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Analytical strategies for floating solar PV policy development in South Korea

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Abstract. Using the SWOT-AHP method, this study identifies the priorities in the development of floating solar photovoltaics (PV) and suggests possible strategies. Our study analyzed the priorities in planning future solar PV strategies based on the opinions of 27 experts. Our results indicate that the government should expand support while emphasizing the benefit of floating solar PV in that it causes less environmental damage compared to onshore solar PV. In addition, the government should properly deal with the public-private conflict regarding the installation of floating solar PV. Floating solar PV itself has not reached a mature technological and institutional stage, but could be an option or alternative for saturated onshore solar PV facilities in Korea.
Keywords: floating solar PV; floating photovoltaic (FPV); Korean energy policy; SWOT-AHP

1. Introduction

In the era of climate change and the post-COVID-19 world, a global focus is achieving cleaner and greener energy production (Kuzemko *et al*. 2020, Vaka *et al*. 2020, Yoshino *et al*. 2020). Renewable energy and related industries have been accepted as a remedy for climate change (Kim and Heo 2016). They have gained further acceptance due to the economic recession caused by the new normal paradigm and COVID-19 (Hosseini 2020). In the same vein, the current Moon administration in Korea has continuously presented ambitious targets and implementation plans toward cleaner energy development.

In 2017, the Moon administration announced the "promotion of eco-friendly future energy" as a major national task (Committee of Government Planning 2017). Continuing along this path, in 2017, the government also announced the 8^{th} electricity basic plan and the Renewable Energy 3020 Implementation Plan (30% carbon reduction target by 2020) toward the target of 20% renewable energy production by 2030, which is 8.88% as of 2019 (KEA 2019). To achieve this ambitious target, the government plans to promote the capacity of renewable energy facilities up to 63.8 GW, and 57% (36.5 GW) will come from solar photovoltaic energy (PV) (Ministry of Trade, Industry, and Energy 2017). Based on these administrative plans, the Korean government is limiting the diffusion of nuclear and coal thermal power generation, and it is currently promoting renewable energy as the core long-term energy source (Cho and Kim 2015).

Among several renewable energy sources, solar and wind energy are considered the most feasible or viable sources in terms of the economic and technical perspectives of the nation (Nam *et al*. 2020, Sukarso and Kim 2020). The most popular style of application of solar energy is through photovoltaic (Oliveira-Pinto and Stokkermans, 2020). Solar photovoltaic (PV) generation has both negative and positive characteristics (Fereshtehpour *et al*. 2021, Goswami and Sadhu 2021), such as low energy density, a narrow land nature, susceptibility to environmental factors, and so on. As a country with a high population density and a narrow land area, a so-called land-constrained country (Gadzanku *et al*. 2021), South Korea has a clear limitation for promoting solar PV (Lee *et al*. 2020). Forests and mountain areas are inevitably damaged when installing offshore (Off shore means solar PVs in the territory. On shore means out of territory such as marine area.) solar PV. To overcome this limitation, the Korean government has turned its attention toward floating solar PV.

Floating solar PV, sometimes referred to as floating photovoltaic (FPV), seems to have emerged as a rising technology around the world (Cazzaniga and Rosa-Clot, 2021). Floating solar PV involves power generation facilities that use the water surfaces of dams, lakes, reservoirs, rivers (Da Silva and Branco 2018, Clemons *et al*. 2021, Sulaeman *et al*. 2021), and even the sea (SERIS 2019, Hooper *et al*. 2021), and does not cause environmental damage during site procurement. In addition, demolition of the facility is also easier than that for onshore solar PV. Nevertheless, there is currently very low utilization of floating solar PV compared to onshore solar PV. Experts have raised concerns that the latter can have negative impacts on the environment (Exley *et al*. 2021) and highlighted the lack of stability as well as economic and technical feasibility (Goswami *et al*. 2019), and even the lack of an institutional framework, including regulations. These arguments have been constantly highlighted in the social sciences. Moore and Hacket (2016) claim that place-based conflicts can be severe, even with sufficient space for solar PV facilities, and various forms of place-

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based participation would be needed in decision-making for implementing solar PV. Huang (2021) determined that the failure of the Shenzhen solar project proves that the success of low-carbon experiments is not necessarily guaranteed by the strong capacities of local governments, and the local communities' acceptance for the new energy system can be a crucial factor. Hence, a more concrete strategy, which considers not just technologies and environment but also social acceptance, will be needed for the deployment of floating solar PV in the nation.

