A STUDY ON POLICY PROPOSALS FOR EXPANSION OF SOLAR PHOTOVOLTAIC SYSTEM BASED ON CBA AND LCOE ANALYSIS IN SOUTH KOREA

By

CHOI, Seungbong

CAPSTONE PROJECT

Submitted to

KDI School of Public Policy and Management

In Partial Fulfillment of the Requirements

For the Degree of

MASTER OF PUBLIC MANAGEMENT

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Committee in charge:

Professor Jongyearn LEE, Supervisor ____________________

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ABSTRACT

A Study on policy proposals for expansion of solar photovoltaic system based on CBA and LCOE analysis in South Korea

By

Seung Bong Choi

Korean government set the target to boost the proportion of renewable energy in power generation to 20 percent by 2030 by replacing 57.3% of renewable energy with solar PV. In order to expand the usage of renewable energy, government has spread various energy policies. However, in the process of spreading various policies to expand solar PV, there have been unexpected inverse effects such as devastation of forest by the expansion of solar PV in forest. This study conducted CBA and LCOE analysis of 1MW utility scale solar PV by taking all possible cases into consideration such as solar radiation and land lease costs which differs by region in South Korea in order to minimize the unexpected adverse effects and expand solar PV effectively. Then, this study gave policy proposals to expand solar PV based on this analysis. It is expected that the results contribute to right decision making process regarding expansion of solar PV. Also, these results can help policymakers to improve the existing solar PV associated with policies and accelerate industrial key players to invest solar PV. Ultimately, it is expected that this study contribute to reducing the burden of electricity rates on people resulting from government's expansion of solar PV.

Key words: solar radiation, 1MW utility solar PV, CBA, LCOE, energy policy.

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1. Introduction

Reduction of Greenhouse gas emissions is one of the most interesting global issue. Countries worldwide are in the process of making various policies to reduce greenhouse gas emissions, in accordance with the Paris agreement. Korean government should also reduce 37% of greenhouse emission by 2030 compared to estimated emission - Business As Usual – according to the Paris agreement. In order to achieve the reduction target, The Korean government has implemented various policies such as improvement of energy efficiency in the building sector and transportation, and energy conversion to new and renewable energy. Especially, energy conversion to reduce GHG emissions worldwide is on the rise. Nuclear and coal-fired power generation started to be reduced and new renewable energy such as solar power and wind power started to be expanded. Like this reason, so many countries have focused on the policy for expansion of renewable energy, especially on solar photovoltaic system. The global solar photovoltaic market has grown remarkably in the past decade. Cumulative global installed solar Photovoltaic capacity grew from 6.1 GW in 2006 to 291 GW in 2016 (IRENA, 2017a).

Korea is no exception. Korean government set the target to boost the proportion of renewable energy in power generation to 20 percent by 2030 in accordance with The 8th Basic Plan of Long-Term Electricity Supply and Demand. Among the total of - 58.5 Gigawatt - renewable energy, Korean government plans to replace 57.3% of renewable energy with solar photovoltaic system (Ministry of Trade, Industry and Energy, 2017). Recently, there has been a growing interest in establishing effective policies to expand the supply and use of renewable in Korea (Kwon, 2012). In order to spread renewable energy, Korean government has introduced Renewable Portfolio Standard, hereafter RPS, since 2012. In spite of government efforts and interest of academia to expand renewable energy, the figures are only approximately 27% - 15.7 Gigawatt - of government target - 58.5Gigawatt - in 2030 as of 2017(Korea energy agency, 2018). Recently, inverse effects of the policy for expanding solar photovoltaic system have risen. Increase in solar photovoltaic installations in forest caused the devastation of forest by damaging decades of old trees that were growing on the site. Korea forest service (2018) estimated that the permitted area and number of solar photovoltaic system installations increased across the country due to the fact that the price of land in the forest was relatively low and the area was large. However, the main reason why solar photovoltaic system installations increased remarkably in forest was Renewable Energy Certificate, hereafter REC, weights adjustment on forest. Actually, government abolished REC weights on forest and unified REC weights with facility installed on general site so as to expand supply of the solar photovoltaic system by simplifying complicated REC weights.

Table 1. Correlation between Permitted area for solar photovoltaic system installations in forest and REC weight.

<table>
<tr><th>Item</th><th>2010</th><th>2012</th><th>2014</th><th>2016</th><th>09. 2017</th></tr>
<tr><td>Permitted area in forest (ha)</td><td>30</td><td>22</td><td>175</td><td>528</td><td>681</td></tr>
<tr><td>REC weights on forest</td><td>0.7</td><td>0.7</td><td colspan="3">1.2 (less than 100kW)
1.0 (More than 100kw)
0.7 (more than 3,000kw)</td></tr>
</table>

* This table was processed using data from KFA and REC weighting scheme

As a result, REC weights on forest increased from minimum 0.7 to maximum 1.2, which increased the profitability on solar photovoltaic system installations in forest. Revenue on solar photovoltaic system consist of System Marginal Price and Renewable Energy Certificate. May in 2018, the government recognized the problem of deforestation caused by renewable energy policies and adjusted REC weight on forest back to 0.7 of 2014. As seen from this example, changes in economic feasibility have significant effect on the expansion of solar photovoltaic system installations.

The study on policy proposals based on economic feasibility for expansion of renewable energy supply is a matter of significant current interest for policymakers. Therefore, there is a rapidly growing literature on policy proposals based on economic feasibility and levelized cost of electricity (KPE, 2018; Lee, Hong, Koo, Kim, 2018; Cha, 2016; Kang & Rohatgi, 2016; Brankera et al. 2011; Lee, 2008). It has been shown that analysis on economic feasibility and levelized cost of electricity have contributed to the expansion of renewable energy supply.

Previous research has paid relatively little attention to analyze economic feasibility and levelized cost of electricity based on regional characteristic factors. The factors are under unique Korea's RPS system, which has different REC weight by facilities type. However, solar photovoltaic power generation has a higher initial investment and unit cost of production compared to fossil fuels based power plants. As mentioned in previous case of REC weight on forest, precise analysis of economic feasibility on solar photovoltaic system reflecting all major factors which can affect economic feasibility are critical to ensure the success of solar photovoltaic system expansion.

Hence, the purpose of this research is to consider the main factors which affect economic feasibility on solar photovoltaic system installations such as solar radiation, land lease fee, and show the levelized cost of electricity and economic feasibility by facility type and region via cost benefit analysis, and finally suggest policy proposals for the expansion of solar photovoltaic system supply.

This research paper will attempt to address the above purpose through the following steps: 1) Collect data on solar radiation and land value by public announcement by region and data which affects costs of solar photovoltaic system installations. 2) Calculate electricity which solar photovoltaic system generates by region. 3) Make assumptions about major factors such as social discount rate, land lease fee rate, inflation rate, loan interest rate, system degradation, corporate tax rate. 4) Showg the economic feasibility and levelized cost of electricity on solar photovoltaic system by region and facility type. 5) Suggest how the government could implement the policies to raise the supply of photovoltaic system.

This paper is divided into three sections. First, I present a thorough literature review on solar PV energy policy based on economic feasibility analysis. Next, I analyze economic feasibility and levelized cost of electricity by region and facility type. Finally, the last section of this paper propose policies on expansion of solar energy supply based on economic feasibility. Having provided a context for this research paper, I will now proceed to review secondary literature on the topics of renewable energy policy focusing on solar energy.

2. Literature Review

In this section I will provide an account of the development of scholarship in the field of renewable energy policy on solar photovoltaic system. The review of renewable energy policies in the context of economic feasibility and levelized cost of electricity has been actively discussed by scholars (Lee, Hong, Koo, Kim, 2018; Lee. 2017; Cha. 2016; Kang & Rohatgi. 2016; Yi. 2016; Brankera et al. 2011; Lee, 2008). The studies have paved the way for later scholars to understand the background of solar energy policy related to economic feasibility and levelized cost of electricity. There are several studies analyzing the economic feasibility reflecting major factors such as different incentives and solar radiation by region (Lee, Hong, Koo, Kim, 2018; Yi, 2016; Lee, 2008). Lee, et al. (2018) analyzes economic feasibility reflecting different solar radiation, electricity price and different incentives by state. As the solar radiation, electricity prices, and solar incentives in the U.S. differ by state. Yi (2016) and Lee (2008) analyzed economic feasibility of solar photovoltaic system considering the fact that solar radiation differ by region, which affects the amount of generation electricity.

There are several studies analyzing the levelized cost of electricity on solar photovoltaic system (Lee, 2017; Cha. 2016; Kang & Rohatgi. 2016; Brankera, et al. 2011). Cha (2016) compared levelized cost of electricity by generation type and capacity scale. Korea energy economic institute (2017) proposed solar photovoltaic system related energy polices by comparing competitive advantages on solar photovoltaic cost structures of major countries and analyzing levelized cost of electricity on solar photovoltaic system reflecting construction cost of major countries.

However, only few research has been conducted on solar energy policy effectiveness on the basis of economic feasibility considering solar radiation, land lease fee, and incentives respectively by region (Yi, 2016; Son, 2017; Lee, et al., 2018, Lee, 2008). Much attention has been paid on the effectiveness of current energy policy focusing on economic feasibility based on average solar radiation and focusing on levelized cost of electricity in due consideration of construction (Lee, 2017; Cha, 2016; Kang & Rohatgi, 2016; Son, 2013; Brankera et al., 2011). Next, I will consider the contemporary context and debate in the field of renewable energy policy in Korea.

This paper mostly agrees with the review direction based on economic feasibility. Analysis based on economic feasibility and levelized cost of electricity have contributed to more transparent construction cost and allowed policy maker, business community, public to have a better understanding on solar photovoltaic system related energy policy proposals (IRENA, 2017b). As a result, it led to increase in solar photovoltaic system installations.

However, these studies have overlooked economic feasibility based on unique Renewable portfolio standard in South Korea. As shown in the case of REC weight adjustment on forest, policy proposal without a thorough review of the detailed factors that affect economic feasibility lead to inverse effects such as forest degradation due to the expansion of solar photovoltaic system. South Korea has unique RPS system on solar photovoltaic which has different REC weights by facility installed type. So, economic feasibility of photovoltaic system installment is determined by the factor of solar radiation, installation costs, REC weight by facility type and land lease fee by region. Yi (2016) pointed out the problems of different economic feasibility caused by different solar radiation and Son (2017) tried to prove the correlation between distribution of solar PV and major factors such as solar radiation, land rent by region. Son (2017) and Yi (2016) explained the reason why distribution rate of photovoltaic system differs by region with the evidence of different solar radiation by region, but Son (2017) failed to prove correlation with distribution rate of solar PV and land rent. I take a similar position on this issue. But a key difference between my paper and Yi & Son's paper is that my research analyzes economic feasibility and levelized cost of electricity on solar photovoltaic system considering facility type, solar radiation and land lease fee all together. This has some important implications for the way the policymakers conduct renewable energy policy especially focusing on photovoltaic system supply.

Before proceeding further, it is necessary to clearly define the key definitions in this paper. At the outset, it is imperative to clarify what Renewable Portfolio Standard, Renewable Energy Certificate, hereafter REC, and levelized cost of electricity, hereafter LCOE, means. Renewable Portfolio Standard is defined as mandatory operators of the electricity generation business that have power generation facilities with a capacity of at least 500MW mandatorily supply at least a certain amount of electricity generated by using new and renewable energy.

