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The Economics Evaluation of Grid-connected Photovoltaic Systems in Residential Houses

Lee, Hyun-Seung* · Kim Sung-Bum** · Shin U-Cheul***

* Sun & Light, Seoul, Korea (5826132@naver.com)
** Department of Architectural Engineering, Graduate School, Daejeon University, Daejeon, Korea (love0206v@naver.com)
*** Corresponding author, Department of Architectural Engineering, Daejeon University, Daejeon, Korea (shinuc@dju.kr)

ABSTRACT

Purpose: To evaluate the economic performance of grid-connected photovoltaic system in residential house, household electricity bill policy of Korea Electric Power Corporation (KEPCO) must be applied precisely, and market tendency and uncertainty of system also need to be considered. In this study, to evaluate the economic feasibility of PV system, we measured PV power generation and electricity consumption of six of Green home in Daejeon through web based remote monitoring system. **Method:** We applied Monte-Carlo simulation based on life cycle cost analysis, to reflect an uncertainty of main factor in economic feasibility evaluation of photovoltaic system. **Result:** First, with deterministic analysis, the difference of NPV of cumulative financial savings among households varied from −3,310 ~ 24,170 thousand won , portraying notably big range. Also the possibility of getting the same result was 50% when applying uncertainty. Second, the higher electricity consumption is, the more economic feasibility of photovoltaic system increases because KEPCO uses progressive taxation in household electricity bill policy. Third, The contribution to variance of electricity price increases in NPV varied from 98.5% to 99.9%. While the inflation rate and annual degradation contributed very little to none.

KEYWORD

Economic evaluation
Green home
Life Cycle Cost analysis
Monte-carlo simulation
Grid-connected photovoltaic system

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1. Introduction

The government is on the trend that activates support for dual green home as well as implementing cost support for the facility to promote supply along with many systematic supports for distribution of bio-energy. Green home refers to the house that takes charge of part of building load through bio-energy source such as ground heat, wind power, sunlight or solar heat and photovoltaic house installed with photovoltaic facility showed the highest distribution rate among the overall green homes in case of 'distribution project for one million green homes.' Since 2005 when the business started, it is now showing increase more than 100 times with 164,828 in the end of 2013 from 1,217.[1)] This distribution growth of photovoltaic facility in residential houses is analyzed to be because of economic profit that can be felt immediately and easy installment thanks to the simplicity of the facility.

The study trend related to the economy of photovoltaic system for residential houses reveals Kim and others[2)] who have performed economic evaluation using RETScreen focused on the calculation of investment retrieval period regarding residential photovoltaic system in the nation and expected it to be 15 years based on net present value when monthly electricity usage is supposed to be 500kWh, with yearly power amount of 2,935kWh based on 3kWp capacity in cases of residential buildings in Seoul area. Additionally, Choi and others[3] supposed photovoltaic installment capacity of residential houses in Seoul area to be 3kW and performed economic analysis regarding 13 factors and 3-stage monthly electricity used using RETScreen. To add, Kim and others[4)] analyzed cost benefit through net present value method targeting monitoring result about photovoltaic amount and electricity used for a year of 11 green homes applying photovoltaic system. Despite the same installment capacity, power amount showed difference by more than 3.2 times, and net present value of electricity saving cost based on the construction within 25 years was shown to be 2,377,000 won ~ 6,497,000 won.

But current situation is that consideration regarding the uncertainty of system or market trend is excluded since system of Korean electricity cost for housing is the simulation analysis not accurately reflecting itself or it has limited to the conclusive evaluation in most studies in the nation. According to this, this study precisely analyzed the electricity cost where electricity cost system of Korean electricity, photovoltaic

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amount and electricity amount are reflected through actually measured data of web-based monitoring system then analyzed uncertainty of life cycle cost analysis which is conclusive through Monte-carlo simulation after selecting 6 green homes to evaluate the economy of grid-connected photovoltaic system applied on residential houses. Through this, we would like to present basic data for economy evaluation regarding grid-connected photovoltaic system in residential houses afterwards.

