Feasibility Study of Solar Energy Generation Potential along the National Highways in Korea

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ABSTRACT

This study aims at conducting two analyses to select the potential sites and to evaluate economic feasibility by using them determined in first analysis in an attempt to effectively support the government-proceeding project of photovoltaic power generation along the national highways in Korea. The first analysis for the potential site selection focuses on determining the potential sites along/near the highway right-of-way including interchanges and disused roads of the National highways. The second analysis for the economic feasibility study has been conducted by applying a cost-benefit analysis. According to B/C ratio and Net Present Value estimated, it turns out that the photovoltaic power generation project at the 261 potential sites in total is economically feasible and profitable. The total area estimated from the national highway right-of-way is about 7 million square meters and B/C ratio is much higher than 1.0 which means that the project itself is not only cost efficient considerably, but helpful to reduce greenhouse gas emission even when applying the minimum power capacity generated from the sites.

Keywords: Photovoltaic power generation, national highways, feasibility study, cost/benefit analysis

1. INTRODUCTION

1.1 Background

Nowadays Korean Government has promoted to construct more solar energy generation facilities to comply with national policies and strategies to reduce greenhouse gas emissions caused by power generation. According to Korea Energy Management Corporation, the government set a national goal of new & renewable power generation to reach 11 percent of total energy consumption until 2035. In addition, they have implemented a national energy efficiency action plan to generate 14.1% of photovoltaic power from 2.7% and 18.2% of wind power from 2.2% by then. Therefore, photovoltaic power generation as of Dec. 2014 was increased by 2.2 times in new installation and by 2.4 times in power generation, indicating annual accumulative energy production grew up to 1,427GWh [1].

Korea Expressway Corporation (KEC) also started to do a business with photovoltaic power generation since 2012, right after they revised “Korea highway cooperation act” in Sep. 2011 because the government implemented a strategy, “Renewable Portfolio Standard”, which is established in 2012. KEC can currently produce 21.2MW power capacity by owning and running two separated sub-corporations, and by leasing eight sites of the Korean Expressways to private power generation companies [2].

However, photovoltaic power generation business has yet to start on the national highways managing by the Ministry of Land, Infrastructure, and Transport because it is very complicated to get permission and/or approval for development activity on the national highway right-of-way since photovoltaic power generation business has not been approved by law even though solar technology is gradually extended to highway traffic field such as traffic lighting devices.

This study thus was intended to conduct two analyses in series. First, it is to select the potential sites for the photovoltaic power generation business on the national highways using Geographic Information System techniques, and next, to evaluate economic feasibility by using the sites selected in the first analysis so that the Korean government can implement efficiently and cost-effectively the photovoltaic power generation project with confidence.

1.2 Case Review of Highway Photovoltaic Power Generation Project (or Business)

In Korea, a photovoltaic power generation plant on a bicycle lane was built on a 4.6km-long section between Sejong city and Daejeon Metropolitan city in 2012 and has been in operation by now. This photovoltaic power generation facility built on the bike lane for the first time in the world has generated 6MWh daily (2,200MWh annually) corresponding to the power that can be supplied to 600 households in a residential area [3].

Another photovoltaic power generation facility on top of sound barrier tunnel (2.7MW) in Sejong city was built on a 2.8km-long Daepyungdong–Sodamdong section as part of the project for promoting the use of environment-friendly energy in Dec. 2015. It can supply the electric power to 900 households annually [4].

Germany has produced the largest volume of new & renewable energy using photovoltaic power facility in the world and the scale of photovoltaic power generation along the highway is also very diverse and huge. For example, “Solar Park” along A-7 highway generates 5.25 MW that can meet the power consumption requirements for 1,650 households annually. What is
noteworthy is, it is in operation in the form of cooperative
in which the citizens participate by investing 1,000 Euros
each with the condition of 3.5% interest for 5 years.
Another facility on the A-62 highway produces 3MW
which can accommodate 750 households [5].

Figure 1: View of photovoltaic power generation facility
on the bicycle lane in Sejong city of Korea (Source: Mael Business Newspaper[3])

Figure 2: Photovoltaic power generation facility along A-7 highway in Germany (Source: GreenTech[5])

When it comes to the U. S., Oregon Department of Transportation (DOT) and Portland General Electric (PGE) jointly built the photovoltaic power facility in the type of Public-Private Partnership (PPP) project in 2008 to generate the power for interchange lighting devices.

