, the increased home value due to the installation of the solar PV system should be considered because a property tax is imposed on an increased home value [57].

According to [73], the home value increases by US$20 for every US$1 decrease in annual energy cost. Therefore, the increased home value due to the installation of the solar PV system can be calculated using equation (1).

$$IHV = ECS_a \times 20 \qquad (1)$$

where, *IHV* stands for increased home value, and ECS_a stands for annual energy cost savings.

- *Energy benefit*: This study used the U.S. EIA data on the residential average retail price of electricity in 2013 for the eight states of the U.S. to calculate the energy benefit from electricity generation [54].

Fourth, this study considered the useful life of the SREC in terms of the trading life and qualification life.

- *Trading life*: NRE generators are eligible to trade the SREC for a certain period of time after the SREC are issued, which is called the trading life [47]. SREC have different trading life depending on the states. SREC have a trading life of two years in North Carolina, five years in New Jersey and Ohio, and three years in the rest of the states [48]. Since the SREC with the expired trading life is no longer valid, it does not offer profits to NRE generators. Therefore, this study assumed that all the SREC are traded in the year that they are issued.
- *Qualification life*: Solar PV systems are eligible to issue the SREC for a certain period of time after the SREC are connected to the grid, which is called the qualification life [47]. Solar PV systems generally have a 15-year qualification life except for Delaware, where the SREC are issued for the first 20 years of the solar PV system life [21]. Therefore, this study assumed the qualification life of 20 years for Delaware and 15 years for the other target states.

3.4. Step 4: Establishing the minimum SREC prices

Based on the collected data and the established assumptions, this study established the minimum SREC prices required for reaching the target payback period of the residential solar PV system in the eight states of the U.S. with SREC markets. The minimum $SREC_p$ should be satisfied with equation (2) for the target payback period (n), which can be calculated using equations (3) to (5). These equations (2) to (5) were modified from the equations used in [59].

$$IIC = \sum_{t=1}^{n} \frac{B_t}{(1+r)^t} - \sum_{t=1}^{n} \frac{C_t}{(1+r)^t} \tag{2}$$

where, IIC stands for initial investment cost, B_t stands for benefit in year t, C_t stands for cost in year t, r stands for real discount rate, and n stands for target payback period.

$$IIC = \left[\left\{ IC_{PV} \times (1 + ST_r) - C_{PV} \times CBI_r \right\} \times (1 - STC_r) \right] \times (1 - FTC_r) \tag{3}$$

where, IIC stands for initial investment cost, IC_{PV} stands for installation cost of the solar PV system, ST_r stands for sales tax rate, C_{PV} stands for capacity of the solar PV system, CBI_r stands for capacity-based incentive rate, STC_r stands for state tax credit rate, and FTC_r stands for federal income tax credit rate (30%).

$$B_t = (EG_t \times PoE_t) + (NoS_t \times SREC_t) \tag{4}$$

where, B_t stands for benefit in year t, EG_t stands for electricity generation in year t, PoE_t stands for average retail price of electricity in year t, NoS_t stands for the number of SREC (1 SREC per 1 MWh) in year t; and $SREC_t$ stands for price per SREC in year t.

$$C_t = (IHV_t \times PT_r) + OMC_t \tag{5}$$

where, C_t stands for cost in year t, IHV_t stands for increased home value in year t, PT_r stands for property tax rate, and OMC_t stands for operation and maintenance cost in year t.

4. Results

Fig. 6 shows the minimum SREC prices required for reaching the target payback period of the residential solar PV system by target city. Since all the eight target cities required higher SREC prices than SACP prices to achieve the payback period within three years, this study did not consider the payback period during the first three years but analyzed the payback period between 4 and 25 years. The minimum SREC prices required for reaching the target payback period were established in various prices from US$4 to US$805.