2. Demonstrated house

Demonstration targets were 6 green homes located in Yusung-gu of Daejeon, completed in 2011 simultaneously. Total floor area is 185㎡ ~ 209㎡ in three-story houses. Fig.1 shows theses.

Fig. 1. View of Housing Complex

These houses are all electric houses that all the energy supply is from electricity, and by the electricity usage of Korean electricity, general electricity of ground heat pump and plug load of lighting and home electronics, electricity for house from forced ventilation system, electricity cooking tool are classified and additional cost is charged. Photovoltaic system in green home is grid-connected to the electricity for residence. At the time of completion, every house was installed with grid-connected photovoltaic system with 3kWp and 2 houses among them installed additional 1kWp on February of 2012.

Fig. 2 shows a distribution diagram of grid-connected photovoltaic system. DC electricity generated in photovoltaic module would supply electricity load after being converted into AC, then remaining electricity is resent to the Korean electricity system.

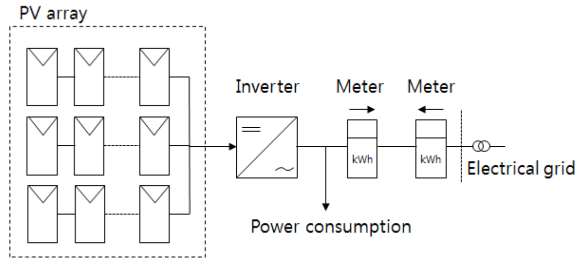

Fig. 2. Diagram of a grid-connected photovoltaic system

Table 1 shows specification of photovoltaic system applied in those houses.

Table 1. Technical characteristics of photovoltaic system

Item		Content
Module	capacity	200W
	solar cell	polycrystalline
	size	1,501mm*997mm*38mm
	rated efficiency	13.36%
Array	capacity	3 & 4kW
Inverter	rated efficiency	95%
	capacity	3kW

Monitoring system was constructed for error diagnosis and system development efficiency from the initial stage of designing these houses. Fig. 3 shows a distribution diagram of web-based remote monitoring system installed in demonstrated houses. Data such as the amount of transmit, electricity consumption of the house, photovoltaic electricity of Korean electricity measured each in 6 houses is sent through TCP/IP communication and saved every minute in the database of the server computer.

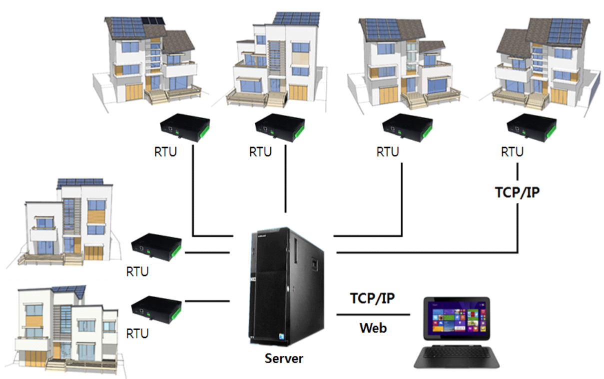

Fig. 3. Diagram of web-based remote monitoring system

3. Economic analysis method

There are concerns over risk occurrence since uncertainty regarding major factors in economy evaluation of photovoltaic system affects economic. To reflect this uncertainty, this study applied Monte-carlo simulation based on life cycle cist (LCC). Life cycle cost analysis is the method that compares the value of targets including every cost such as profit generated or maintenance cost arising during the certain period of analysis targets and initial investment. Among the discounted cash flow, this study used net present value that evaluates investment plan by comparing the sum of net future value after converting it to the net present value, and net present value is calculated like equation 1.

$$NPV = \pm \sum_{i=1}^{M} \sum_{t=1}^{N} \frac{C_i \cdot (1+j)^t}{(1+r)^t} - C_o \quad (1)$$

Here, Co refers to initial investment cost, m refers to the number of cost generated, Ci to the kind of cost generated, j to yearly inflation rate, r to discount rate, N to total period of business, t to time.

On the other side, Monte-carlo simulation substitutes variables with probability density drawing the result of continuous probability distribution generating random numbers and expects the degree of result range and occurrence. The result shown through this gets representativeness towards analysis target reflecting uncertainty of the target. This study used crystal ball[5)] developed by Oracle company and has performed Monte-carlo simulation.