With this context, the current study seeks to fulfill two research purposes related to the development of solar PV:

1. Identify priorities for the development of floating solar PV
2. Propose possible development strategies for floating solar PV

The rest of this paper is organized as follows. A literature review is presented along with a state-of-the-art floating solar PV system in section 2. In section 3, the SWOT-AHP methodology is developed with the theme of floating solar PV. Our analysis results are presented in section 4. Possible strategies based on the four core factors of strengths, weaknesses, opportunities, and threats are discussed in section 5. Finally, the implications and limitations of the study are addressed in section 6.

2. State-of-the-art floating solar PV and policies in South Korea

The floating solar market is growing rapidly in East Asia, including China, Japan, and Korea, Europe, including the UK, France, and the Netherlands, and other countries such as India, Brazil, and Vietnam. Unlike onshore solar PV, many energy projects have been deployed in developing countries where hydro resources are abundant. Based on a World Bank report, the potential of floating solar PV generation ranges from a conservative estimate of 404 GW to a best-case scenario of 4,044 GW. Currently, enterprises such as Thames Water (UK), Pristine Sun (US), and Ciel et Terre (France) are competing in the global floating photovoltaic market.

South Korea has a suitable hydro environment for implementing floating solar PV. Specifically, it has numerous dams and reservoirs built and supervised by public agencies. The potential of floating solar PV in Korea exceeds 6 GW. Since the Korean government adopted the RPS (Renewable Portfolio Standard) (RPS is a system that obligates suppliers with a certain amount (500,000 kW) of power generation to supply a fixed percentage of total power generation with new and renewable energy (KEA, 2019). The obligated supplier proves that it has fulfilled its obligations by submitting the certificate to the certification authority.) as a policy instrument from 2012 (Kim *et al*. 2013), the obligated generation companies have planned the implementation of new floating solar PV facilities through 134 projects with a total capacity of 24,928 MW (Ministry of Trade, Industry and Energy 2018). As shown in Table 1 below, the weight of the renewable energy certificate (REC) differs within solar PV considering the environmental impact, level of technology, generation cost, and potential.

Table 1 Weight of certificate (REC)

	REC weight	Type of installation	Type of land use	Capacity
Solar PV	0.7	Not using existing building	Offshore: Land for field, orchard, farm, forest, or grass land	
	1.0		Offshore: Other land use	Over 100 kw
	1.2			Under 100 kw
	1.5		-Floating Solar PV -Using existing building	

KEA Homepage (www.energy.or.kr, Accessed 18th September, 2020)

Fig. 1 Floating solar PV facilities of K-water (Kim 2018)

Floating solar PV offers the highest REC weight of 1.5 compared to conventional offshore solar PV. Therefore, the obliged operators have the potential of prioritizing floating solar PV over land solar PV.

The first floating solar PV facility in Hap-Chun dam was launched in 2012 by K-water (Korea Water Resources Corporation). At the time, it was evaluated as the world's largest and most economically feasible facility. Since then, K-water has been producing 5,500 KW of floating solar power in three dams, including the original Hap-Chun dam, the Boryeong Dam launched in 2016, and the Chungju Dam launched in 2017 (see Fig. 1). Aside from the five solar PV facilities run by K-Water, small floating solar PV facilities have also been implemented by the Korea Rural Community Corporation. As of 2019, 20 floating solar facilities (18 MW) are in operation, and the corporation plans to open 10 more facilities (15 MW) by the end of 2020. The distribution of floating solar PV facilities is geographically illustrated in Fig. 2.