Starting with 104kw capacity photovoltaic power generation to supply electricity to interchanges on I-5 and I-205 in Portland, a similar small power facility began to be constructed by California, Ohio, and Massachusetts DOTs. In the states of Colorado, Florida, and Missouri, photovoltaic power generation using highway rest areas and service plazas are in operation. Additionally, “Baldock Solar highway” in the Oregon state was built in 2012 with 175MW photovoltaic power facility installed at I-5 Baldock rest area [6].

Figure 3: Photovoltaic power generation facility in the state of Oregon in the U.S. (Source: Oregon Gov. [6])

Ohio DOT built 100kW photovoltaic power facility near I-280 Veterans’ Glass City Skyway Bridge and the power generated is sent to system power or utilized for LED lightings on the bridge. Massachusetts DOT completed an 112kW photovoltaic power facility on slope of Route 44 in collaboration with Carver Town.

Massachusetts DOT gives a permit for airspace lease in return for the rent $880 annually from the town and the power generation is used for operation of wastewater treatment facility.

From the cases reviewed above, photovoltaic power generation is usually implemented within the right-of-way or using nearby site. Some projects are involved with PPP, besides government-led project. Local government or private investors are granted for a certain payback which is economically efficient.

1.3 Literature Review

In this section, some studies will be reviewed in terms of economic feasibility study or financial analysis of photovoltaic power generation project.

Kim [7] performed an economic feasibility study of photovoltaic power generation of road noise barrier nationwide by using a simple economic method based on actual cost and an economic evaluation method by converting from future potential profit and cost to net present value (NPV). In this study power generation cost was estimated based on 30 years of system service life, 0.75 of performance coefficient, 4.1kWh/m² of solar radiation on slope, and 7.0% of discount rate. As a result of benefit/cost analysis of a 2,477km-long section with noise barrier, B/C ratio was 1.02 and NPV was about $50K with 734MW capacity. A sensitivity analysis says that it is economically feasible in case of 5% discount rate and 25 years of service life. If the discount rate is 6% or higher, operation period should be extended to 30 years or longer.
TRB [8] conducted a feasibility study for using traffic infrastructure for solar / wind power energy. For solar energy generation, Life-Cycle Cost Analysis (LCCA) of fixed pole system photovoltaic power generation was applied. The results indicate that installing 3.6kW photovoltaic power generation system on the roof of DOT building in outskirt of Salt Lake City in the state of Utah caused a loss of $7,383 when 20 years of service life was applied, referring that photovoltaic power generation system without subsidy more than half of the total cost would remain uneconomical.

Florida International University [9] and Good Company funded by Florida DOT conducted a financial analysis of value extraction project that can be implemented on highway by comparing their alternatives with projects already completed or on-going in other states and by selecting most likely achievable project in the state of Florida. From the results after analyzing and comparing 300kW and 1MW system using internally-developed Financial Analysis Screening Tool, 300kW would be more favorable in profitability considering the current subsidy system for clean & renewable energy project in Florida. Considering scale of economy, 1MW capacity seems to be much profitable, but the result shows that 300kW capacity project can be processed and economic because there are still legal barriers to be improved at that stage.

From the findings above, the feasibility study of photovoltaic power generation using traffic facilities and infrastructure has been applied in the U. S. since 2012. In case of small-scale solar power generation project like 3kW, it appears to be less economically efficient than other projects since electric power production volume is very low compared to an initial investment such as huge installation cost, and thus without government’s subsidy or incentive, the photovoltaic power generation project should be scaled up to get the return on the investment. In the U. S. the state DOT cannot be allowed to receive the subsidy directly from the government, which makes the government-led power generation project more uneconomical. Thus, it can be interpreted that the photovoltaic power generation project on highway facility or transportation infrastructure should be implemented as a PPP-type or a lease-type rather than the government-led project to be more cost efficient.

2. SELECTION OF POTENTIAL SITES

This section describes the method and results in selecting the potential sites suitable to the photovoltaic power generation for the study. First, it is necessary to set the criteria and scope, and second collect the original data, usually based on geographic information, and analyze the spatial data so as to identify the specific information on the potential sites for solar energy generation.

2.1 Criteria and Scope in Determining the Potential Sites

The scope determined initially for analyzing the potential sites for the photovoltaic power generation using highway facilities are outlined as Table 1 below. The private-owned land was excluded from the evaluation for the study. The Korean Expressways and National highways could be considered in the study because local government-owned roads are not under the maintenance of the Ministry of Land, Infrastructure, and Transport (MOLIT). But given the feasibility study was carried out by KEC and some projects are underway now, Expressways were excluded from this study eventually.

