**Derivation of Supply Curve of PV ~**

**Impact of Setback regulation ~**

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**Abstract**

This is an abstract.

#용어정의: PV potential, solar potential, generation potential, capacity potential?

**Keywords:** Keword1, Keword-2, Keyword-3

1. Introduction

As the 13th largest greenhouse gas (GHG) emitter, South Korea accounted for 1.3% of the global GHG emissions [1]. The country has pledged to achieve its nationally determined contribution (NDC) by 2030 and carbon neutrality by 2050 [2,3]. Like many nations, South Korea views the expansion of renewable energy as a key strategy for decarbonization. Globally, renewable energy represented 27.8% of the total electricity generation, whereas in South Korea, the share was significantly lower at 6.1% [4]. Even if the renewable energy generation share is lower than other countries, South Korea decided to lower the renewable energy target for 2030 from 30% to 22% [5]. The decision is based on the current government’s willingness to enlarge the role of nuclear power in the middle of energy transition.

In 2021, global renewable energy generation amounted to 7,857TWh, with hydro energy accounting for 4,400 TWh (56%), wind energy for 1,838 TWh (23%), solar energy for 1,033 TWh (13%), and other renewable sources contributing 586 TWh (8%). In terms of South Korea's renewable energy generation in 2022, the country produced a total of 50.4 TWh, distributed as follows: 30.7 TWh (61%) from solar energy, 11.9 TWh (24.0%) from bio energy, 3.4 TWh (7%) from wind energy, 3.5 TWh (7%) from hydro energy, and 0.8 TWh (1%) from other sources [6]. When comparing South Korea and the global status in terms of using renewable energy, there are significant differences in the types of renewable resources predominantly utilized. Globally, hydro energy is the largest contributor, making up 56% of total renewable generation. In contrast, South Korea heavily relies on solar energy, which accounts for 56.6% of its renewable energy production, far exceeding the global average of 13%. This highlights a stark contrast in renewable energy strategies, with South Korea placing a much greater emphasis on solar energy compared to the global status, where hydro and wind energy dominate.

According to the carbon neutrality scenario of South Korea, the renewable energy generation in 2050 is projected to be 889.9 TWh under Scenario A and 736.0 TWh under Scenario B. Assuming the current share of solar energy in renewable energy generation (61%) remains constant, solar power generation in 2050 would amount to 542 TWh under Scenario A and 449 TWh under Scenario B. Considering that the theoretical, technical, and economic PV potential of South Korea in 2020 was estimated to be 137,347 TWh/year, 3,117 TWh/year, and 495 TWh/year, respectively [7]. It indicates that the minimum required amount (449TWh) for carbon neutrality can likely be met when the economic potential (495TWh) is fully utilized. However, only 6% (30.7TWh) of the economic PV potential (495TWh) is currently being utilized.

There are several reasons for this underutilization of PV potential. The shapes of the renewable portfolio and energy mix are determined by many factors such as natural environment, energy security, economy, politics and others [8]. Energy policies could facilitate the expansion of the renewable energy internalizing positive externalities from renewable energy [9,10]. On the other hand, some regulations could be barriers for promotion of renewable energy, even if the regulations have other purposes in the afraid of drastic and thoughtless expansion of renewable energy. In many countries environmental licensing are said to be a cause of delays in the completion of renewable energy farms [11–15]. In South Korea, setback regulation is controversial. Setback regulation means that PV facilities must maintain a minimum setback distance from designated sites (ex. residential areas, roads, parks, and cultural heritage) to be eligible for installation. As a result of opposition from local residents to installation of PV facilities, local governments are introducing the setback regulations [16]. Local residents oppose the installation of PV facilities due to concerns over environmental and visual impacts [17–20]. Even if efforts, for example sharing economic benefits from PV facilities [21–24], the participation of residents in the PV development process [25], increase of perceived trust of PV [26] and others, are being made to increase residents' acceptance of PV facilities, the opposition by residents is a major obstacle to the expansion of PV facilities. Especially in South Korea, setback regulations are detrimental due to i) the country's heavy reliance on PV and ii) the country's limited land area. As previously mentioned, 61% of South Korea's renewable energy generation comes from solar power. And South Korea ranks 22nd in population density among 216 countries worldwide, with 530 people living per square kilometer [27]. It is hard to find available sites that can meet all the necessary conditions for siting PV facilities. Therefore, it is important to examine the impact of setback regulations on PV potential in South Korea.

When setback regulations are applied nationwide, only 23% of the potential generation of PV can be utilized (566TWh out of 2,507TWh). In contrast, if these regulations were relaxed to 300 meters and 100 meters, the utilization rate of the potential would increase to 25% (625TWh) and 54% (1,365TWh), respectively [28]. In Incheon province, which faced the least setback regulations, only 68% of the potential site area was usable due to these restrictions. On the other hand, in Chungbuk and Chungnam, the regions most affected by setback regulations, only 22% of the potential site area could be utilized [29]. In three counties—Hampyeong in Jeollanam-do, Hamyang in Gyeongsangnam-do, and Gumi in Gyeongsangbuk-do—due to setback regulations, 54%, 53%, and 32% of the respective potential PV installation area are available [30].