Table 2 is the variable feature introduced for LCC analysis, setting inflation rate of electricity cost, consumer price as social factors, and yearly change rate of photovoltaic efficiency as physical factors as variables. Discounted rate was applied by 5.5% which is the social discount rate proposed by Korean Development Institution(KDI).

Base price of photovoltaic system for green home distribution in 2011 was 5,650,000 won / 1kWp and the government supplied up to 50% of maximum capacity, 3kWp. Thus, the real cost the residents have to bear was 8,475,000 won when it is 3kWp, 141,425,000 won when it is 4kWp.

In LCC analysis of this research, amount of electricity used in the house and generation excluding yearly change rate of photovoltaic generation in each house were supposed to be the same, excluding breakup and disposal cost of photovoltaic system.

Table 3 shows the statistical features of variables applying Monte-carlo simulation. Inflation rate of electricity cost and consume r price is supposed as a normal distribution, while yearly change in photovoltaic system is supposed as triangular distribution. [7)]

Table 2. Parameters used in the LCC analysis

Item	Content
Initial cost	5,650,000 ₩/kWp
Subsidy	50 % of initial cost
Annual maintenance cost	0.5 % of initial cost
Economic lifetime	25 years
Price increases of electricity	2.8%
Annual inflation rate	3.2%
Annual degradation	0.7%
Discount rate	5.5%

Table 3. Assumptions used in Monte Carlo simulation

Variables	Distribution	Mean (mode)	Max	Min	Std.Dev
Price increases of electricity	Normal	2.8	-	-	1.9
Inflation rate	Normal	3.2	-	-	0.96
Annual degradation	Triangular	(0.7)	1.0	0.5	

4. Electricity usage of housing and photovoltaic generation amount

Fig. 4 shows monthly generation amount by unit capacity of photovoltaic system (kWp) of real houses in 2013 (AC). Average generation amount in March is 154kWh, showing us that it is larger by 65% compared to the least one in December, 93kWh.

Fig. 5shows monthly electricity usage in each house. Electricity usage relatively decreases in the between period where solar generation amount increases and electricity usage between houses show a large difference compared to the solar generation.

Fig. 6 shows yearly total generation amount and electricity usage in each house. Yearly average generation amount of A house and D house installed with 4kWp capacity was 5,611kWh, remaining houses installed with 3kWp show almost same generation amount with 4,297kWh (standard deviation, σ = 35.9). Yearly average electricity usage is 4,289kWh(σ = 1,103) in electricity usage, revealing a big deviation. D house mostly used shows 6,443kWh, spending more by 120% compared to the least amount of C house, 2,839kWh.

On the other side, electricity cost of grid-connected photovoltaic house is composed of basic rate, electricity cost, VAT. Electricity is charge according to the electricity scale for houses of Korean electricity regarding the cost of electricity usage (energy at receiving end - surplus electricity usage) after the cost offset, and VAT is added to the energy at receiving end, not electricity usage after it. But when surplus electricity usage is more than the energy at receiving end, what remains is transferred to next month.