3. Methods

3.1 SWOT-AHP analysis

SWOT analysis is generally used in the social sciences, including fields like business administration and public policy. It considers the natural characteristics of the target program or process, that is, strengths, weaknesses, opportunities, and threats (Arslan and Turan 2009). Among these four factors, strengths and weaknesses are internal factors while opportunities and threats are external factors. The initial purpose of SWOT analysis is to reduce the negative effects of the internal weakness and external threats, and to maximize the positive effects of internal strengths and external opportunities (Saaty 1987). Researchers qualitatively categorize the characteristics of certain programs in terms of four dimensions. SWOT analysis is useful for developing rationales for strategic

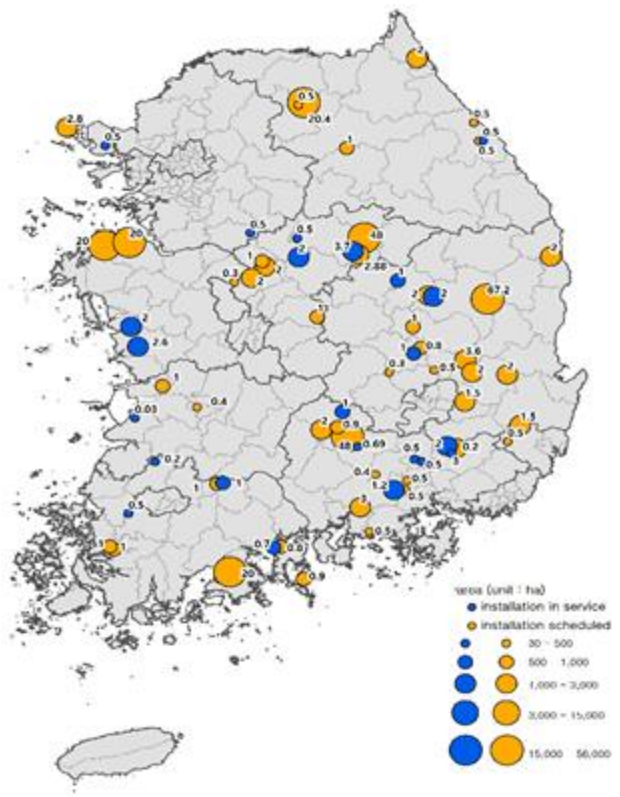

Fig. 2 Nationwide distribution of floating solar PV

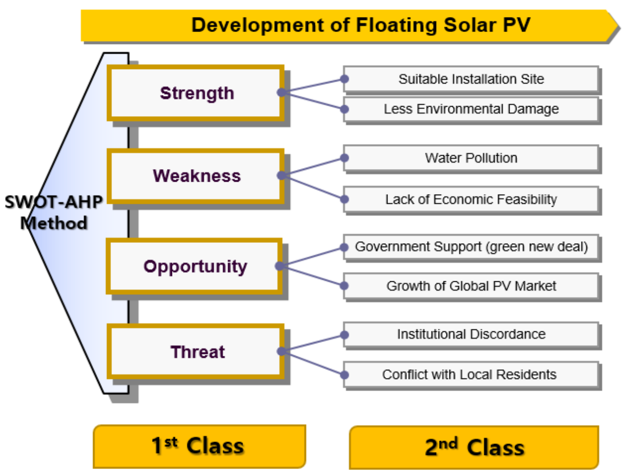

Fig 3 SWOT factors related to the development of floating solar PV

decision-making, but as it does not provide empirical results (Suman *et al*. 2020), this methodology lacks the ability to specify the most influential factor. Therefore, merging the analytic hierarchy process (AHP) and SWOT could provide increased explanatory power for improved decision-making (Kurttila *et al*. 2000).