So, unused land under ramps of interchanges and disused roads due to the newly constructed highways might be feasibly considered. In case of disused roads, only when area of which is large enough to accommodate solar arrays were included in the site selection.

<table>
<thead>
<tr>
<th>Site</th>
<th>Category</th>
<th>Applicability</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private land</td>
<td>Private-owned</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Government-owned land</td>
<td>Interchanges, junctions of national highways</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Disused roads of national highways</td>
<td>○</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unused land along/near national highways</td>
<td>○</td>
<td>Δ</td>
</tr>
</tbody>
</table>

2.2 Collection of the Original Data

In order to measure area of unused land of interchanges and disused roads of national highways and identify location of the potential sites clearly from the highways, GIS-based data were collected from various sources. The following is the list collected for the study:

<table>
<thead>
<tr>
<th>#</th>
<th>Data Name</th>
<th>Source</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Numerical map (topographic map)</td>
<td>National Geographic Information Institute (NGII)</td>
<td>2015</td>
</tr>
<tr>
<td>2</td>
<td>Motorway statistical data</td>
<td>MOLIT</td>
<td>2014</td>
</tr>
<tr>
<td>3</td>
<td>Transportation digital map</td>
<td>Korea Transport Institute</td>
<td>2014</td>
</tr>
</tbody>
</table>
Information relating highways was obtained through numerical map (topographic map) of National Geographic Information Institute or transportation digital map of Korea Transport Institute. Motorway statistical data from the MOLIT was also used to identify the auto-only-highway among national highways. Cadastral map data and official land price data were used to estimate the land lease fee which should be paid for the power generation. Basic requirements of disused road on the national highways for photovoltaic power generation are outlined as below.

<table>
<thead>
<tr>
<th></th>
<th>Cadastral map</th>
<th>Official land value</th>
<th>Land lease fee calculation equation</th>
<th>Disused road status</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Local government</td>
<td>MOLIT</td>
<td>MOLIT</td>
<td>MOLIT</td>
</tr>
<tr>
<td>5</td>
<td>2014</td>
<td>2015</td>
<td>2015</td>
<td>2015</td>
</tr>
</tbody>
</table>

2.3 Spatial Information Analysis Results

Figure 4 shows a method of spatial analysis in sequence using the original data collected previously.

First, the spatial information on interchanges/junctions and disused roads of the national highways was collected and the GIS-based actual area was estimated accordingly. Second, the land price of each land piece was calculated using the data of cadastral map and official price value. Last, the land lease fee was estimated by applying the land lease fee calculation equation provided by the MOLIT.

Figure 4: Description of a spatial analysis method

Optimal potential sites for the photovoltaic power generation determined through the process above totaled 261. The interchanges at speed limit 80 km/h or less on the national highways are mostly a diamond-type interchange which is considered interrupted flow allowing easy access to the site and inappropriate for the power generation. Those interchanges were excluded by on purpose. Distribution of the potential sites nationwide by administrative district is shown in the Figure 5 below. 50 sites are located in Gyeonggi and Gyungbuk Province, respectively, which were followed by Jeonbuk and Chungbuk provinces. Total area of 261 sites nationwide was estimated at 7 million m² (see Table 3.)

Figure 5: Distribution of the potential sites for the photovoltaic power generation
Average lease fee of the potential sites for the photovoltaic power generation on the national highways is shown in Figure 8. The highest lease fee is about 2.5 million won in Gyeonggi Province which was followed by Chungnam province while Chungbuk and Jeonbuk provinces have more sites but low lease fees indicating favorable requirements.

Figure 8: Average lease fee for the potential sites

Compared with the number of sites by administrative district above, Gyeongbuk and Jeonbuk Provinces are seemingly the most feasible areas to implement the project.

3. ECONOMIC FEASIBILITY EVALUATION

Evaluation of Economic feasibility of the photovoltaic power generation at the potential sites was conducted by using the estimated data described above such as the area and the lease fee of the sites based on the location. Power generation capacity, installation/operation/maintenance costs, revenue and benefit from greenhouse gas reduction, and trading price of the electric power were considered to determine the applicability of the photovoltaic power generation on the highways and then to comprehensively evaluate the multi-variable criteria for the study. The evaluation scope and method was described in the following Figure 9.