This study aims to examine the impact of setback regulations on PV potential in Gyeonggi province, a province out of 17 ones in South Korea. Gyeonggi province accounts for 10.2 % of the country’s area [31] and 27% of its population [32]. It is the region where the introduction of renewable energy is most urgently needed among the 17 ones in South Korea. First, a regional differential electricity pricing system is currently being discussed in South Korea, and it is expected that a region's electricity self-sufficiency rate will determine retail electricity prices. Gyeonggi Self Sufficiency: 59% [33]. Therefore, Gyeonggi Province needs to increase its power supply to avoid economic losses caused by rising electricity prices. Second, South Korea has XX RE100 companies, and XX of them are headquartered in Gyeonggi Province [34,35]. Supplying these companies with locally produced renewable energy (e.g., through PPAs) will help them achieve their RE100 goals, preventing economic losses. Third, the governor of Gyeonggi Province is strongly committed to expanding solar power [36]. Despite the national renewable energy supply target being lowered in the 10th Basic Plan for Electricity Supply and Demand, the governor has declared a goal to install 9 GW of solar power during their term. In this context, the expansion of solar power in Gyeonggi Province is crucial.

Gyeonggi Province is composed of 28 cities and 3 counties (hereafter referred to as "cities" without distinguishing between cities and counties). Out of the 31 cities, 12 have implemented setback regulations. These regulations mostly pertain to distances from residential areas and roads, with setback distances ranging from a minimum of 100 meters to a maximum of 500 meters (see Appendix for details).

토지분류를 다양하게 했다는 장점,

Novelty of this paper

토지분류를 했다는 점.

setback영향을 경제적으로 파악했다는 점.

#### Administrative Definition ####

Ko (2023) Rural opposition에서 아래 문구 인용.

South Korea has three-tier local governance systems: Tier 1 (province-level or state-level) includes 8 provinces and 7 metropolitan cities, including Seoul. Tier 2 (county-level) includes 226 counties and cities affiliated with the Tier 1 governments, and 2 autonomous jurisdictions (Sejong city and Jeju Island) excluded from the analysis. Lastly, Tier 3 (town-level) governments are affiliated with the Tier 2 governments. The unit of analysis of this study is a county-level (Tier 2) government. I will generally refer to these tier 2 governments as “counties,” even though some county-level governments are titled “cities.” Ulleung county is also excluded in the event history analysis to follow since it is an island and therefore cannot account for spatial frailties (N = 225).

Objective:

1) explore suitable sites for PV deployment. (GIS-based approach)

2) scenario analysis (No Setback vs. Setback)

3) Supply curve

Comparison of PV energy potential

4) Compare supply curve of PV (LCOE assumption)

4)

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텍스트, 전자제품, 스크린샷, 웹사이트이(가) 표시된 사진

자동 생성된 설명

Fig. . Study Design

1. Methodology
   1. GIS-based approaches

Land-use types are categorized.

# 9가지 유형별 대표 사진

|  |  |  |
| --- | --- | --- |
| 스크린샷, 태양광 발전, 태양 에너지, 태양 전지 패널이(가) 표시된 사진  자동 생성된 설명 | 스크린샷, 태양광 발전, 태양 에너지, 태양 전지 패널이(가) 표시된 사진  자동 생성된 설명 | 스크린샷, 태양광 발전, 태양 에너지, 태양 전지 패널이(가) 표시된 사진  자동 생성된 설명 |
| 스크린샷, 태양광 발전, 태양 에너지, 태양 전지 패널이(가) 표시된 사진  자동 생성된 설명 | 스크린샷, 태양광 발전, 태양 에너지, 태양 전지 패널이(가) 표시된 사진  자동 생성된 설명 | 스크린샷, 태양광 발전, 태양 에너지, 태양 전지 패널이(가) 표시된 사진  자동 생성된 설명 |
| 스크린샷, 태양광 발전, 태양 에너지, 태양 전지 패널이(가) 표시된 사진  자동 생성된 설명 | 스크린샷, 태양광 발전, 태양 에너지, 태양 전지 패널이(가) 표시된 사진  자동 생성된 설명 | 스크린샷, 태양광 발전, 태양 에너지, 태양 전지 패널이(가) 표시된 사진  자동 생성된 설명 |

Fig. . Representative examples of PV installation across nine land-use types.

* + 1. Industrial complex

- 산업단지 정의 및 유형 설명.