First, Charlotte was shown to be the city with the lowest minimum SREC prices required for reaching the payback period within 12 years. In Charlotte, the minimum SREC price required for reaching the payback period of four years was US$304. On the other hand, Boston was shown to be the city with the lowest minimum SREC prices required for reaching the payback period between 13 and 25 years. Such a result can be examined in two aspects: In Charlotte, compared to the other states, (i) considerably lower initial investment cost of the solar PV system is spent thanks to state tax credits, and therefore, relatively lower minimum SREC price is required for reaching short payback period; and (ii) the annual energy benefits from electricity generation are small due to low electricity price, and therefore, relatively higher minimum SREC price is required for reaching long payback period.

Second, the District of Columbia, Columbus, and Philadelphia required relatively high minimum SREC prices for reaching the payback period between 4 and 25 years. Particularly, in Philadelphia, the minimum SREC prices required for reaching the payback period between 4 and 25 years were within US$367~US$805, the highest among the all eight target cities.

Third, the result showed that as the target payback period becomes shorter, the minimum SREC prices in all the target cities tend to soar rapidly. This means that in order to reach short payback period, compared to the long payback period, relatively higher minimum SREC price would be required to return the investment cost of the solar PV system.

5. Discussion

5.1. Comparative analysis from the perspectives of residents

This study conducted the comparative analysis from the perspective of residents who can acquire the benefit from trading the SREC in the U.S. with SREC markets as follows: (i) financial analysis of the residential solar PV system; and (ii) willingness-to-pay analysis of the residential solar PV system.

5.1.1. Financial analysis of the residential solar PV system

This study conducted the financial analysis of the residential solar PV system based on the SREC and SACP prices by target city. Fig. 7 shows the comparison chart of the minimum SREC prices required for reaching the target payback period by target city, which also provides the range of the SREC traded price in 2013 and the SACP prices in 2013 by target city. This study presented the range of SREC prices instead of standard deviation or variance of SREC prices, often used measure for the price volatility in financial analysis, to simply and easily compare various SREC prices at a glance and to ultimately provide insights regarding the SREC price to residents and state governments. Furthermore, in order to provide the detailed analysis results by each target city, Figs. 8 to 15 shows the minimum SREC prices required for reaching the target payback period between 4 and 25 years in each target city. In addition, Table 3 shows the expected payback period by considering the SACP prices in 2013 and the maximum, average and minimum SREC traded prices in 2013.

First, when the SREC is sold at its maximum or average traded price, the payback period in all target cities, except Philadelphia, would fall within 25 years. In particular, the expected payback period in Charlotte was shown to be five years when the SREC is sold at its average traded price (US$273), the shortest among target cities. The expected payback period in the District of Columbia was seven years, the second shortest when the SREC is sold at its average traded price (US$396, which is relatively higher than other target states).

Second, when the SREC is sold at its minimum traded prices, the payback period only in Boston, Newark, Wilmington, Baltimore, and the District of Columbia would fall within 25 years. Although the expected payback period in Charlotte was shortest among the eight target cities when the SREC is sold at its maximum or average traded price, the payback period would not fall within 25 years when the SREC is sold at its minimum traded price. It is because the range of the SREC traded price for Charlotte was US$30~US$471, showing too much a gap between the maximum and minimum SREC traded prices. In other words, it was shown that high SREC price volatility resulted in high difference in the economic feasibility of the residential solar PV system by the SREC prices.

Third, when the SREC is sold at the SACP price, the payback period in all target cities except Charlotte and Philadelphia, which do not adopt SACP, would fall within eight years. In particular, the expected payback period in Boston was four years when the SREC is sold at the SACP price, the shortest among eight target cities. On the other hand, the payback period in Philadelphia would not fall within 25 years even if the SREC is sold at the SACP price. Meanwhile, if the SREC price is higher than the SACP price, electricity suppliers find it more cost-effective to pay the penalty than to purchase the SREC. Therefore, it is extremely rare for the SREC to be traded at a higher price than the SACP.