Renewable energy certificate, hereafter REC, refers to a unit of issuance and transaction of the supply certificate, it is a unit to be issued by multiplying electricity of MWh generated from the new and renewable resources by REC weight. LCOE is often cited as a convenient summary measure of the overall competiveness of different generating technologies. It represents the per-Megawatt-hour cost of building and operating a generating plant over an assumed financial life and duty cycle (EIA, 2018).

The purpose of this study is to analyze economic feasibility and show LCOE on solar photovoltaic system considering facility type, solar radiation and land lease fee which mainly effect on economic feasibility under the current RPS system. This study would eventually increase our understanding of economic feasibility by region and facility type, and help the private sector to invest in photovoltaic system and expand the supply of solar energy.

Policies that affect renewable energy activation are so diverse. There are various policies in expanding supply of solar photovoltaic system: distribution of 1 million of green house with solar panel, encouraging private sectors to invest in the supply of solar photovoltaic system, energy policy of local government to attract more solar photovoltaic system by giving subsidies. This paper will particularly discuss **economic feasibility and levelized cost of electricity on solar photovoltaic system** reflecting solar radiation and land lease fee by region and facility type. Here, my paper will limit the scope of research as a policy to expand solar photovoltaic system based on economic feasibility analysis and LCOE under Renewable Portfolio Standard. Rest of the policies could be the subject of future valuable research.

3. Analysis of economics on solar PV in South Korea

3.1. Method

The data collection method in this study is collecting data relevant to estimating the electricity generation amount and land lease cost. In order to analyze economic feasibility and compare generation unit cost price of solar PV by facility type and region, this study use cost-benefit analysis (CBA) and levelized cost of electricity (LCOE). This study analyzes CBA and LCOE on four types of solar PV facility - on general site, on existing building, on water, in forest - by region. This is done by limiting its utility scale to 1MW solar PV installed by small size corporations. In case of solar PV installed on existing building, the cases will be limited to the sites which have enough space to install 1 MW solar PV such as roof of factory, water purification facility, etc.

3.2. Data collection

There are three key factors that affect economic feasibility in installing solar PV. In terms of energy output, the amount of electricity generated by solar PV is directly proportion to solar radiation and system efficiency. Solar radiation differs by region. Therefore, this study collects solar radiation and estimate amount of generation electricity based on collected solar radiation. This study assumes that system efficiency is the same because the equipment of solar PV is standardized and industry players in solar PV choose the similar efficiency equipment to generate more electricity. In terms of cost, the three costs of solar PV cost - capital expenditure, operation and maintenance, land lease affect total cost. Land lease costs considerably differ by region. Therefore, this study collect Land price by public announcement and estimate reasonable land lease cost by region. This study assumes that Solar PV cost, operation and maintenance costs have no difference, as referred to above.

3.2.1 Solar radiation

It is key to collect abundant data of solar radiation to minimize errors. KMA report on solar PV optimization (2008) recommended adopting the recent 20 years data of solar radiation, considering the fact that solar radiation shined brightly or darkly every 10 years and lifetime of solar PV. There are 21 measuring stations satisfying the above conditions in Korea. This study collects recent 20 years' solar radiation data in each regions and convert these 21 cities data into 15 cities and provinces data by applying average value when the data is more than one in each province. Collected data of 21 cities are shown below. Average solar radiation countrywide is 3.687(kwh/m^2). Solar radiation range is between 3.39(90.6%) ~ 3.93(106.6%). It shows 16% gap between the lowest region in Seoul and highest in Daejeon.

Table 2. Horizontal solar radiation of 21 cities and 15 provinces (2009~2017)

21cities (raw data)			
N	City	Radiation (kWh/m²)	remarks
1	Seoul	3.339	90.6%
2	Incheon	3.603	97.7%
3	Suwon	3.543	96.1%
4	Daegwallyong	3.704	100.5%
5	Chuncheon	3.658	99.2%
6	Gangneung	3.644	98.8%
7	Wonju	3.673	99.6%
8	Cheongju	3.653	99.1%
9	Seosan	3.609	97.9%
10	Chupungryoung	3.664	99.4%
11	Daejeon	3.930	106.6%
12	Mokpo	3.793	102.9%
13	Gwangju	3.808	103.3%
14	Jeonju	3.659	99.2%
15	Busan	3.876	105.1%
16	Jinju	3.797	103.0%
17	Ddaegu	3.829	103.9%
18	Andong	3.673	99.6%
19	Pohang	3.663	99.3%
20	Jeju	3.663	99.4%
21	Jeju(gosan)	3.647	98.9%
Nationwide(average)		3.687	100.0%

15 provinces			
N	City	Radiation (kWh/m²)	remarks
1	Seoul	3.339	90.6%
2	Incheon	3.603	97.7%
3	Gyeonggi	3.543	96.1%
4	Gangwon	3.670	99.5%
5	Chung-Buk	3.653	99.1%
6	Chungnam	3.637	98.6%
7	Daejeon	3.930	106.6%
8	Jeonnam	3.793	102.9%
9	Gwangju	3.808	103.3%
10	Jeonbuk	3.659	99.2%
11	Busan	3.876	105.1%
12	Gyeongnam	3.797	103.0%
13	Ddaegu	3.829	103.9%
14	Gyeonbuk	3.668	99.5
15	Jeju	3.655	99.1%
Nationwide(average)		3.687	100.0%

3.2.2 Capacity factor and generation electricity amount

Capacity factor and amount of generation electricity are determined by solar radiation and system efficiency.

$$\boldsymbol{Capacity\ \ factor}\ (\%) = \frac{\boldsymbol{SR^{h}}(\frac{\boldsymbol{kwh}}{\boldsymbol{m^2}})}{(\frac{\boldsymbol{24h}}{\boldsymbol{day}} \times \frac{\boldsymbol{1kw}}{\boldsymbol{m^2}})} \times \boldsymbol{S_{ef}}(\%) \times \boldsymbol{W^{OP}} \quad (1)$$

$$S_{ef}(\%) = V_{tt}A \times N_{ef} \times TR_{ef} \times S_f \quad (2)$$

$$Electricity_{per\ year} = Capacity\ \ factor\ (\%) \times 365\,(day) \times 24\,(h) \times Capacity \qquad (3)$$

Where, SR^h = Horizontal solar radiation, S_{ef} = System efficiency, W_{op}= solar radiation of Optimal (1.12)

V_{ld} = line Voltage drop (97% within 60m), IN_{ef} = Inverter efficiency (98%, euro),

TR_{ef} = Transformer efficiency (98.6%, KSC 4311), S_f = Safety factor (0.95)

Table 3 shows the utilization rate and generation of each regions computed using the solar radiation

Table 3. Capacity factor and generation electricity of 1MW solar PV by region

N	City	Radiation (kWh/㎡)	Capacity Factor (%)	generation electricity (MWh/base year)	Remark
1	Seoul	3.339	13.90	1,218	90.6%
2	Busan	3.876	16.14	1,413	105.1%
3	Ddaegu	3.829	15.94	1,396	103.9%
4	Incheon	3.603	15.00	1,314	97.7%
5	Gwangju	3.808	15.85	1,388	103.3%
6	Daejeon	3.930	16.36	1,433	106.6%
7	Gyeonggi	3.543	14.75	1,292	96.1%
8	Gangwon	3.670	15.28	1,338	99.5%
9	Chung-Buk	3.653	15.21	1,332	99.1%
10	Chungnam	3.637	15.14	1,326	98.6%
11	Jeonbuk	3.659	15.23	1,334	99.2%
12	Jeonnam	3.793	15.79	1,383	102.9%
13	Gyeonbuk	3.668	15.27	1,337	99.5%
14	Gyeongnam	3.797	15.81	1,385	103.0%
15	Jeju	3.655	15.22	1,333	99.1%
Nationwide (average)		3.687	15.35	1,345	100.0%

3.2.3 Land lease costs

Approximately 12,000m^2 of land is needed to install 1MW solar PV with 350WP module. Land lease costs are very site-and market-specific. Lee (2018), in his research on analysis of LCOE on solar PV, estimated land lease cost as 1.5million won per 100 kWP. Korea power exchange

(2018) estimated land costs for solar PV installations as 17,602KRW/m2 by adopting the official declared value of land of Jeonnam, while Korea power exchange estimates LCOE of solar PV in South Korea. This study computes land lease costs by multiplying official declared value of land (ODVL) by the rate that related act represents based on the rate representing the difference in regions of the official declared value of land. Average land registry price is 48,145 KRW. Average forest and river registry prices are 4,105KRW and 30,200KRW respectively. So approximately 8.5% weighting for forest and 62.7% weighting for river are multiplied in calculating land price of forest and river.

Table 4. Land lease fee rate by related ACT

Item	Land	River	Forest
Rate (%)	5	1.5	5
ACT	Enforcement decree of the state property Act Article 29 (Methods of calculating usage fee rate and fees)	Enforcement decree of the river Act Article 42 (Collection of Occupation Fees, etc.)	State forest administration and management Act Article 23 (Lease Charges, etc.)

The results of land lease cost per year by site is estimated in table 5. Land lease costs are very city-specific. In general, Land lease costs (1 MW solar PV) represent below 15 million KRW except metropolitan cities and Jeju city.

Table 5. Estimated land lease costs per year for 1MW (12000m^2) by site

N	City	2018 ODVL (kRW/m^2)	on land (general, building) (million KRW)	on water (million KRW)	in forest (million KRW)
			5%	1.5%×62.7%wieght($\frac{p_r}{P_l}$)	5%× 8.5%wieght($\frac{p_f}{P_l}$)
1	Seoul	2,419,275	1,451.6	273.2	123.8
2	Busan	295,960	177.6	33.4	15.1
3	Ddaegu	189,113	113.5	21.4	9.7
4	Incheon	252,681	151.6	28.5	12.9
5	Gwangju	128,170	76.9	14.5	6.6
6	Daejeon	180,935	108.6	20.4	9.3
7	Gyeonggi	126,635	76.0	14.3	6.5
8	Gangwon	6,779	4.1	0.8	0.3

9	Chung-Buk	14,412	8.6	1.6	0.7
10	Chungnam	24,215	14.5	2.7	1.2
11	Jeonbuk	12,487	7.5	1.4	0.6
12	Jeonnam	9,020	5.4	1.0	0.5
13	Gyeonbuk	10,117	6.1	1.1	0.5
14	Gyeongnam	23,669	14.2	2.7	1.2
15	Jeju	40,021	24.0	4.5	2.0
Nationwide(average)		48,145	28.9	5.4	2.4

3.3. CBA and LCOE Analysis on solar PV

3.3.1 Conception of Cost benefit analysis (CBA)

Cost-benefit analysis is generally conducted to evaluate economic feasibility on projects. Cost-benefit analysis uses the benefit-cost ratio (B/C ratio), the net present value (NPV) Internal Rate of Return (IRR) in calculation. The meaning of each indicator is as follows.

a. B/C ratio: if the benefit / cost ratio is 1.0 or more (B/C ≥ 1.0), it is economically feasible

b. Net present value: if the net present value is more than 0 (NPV ≥ 0) by converting all the costs and benefits associated with the business into the present value of the base year, it is economically feasible.

c. Internal rate of return: this is a method to obtain the discount rate R, which is equal to the current value of the benefit and the cost. It is a discount rate that makes the net present value of project as zero. If the internal rate of return is higher than the social discount rate, it is economically feasible.