Basic requirements to estimate the power generation capacity, costs including from design to operation/maintenance, total revenue, carbon dioxide reduction benefit, and so on are listed in the box below. The Maximum capacity was referred from the case of the U.S. while the minimum capacity, operating hours, and costs were derived from the data of application sample from Korea Expressway Corp.

<table>
<thead>
<tr>
<th>Basic requirements for economic feasibility analysis of photovoltaic power generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>· Road category: IC/JC of national highways (focusing on auto-only), disused road</td>
</tr>
<tr>
<td>· Capacity: Max 0.25kw/㎡ ~ Min 0.05kw/㎡</td>
</tr>
<tr>
<td>· Operating hours : 3.5~3.7 hrs</td>
</tr>
<tr>
<td>· Cost: Installation, lease fee, operation and</td>
</tr>
</tbody>
</table>
- Installation cost: 2 million won/kw
- Operation/Maintenance cost: 30,000 won/kw/year
- Highway right-of-way lease fee: 5% of land price (per 1 m²)
- Revenue: SMP (Sales Market Price) + REC (Renewable Energy Certificate)
- Sales price: SMP 97 won/kwh, REC 93 won/kwh (2015.12)
- Greenhouse gas coefficient: 0.45 kg/kwh
- Greenhouse gas cost: 150,000 won/ton CO₂ (MOLIT)
- Job creation: 35.5 persons/MW (KEMC data)

* Based on data from Korea Expressway Corp and solar energy suppliers

Table 4: Accumulative power generation volume, cost, revenue and carbon dioxide reduction

<table>
<thead>
<tr>
<th>Operating hours</th>
<th>Estimated power generation (mil Mwh)</th>
<th>Estimated Annual Cost (100bil won)</th>
<th>Estimated revenue (100bil won)</th>
<th>Carbon reduction (mil ton CO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;Based on 0.25 kw/m² - 55,000 job creation&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.7h</td>
<td>48.6</td>
<td>43.2</td>
<td>56.2</td>
<td>21.9</td>
</tr>
<tr>
<td>3.5h</td>
<td>45.9</td>
<td>43.2</td>
<td>53.2</td>
<td>20.7</td>
</tr>
<tr>
<td>&lt;Based on 0.05 kw/m² - 11,000 job creation&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.7h</td>
<td>9.7</td>
<td>8.8</td>
<td>11.2</td>
<td>4.4</td>
</tr>
<tr>
<td>3.5h</td>
<td>9.2</td>
<td>8.8</td>
<td>10.6</td>
<td>4.1</td>
</tr>
</tbody>
</table>

According to the results above, accumulative estimated electricity volume is dependent on the capacity and operating hours. The maximum accumulative volume based on the capacity 0.25 kw/m² and 3.7 operating hours was 4,860 MWh annually, and the minimum volume based on the capacity 0.05 kw/m² and 3.5 operating hours was 920 MWh annually. Capacity-based annual total cost in present value of 2015 was 4.3 trillion won in maximum and 0.88 trillion won in minimum. For the economic analysis, besides revenue, greenhouse gas coefficient was applied to estimate the carbon reduction cost and the results say that the maximum amount of the reduction using 3.7 operating hours was 22 million ton-equivalent which corresponds to one fifth of total carbon dioxide emission of transport sector in Korea.

The profitability and economic feasibility of the 261 potential sites on the national highways are outlined in Table 5. The profitability (referring profit-cost ratio) only was from 1.2 to 1.3 increasing to 1.77 in maximum when considering the carbon reduction benefit. The MOLIT's guideline [9] says that exceeding 1.0 of b/c ratio means that the project itself is very economically feasible to implement. The NPV estimated between 100 and 1,300 billion won shows that the photovoltaic power generation project on the 261 sites is economically feasible.