- 산업단지를 골라낸 방법

* + 1. Logistics complex

- 물류단지 정의 및 유형 설명.

- 물류단지를 골라낸 방법

* + 1. Residential complex
    2. Public buildings
    3. Mountainous area
    4. Farmland
    5. Parking lot
    6. Roadside land
    7. Water

Table. . Summary of land-use types

|  |  |  |
| --- | --- | --- |
| Land-use type | Description | Data source |
| Industrial complex |  |  |
| Logistics complex |  |  |
| Residential complex |  |  |
| Public buildings |  |  |
| Mountainous area |  |  |
| Farmland |  |  |
| Parking lot |  |  |
| Roadside land |  |  |
| Water |  |  |

* + 1. Geographical constraint

법적, 지형적 규제를 검토한 사항들에 대한 설명.

- (농지) 농업보호구역, 농업진흥지역

- (산지) 보전산지, 경사 15도.

- (전체) 이격거리

* 1. Calculation of PV potential

Annual (8,760 hours) theoretical potential generation ( in kWh) of PV in the given area ( in m2) is calculated as the global horizontal irradiation ( in kW/m2) as followings.

The theoretical potential is limited to deliver meaningful information to policy makers. Geographical and technical constraints would be taken into account when we try to find more realistic estimation for the PV potential. The geographical and technical potential would be calculated as followings. [37–42]

Here, (in kWh/m2) is geographical and technical generation potential under geographical (ex. protected area) and technical constraints (ex. PV module efficiency). (unitless) is generator-to-system area ratio, which is the ratio of the area occupied by the PV generator (including PV arrays and the spaces between them) to the total suitable area available for the PV system. It indicates how efficiently the available area is utilized for placing PV systems. (unitless) is the packing factor, the ratio of the total PV array area to the land area PV arrays occupy. It measures how densely the PV arrays are packed within the occupied space. (unitless) is the performance ratio, the ratio of the actual generation achievable in practice to the ideal generation under no-losses conditions. Regardless of module efficiency and shading effect, it measures PV system losses from array temperature, surface soiling, panel degradation etc.[[2]](#footnote-3) is the module efficiency. is the shading factor.

In this study, instead, the reduced formula is applied as followings.

Here, (in kWh) is annual geographical and technical potential at an individual site (), located within a city& county (), classified as land-use type () and PV technology type (). (in m2) is the area of the individual site. (unitless) is the area factor, which represents the proportion of the area occupied by PV systems to the total area. It has the exact same meaning of in (eqn#). (in m2/kW) is the density factor, which represents the area required per 1kW of PV capacity. It indicates how densely PV systems are installed in a given area based on their capacity. (unitless) is the capacity factor of a PV system, defined by the ratio of the actual power generation to theoretical power generation if the PV system has generated at its maximum power output during same period [43,44]. The differences between the formula in the previous studies and the formula (# Eqn) in this study are i) measurement of PV installation size (PV module area in m2 vs. PV capacity in kW), and ii) measurement of PV system’s efficiency (disaggregation into performance ratio, module efficiency, and shading effect vs. capacity factor as integrated efficiency). In previous studies [sources], solar radiation that could be utilized by a PV system is measured, which is represented as in eqn#, while in this study, PV capacity that could be installed in the individual site is measured, which is represented as in eqn#. And in previous studies, energy losses associated with solar-to-electric power conversion, including shading losses are represented into three parts, which is represented as in eqn#, while in this study, the capacity factor, represented as in eqn#, the definition-based parameter, includes technical efficiency, shading effects, surface soiling etc.

* + 1. Total area

Data for the area of individual site is obtained from GIS-based approach as previous section describes. XX% (XXm2) of the total Gyeonggi province area (XXm2) is explored which counts totally 100,000 individual sites.

* + 1. Area factor: total area to PV system area

Fig. 3 (c) shows the graphical concept of the area factor (). 100% of the total area cannot be utilized for PV system installation, since facilities that have nothing to do with PV operation or unsuitable terrain for placing PV systems in its shape and size or other reasons may be included in the total area. Such surrounding environment varies in all shapes for each individual site, making it unfeasible to investigate every sites. Previous studies, instead, assumes that 70% of the total area could be utilized for PV system installation, which called generator to system ratio or area factor [37,45,46].

In this study, data for the area factor is calculated using actual PV installation cases data, or in some cases, is assumed, depending on the land-use types. As a result of the review on the actual cases data, for the industrial complex, logistics complex, residential complex and public building case, 54.5% of the total area is being utilized for a PV system on average. In parking lot and roadside land, 18.9% and 28.4 % of the individual site area is being utilized for a PV system respectively. The observed area factors are applied in this study. In the cases of the mountainous area and farmland, the data-absent cases, their area factors are assumed to be 40% and 5% respectively.