$$B/C = \sum_{t=0}^{n} \frac{B^t}{(1+r)^t} / \sum_{t=0}^{n} \frac{C^t}{(1+r)^t} \quad (4)$$

$$NPV = \sum_{t=0}^{n} \frac{B^t}{(1+r)^t} - \sum_{t=0}^{n} \frac{C^t}{(1+r)^t} \quad (5)$$

$$IRR = r, where \ \sum_{t=0}^{n} \frac{B^t}{(1+r)^t} = \sum_{t=0}^{n} \frac{C^t}{(1+r)^t} \quad (6)$$

Where, B^t = present value of benefit, C^t = present value of cost, r = discount rate, n = number of years

3.3.2 Conception of levelized cost of electricity (LCOE)

The analysis method of levelized cost of electricity, hereafter LCOE, is generally used to measure the overall competiveness of different generating technologies and compare power generation cost from different sources. It represents the per-Megawatt-hour cost of building and operating a generating plant over an assumed financial life and duty cycle (EIA, 2018). LCOE is the average actual generation cost (KRW) per unit of power (kWh) produced by a particular power plant, calculated by dividing the present value of the total cost of the power generation facility by the present value of the total power generation (Lee, 2017).

$$LCOE_t = \frac{CAPEX_t + \sum_{n=1}^{T} \frac{OM_n + FC_n}{(1+r)^n}}{\sum_{n=1}^{T} \frac{(1-d)^n \times CF \times 365\,(days) \times 24\,(hours) \times Capacity}{(1+r)^n}} \tag{7}$$

Where, $CAPEX_t$ = present value of capital expenditures, r= discount rate, CF =capacity factor, n = number of years, OM_n = operations and maintenance costs, FC_n = financing costs

3.3.3 Main assumptions for CBA and LCOE analysis

The key factors that affect present value of benefit and cost such as discount rate, system costs, financing and incentives, capacity scale, capital ratio, system life, system degradation rate and energy output were determined using the following assumptions (Lee, 2017;Branker et al, 2011).

a. Discount rate

The discount rate is an important factor in analyzing economic feasibility of long-term projects. Lee and Kim (2015) estimated the level of social discount rate in Korea at 3.26%

through the survey conducted to the members of the resource, environmental, and international economic associations. Preliminary feasibility study guideline in Korea represents 4.5% discount rate (MOEF, 2018). In this study, in order to take conservative approach to discount rate, 4.5% discount rate is applied.

b. Inflation rate (2.27%)

Inflation rate in Korea is 2.27% for the previous 10 years in average.

Table 6. Consumer price index in Korea (2008~2017) from bank of Korea

2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Average
82.24	86.08	88.45	91.05	94.72	96.79	98.05	99.30	100.00	100.97	102.93	**2.27%**

* (Reference) Consumer price index from Economic statistics system of bank of Korea

c. Utility scale of solar PV (1MW)

IRENA (2017b) defined utility scale as above 1MW capacity of solar PV. According to the statistics on renewable energy supply in 2016 (KEA, 2017), 72% (18% of total) of utility scale is between 1MW and 5MW. The analysis for utility scale is limited to 1MW solar PV by facility type installed on general site and existing building and on surface of the water.

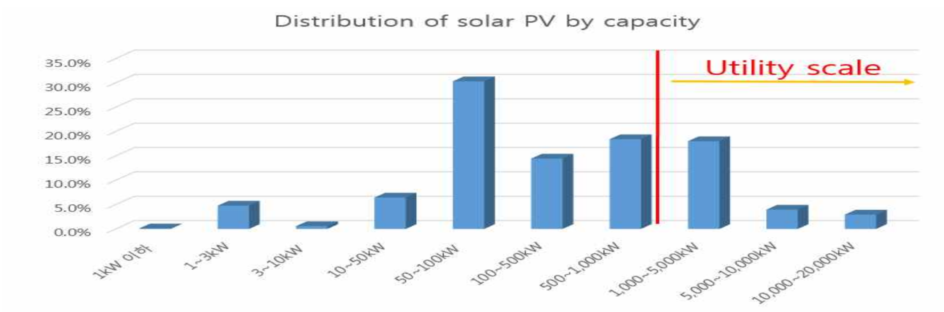


Figure 1. Distribution of solar PV by capacity

d. Corporation tax rate (20%)

Considering capacity size of solar PV (1MW), the project is generally conducted on small size corporation (revenue is between 1~20billiion won). Corporation tax rate for these small size corporations is 20%.

e. Tax incentives

In accordance with restriction of special taxation act Article 7 (Special tax reductions or exemptions for small or medium enterprises), types of business eligible for tax reduction or exemption is business generating new and renewable energy. Small sized corporations get tax reduction 20% in the Seoul Metropolitan area and 30% in an area outside the Seoul Metropolitan area.

f. Loan interest rate (5.11%)

Loan interest rate for small size corporation is 5.11% for the previous 10 years in average.

Table 7. Loan interest rate for small size corporation (2008~2017) from bank of Korea

2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	average
7.31%	5.65%	5.68%	6.00%	5.66%	4.92%	4.60%	3.87%	3.69%	3.71%	**5.11%**

* (Reference) Loan interest rate to small corporation from Economic statistics system of bank of Korea

g. Land price change rate (1.59%)

Land price change rate is 1.59% for the previous 10 years in average.

Table 8. Land price change rate (2009~2017) from Korea appraisal board

2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	average
-0.32%	0.96%	1.05%	1.17%	0.96%	1.14%	1.96%	2.40%	2.70%	3.88%	**1.59%**

* (Source) https://www.r-one.co.kr/rone/resis/statistics/statisticsViewer.do

h. Operations and Maintenance costs

IRENA (2017b) reported that O&M costs for utility-scale solar PV in U.S have been reported to be between USD 10/kW and 18/kW per year. According to empirical O&M cost data publicly availabl, solar PV O&M costs were around $16/kWAC-year in 2015 (Bolinger and Seel, 2016). When O&M costs are exchanged into KRW, the cost is around 18.2 million KRW (1140 KRW/$, 10. 31th. 2018). This study assume O&M costs as 1% of capital expenditure. O&M costs are between 18 ~ 26.2 million KRW per year.

Table 9. O&M costs of 1MW solar PV by facility type

Item	On water	Existing building	General site
Won/1MWp (million)	26.2	23.1	16.6
Facility type			

i. Capital expenditure (CAPEX)

Total installment cost of K-water solar from completed construction in 2017 will be applied to capital expenditure of this study for the solar PV type installed on existing building and on the surface of water. Capital expenditure for economic analysis of KEA website on Solar PV installed on general site is applied to capital expenditure for the solar PV on general site.

Table 10. 1MW solar PV Capital expenditure by facility type

Item	On water	Existing building	General site
KRW/1MWp (million)	2.62	2.31	1.66
remarkable	K-water (3MW)	K-water (1.2MW)	KPE (study on LCOE by generation sources)

j. Debt ratio (70%)

Debt ratio is set at 70% due to the diverse of financial condition of small-sized corporation. Lee (2017) estimated debt ratio as 70% in analyzing LCOE

k. System life (20 years)

System life for solar PV module is generally considered to be between 20 - 25years. Several study on analysis of LOCE applied between 20-25years for system life (Lee, 2017; Tilak et al. 2014; Chang.2013; Branker et al. 2011) and several study applied 25years. In this study, in order to take conservative approach to system life, 20years is applied.

l. REC weights by facility type on solar PV

In accordance with to renewable portfolio standard (RPS), solar PV installed on the existing buildings get 1.5 REC weighting, on the general site get 1.0 REC weighting, and on the water get 1.5 REC weighting.

Table 11. REC weight scheme on solar PV

REC weighting	Energy source and critia	
	Facility type	**Criteria**
0.7	Facilities in forest	
1.2	Facility installed ongeneralsite	Less than 100kW
1.0		More than 100kW
0.7		More than 3,000kW
1.5	Facility installed onexistingbuildings	Less than 3,000kW
1.0		More than 3,000kW
1.5	Facilities floating on the water	

m. System degradation rate (0.8%)

System degradation of solar PV module is guaranteed by manufactures. Manufacturers generally guarantee 92% for 10 years and 85% for 25 years. This study applies 0.8% system degradation.

n. Construction Period (2years)

This study assumes that construction period on solar PV is two years (1 year for design, 1 year for construction). Delay of solar PV installations is generally happening due to the objection of people and delay of permission to connect solar PV to grid.

o. Electricity price (SMP + REC)

Ministry of trade, industry and energy makes a fixed price bid announcement twice a year for the first half and the second half. The first half 2018 prices of SMP and REC are as shown below, and the fixed price for system marginal price and renewable energy certificate is applied for 20 years. It is allowed for Power Generation Corporation below 3MW capacity to participate in the bid. In this study, the prices of SMP and REC in the first half of 2018 are applied to calculate total revenue. SMP and REC prices are key factors in judging profitability. Revenue is calculated by multiplying the amount of generation electricity by SMP and REC prices.

Table 12. SMP and REC prices in the first half of 2018

Item	Land	Jeju Island
SMP (KRW)	95.30	134.100
REC (KRW)	84.635	55.549

3.3.4 CBA and LCOE analysis

This study analyzes B/C ratio, NPV, IRR and LCOE of solar PV by region in order to compare and the difference of solar radiation and land lease costs by region (15 metropolitan cities and provinces) and its effects on CBA and LCOE. 15 metropolitan cities and provinces are selected based on available solar radiation. This study also shows CBA and LCOE by type of solar PV when solar PV is installed on the water, existing building, and general site. Major indices applied to compute CBA and LCOE are as below table 13 and 14. Table 13 is common applied indexes and Table 14 is differently applied indices by region in analyzing CBA and LCOE.

Table 13. Common indices for 1MW solar PV.

Item	On water	Existing building	General site and forest
Capacity (MW)	1	1	1
CAPEX (million KRW)	2620	2310	1660
O&M costs (million KRW)	26.2	23.1	16.6
Discount rate (%)	4.5	4.5	4.5
Debt ratio (%)	70	70	70
Corporation tax rate (%)	20	20	20
Inflation rate (%)	2.27	2.27	2.27
Land price change rate (%)	1.59	1.59	1.59
System life (years)	20	20	20
System degradation rate (%)	0.8	0.8	0.8
Loan interest rate (%)	5.11	5.11	5.11
REC weight	1.5	1.5	1.0
Construction periods(year)	2	2	2
Electricity price(KRW)	Land (SMP : 95.33,REC :84.635) Jeju (SMP : 134.1,REC :55.549)		

Table 14. Indices determined by region for analysis CBA and LCOE of 1MW solar PV

N	City	Capacity factor (%)	Tax incentive (%)	Land (general, existing building)	water	forest
				Million KRW		
1	Seoul	13.90	20	1,451.6	273.2	123.8
2	Busan	16.14	30	177.6	33.4	15.1
3	Ddaegu	15.94	30	113.5	21.4	9.7
4	Incheon	15.00	20	151.6	28.5	12.9
5	Gwangju	15.85	30	76.9	14.5	6.6
6	Daejeon	16.36	30	108.6	20.4	9.3
7	Gyeonggi	14.75	20	76.0	14.3	6.5
8	Gangwon	15.28	30	4.1	0.8	0.3
9	Chung-Buk	15.21	30	8.6	1.6	0.7
10	Chungnam	15.14	30	14.5	2.7	1.2
11	Jeonbuk	15.23	30	7.5	1.4	0.6
12	Jeonnam	15.79	30	5.4	1.0	0.5
13	Gyeonbuk	15.27	30	6.1	1.1	0.5
14	Gyeongnam	15.81	30	14.2	2.7	1.2
15	Jeju	15.22	30	24.0	4.5	2.0
Nationwide		15.35	30	28.9	5.4	2.4

This study conducted a sensitivity analysis only for the nationwide case on the condition that solar PV installation costs decline 10% in near future, considers the cost decline of solar PV due to the rapid development of technology. In fact, the speed of cost reduction is remarkable. According to the report of the export-import bank of Korea (2018) in 2017, price of fixed-axis solar PV was \$ 1 / W, down to 1/3 of 2010 price.

a. CBA and LCOE analysis on Solar PV installed on general site by region

This study analyzes B/C ratio, NPV, IRR and LCOE by region when solar PV is installed on general site. In accordance with RPS, this study applies 1.0 REC weighting in computing CBA and LCOE. Revenue is generated by transacting SMP and REC in market. Total Revenue is calculated by this equation "Revenue = generation electricity × [(SMP+ (REC price× REC weighting, here "1")]. This study also computes land lease costs which made B/C= 1, when B/C is less than 1 in order to show reasonable land lease costs for that area. Summary of the analysis is as below table 15, and the results were expressed in maps of B/C ratio and LCOE with rankings of those values by regions to help understanding the results easily.