5.1.2. Willingness-to-pay analysis of the residential solar PV system

Based on the aforementioned financial analysis of the residential solar PV system, this study conducted the willingness-to-pay analysis of the residential solar PV system by target city. While the target payback period can differ by residents' preferences, it was generally shown that if the payback period is guaranteed as within 10 years, residents tend to take a positive attitude toward the installation of the solar PV system [74, 75]. Therefore, this study conducted the willingness-to-pay analysis of the residential solar PV system based on the expected payback period of 10 years as a sample scenario (refer to Figs. 7 to 15, and Table 3). Using the result of this study (i.e. the proposed minimum SREC prices required for reaching each target payback period), it is possible to conduct the willingness-to-pay analysis of the residential solar PV system for all expected payback period from 4 to 25 years.

First, the payback period in Boston and the District of Columbia came out to fall within 10 years with all the SREC traded prices. The expected payback period in Boston was nine years, even if the SREC is sold at its minimum traded price of US$182. Meanwhile, the expected payback period in the District of Columbia was shown to be nine years when the SREC is sold at its minimum traded price, due to the relatively high minimum SREC traded price of US$315. That is, residents in these two target cities were shown to take a positive attitude toward the installation of the solar PV system.

Second, whether the payback period will fall within 10 years depends on the SREC traded prices for Charlotte, Newark, and Wilmington. The expected payback period in Charlotte was shown to be five years, even if the SREC is sold at its average traded price (US$273). The payback period in Newark and Wilmington would fall within eight years, only when the SREC is sold at its maximum traded price (US$268 and US$202, respectively).

Third, the payback period in Baltimore, Columbus, and Philadelphia would not fall within 10 years, no matter what value the SREC traded prices is.

5.2. Comparative analysis from the perspectives of state governments

This study conducted the comparative analysis from the perspective of state governments who can encourage the implementation of the solar PV system by trading the SREC in the SREC market as follows: (i) comparative analysis between the required and retired SREC; and (ii) comparative analysis of the installed capacity of the solar PV system.

5.2.1. Comparative analysis between the required and retired SREC

The states that implement the solar carve-out have established the number of SREC required annually for achieving solar carve-out requirements for the next 10 to 20 years. Therefore, it is necessary for electricity suppliers to retire the SREC required for achieving solar carve-out requirements. This study conducted the comparative analysis between the required and retired SREC to find out how well the target states comply with the solar carve-out. Fig. 16 shows the comparison chart of the required SREC and the retired SREC in 2013 by target state. This study used both the number of the required SREC in 2013 provided by the *SRECTrade* and the number of the retired SREC in 2013 provided by the *PJM-GATS* and state governments. In addition, Fig. 16 shows the compliance rate of the solar carve-out, which provides the ratio of the number of retired SREC to the number of the required SREC. Meanwhile, since both *PJM-GATS* and *NC-RETS* do not offer the data on the retired SREC in North Carolina, North Carolina was excluded from the analysis performed in this study [18].

First, the compliance rate of the solar carve-out in Massachusetts, New Jersey, and Pennsylvania was higher than 100%, showing that these states have met the solar carve-out requirements. Retiring 596,143 SREC while 596,000 SREC are required, New Jersey was shown to have retired the largest number of SREC among all the target cities [76]. Maryland and Ohio showed the compliance rate of 85% and 98%, respectively, showing that these cities have met a considerable amount of the solar carve-out requirements, yet not fully achieved.

Second, the expected payback period with SREC traded prices for Delaware and Maryland, which could not meet the solar carve-out requirements, ranged in 8 to 16 years and 12 to 17 years, respectively. The expected payback period with SREC traded prices for these two target states was shown to be relatively longer, compared to those for Massachusetts (seven to nine years) and New Jersey (8 to 13 years), which met the solar carve-out requirements. This can demonstrate that the solar carve-out requirements were met in the states where the expected payback period with the SREC traded prices is relatively short. Meanwhile, the expected payback period with the SREC traded prices in the District of Columbia, which could not meet the solar carve-out requirements, was short at between 6 and 9 years due to the high SREC traded price. However, the minimum SREC prices required for reaching the target payback period in the District of Columbia were US$100~US$600, relatively higher than those of the other target states. That is, if there are no SREC sales profits, the higher the minimum SREC prices are required for reaching the target payback period, the more difficult it would be to guarantee the economic feasibility of the residential solar PV system, and thus, it is insufficient to promote the compliance with the solar carve-out requirements.