* + 1. Density factor: PV system area to PV capacity

Fig. 3 (d) shows the graphical concept of the density factor (). As a roof-top PV for three building types, single-family, multi-family and apartment complex, the density factors were assumed to be 11.7, 4.7, 4.7 (kW/m2) respectively in previous studies [47]. As a conventional ground-mounted PV, the density factor was 9.57, 13.16 (kW/m2) in previous studies [48,49]. For more efficient land-use, new types of PV technologies such as PV tree [48–50] and agroPV [51–53] would be considered.

In this study, the data for the density factor is calculated using the actual PV installation cases data as well. Unlike the area factor, the density factor is applied depending on the PV technology types. For the cases of roof-top and ground-mounted PV, the area of 7.23m2 and 11.50m2 is being utilized for a PV system of 1kW capacity on average respectively. The observed density factors are applied in this study.

* + 1. Capacity factor: PV capacity to PV generation

Data for capacity factor is obtained from XX, which is calculated based on the actual power market data, where XX. Capacity factor includes all types of losses

The capacity factor is applied differently depending on the city& county where the individual sites are located.

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자동 생성된 설명

Fig. .

PF (Apv/Agen)

Ground Cover Ratio or (Spacing factor): Elkadeem et al. (2022) : the ratio of total land requirements compared to the actual surface area of PV panels: 20%

Ouchani et al. (2021): Ground Coverage Ratio: 20%

IRENA (2014): Ground Coverage Ratio: 20%

Land Occupancy Factor (LOF) : 1.4: Yushcenko et al. (2018) : ratio of total land requirements to the surface of PV panels.

()

Vyas et al. (2022), Land Cover Ratio (LCR) : 13.16(m2/kW) : Land Coverage Ratio, which is the ratio of land area occupied by the structures (which becomes unusable for any other purpose) to the total land area available at the project site(area occupied by structure/foundation of SPV tree can be seen in graphical representation in Fig3.))

오명찬 (PhDThesis) Table5.2

태양 전지, 태양광 발전, 태양 에너지, 태양의이(가) 표시된 사진

자동 생성된 설명

* 1. Assumption of LCOE

LCOE assumption from KEEI. Draw a graph.

* 1. Scenario

지도, 텍스트, 아틀라스이(가) 표시된 사진

자동 생성된 설명

|  |  |
| --- | --- |
| Scenario | Description |
| No Setback | PV generation potential without Setback regulation |
| Setback | PV generation potential under Setback regulation |

Coefficient >> LCR (Land Coverage Ratio)

Power-based direct land use : Martin-Chivelet (2016)

Ground Cover Ratio or (Spacing factor): Elkadeem et al. (2022) :20%: the ratio of total land requirements compared to the actual surface area of PV panels.

Ratio >> ELR이라고 명명하자. (Effective Land Ratio)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Explored suitable sites for PV | | | Applied parameters | | | | LCOE |
| Land-use type | Area (m2) | Number of sites | PV type | Area factor  (unitless) | Density factor (m2/kW) | Capacity factor |
| Industrial complex | 25,293,157 | 25,128 | Roof-top PV | 54.5 | 7.23 | Applied geographically\* | Applied geographically\* |
| Logistics complex | 5,450,717 | 1,848 |
| Residential complex | 44,657,356 | 132,000 |
| Public buildings | 5,618,738 | 12,810 |
| Mountainous area |  |  | Ground-mounted PV | 40 | 11.50 | Applied geographically\* |
| Farmland |  |  | 5 |
| Parking lot |  |  | 18.9 |
| Roadside land |  |  | 28.4 |
| Water | 56,372,992 | 446 | Floating PV |  |  |

\* It is applied differently depending on the city & county where the individual site is located.

1. Results
   1. Geographical potential of PV

GIS

s

|  |  |
| --- | --- |
| No Setback | Setback |
| Total | Total |
| 텍스트, 지도, 도표, 폰트이(가) 표시된 사진  자동 생성된 설명 |  |
| 지도, 텍스트, 아틀라스, 폰트이(가) 표시된 사진  자동 생성된 설명 |  |
| Industrial complex |  |
| Logistic complex |  |
| Residential complex |  |
| Public buildings |  |
| Parking lot |  |
| Roadside |  |
| Water |  |

Fig. . Geographical potential of PV generation

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Area** |  |  |  |  |  |  |
|  | M2 |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
|  | kWh |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |

* 1. Supply curve of PV

스크린샷, 다채로움, 도표, 그래프이(가) 표시된 사진

자동 생성된 설명

* 1. CO2 mitigation potential of PV

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1. Conclusions

Electrification

**CRediT authorship contribution statement**

**Seungho Jeon:** ABC. **Gildong Hong:** ABC. **Gyeonggi Do:** AB

**Declaration of competing interest**

The authors declare that they have no know competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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2. Definition of PR depends on researchers. [↑](#footnote-ref-3)