Table 15. CBA (NPV, B/C, IRR) and LCOE result for solar PV installed on general site

City	Capacity factor (%)	Land lease cost (million KRW)	Condition(B/C =1) Land lease cost (million KRW)	NPV (million KRW)	B/C	IRR (%)	LCOE (KRW/kwh)
Seoul	13.90	1,451.6	-11.7	-34,451	0.07	n/a	2498.0
Busan	16.14	177.6	46.0	-2,723	0.53	n/a	337.8
Ddaegu	15.94	113.5	44.7	-1,220	0.72	-7.88	251.5
Incheon	15.00	151.6	32.3	-2,437	0.54	n/a	331.8
Gwangju	15.85	76.9	44.3	-478	0.86	1.08	208.1
Daejeon	16.36	108.6	49.9	-976	0.76	-3.73	235.7
Gyeonggi	14.75	76.0	30.7	-690	0.80	-0.65	223.7
Gangwon	15.28	4.1	38.8	482	1.20	7.57	150.6
Chung-Buk	15.21	8.6	37.6	404	1.16	7.09	155.1
Chungnam	15.14	14.5	36.6	309	1.12	6.49	160.8
Jeonbuk	15.23	7.5	37.8	422	1.17	7.20	153.9

Jeonnam	15.79	5.4	44.9	546	1.22	7.95	147.7
Gyeonbuk	15.27	6.1	38.4	450	1.18	7.37	152.4
Gyeongnam	15.81	14.2	44.9	427	1.16	7.23	154.7
Jeju	15.22	24.0	47.5	328	1.12	6.61	169.4
Nationwide	**15.35**	**28.9**	**38.9**	**142**	**1.05**	**5.43**	**171.2**

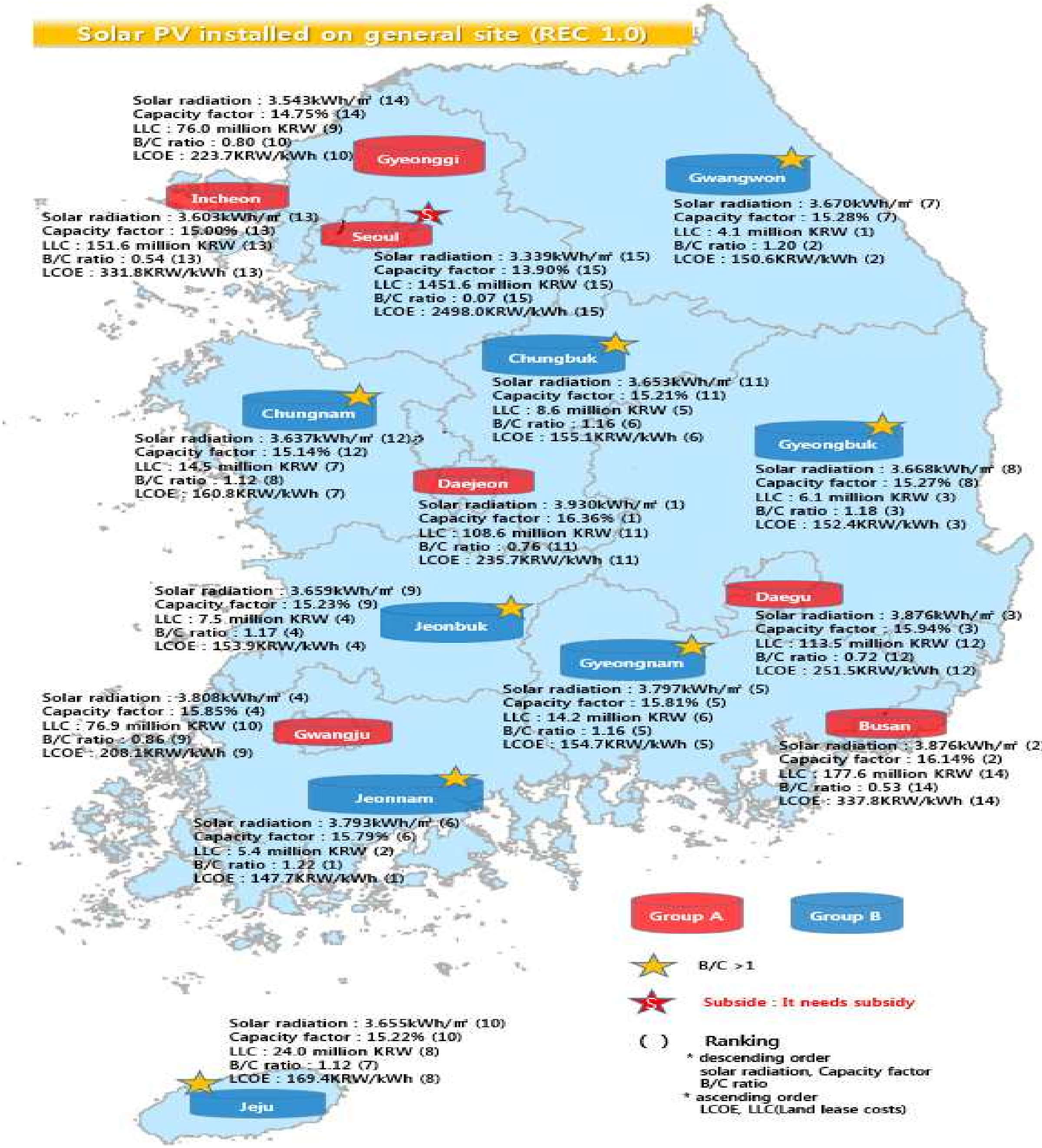


Figure 2 Information map on solar PV installed on general site.

The result shows a wide variability in the BC ratio and LCOE values. BC ratio range is between 0.07 and 1.20 and BC ratio of nationwide is 1.05. LCOE range is 147.7(KRW/kwh) ~ 2498(KRW/kWh) and LCOE of nationwide is 171.2KRW. BC ratio was less than 1 in metropolitan cities, including Gyeonggi Provinces (7 locations). In case of Daejeon, BC ratio is 0.76 despite being the highest capacity factor (16.36%).

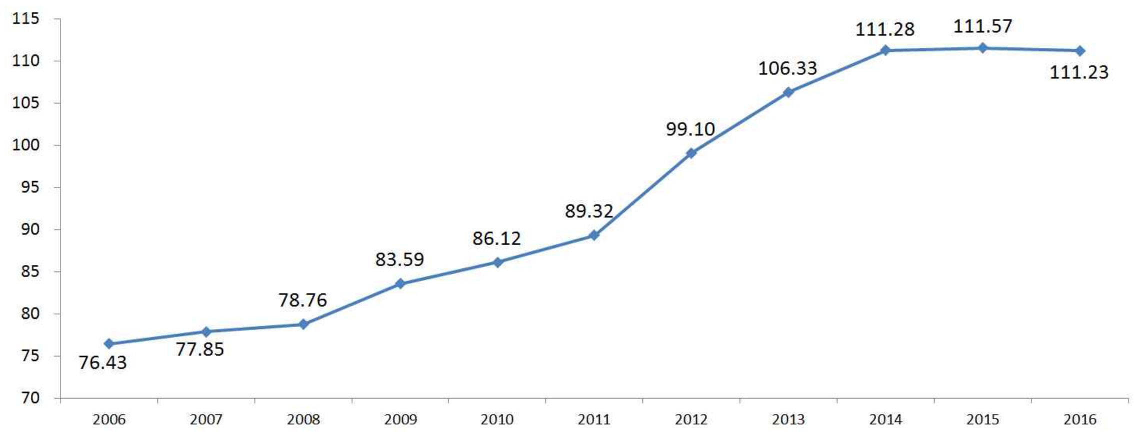
On the other hand, BC ratio is over 1 (1.05~1.20) in 8 provinces except Gyeonggi province whose land lease costs are relatively low, which explains that the factor which affects most in economic feasibility is land lease costs. Land lease cost of Jeonnam (5.4 million KRW) is higher than those of Gangwon (4.1 million KRW), but BC ratio is 1.22 and 1.20 respectively, which shows that the difference in the amount of solar radiation by region is a second factor affecting BC ratio. LCOE by region was 147.7 ~ 2498 KRW. LCOE is 208.1~2498 KRW in metropolitan cities including Gyeonggi province. LCOE in 8 provinces except Gyeonggi province is 147.7~169.4KRW

If we calculate the land lease cost which make BC 1 for the cities whose BC ratio are less than 1 in order to reflect reasonable lease cost in those area, Land lease cost in metropolitan cities including Gyeonggi province is -11.7 ~ 49.9 million KRW. Main differences in land lease cost are caused by solar radiation by region. In the case of Seoul, it shows that solar PV installation is not economically feasible without annual subsidies of 11.7million KRW due to relatively low solar radiation. This study conducted sensitivity analysis on the nationwide case when solar PV costs decline 10%. The result is as below table 16.

Table 16. Sensitivity analysis on nationwide of solar PV installed on general site

Sensitive	B/C	LCOE (KRW/kWh)	Present value of cost (unit : KRW)					
			Total (%)	CAPEX (%)	Loan interest (%)	O&M (%)	Land lease costs (%)	Corporation tax (%)
100%	1.05	171.2	2801 (100)	1664 (59.2)	243 (8.6%)	261 (9.3%)	457 (16.3%)	186 (6.6%)
90%	1.13	158.7	2604 (100)	1497 (57.5)	195 (7.5)	235 (9.0)	457 (17.5)	220 (8.5)

This result shows that LCOE (171.2KRW/kWh) of solar PV is much higher than electricity sales price (111.23KRW/kWh) of 2016, it needs 50% decline of CAPEX (111.68.KRW) in order to meet the level of electricity sales price of 2016.



*(reference) the 8th basic plan of long-term electricity supply and demand in MOTIE

Figure 3 Year basis electricity sales price trend (unit: KRW/kWh)

According to the report of Korea power exchange on levelized cost of electricity (2018), LCOE from fossil fuels was 81.22KRW/kWh as of 2017 and LCOE would increase to 100.06 KRW/kWh in 2030. This study expects that LCOE of solar PV on general site is required to reduce 60% of CAPEX - initial investment cost - as of today in order to meet LCOE from fossil fuels in 2030. The time to reach grid parity is expected to advance, taking into account cost reduction of solar PV owing to rapid development of technology. Global major research institution predicted LCOE of solar PV as below table 17.