Third, although the expected payback period in Pennsylvania came out to be difficult to fall within 25 years when the SREC is sold at its traded prices, the solar carve-out requirements were met. This is because Pennsylvania allows electricity suppliers to purchase the SREC issued in the other states in order to meet the solar carve-out requirements. In addition, Ohio also allows electricity suppliers to use the SREC issues in the other states to meet 50% of the total solar carve-out requirements. Therefore, Pennsylvania and Ohio have the potential to meet the solar carve-out requirements, regardless of the economic feasibility of the residential solar PV system in each state, thanks to the SREC from the other states [48].

5.2.2. Comparative analysis of the installed capacity of the solar PV system

To examine how well the solar PV system is distributed in each target state, this study conducted the comparative analysis of the installed capacity of the solar PV system by target state. Fig. 17 shows the installed capacity of the solar PV system in 2013 by target state.

First, among the eight states, New Jersey was show to have the largest number of the residential solar PV systems (41.7MW), followed by Massachusetts (28.7MW) and Maryland

(21.6MW). The capacity of residential solar PV systems installed in these three states was higher than the average installed capacity of the residential solar PV system in the entire U.S. states (16.98MW) [77]. Particularly, the expected payback period with SREC traded prices in Massachusetts and New Jersey was seven to nine years and 8 to 13 years, respectively, which was shorter than that of the other states. That is, it is shown that a large number of residential solar PV systems were installed in Massachusetts and New Jersey, due to high cost effectiveness of the residential solar PV system.

Second, Maryland, which showed the high installed capacity of the residential solar PV system, was analyzed to have relatively long payback period with SREC traded prices. According to *Shining Cities*, published by Environment America Research & Policy Center in 2014, the installed capacity of the solar PV system per capita for Maryland is 8W/person, ranked in 31st among 57 cities in the U.S. [78]. That is, while the total installed capacity of the residential solar PV system in Maryland is high, it is difficult to say that the residential solar PV system has been widely implemented, due to low cost effectiveness of the residential solar PV system. Meanwhile, Delaware and the District of Columbia, which showed the low installed capacity of the residential solar PV system, were analyzed to have relatively short payback period with SREC traded prices. The installed capacity of the solar PV system per capita for Delaware and the District of Columbia is 96W/person and 13W/person, respectively, which is the third and 25th highest among the 57 cities in the U.S. [78]. That is, while the total installed capacity of the residential solar PV system in Delaware and the District of Columbia is small, it can be determined that the residential solar PV system has been widely implemented, due to high cost effectiveness of the residential solar PV system.

Third, Ohio and Pennsylvania, which were analyzed to have relatively long payback period with SREC traded prices, showed the low installed capacity of the residential solar PV system. The installed capacity of the solar PV system per capita for Ohio and Pennsylvania is 2W/person and 6W/person, respectively, showing that both the installed residential solar PV and the installed solar PV per capita are low. Therefore, it can be determined that the residential solar PV system is hardly distributed in these states, since it is hard to achieve the economic feasibility of the solar PV system within the desired payback period by the residents.

6. Conclusions

This study aimed to establish a base price for SREC in order to encourage the implementation of residential solar photovoltaic systems in the U.S. Toward this end, this study conducted the LCC analysis to establish the minimum SREC prices required for reaching the target payback period of the residential solar PV system. This study did not use a single value for the target payback period, but rather established the minimum SREC prices for every year during the useful life of the solar PV system to provide some guidance on the SREC price according to both residents' and state governments' preferences. Based on the proposed minimum SREC prices required for reaching each target payback period, this study conducted the comparative analysis from the perspectives of both residents and state governments as follows: (i) financial analysis of the residential solar PV system; (ii) willingness-to-pay analysis of the residential solar PV system; (iii) comparative analysis between the required and retired SREC; and (iv) comparative analysis of the installed capacity of the solar PV system. As a result, main findings are summarized below (refer to Fig. 18).