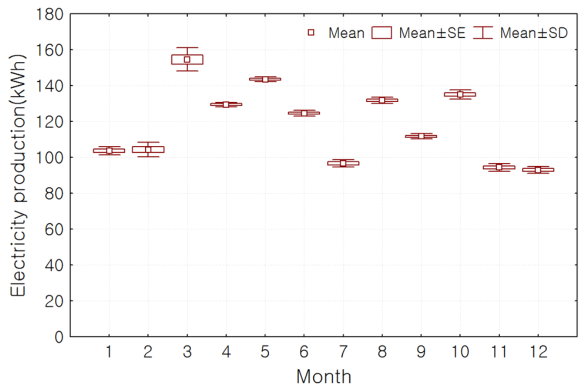

Fig. 4. Monthly electricity production

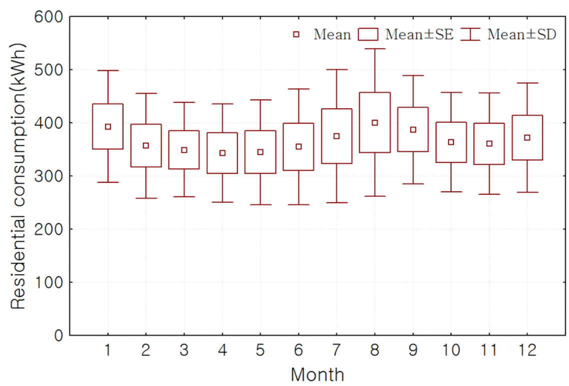

Fig. 5. Monthly residential consumption

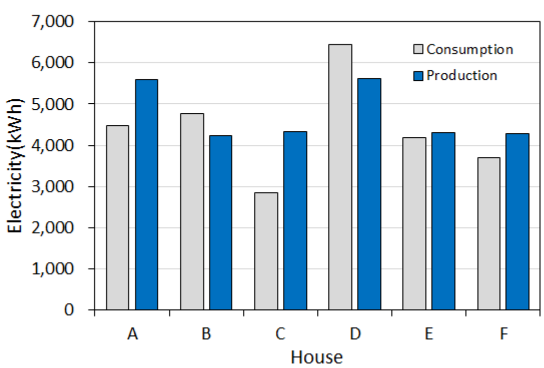

Fig. 6. Annual electricity production and consumption

Table 4 shows yearly dump energy transmitted reversely in real time in grid connection from photovoltaic electricity. Electricity produced in photovoltaic system was supplied to the real time load by 28.8% on average among 6 houses and remaining 71.3% was reversely transmitted to the grid. Electricity cost can be saved by reducing dump power reversely transmitted increasing the realtime electricity usage in the process of photovoltaic system according to the charging system of Korean electricity as stated earlier.

Table 4. Annual exporting surplus electricity to grid

House	PV production	Export to grid	Self-consumption	Ratio (%)
A	5,607	3,620	1,447	71.4
B	4,245	2,816	1,429	66.3
C	4,341	3,478	863	80.1
D	5,615	3,705	1,910	66.0
E	4,316	3,130	1,186	72.5
F	4,285	3,049	1,236	71.2

5. Result analysis

Table 5 summarizes the result of economic evaluation by net present value law which is deterministic fixing variables. It shows different result in a big scale in economy by houses. Net present value and investment collection period of D house where 4kW capacity was installed were respectively 24,170,000 won and 8 years showing the highest economy, on the other hand, net present value of C house which was installed with 3kW capacity was −3,310,000 won, and it was estimated disinvestment is hard within persisting period.

Fig. 7 shows investment collection period expected in photovoltaic system compared to electricity consumption. In electricity charging system for houses according to the current progressive stage system, we can see that economy gets higher with photovoltaic system as electricity consumption is larger and proper capacity design is required considering electricity load in the initial stage of the design.

Table 6 summarizes deterministic economy evaluation result by Monte Carlo simulation, and it shows that average net present value in every houses is rather expected a little bit higher than deterministic interpretation. Especially, F house showed higher average net present value with 1,272,000 won compared to the deterministic interpretation result. Coefficient of variance is the highest with 1.99 in F house, while A house showed 1.03 and other remaining houses showed 0.4725 on average which is relatively low level of variability.

Fig. 8 ~ Fig. 13 are histograms that showed net present value in probabilistic concept regarding saved cost of electricity consumption charged after being accumulated for 25 years and initial investment cost by each house. 6 houses all show normal distribution form. Net present value of saved cost within 95% confidence interval was shown to be −2,725,000 ~ 15,143,000 in A house, 2,506,000 ~ 19,109,000 in B house, −5,561,000 ~ 493,000 in C house, 11,000,000 ~ 46,600,000 in D house, 8,38,000 ~ 15,244,000 in E house, −2,680,000 ~ 71,27,000 in F house. To add, the probability that net present value would be higher than zero within the persisting period was expected to be 84.8% in A house, 99.9% in B house, 3.9% in C house, 100% in D house, 99.2% in E house, 66% in F house. Especially, C house has 96.1% probability that it would not retrieve photovoltaic system installment cost. On the other side, the probability that net present value would be realized in deterministic interpretation was shown to be 49.8 ~ 49.9%.