Table 17. Prediction of solar PV LCOE

Item	**IRENA**	BNEF NEO	OECD/IEA	KEEI	HRI
range	**global weighted average**	South Korea	global average	South Korea	South Korea
year	**’15yr ⇨ ’25yr**	’17yr ⇨ ’30yr	’15yr ⇨ ’30yr	’16yr ⇨ ’24yr	’16yr ⇨ ’30yr
cost reduction	**59%↓**	66%↓	41~50%↓	36%↓	31%↓

*(reference) the 8th basic plan of long-term electricity supply and demand in MOTIE

b. CBA and LCOE analysis on Solar PV installed on existing building by region

This study analyzes B/C ratio, NPV, IRR and LCOE by region when solar PV is installed on existing building. In accordance with RPS, this study applies 1.5 REC weighting in computing CBA and LCOE. This study also computes land lease costs which made B/C= 1, when B/C is less than 1. Summary of the analysis is as below table 18 and also the results were expressed in maps of B/C ratio and LCOE with rankings of those values by regions to help understanding the results easily and make decisions conveniently as below figure 4.

Table 18. CBA (NPV, B/C, IRR) and LCOE result for solar PV installed on existing building

City	Capacity factor (%)	Land lease cost (million KRW)	Condition(B/C =1 Land lease cost (million KRW)	NPV (million KRW)	B/C	IRR (%)	LCOE (KRW/kwh)
Seoul	13.90	1,451.6	-28.6	-34,742	0.09	n/a	2560.0
Busan	16.14	177.6	34.3	-2,859	0.57	n/a	387.9
Ddaegu	15.94	113.5	32.6	-1,367	0.73	-3.71	302.5
Incheon	15.00	151.6	17.4	-2,651	0.57	n/a	387.4
Gwangju	15.85	76.9	31.7	-667	0.85	1.08	261.5
Daejeon	16.36	108.6	39.0	-1,103	0.78	-1.61	285.2
Gyeonggi	14.75	76.0	15.1	-934	0.79	-0.47	281.5
Gangwon	15.28	4.1	24.8	293	1.09	5.87	204.7
Chung-Buk	15.21	8.6	23.3	208	1.06	5.48	209.4
Chungnam	15.14	14.5	22.1	108	1.03	5.01	215.5
Jeonbuk	15.23	7.5	23.6	228	1.07	5.57	208.2
Jeonnam	15.79	5.4	32.4	379	1.11	6.27	200.0
Gyeonbuk	15.27	6.1	24.3	258	1.08	5.71	206.5
Gyeongnam	15.81	14.2	32.5	258	1.07	5.71	207.1
Jeju	15.22	24.0	18.1	-83	0.98	4.10	222.5
Nationwide	**15.35**	**28.9**	**25.1**	**-53**	**0.99**	**4.25**	**225.5**

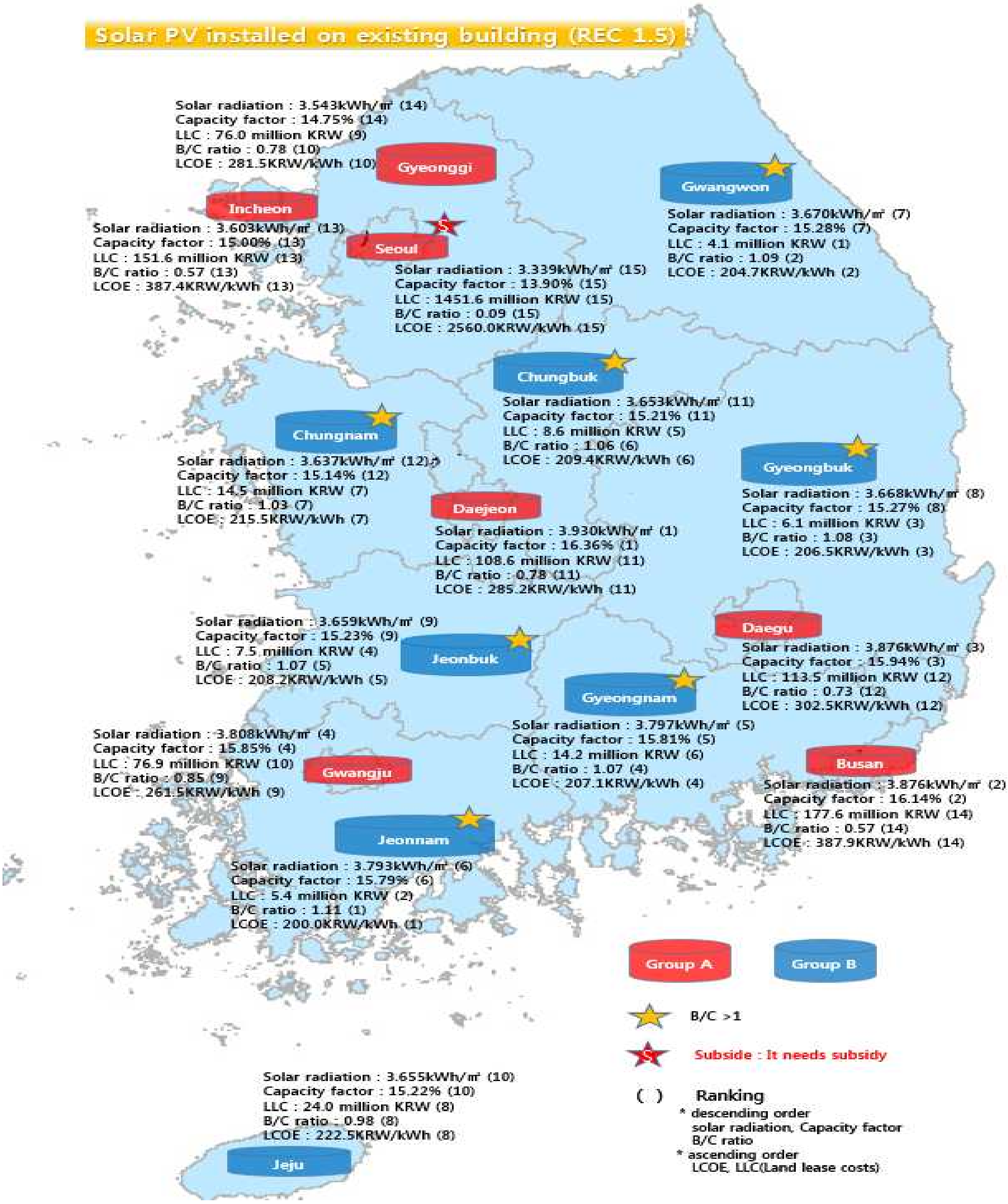


Figure 4. Information map on solar PV installed on existing building

This result shows a wide variability in the BC ratio and LCOE values, BC ratio range is between 0.09 and 1.11 and LCOE range is 200(KRW/kwh) ~ 2560(KRW/kWh). BC ratio was less than 1 in metropolitan cities including Gyeonggi and Jeju Provinces (eight locations).

In case of Daejeon, BC ratio is 0.78 despite having the highest capacity factor (16.36%). When we compare BC ratio on general site and on existing building for Daejeon, BC ratio slightly increased from 0.76 on general site to 0.78 on existing building. It explains that increased REC weighting has a positive effect on BC ratio despite increased capital expenditure. On the other hand, BC ratio of Jeju provinces decreased from 1.12 on general site to 0.98 on existing building. It explains that increased revenue ratio by increased REC weighting is less than the increased capital expenditure in Jeju, especially due to relatively low REC price in Jeju, 68.283KRW/kWh, compared to those of land, 84.635KRW/kWh.

On the other hand, BC ratio is over 1 (1.03~1.11) in 7 provinces except Gyeonggi and Jeju provinces whose land lease costs are relatively low, which explains that the factor which affects most in economic feasibility is land lease costs. Land lease cost of Jeonnam (5.4 million KRW) is higher than those of Gangwon (4.1 million KRW), but BC ratio is 1.11 and 1.09 respectively, which shows that the difference in the amount of solar radiation by region is a second factor affecting BC ratio. The range of LCOE by region is between 200 ~ 2560 KRW. LCOE is between 261.5~2560 KRW in metropolitan cities including Gyeonggi province. The range of LCOE in 8 provinces except Gyeonggi province is between 200~222.5 KRW. LCOE of existing building is relatively higher than LCOE of general site. The reason is that LCOE is determined by generation electricity divided by cost. Construction cost of solar PV on existing building is greater than those of solar PV on general site.

If we calculate the land lease cost which make BC 1 for the cities whose BC ratio are less than 1 in order to reflect reasonable lease cost in those area, Land lease cost in metropolitan cities including Gyeonggi province is -28.6 ~ 39.0 million KRW, main difference of land lease cost are caused by solar radiation by region. In the case of Seoul, it shows that solar PV installation is not economically feasible without annual subsidies of 28.6 million due to relatively low solar radiation. This study conducted sensitivity analysis on the nationwide case when solar PV costs decline 10%. The result shows that 10% reduction of solar PV installation costs on existing building makes it economically feasible by the increase of B/C ratio from 0.99 to 1.07 as below table 19.

Table 19. Sensitivity analysis on nationwide of solar PV installed on existing building

Sensitive	B/C	LCOE (KRW/kWh)	Present value of cost (unit : KRW)					
			Total (%)	CAPEX (%)	Loan interest (%)	O&M (%)	Land lease costs (%)	Corporation tax (%)
100%	0.99	225.47	3700 (100)	2315 (62.6)	372 (10.1)	363 (9.8)	457 (12.3)	193 (5.2)
90%	1.07	207.79	3410 (100)	2084 (61.1)	298 (8.7)	327 (9.6)	457 (13.4)	245 (7.2)

c. CBA and LCOE analysis on Solar PV installed on water by region

This study analyzes B/C ratio, NPV, IRR and LCOE by region when solar PV is installed on the surface of water. In accordance with RPS, this study applies 1.5 REC weighting in computing CBA and LCOE. This study also computes land lease costs which made B/C= 1, when B/C is less than 1. Summary of the analysis is as below table 20. The analysis results were expressed in maps of B/C ratio and LCOE with rankings of those values by regions to help understanding the results easily and make decisions conveniently as below figure 5.