First, in Massachusetts and New Jersey, the economic performance and deployment of the solar PV system was excellent from the perspective of both residents and state governments. From the perspective of residents, it was shown that the investment cost of the solar PV system could be recovered within 9 and 13 years, respectively. In addition, from the perspective of state governments, it was shown that these two states complied with the solar carve-out requirements, and showed high installed capacity of the residential solar PV system.

Second, in Delaware and the District of Columbia, the economic performance of the solar PV system from the perspective of residents was rather high, but the deployment of the solar PV system from the perspective of state governments and the compliance with the solar carve-out requirements were low. From the perspective of residents, it was shown that the investment cost of the solar PV system could be recovered within 16 years and 9 years, respectively. However, from the perspective of state governments, the total installed capacity of the residential solar PV system was relatively low, and the compliance rate of the solar carve-out requirements, 39% and 62%, respectively, was the lowest among the eight target states. Therefore, it is necessary to provide an additional policy instrument that can promote the compliance with the solar carve-out requirements.

Third, in North Carolina, there was huge deviation in the economic performance of the solar PV system due to the high SREC price volatility from the perspective of residents, and the deployment of the solar PV system from the perspective of state governments was low. In particular, from the perspective of state governments, neither the SACP nor SREC was carefully considered for policy development, showing that the solar carve-out was not systematically implemented. Therefore, it is necessary to establish policies that limit the high SREC price volatility and promote solar carve-out systematically.

Fourth, in Maryland, Ohio, and Pennsylvania, the overall economic performance and deployment of the solar PV system was poor from the perspectives of both residents and state governments. In particular, from the perspective of residents, it was shown that the investment cost of the solar PV system in Pennsylvania could not be recovered within 25 years. From the perspective of state governments, both the total installed capacity of the residential solar PV system and the installed capacity of the solar PV system per capita were low. Therefore, it is urgent to establish and revise the solar incentives and the SREC-related policies.

The proposed base price for SREC and comparison analysis from the perspective of both residents and state governments are significant and meaningful in terms of several aspects: (i) provide some guidance on SREC price to guarantee economic feasibility of the solar PV system from the perspective of residents; (ii) provide some guidance on SREC price to guarantee SREC floor price through regulation from the perspective of state governments; (iii) help residents to prepare against the SREC price volatility and overcome the risk related to the investment on solar PV systems; and (iv) evaluate and compare the performance of states with SREC markets regarding the compliance with the solar carve-out and deployment of the solar PV system. In summary, this study can help both residents and state governments to get financial advice for installing solar PV system and improving the solar incentives and the SREC-related policies.

Acknowledgements

This research was supported by a grant(16CTAP-C114950-01) from Technology Advancement Research Program (TARP) funded by Ministry of Land, Infrastructure and Transport of Korean government.

References

[1] Jeong K, Koo C, Hong T. An Estimation Model for Determining the Annual Energy Cost Budget in Educational Facilities using SARIMA (seasonal autoregressive integrated moving average) and ANN (artificial neural network). Energy 2014;71:71-79.

[2] Koo C, Hong T, Lee M, Park H. Development of a New Energy Efficiency Rating System for the Existing Residential Buildings. Energy Policy 2014;68:218-231.

[3] Ji C, Hong T, Park H. Comparative Analysis on Decision Making Methods for Integrating Cost and CO2 emissions: Focused on Building Structural Design. Energy and Building 2014;72:186-194.

[4] Hong T, Koo C, Kim H, Park H. Decision Support Model for Establishing the Optimal Energy Retrofit Strategy for Existing Multi-Family Housing Complexes. Energy Policy 2014;66:157-169.

[5] Koo C, Park S, Hong T, Park H. An Estimation Model for the Heating and Cooling Demand of a Residential Building with a Different Envelope Design using the Finite Element Method. Applied Energy 2014;115:205-215.

[6] Hong T, Kim J, Koo C. LCC and $LCCO_2$ analysis of green roofs in elementary schools with energy saving measures. Energy and Buildings 2012;45:229-239.