Profitability is very critical element because the photovoltaic power generation project is mostly implemented by private investors or by a firm of public-private project investment. Thus cost and revenue for the evaluation period shall be accurately estimated to decide whether the project is profitable or not and then the economic feasibility shall be analyzed considering benefit of the carbon dioxide reduction. Profitability and economic feasibility can be diagnosed using a Cost-benefit analysis which can be applied to calculate B/C ratio and Net Present Value (NPV) according to the MOLIT's guideline [10]. Accumulative estimated electricity volume, cost, revenue and the carbon dioxide reduction benefit of the power generation are outlined in Table 4 below.
The first analysis for site selection focuses on the department of Gyeongbuk and Jeonbuk Provinces, and estimated electricity volume was not considered in cost and subsidy, and thus, it is possible that oversupply would possibly cause unexpected problems. Installation cost and prediction by the U.S. Department of Energy show that there was no estimation for demand and supply, and thus, the potential of the photovoltaic power generation system keeps varying but the annual transaction price considering demand and supply was not estimated. The study of the efficiency of photovoltaic power generation on the national highways in Korea and the second analysis showed that the sites along near the highway right-of-way including Interchanges/Junctions and disused roads of the national highways. Estimates of the total area and the official price of land pieces chosen had been conducted with the GIS-based data provided by the Ministry of Land, Infrastructure, and Transport, National Geographic Information Institute, and Korea Transport Institute, and so on. The results from the first analysis show that the sites within the Gyeongbuk and Jeonbuk Provinces are seemingly the most feasible areas to implement the photovoltaic power generation project due to the number of sites and their low land lease fees. The second analysis for the economic feasibility evaluation had been conducted by applying a cost-benefit analysis. According to B/C ratio and Net Present Value estimated through the analysis, it turned out that the photovoltaic power generation project at the 261 sites in total, mainly selected from the Interchanges/Junctions of the national highways with speed limit at and over 80km/h and disused roads available, is economically feasible and profitable. The total feasible area estimated from the national highway right-of-way is about 7 million square meters and B/C ratio is much higher than 1.0 which means that the project itself is not only cost efficient considerably, but helpful to reduce greenhouse gas emission even when applying the minimum power capacity generated from the sites.

Table 5: Power generation, cost, revenue and greenhouse gas emission reduction

<table>
<thead>
<tr>
<th>Operating hours</th>
<th>Profitability (P/C)</th>
<th>Economic feasibility* (B/C)</th>
<th>Economic feasibility* (NPV, 100bil won)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.7h</td>
<td>1.30</td>
<td>1.77</td>
<td>13.1</td>
</tr>
<tr>
<td>3.5h</td>
<td>1.23</td>
<td>1.67</td>
<td>10.1</td>
</tr>
<tr>
<td>3.7h</td>
<td>1.27</td>
<td>1.72</td>
<td>2.4</td>
</tr>
<tr>
<td>3.5h</td>
<td>1.20</td>
<td>1.63</td>
<td>1.8</td>
</tr>
</tbody>
</table>

*)Economic feasibility includes greenhouse gas emission reduction benefit

4. CONCLUSIONS AND FUTURE STUDY

This study was intended to conduct two analyses in sequence to select the potential sites of the photovoltaic power generation on the national highways in Korea and to evaluate economic feasibility of them in order to support an efficient progress of the government-leading clean & renewable energy project. The first analysis for the potential site selection focuses on determining the sites along near the highway right-of-way including Interchanges/Junctions and disused roads of the national highways. Estimates of the total area and the official price of land pieces chosen had been conducted with the GIS-based data provided by the Ministry of Land, Infrastructure, and Transport, National Geographic Information Institute, and Korea Transport Institute, and so on. The results from the first analysis show that the sites within the Gyeongbuk and Jeonbuk Provinces are seemingly the most feasible areas to implement the photovoltaic power generation project due to the number of sites and their low land lease fees. The second analysis for the economic feasibility evaluation had been conducted by applying a cost-benefit analysis. According to B/C ratio and Net Present Value estimated through the analysis, it turned out that the photovoltaic power generation project at the 261 sites in total, mainly selected from the Interchanges/Junctions of the national highways with speed limit at and over 80km/h and disused roads available, is economically feasible and profitable. The total feasible area estimated from the national highway right-of-way is about 7 million square meters and B/C ratio is much higher than 1.0 which means that the project itself is not only cost efficient considerably, but helpful to reduce greenhouse gas emission even when applying the minimum power capacity generated from the sites.

Constraints in this study were found as follows: first, since the study aimed at selecting the potential sites and evaluating the feasibility from the Interchanges/Junctions and disused roads available in total national highways, estimated electricity volume was not predicted at a site specific-level. Second, installation cost of the photovoltaic power generation system keeps varying but the annual transaction price considering demand and supply was not estimated. According to the installation cost and prediction by the U.S. Department of Energy, the cost is on the decline every year and in such a case, oversupply would possibly cause unexpected decrease in cost and subsidy, and thus, it can be recommended to consider such variable factors in the future study [11].

Figure 10: Photovoltaic power generation system installation cost by the U.S. department of energy [11]

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REFERENCES

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