Table 20. CBA (NPV, B/C, IRR) and LCOE result for solar PV installed on water

City	**Capacity factor** (%)	**Land lease cost** (million KRW)	**Condition(B/C =1 Land lease cost** (million KRW)	**NPV** (million KRW)	**B/C**	**IRR** (%)	**LCOE** (KRW/kwh)
Seoul	13.90	273.2	-29.7	-6,630	0.33	n/a	668.4
Busan	16.14	33.4	9.1	-352	0.92	2.97	242.6
Ddaegu	15.94	21.4	6.4	-215	0.95	3.58	234.9
Incheon	15.00	28.5	-8.2	-537	0.87	2.13	255.7
Gwangju	15.85	14.5	5.0	-136	0.97	3.92	230.1
Daejeon	16.36	20.4	12.7	-110	0.97	4.03	228.5
Gyeonggi	14.75	14.3	-11.7	-377	0.90	2.86	246.1
Gangwon	15.28	0.8	-3.0	-53	0.99	4.28	225.8

Chung-Buk	15.21	1.6	-4.4	-84	0.98	4.14	227.4
Chungnam	15.14	2.7	-5.6	-119	0.97	4.00	229.5
Jeonbuk	15.23	1.4	-4.2	-79	0.98	4.17	227.0
Jeonnam	15.79	1.0	4.6	52	1.01	4.72	219.4
Gyeonbuk	15.27	1.1	-3.5	-65	0.98	4.22	226.3
Gyeongnam	15.81	2.7	4.8	31	1.01	4.63	220.6
Jeju	15.22	4.5	-9.5	-201	0.95	3.64	229.7
Nationwide	**15.35**	**5.4**	**-2.3**	**-111**	**0.97**	**4.03**	**229.0**

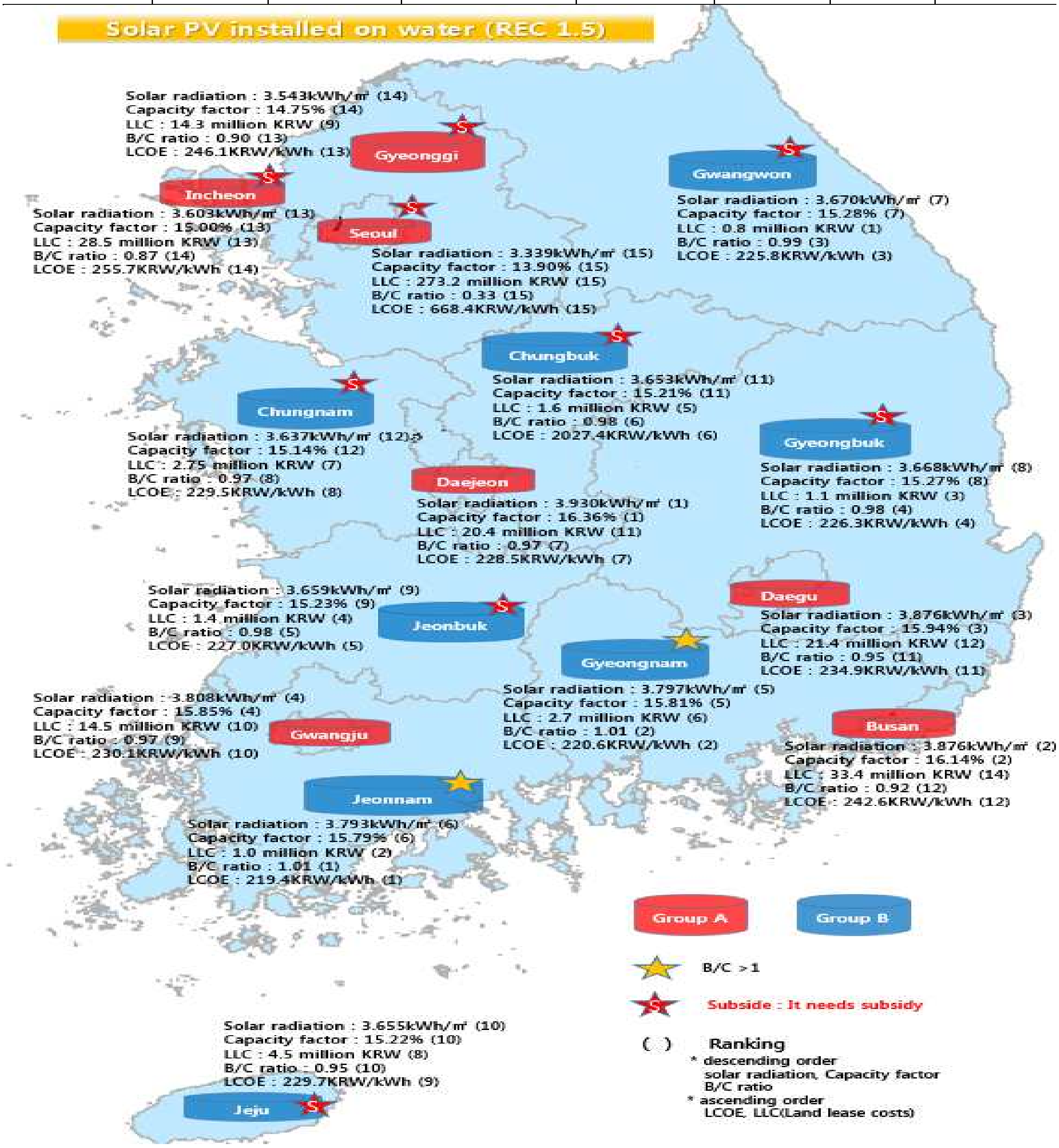


Figure 5. Information map on solar PV installed on water

This result shows a wide variability in the BC ratio and LCOE values; BC ratio range is between 0.33 and 1.01 and LCOE range is 219.4(KRW/kwh) ~ 668.4(KRW/kWh). BC ratio was less than 1 in all metropolitan cities and provinces except Jonnam and Gyeongnam. It explains that increase in capital expenditure is much greater than decrease in land lease costs.

The range of LCOE by region is between 219.4 ~ 668.4 KRW. The range of LCOE is between 219.4~255.8 KRW in all metropolitan cities and provinces except Seoul. Variation is much smaller than the variation of existing building (200.0~387.9 KRW). Only 4 regions - Busan, Daegu, Gwangju, Daejeon - Among 13 metropolitan cities and provinces where BC ratio is less than 1 are economically feasible without annual subsidies. Those 4 metropolitan cities are included in highest level of solar radiation - Rankings 1~4 among 15 -. If we ignore land lease cost, only cities included in the highest level of solar radiation - Rankings 1~6, among 16 - have more than 1 BC ratio. In case of Economic feasibility on solar PV installed on the water, we see that solar radiation is the factor that affects most in economic feasibility. This study conducted sensitivity analysis on the nationwide case when solar PV costs decline 10%. The result shows that 10% reduction of solar PV installation costs on water makes it economically feasible by the increase of B/C ratio from 0.97 to 1.07 as below table.

Table 21. Sensitivity analysis on nationwide of solar PV installed on water

Sensitive	B/C	LCOE (KRW/kWh)	Present value of cost (unit : KRW)					
			Total (%)	CAPEX (%)	Loan interest (%)	O&M (%)	Land lease costs (%)	Corporation tax (%)
100%	0.97	229.00	3758 (100)	2626 (69.9)	432 (11.5)	412 (11.0)	86 (2.3)	202 (5.4)
90%	1.07	208.66	3424 (100)	2363 (69.0)	344 (10.1)	371 (10.8)	86 (2.5)	260 (7.6)

d. CBA and LCOE analysis on Solar PV installed in forest with regard to REC adjustment from 1.0 to 0.7 (REC 1.0 →0.7)

This study analyzes B/C ratio, NPV, IRR and LCOE by region as REC weighting for forest was adjusted from 1.0 to 0.7 in 2018. The analysis results were expressed in maps of B/C ratio and LCOE with rankings of those values by regions to help understanding the results easily and make decisions conveniently. Summary of the analysis is as below table 22.

Table 22. CBA (NPV, B/C, IRR) and LCOE result for solar PV installed on water

City	NPV (million KRW)		B/C		IRR(%)		LCOE (KRW/kwh)	
	1.0	**0.7**	**1.0**	**0.7**	**1.0**	**0.7**	**1.0**	0.7
Seoul	-3,977	-4,568	0.40	0.33	n/a	n/a	447.5	461.9
Busan	469	82	1.18	1.03	7.49	5.04	152.8	149.7
Ddaegu	511	134	1.20	1.05	7.74	5.38	149.9	146.8
Incheon	306	-56	1.12	0.98	6.47	4.12	160.7	158.0
Gwangju	540	162	1.22	1.07	7.91	5.56	148.1	144.9
Daejeon	586	200	1.23	1.08	8.19	5.80	146.4	143.1
Gyeonggi	356	1	1.14	1.00	6.78	4.50	157.3	154.5
Gangwon	534	171	1.22	1.07	7.88	5.62	147.5	144.3
Chung-Buk	514	152	1.21	1.06	7.76	5.50	148.3	145.2
Chungnam	494	134	1.20	1.06	7.63	5.38	149.3	146.2
Jeonbuk	517	156	1.21	1.07	7.78	5.52	148.1	144.9
Jeonnam	615	242	1.25	1.10	8.36	6.07	143.7	140.4
Gyeonbuk	527	165	1.22	1.07	7.83	5.58	147.7	144.5
Gyeongnam	607	234	1.25	1.10	8.32	6.02	144.1	140.8
Jeju	633	398	1.26	1.16	8.47	7.05	150.7	148.4
Nationwide	512	148	1.21	1.06	7.75	5.47	148.7	145.5

As REC weighting for forest was adjusted from 1.0 to 0.7, this result shows BC ratio decreases from 0.4~1.26 to 0.33~1.16 and BC ratio of nationwide decreases from 1.21 to 1.06. LCOE was changed from 143.7 ~ 447.5 to 140.8 ~461.9 KRW and LCOE of nationwide was changed from 148.7 to 145.5KRW. The change of LCOE through REC adjustment is explained by the increase of loan interest costs which is delayed by the decrease of revenue. Although economic feasibility decreased, most of regions still have economic feasibility as shown in figure 6.

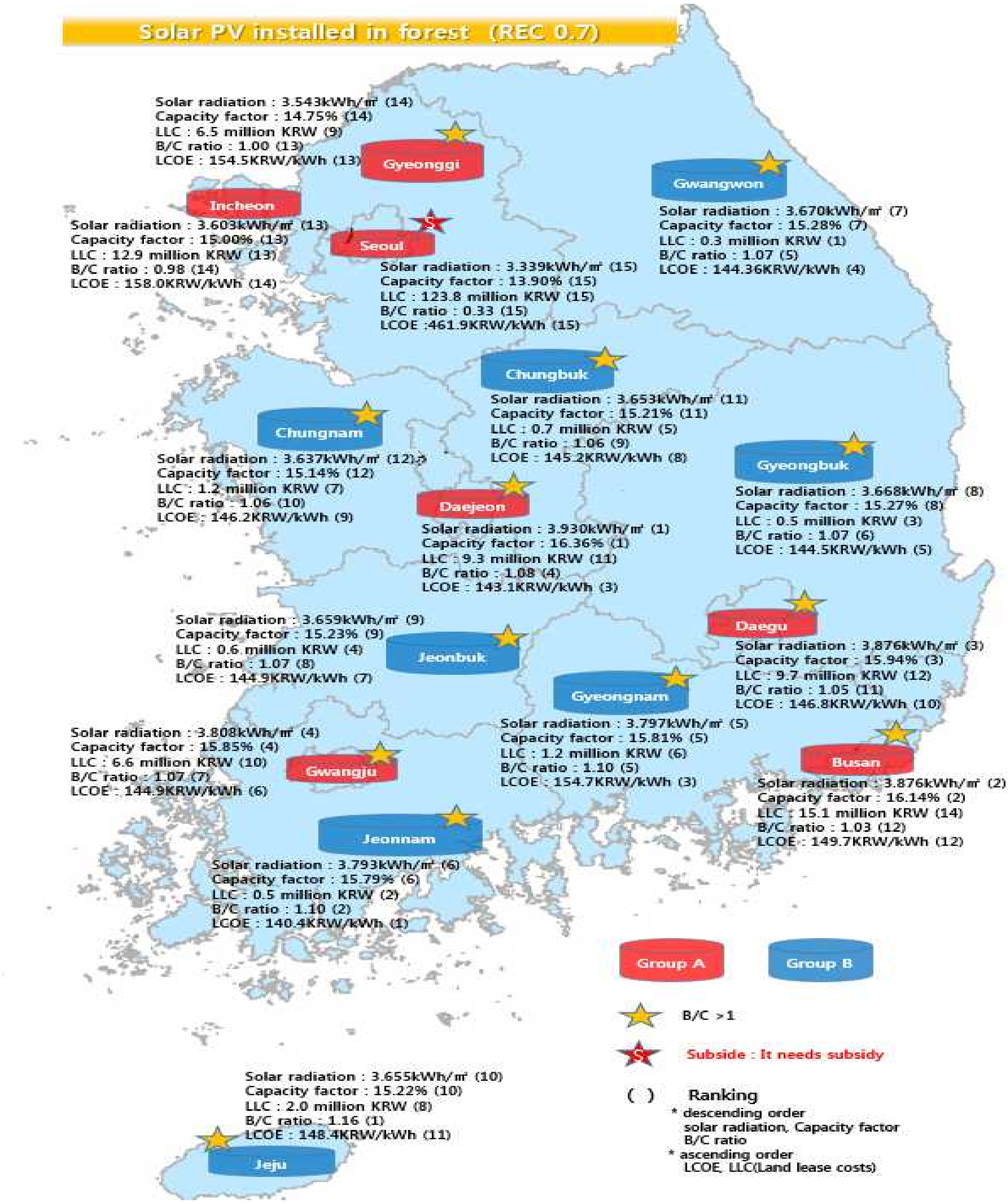


Figure 6. Information map on solar PV installed in forest (REC 0.7)