Table 5. Results of LCC analysis

House / Item	A	B	C	D	E	F
Initial cost (thousand ₩)	14,125	8,475	8,475	14,125	8,475	8,475
NPV (thousand ₩)	3,879	8,638	-3,310	24,170	61,61	945
Payback period (years)	19	11	(31)	8	13	22

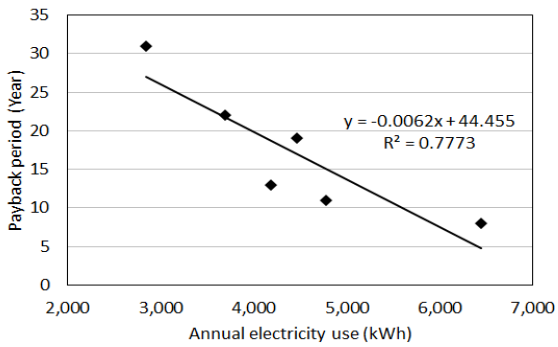

Fig. 7 Payback period as function of annual electricity use

Table 6. Results of Monte Carlo simulations

House / Item	A	B	C	D	E	F
Mean (NPV) (thousand ₩)	4,483	9,201	-3,114	25,356	6,648	1,272
Standard derivation	4,613	4,285	1,560	9,187	6,648	2,529
Coeff. of Variability	1.03	0.47	-0.5	0.36	0,56	1.99
Mean Std. error	15	14	5	29	12	8