AHP is frequently used for decision-making with multiple criteria (Saaty 1987). AHP is a useful decision-making tool based on pairwise comparison (Kim *et al*. 2008). It is widely used in various fields, including planning, optimization, problem solving, business strategy, selecting alternatives, and so on. This technique is not only used in decision-making (to choose), but also in assessing the urgent task in policy (to prioritize). Since conventional SWOT analysis is qualitative in nature, the additional AHP can fulfill and integrate the methodological completeness by providing both qualitative and quantitative approaches (Saaty and Vargas 2012, Ananda and Herath 2003, Etongo *et al*. 2018).

The current study applied the research steps of SWOT-AHP analysis suggested by Kurttila *et al*. (2000) and Etongo *et al*. (2018). The first step is to identify the key factors that can affect the decision-making process of designing the strategies from the list. The list was constructed based on the opinions of experts. Etongo *et al*. (2018) recommended the number of factors under the SWOT group to be less than 10. For the pairwise comparison, we rigorously selected two subfactors for each group. In the second step, we conducted a pairwise comparison using nine-point scale questionnaires within the subfactors of each SWOT group. A pairwise comparison is conducted for each factor, and the weight for each subfactor is calculated. The third step includes a pairwise comparison of the four above factors: strengths, weaknesses, opportunities, and threats. We also compute the consistency index (CI). The AHP suggests a proper way to analyze and test the consistency of a pairwise matrix (Solangi *et al*. 2019). The CI formula is presented below.

$$CI = (\lambda\_max \cdot n)/(n-1) \qquad (1)$$

Additionally, in the fourth step, sensitivity analysis was conducted to confirm the robustness of the results of the SWOT-AHP methodology.

3.2 Qualitative SWOT methodology

To identify the key factors for decision-making in floating solar PV, two of the researchers made a preliminary list of each of the strengths, weaknesses, opportunities, and threats groups. For each of the subfactors, there were two to five candidates. With this list, eight of the experts who participated in the government meeting recommended a final list with two subfactors for each of the four SWOT categories. By conducting a parsimonious pairwise comparison, we employed a rigorous CR of 0.1, as recommended by Saaty (1987). The final factors used in the SWOT-AHP analysis are presented in Fig. 3.

3.3 Data sampling for AHP

The participants of SWOT-AHP were selected through snowball sampling. The very first participants were the eight experts who participated in the government meeting concerning the theme of floating solar PV on August 20th, 2020. In this meeting, the eight experts evaluated the preliminary SWOT analysis that was qualitatively conducted by two of the co-authors. Next, each of these experts recommended two or three more experts who are acquainted with floating solar PV policy. In total, 35 experts were recommended, and 27 ultimately participated in the SWOT-AHP survey. Several participant groups were created: A total of two of the participants were from the national assembly research service. Another two were from the Ministry of Environment. A total six of the participants were from K-water (public enterprise), and four were from the Korea Rural Community Corporation (public enterprise). A total of eight of the experts were scholars in the fields of civil engineering, environmental engineering, chemical engineering, environmental economics, and public policy. Of the experts, three were from environmental NGOs who are actively engaged in water policy. Finally, one expert was from the Korea Development Bank, which oversees green financing, and the other expert was from the water industry council.

4. Results

4.1 Analysis of SWOT

SWOT analysis is a simple but powerful instrument for strategic planning in various fields (Gürel and Tat 2017). The original purpose of SWOT analysis was to build a competitive strategy. In analyzing an object, two environments should be considered: the internal environment and the external environment. Strength and weakness factors belong to the internal environment, while opportunities and threats are included in the external environment. Both the co-authors made a preliminary list of each of the SWOT factors based on the government report, then eliminated factors according to the experts' opinions. Only two important factors remained under each factor of SWOT. The eight main subfactors of each SWOT group are qualitatively analyzed as follows:

Strength 1. Easy Installation. Compared to offshore solar PV facilities, floating PVs are adequate in terms of searching for a proper candidate site and easily constructing the relevant facilities. Floating solar PVs are installed in the water surface, which is barely utilized for other purposes. Reservoirs and dams typically have calm water surfaces, and the identification of a suitable site is based on geographical conditions, such as topography, flow rate, shadow, water depth, solar radiation, etc. (Lee *et al*. 2012). In addition, the compensation of land does not matter for floating solar PV. In the current Korean situation, there is a saturation of offshore solar PV, and it is increasingly difficult to find a proper site. As a result, the abundance of suitable sites in Korea can be considered a powerful strength.

Strength 2. Less Environmental Damage. Floating solar PVs are less harmful for the environment than onshore renewable energy facilities, including solar PVs and wind power generation. In many cases, onshore solar PVs have been constructed in agricultural land, forests, or mountain areas, and the quality of the local environment around such facilities has been degraded as a result. Floating solar PVs do not cause such environmental degradation. Further, they also block direct sunlight, which can have a positive effect on preventing green algae (KEI 2020).

Weakness 1. Water Pollution. There is no consensus regarding the causal relationship of water pollution and floating solar PV. This uncertainty should be considered an obvious weakness and limitation of floating solar PV based on the principle of prevention. In addition, apart from the actual consequences, people feel reluctant to install facilities that can be used for drinking water and agricultural water. The Korea Environment Institute has been monitoring the water quality around floating solar PV installations since 2012 and no significant water pollution has been found. However, constant monitoring is still necessary.

Weakness 2. Lack of Economic Feasibility. The price competitiveness of solar power itself is increasing due to technological advances, but it still lacks economic feasibility compared to conventional energy resources such as fossil fuels and nuclear energy. In addition, the grid connection price is also expensive, and the initial investment cost of floating solar power is about 18% higher than that of onshore.

Opportunity 1. Government Support. Under the Green New Deal plan presented by the Moon administration in July 2020, supporting the new renewable energy industry is a core task. In the plan, floating solar PV was selected as an intensive project. Therefore, the public investment toward floating solar PV is expected to increase.

Opportunity 2. Growth of Global PV market. The solar market is growing at a rapid pace. In addition, as solar components and technologies continue to advance, the overall solar industry is expected to grow.

Threat 1. Institutional Discordance. In the process of environmental impact assessment as well as licensing and permission, there is discord in the legal system. The lack of participation in decision-making (governance) by core actors of the Ministry of Environment, Ministry of Trade, Industry, and Energy, K-water, and the Korea Rural Community Corporation causes a delay in implementing the facilities.

Threat 2. Conflict with Local Residents. The major causes of cancellations and postponements of solar power plants can be attributed to low local acceptance (Woo *et al*. 2019). Local residents oppose the installation of floating solar power in local reservoirs due to problems such as electromagnetic waves and negative effects on the landscape. The appearance of a floating body on the water can be very strange to local residents, and it leads to degradation of the beautiful landscape.

4.2 Analysis of first class

The matrix of four factors in the first class is presented in Table 2 below. Each CR was determined, and it was generally 0.001. The average CI was determined to be 0.010 while the RI was found to be 0.900. The priorities of the four factors in the first class are illustrated in Fig. 4. The average weight of the strength factor was set at 0.275, which is equivalent to the first ranking among the SWOT factors in this class. As a result, the strength factor was found to be the most important among the four factors. In planning future strategies, the strength of floating solar PV should be maximized.

The average weight of the weakness factor was calculated as 0.22, which scored fourth in terms of ranking.