When it compares B/C ratio of forest with BC ratio of general site, B/C ratio of general site in 8 provinces except metropolitan cities and Gyeonggi are between 1.12 ~ 1.22 and B/C ratio of forest (REC weighting 0.7) are between 1.06 ~ 1.16. Summary is as below table 23.

Table 23. BC ratio of 8 province (forest Vs general site)

BC ratio	Gangwon	Chungbuk	Chungnam	Jeonbuk	Jeonnam	Gyeonbuk	Gyeongnam	Jeju
Forest	1.07	1.06	1.06	1.07	1.10	1.07	1.10	1.16
General site	1.20	1.16	1.12	1.17	1.22	1.18	1.16	1.12

According to Korea forest agency (2018), solar PV installations areas in forest are as below table 24 as of September 2017. Solar PV installations areas are concentrated in 5 provinces (Gangwon, Chungnam, Jeonbuk, Jeonnam, Gyeonbuk). As REC weight for forest decreased, solar PV installations are expected to move from forest to general site in those 5 provinces.

Table 24. Solar PV installations area in forest (09. 2017, source from Korea forest agency)

Area	Gangwon	Chungnam	Jeonbuk	Jeonnam	Gyeonbuk	Etc.
proportion	15%	13%	11%	22%	22%	17%

This study conducted sensitivity analysis on the nationwide case when solar PV costs decline 10%. The result is as below table 25.

Table 25. Sensitivity analysis on nationwide of solar PV installed in forest

Sensitive	B/C	LCOE (KRW/kWh)	Present value of cost (unit : KRW)					
			Total (%)	CAPEX (%)	Loan interest (%)	O&M (%)	Land lease costs (%)	Corporation tax (%)
100%	1.06	145.5	2388 (100)	1664 (69.7)	243 (10.2)	261 (10.9)	39 (1.6)	181 (7.6)
90%	1.16	132.96	2182 (100)	1497 (68.6)	195 (8.9)	235 (10.8)	39 (1.8)	216 (9.9)

When comparing B/C ratio of general site with those of forest above these five areas, general sites were shown to have comparative advantage to forest in B/C ratio, even assuming

CAPEX decline to 70%. So, REC adjustment for forest is proper and enough to induce investment in forest towards investment on general site. The result is shown as below in table 26.

Table 26. Comparison of B/C ration between forest and general site when CAPEX declines to 70% through Sensitivity analysis.

Name	B/C ratio of forest			B/C ratio of general site		
	100%	90%	70%	100%	90%	70%
Gangwon	1.07	1.18	1.44	1.20	1.30	1.57
Chung-Buk	1.06	117	1.43	116	1.26	1.51
Chungnam	1.06	1.16	1.42	1.12	1.21	1.45
Jeonbuk	1.07	1.17	1.48	1.17	1.27	1.53
Jeonnam	1.10	1.21	1.47	1.22	1.32	1.59
Gyeonbuk	1.07	1.17	1.43	1.18	1.28	1.54
Gyeongnam	1.10	1.20	1.46	1.16	1.26	1.50

e. Summary of B/C ratio and LCOE for all types of solar PV

Summary of B/C ratio, LCOE and sensitivity analysis with respect to all type solar PV by region is shown in table 27 and 28. The results were expressed in maps of B/C ratio and LCOE with rankings of those values by regions to help understanding the results easily and make decisions conveniently as shown in figure 7 and 8. In figure 7, when it compared cumulative solar capacity with the result of B/C ratio, this study shows an interesting fact that cumulative capacity of solar PV by region was generally shown to be in proportion to ranking of B/C ratio of general site. It explains that economic feasibility is the most powerful motivation in distribution of solar PV. Slight differences of rankings between B/C ratio and cumulative capacity of solar PV by region are explained by the following limitations in expanding solar PV, such as lack of grid capacity to connect solar PV, acceptance of people by region, geographical characteristics like Gangwon, composed of forest rather than flat land regarded as a proper site to install solar PV.

Table 27. Summary of B/C ratio and LCOE for all types of solar PV

City	C.F%	Present value of MWH	General site		Building		Water		Forest	
			B/C	LCOE (KRW/kWh)	B/C	LCOE (KRW/kWh)	B/C	LCOE (KRW/kWh)	B/C	LCOE (KRW/kWh)
Seoul	13.90	14,862	0.07	2498.0	0.09	2560.0	0.33	668.4	0.33	461.9
Busan	16.14	17,252	0.53	337.8	0.57	387.9	0.92	242.6	1.03	149.7
Ddaegu	15.94	17,043	0.72	251.5	0.73	302.5	0.95	234.9	1.05	146.8
Incheon	15.00	16,038	0.54	331.8	0.57	387.4	0.87	255.7	0.98	158.0
Gwangju	15.85	16,947	0.86	208.1	0.85	261.5	0.97	230.1	1.07	144.9
Daejeon	16.36	17,493	0.76	235.7	0.78	285.2	0.97	228.5	1.08	143.1
Gyeonggi	14.75	15,770	0.80	223.7	0.79	281.5	0.90	246.1	1.00	154.5
Gangwon	15.28	16,334	1.20	150.6	1.09	204.7	0.99	225.8	1.07	144.3
ChungBuk	15.21	16,260	1.16	155.1	1.06	209.4	0.98	227.4	1.06	145.2
Chungnam	15.14	16,188	1.12	160.8	1.03	215.5	0.97	229.5	1.06	146.2
Jeonbuk	15.23	16,284	1.17	153.9	1.07	208.2	0.98	227.0	1.07	144.9
Jeonnam	15.79	16,883	1.22	147.7	1.11	200.0	1.01	219.4	1.10	140.4
Gyeonbuk	15.27	16,325	1.18	152.4	1.08	206.5	0.98	226.3	1.07	144.5
Gyeongnam	15.81	16,900	1.16	154.7	1.07	207.1	1.01	220.6	1.10	140.8
Jeju	15.22	16,269	1.12	169.4	0.98	222.5	0.95	229.7	1.16	148.4
Nationwide	15.35	16,411	1.05	171.2	0.99	225.5	0.97	229.0	1.06	145.5

Table 28. Summary of sensitivity analysis on nationwide case for all types of solar PV

type	Sensitive	B/C	LCOE (KRW/kWh)	Present value of cost (unit : KRW)					
				Total (%)	CAPEX (%)	Loan interest (%)	O&M (%)	Land lease costs (%)	Corporation tax (%)
general	100%	1.05	171.2	2801 (100)	1664 (59.2)	243 (8.6)	261 (9.3)	457 (16.3)	186 (6.6)
	90%	1.13	158.7	2604 (100)	1497 (57.5)	195 (7.5)	235 (9.0)	457 (17.5)	220 (8.5)
building	100%	0.99	225.47	3700 (100)	2315 (62.6)	372 (10.1)	363 (9.8)	457 (12.3)	193 (5.2)
	90%	1.07	207.79	3410 (100)	2084 (61.1)	298 (8.7)	327 (9.6)	457 (13.4)	245 (7.2)
water	100%	0.97	229.00	3758 (100)	2626 (69.9)	432 (11.5)	412 (11.0)	86 (2.3)	202 (5.4)
	90%	1.07	208.66	3424 (100)	2363 (69.0)	344 (10.1)	371 (10.8)	86 (2.5)	260 (7.6)
forest	100%	1.06	145.5	2388 (100)	1664 (69.7)	243 (10.2)	261 (10.9)	39 (1.6)	181 (7.6)
	90%	1.16	132.96	2182 (100)	1497 (68.6)	195 (8.9)	235 (10.8)	39 (1.8)	216 (9.9)