[7] Lee M, Koo C, Hong T, Park H. Framework for the Mapping of the Monthly Average Daily Solar Radiation using an Advanced Case-Based Reasoning and a Geostatistical Technique. Environmental Science and Technology 2014;28:4604-4612.

[8] Hong T, Koo C, Park J, Park H. A GIS (geographic information system)-based optimization model for estimating the electricity generation of the rooftop PV (photovoltaic) system. Energy 2014;65:190-199.

[9] Hong T, Koo C, Kwak T, Park H. An economic and environmental assessment for selecting the optimum new renewable energy system for educational facility. Renewable and Sustainable Energy Reviews 2014;29:286-300.

[10] Koo C, Hong T, Park H, Yun G. Framework for the Analysis of the Potential of the Rooftop Photovoltaic System to Achieve the net-Zero Energy Solar Buildings. Progress in Photovoltaics: Research and Applications 2014;22:462-478.

[11] Hong T, Koo C, Kwak T. Framework for the Implementation of a New Renewable Energy System in an Educational Facility. Applied Energy 2013;103:539-551.

[12] Koo C, Hong T, Lee M, Park H. Estimation of the Monthly Average Daily Solar Radiation using Geographical Information System and Advanced Case-Based Reasoning. Environmental Science & Technology 2013;47:4829-4839.

[13] Renewables 2014: Global status report. Renewable Energy Policy Network for the 21st Century (REN21); 2014.

[14] Presidential Memorandum -- Federal Leadership on Energy Management: Available at https://www.whitehouse.gov/the-press-office/2013/12/05/presidential-memorandum-federal-leadership-energy-management; October 16 2015.

[15] Rabe BG. The expanding role of U.S. state renewable portfolio standards. Michigan University; 2006.

[16] Wiser R, Barbose G, Holt E. Supporting solar power in renewables portfolio standards: Experience from the United States. Energy Policy 2011;39:3894-3905.

[17] Fabrizio KR, Hawn O. Enabling diffusion: How complementary inputs moderate the response to environmental policy. Research Policy 2013;42:1099-1111.

[18] Gaul C, Carley S. Solar set asides and renewable electricity certificates: Early lessons from North Carolina’s experience with its renewable portfolio standard. Energy policy 2012;48:460-469.

[19] Bird L, Heeter J, Kreycik Cl. Solar renewable energy certificate (SREC) markets: Status and Trends. National Renewable Energy Laboratory (NREL), Colorado; 2011.

[20] Zeng Y, Klabjan D, Arinez J. Distributed Solar Renewable Generation: Option Contracts with Renewable Energy Credit Uncertainty. Energy Economics

2015;48:295-305.

[21] Mann W. Solar Renewable Energy Certificate Markets: Assessing the Volatility Impact. 2014;73. Available at http://openscholarship.wustl.edu/wushta_spr2014/73.

[22] Glickstein J. New York's Proposed Solar Renewable Energy Market: Lessons Learned From Other States SREC Markets and Recommendations in Moving Forward. Pace Environmental Law Review 2013;30:1248.

[23] 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;44:217-225.

[24] Dincer F. The analysis on photovoltaic electricity generation status, potential and policies of the leading countries in solar energy. Renewable & Sustainable Energy Reviews 2011;15:713-720.

[25] Hui L, Hongtao Y. Multilevel governance and deployment of solar PV panels in U.S. cities. Energy Policy 2014;69:19-27.

[26] Shrimali G, Jenner S. The impact of state policy on deployment and cost of solar photovoltaic technology in the U.S.: A sector-specific empirical analysis. Renewable Energy 2013;60:679-690.

[27] Solangi KH, Islam MR, Saidur R, Rahim NA, Fayaz H. A review on global solar energy policy. Renewable & Sustainable Energy Reviews 2011;15:2149-2163.

[28] Li H, Yi H: Multilevel governance and deployment of solar PV panels in U.S.cities. Energy Policy 2014;69:19-27.

[29] Sener C, Fthenakis V: Energy policy and financing options to achieve solar energy grid penetration targets: Accounting for external costs. Renewable and Sustainable Energy Reviews 2014;32:854-868.