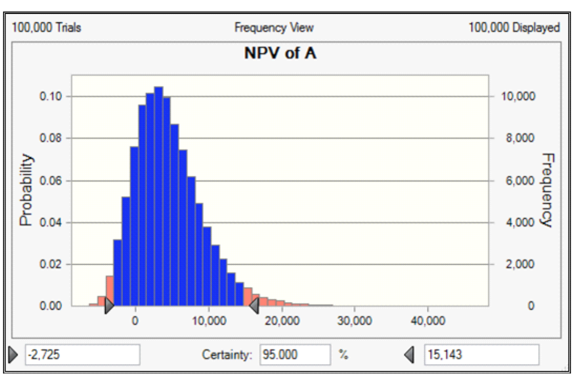

Fig. 8 NPV histogram of house A

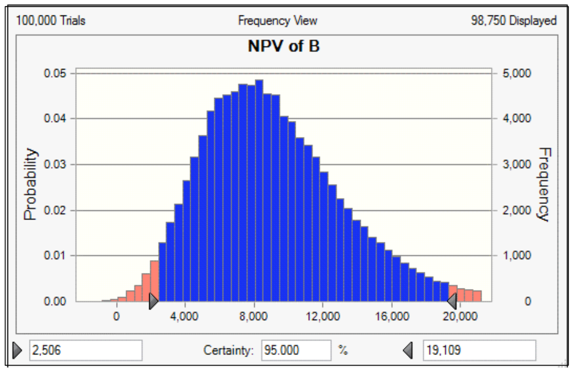

Fig. 9 NPV histogram of house B

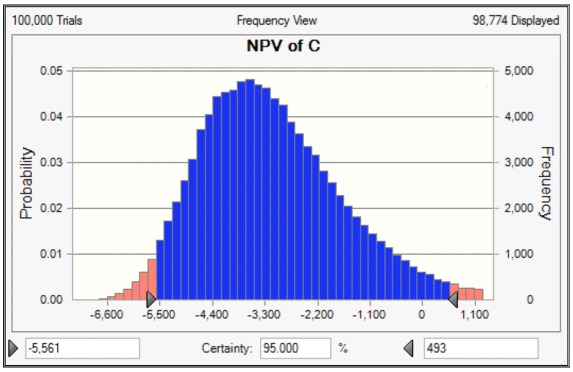

Fig. 10 NPV histogram of house C

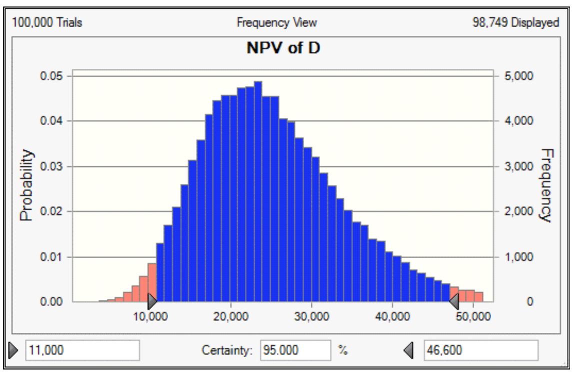

Fig. 11 NPV histogram of house D

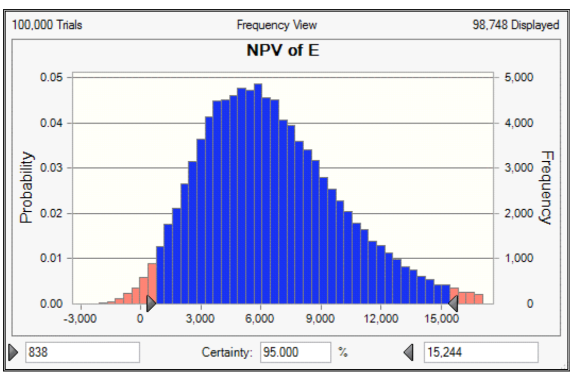

Fig. 12 NPV histogram of house E

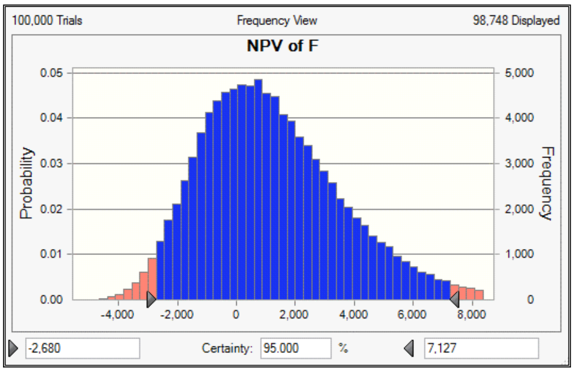

Fig. 13 NPV histogram of house F

Table 7 shows contribution to variance by each house regarding net present value of reduction cost. Contribution to variance in inflation rate of electricity cost became the dominant factor with 98.5 ~ 99.9%, having almost no contribution in case of inflation rate and yearly change rate.

Table 7. Contribution to variance

Item	Contribution to Variance (%)					
	A	B	C	D	E	F
Price increases of electricity	99.7	99.8	98.5	99.9	99.7	99.4
Inflation rate	0.3	0.2	1.5	0.1	0.3	0.6
Annual degradation	0.0	0.0	0.0	0.0	0.0	0.0

6. Conclusion

This study installed web-based remote monitoring system then analyzed that measured data targeting 6 green home located in Daejeon to evaluate economy of grid-connected photovoltaic system applied in residential houses. It applied Monte Carlo simulation based on life cycle cost analysis to reflect uncertainty about major factors in economy evaluation of photovoltaic system and followings summarize its result.

First, net present value of deterministic interpretation about photovoltaic system facility in 6 houses showed big difference by −3,310,000 ~ 24,170,000 won and the probability that it would be realized in the reality reflecting uncertainty was expected to be about 50%.

Second, photovoltaic system gets high economy as electricity consumption is higher in electricity charging system for residential houses according to the progressive stage system of Korean electricity. While net present value of D house installed with 4kW capacity of photovoltaic system within 95% confidence interval was shown to be 11,000,000 ~ 46,600,000 won, C house installed with low capacity of 3kWp was expected that it would be hard to have disinvestment with −5,561,000 ~ 493,000 won value and this result contributes to the difference in electricity consumption of two houses.

Third, contribution in changes in electricity inflation rate regarding net present value of reduction cost became the dominant factor with 98.5~99.9%, and contribution was shown not to exist in case of inflation rate and yearly change rate.

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