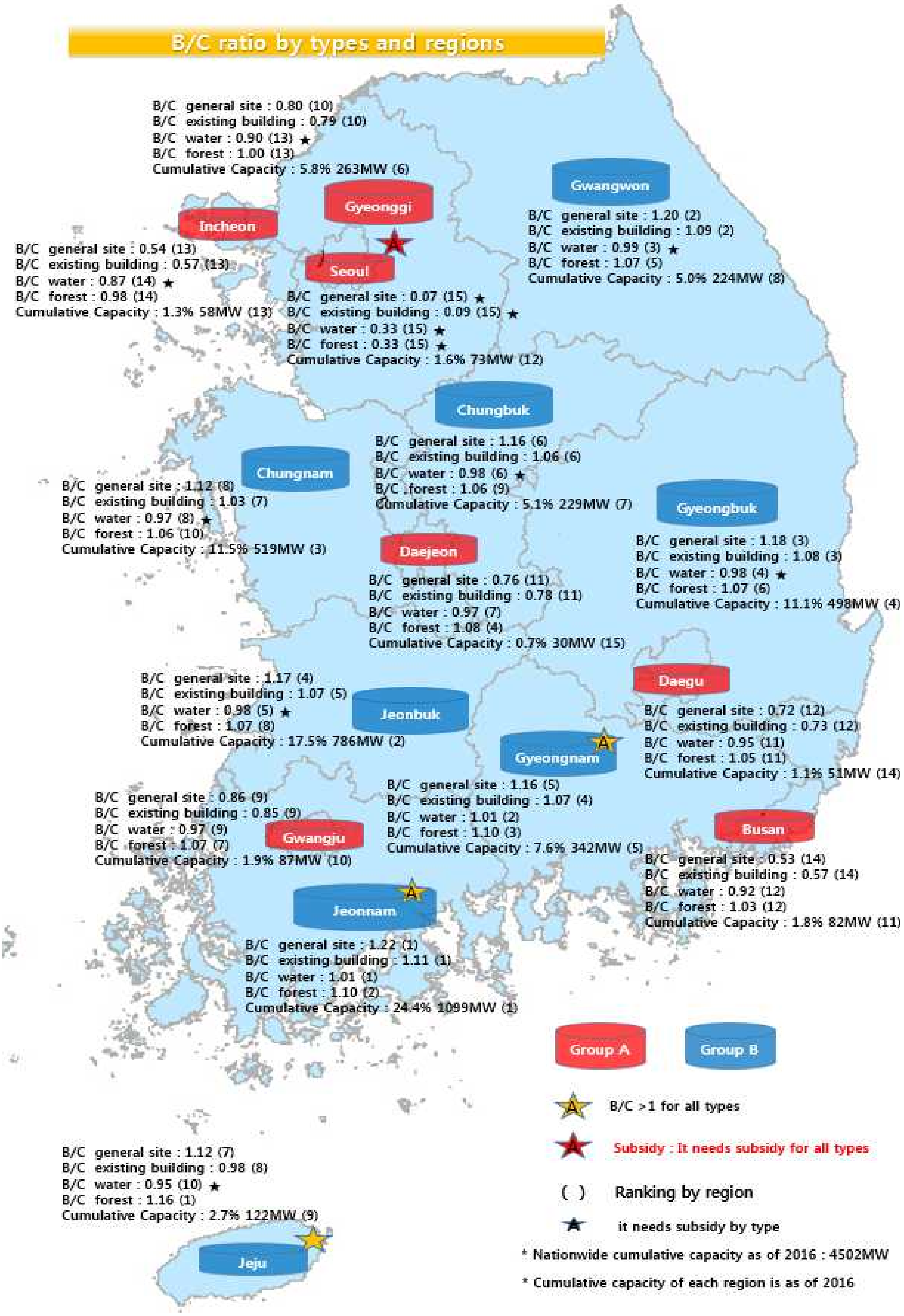


Figure 7. Information map on B/C ratio by types and regions

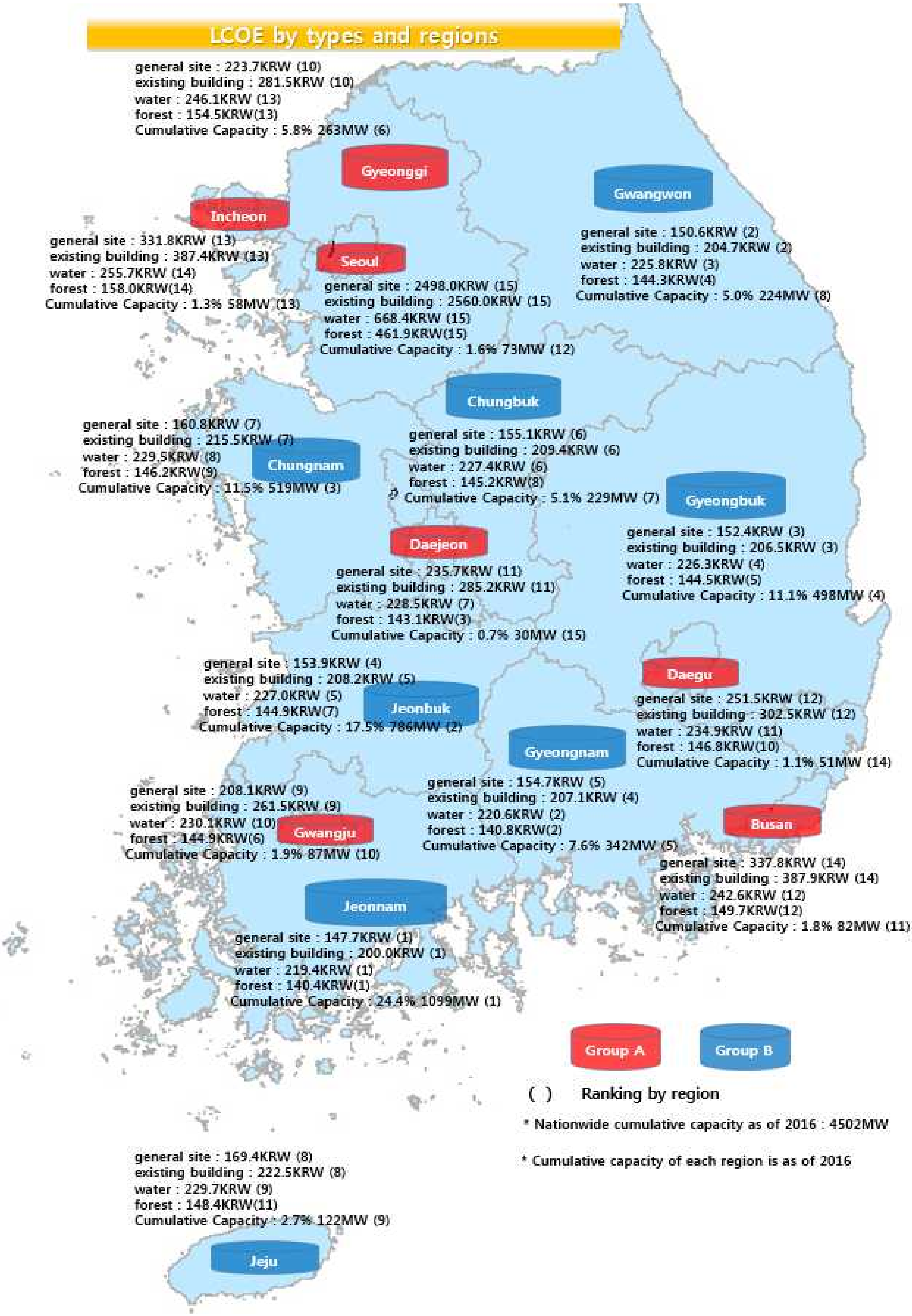


Figure 8. Information map on LCOE by types and regions

4. Policy proposals

Korean government set the target to boost the proportion of renewable energy in power generation to 20 percent by 2030. Among total of - 58.5Gigawatt - renewable energy, Korean government plans to replace 57.3% of renewable energy with solar PV. In order to spread renewable energy, Korean government has introduced renewable portfolio standard since 2012 and spread various energy policies such as distribution of 1 million green house with solar panel, zero energy building certification mandatory, and farming solar PV. However, in the process of spreading various policies to expand solar PV, there has been unexpected inverse effects such as devastation of forest by the expansion of solar PV in forest. In order to minimize the unexpected adverse effects and expand solar PV effectively, this study analyzed the economic feasibility and LCOE with respect to the types of utility scale (1MW) solar PV by region in South Korea and give policy proposals based on this analysis.

In case of Seoul, if other conditions are the same except land lease costs and solar radiation, we cannot secure economic feasibility without subsidy of government due to low solar radiation and high land lease costs. It is necessary to implement mandatory policies such as zero energy building certification mandatory led by public institution until LOCE of solar PV decrease to secure economic feasibility. Limited subsidy should be allocated to metropolitan cities that have relatively higher solar radiation than Seoul so as to maximize efficiency of subsidy and use limited resources to the greatest advantage.

In case of other metropolitan cities, especially Daejeon, Busan, Daegu, Gwangju, considering those cities are most abundant with solar radiation (ranking 1~4, among 15 regions). If other conditions are the same except land lease costs and solar radiation, most subsidy needs to be concentrated on these area. Incheon and Gyeonggi including those four cities, can secure economic feasibility within reasonable land lease costs, so government needs to encourage industry players to install solar PV in those area by offering incentives such as tax exemption and low loan interest rate.

In case of seven provinces except Gyeonggi and Jeju, they are shown to secure economic feasibility for solar PV installed on existing building and general site. Land lease costs are relatively low and potential land area to install solar PV is huge; these regions account for 82% of land area in South Korea. Policies are needed to increase public acceptance of solar PV projects. If other conditions are the same except land lease costs and solar radiation, so, government needs to concentrate on public campaign to reduce aversion of people on solar PV installations and give incentives to people or village that attracts solar PV. Furthermore, government needs to activate solar PV installation business that consists of people in those village such as cooperatives by giving incentives such as financial support, low loan interest rate, and fixed SMP and REC price. As a compensation of those areas where people are cooperative in installing solar PV, government needs to attract and invest solar related industries to those areas. Moreover, offering land for free and giving tax exemption to companies which invest solar related industry could lead to increase of employment.

With regard to utility scale (1MW) solar PV installed on water, this cannot secure economic feasibility in most areas except Jeonnam and Gyeongnam due to the higher installation cost (CAPEX) as of today. But floating solar PV has large potential globally, with enormous opportunities in Asia. It is a global trend to expand floating solar PV. KEI (2017) estimated that potential capacity of domestic floating solar PV was about 8783MW in Korea. Sensitivity analysis result on floating solar PV showed that 10% reduction of solar PV installation costs made it economically feasible for the most regions which have high solar radiation except Seoul, Gyeonggi, Incheon which have lower solar radiation. If other conditions are the same except land lease costs and solar radiation, therefore, effort is needed to develop the technology associated with floating solar PV so that it leads to the cost reduction of floating solar PV. At the same time, subsidy or benefits is needed to be concentrated on the regions which has high solar radiation to encourage key players to invest floating solar PV on these area. Also, effort is needed to foster floating solar PV industry by using two trap methods with respect to agricultural reservoir and dam. 1MW utility scale or small sized floating solar PVs is need to be recommended to be installed on agricultural reservoir considering it requires less total cost due to less water level change relative to multi-purpose dam. Installation of large utility scale solar PV installed on dam should be led by public corporation "K-water" considering the fact that floating solar PV installed on drinking water dam, until technology is accumulated to manage floating solar PV on dam safely and cost-effectively.

With regard to conversion of site or region, this study showed that REC adjustment in forest would induce investment from forest towards general site due to comparative advantage in B/C ratio of general site to forest. So, government needs to keep implementing REC weighting adjustment to activate or deactivate certain areas.

This study analyzed the total cost for lifetime of solar PV of nationwide cases of each type and found that 15.2% of total costs for the solar PV installed on general site, 15.3% of total costs for the solar PV installed on existing building and 17.7% of total costs for the solar PV installed on water consisted of loan interest costs and corporation tax. If other conditions are the same except land lease costs and solar radiation, this study suggests that government reduces loan interest rate and corporation tax in order to help key players to secure economic feasibility, activate solar PV installations, and foster the business associated with solar PV.

Lastly, since this study found that CAPEX and land lease costs were the greatest determining factor of LCOE and economic feasibility through analysis of LCOE and CBA, efforts are needed to reduce CAPEX. Furthermore, technology development is needed to increase module efficiency which is directly connected to the decrease of installation area.

5. Conclusions

This study started with the idea that analysis of economic feasibility and LCOE would contribute to the expansion of economically feasible solar PV and minimize the unexpected reverse effects such as devastation of forest.

This study conducted economic feasibility and LCOE of solar PV systems by considering solar radiation and land lease costs which differs by region in South Korea. Also, it suggested land lease costs range for areas which cannot secure economic feasibility due to high land lease costs. Then, this study conducted sensitivity analysis in order to predict economic feasibility when CAPEX decreased 10% and compared LCOE of fossil fuels. The analysis results were expressed in maps of B/C ratio and LCOE by region with rankings to help understanding the results easily and make decisions conveniently. This study gave policy proposals to expand solar PV based on this analysis. It is expected that the results of this could help in the decision making process regarding expansion of solar PV. Also, the results can help policymakers to improve the existing solar PV associated with policies and accelerate industrial key players to invest in solar PV. LCOE can be reduced if policymakers consider the results of this study and apply the proposed policies. Ultimately, this study can help reduce the burden of electricity rates on people resulting from government's expanding solar PV projects.

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