[30] Dawn S, Tiwari PK, Goswami AK, Mishra MK: Recent developments of solar energy in India: Perspectives, strategies and future goals. Renewable and Sustainable Energy Reviews 2016;62:215-235.

[31] Rohankar N, Jain AK, Nangia OP, Dwivedi P: A study of existing solar power policy framework in India for viability of the solar projects perspective. Renewable and Sustainable Energy Reviews 2016;56:510-518.

[32] Sahu BK: A study on global solar PV energy developments and policies with special focus on the top ten solar PV power producing countries. Renewable and Sustainable Energy Reviews 2015;43:621-634.

[33] Dusonchet L, Telaretti E: Comparative economic analysis of support policies for solar PV in the most representative EU countries. Renewable and Sustainable Energy Reviews 2015;42:986-998.

[34] Huijben JCCM, Podoynitsyna KS, Rijn MLB, Verbong G.P.J: A review of governmental support in struments channeling PV market growth in the Flanders region of Belgium(2006–2013). renewable portfolio standard. Renewable and Sustainable Energy Reviews 2016;62:1282-1290.

[35] Branker K, Pathak MJM, Pearce JM. A review of solar photovoltaic levelized cost of electricity. Renewable & Sustainable Energy Reviews 2011;15:4470-4482.

[36] Lakhani R, Doluweera G, Bergerson J. Internalizing land use impacts for life cycle

cost analysis of energy systems: A case of California's photovoltaic implementation. Applied Energy 2014;116:253-259.

[37] Jiang A, Zhu Y. Impact of incentives and system efficiency on the life cycle cost of photovoltaic systems. International Journal of Construction Education and Research 2012;8:204-222.

[38] Swift KD. A comparison of the cost and financial returns for solar photovoltaic systems installed by businesses in different locations across the United States. Renewable Energy 2013;57:137-143.

[39] Kwon T: Rent and rent-seeking in renewable energy support policies: Feed-in tariff vs. renewable portfolio standard. Renewable and Sustainable Energy Reviews 2015;44:676-681.

[40] Sun P, Nie P: A comparative study of feed-in tariff and renewable portfolio standard policy in renewable energy industry. renewable portfolio standard. Renewable and Sustainable Energy Reviews 2015;74:255-262.

[41] Chapman AJ, McLellan B, Tezuka T: Residential solar PV policy: An analysis of impacts, successes and failures in the Australian case. Renewable Energy 2016;86:1265-1279

[42] Coulon M, Khazaei J, Powell WB: SMART-SREC: A stochastic model of the New Jersey solar renewable energy certificate market. Renewable and Sustainable Energy Reviews 2015;73:13-31.

[43] Zhou D, Bradley DR. Solar renewable energy credits (SRECs) price forecast - A linear optimization approach. World Renewable Energy Forum (WREF); 2012.

[44] PJM: Available at www.pjm.com/about-pjm; January 28 2015.

[45] Pierpont B. Limiting the cost of Renewables: Lessons for California. Climate Policy Initiative. Climate Policy Initiative (CPI); 2012.

[46] Stockmayer G, Finch V, Komor P, Mignogna R. Limiting the costs of renewable portfolio standards: A review and critique of current method. Energy Policy 2012;42:155-163.

[47] Database of State Incentives for Renewables & Efficiency (DSIRE): Available at www.dsireusa.org; January 28 2015.

[48] SRECTrade: Available at www.srectrade.com; January 28 2015.

[49] Flett Exchange: Available at www.flettexchange.com; January 28 2015.

[50] Khouzam K, Tibaldi R. Economic Evaluation of Domestic Grid-Connected Photovoltaic Systems. Proceedings of Solar '97 - Australian and New Zealand Solar Energy Society 1997;132.

[51] Muneer W. Large-Scale Solar PV Investment Planning Studies. MA thesis, Waterloo University; 2011.

[52] Kirchler E, Hoelzl E, Kamleitner B. Spending and credit use in the private household. The Journal of Socio-Economics 2008;37:519-532.

[53] Rai V, Sigrin B. Diffusion of environmentally-friendly energy technologies: buy versus lease differences in residential PV markets. Environmental Research Letters 2013;8:1-8.

[54] U.S. Energy Information Administration (EIA): Available at www.eia.doe.gov;

January 28 2015.

[55] Hetter J, Nicholas T. Status and Trends in the U.S. Voluntary Green Power Market. National Renewable Energy Laboratory (NREL); 2012.

[56] Koo C, Hong T, Lee M, Kim J. An Integrated Multi-Objective Optimization Model for Determining the Optimal Solution in Implementing the Rooftop Photovoltaic System. Renewable & Sustainable Energy Reviews 2016;57:822-837.

[57] Lee M, Hong T, Koo C, Kim CJ. A Break-Even Analysis of Residential Solar Photovoltaic Systems Considering State Solar Incentives. Paper scheduled for publication in Technological and Economic Development of Economy.

[58] Natural Resource Canada: Available at www.nrcan.gc.ca/home; January 28 2015.

[59] 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. Under review in Renewable & Sustainable Energy Reviews.

[60] Renewables 2013: Global status report. Renewable Energy Policy Network for the 21st Century (REN21); 2013.

[61] PV Inverter World Market Report 2014. HIS Technology; 2014.

[62] Friedman B, Ardani K, Feldman D, Citron R, Margolis R. Benchmarking Non-Hardware Balance-of-System (Soft) Costs for U.S. Photovoltaic Systems, Using a Bottom-Up Approach and Installer Survey – Second Edition. National Renewable Energy Laboratory (NREL); 2013.

[63] Open PV Project Breakeven Analysis: Available at openpv.nrel.gov/breakeven;

January 28 2015.

[64] SolarPowerRocks: Available at www.solarpowerrocks.com; January 28 2015.

[65] Yingli Solar: Available at www.yinglisolar.com/en/; January 28 2015.

[66] Sarzynski A. The Impact of Solar Incentive Programs in Ten States. George Washington Institute of Public Policy; 2009.

[67] Solar Energy Industries Association (SEIA): Available at www.seia.org; January 28 2015.

[68] Kim J, Hong T, Koo C. Economic and Environmental Evaluation Model for Selecting the Optimum Design of Green Roof Systems in Elementary Schools. Environmental Science & Technology 2012;46:8475-8483.

[69] Hosenuzzaman M, Rahim NA, Selvaraj J, Hasanuzzaman M, Malek ABMA, Nahar A. Global prospects, progress, policies, and environmental impact of solar photovoltaic power generation. Renewable & Sustainable Energy Reviews 2015;41:284-297.

[70] Federal Reserve Bank (FRB): Available at www.federalreserve.gov/releases/h15/data.htm#fn11; January 28 2015.

[71] USInflation.org: Available at usinflation.org/us-inflation-rate/; January 28 2015.

[72] Barbose G, Weaver S, Darghouth N. Tracking the Sun VII. Lawrence Berkeley National Laboratory (LBNL); 2014.

[73] Nevin R, Watson G. Evidence of Rational Market Valuations for Home Energy Efficiency. The Appraisal Journal 1998;68:401-409.

[74] Haw LC, Sopian K, Sulaiman Y. Public Response to Residential Building Integrated

Photovoltaic System (BIPV) in Kuala Lumpur Urban Area. Proceedings of the 4th IASME /WSEAS International Conference on Energy & Environment 2009:212-219.

[75] Sigrin B, Drury E. Diffusion into New Markets: Economic Returns Required by Households to Adopt Rooftop Photovoltaics. Association for the Advancement of Artificial Intelligence (AAAI) Fall Symposium 2014.

[76] Department of Energy Resources (DOER): Available at www.mass.gov/eea/; January 28 2015.

[77] U.W. Solar Market Trends 2012. Interstate Renewable Energy Council (IREC); 2013.

[78] Burr J, Dutzik T, Schneider J, Sargent R. Shining Cities: At the Forefront of America's Solar Energy Revolution. Environment America Research & Policy Center; 2014.

FIGURE Captions