Table 2 Pairwise comparison matrix

Matrix	Strength	Weakness	Opportunity	Threat
Strength	1.00	1.34	1.07	1.03
Weakness	0.75	1.00	0.88	0.93
Opportunity	0.93	1.14	1.00	1.03
Threat	0.97	1.08	0.97	1.00
RI: 0.9000, CI: 0.010, CR: 0.001				

Fig. 4 Average weight of first class

Table 3 Analysis of second class and priorities within subfactors

First Class	Second Class	Weight	Second Class Ranking	Priorities within Subfactors
Strength	S1. Suitable Installation Site	0.4490	2	
	S2. Less Environmental Damage	0.5510	1	○
Weakness	W1. Water Pollution	0.5120	2	
	W2. Lack of Economic Feasibility	0.4480	1	○
Opportunity	O1. Government Support	0.5914	1	○
	O2. Growth of Global PV Market	0.4086	2	
Threat	T1. Institutional Discordance	0.3330	2	
	T2. Conflict with Local Residents	0.6670	1	○

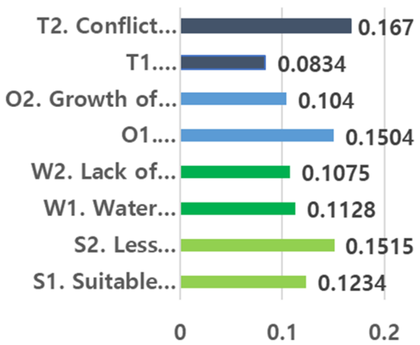

Fig. 5 Final importance of second class considering first class

This means that when planning our strategy, we should not put too much effort into minimizing the weakness of floating solar PV, and this result offers a rationale for more actively expanding such PV without the need for excessive anxiety regarding the negative effects. Next, the average weight of the opportunity factor was found to be 0.254, which was the second-highest value. This factor should be prioritized more than weakness and other opportunity factors. In preparing the strategies, we should concentrate on the internal and external positive effects rather than negative factors. Finally, the average weight of the threat factor was determined to be 0.250, which ranked third. However, there is not a substantial gap between the priorities of the second and third factors, so the threat factors should also be an important consideration in the stage of planning strategies.

4.3 Analysis of second class factors

The subfactors of strength consist of S1 (suitable installation site) and S2 (less environmental damage). The average weights were set at 0.4490 for S1 and 0.5510 for S2. Based on this calculation, S2, less environmental damage, has more priority than S1. Next, the subfactors of weakness include W1 (water pollution) and W2 (lack of economic feasibility). Comparing these two, W2 should be prioritized. The subfactors of opportunity include O1 (government support) and O2 (growth of global PV market). The average weights for the subfactors of opportunity were set at 0.5914 and 0.4086 for O1 and O2, respectively. Therefore, O2, government support, should be prioritized. Finally, the subfactors of threat were set at 0.3330 for institutional discordance (T1) and 0.6670 for conflict with local residents (T2). Comparing these two, T2 has significant priority over T1. As a result, T2 should take precedence in setting strategies for floating solar PV. These results are reported in Table 3.

The final importance of the second class, considering the average weights of the first class factors, are illustrated in Fig. 5 below. The final importance of S1, suitable installation site, was calculated as 0.1234, which ranked fourth among the eight subfactors. The importance of S2, less environmental damage, was set at 0.1515, which is the second-highest rank. In addition, W1, water pollution, was ultimately calculated as 0.1128 (fifth), and W2, lack of economic feasibility, was set at 0.1075 (sixth). Next, the final importance of government support (O1) was determined as 0.1504, which was scored third among the eight subfactors. Then, O2, growth of the global PV market, was finally weighted as 0.104, which is the second-lowest ranking. Further, T1, institutional discordance, was set at 0.0834, which was the lowest final importance among the eight subfactors. Finally, T2, conflict with local residents, was found to be the highest ranking with a weight of 0.167. Therefore, the problem of local conflict should take priority in setting floating solar PV development strategies. The concrete results of the final importance of the eight subfactors are illustrated in Fig. 5.

5. Possible development strategies

Based on the AHP result, 10 combinations were derived from the first class, as shown in Table 4. The most efficient strategy for the development of floating solar PV is the S-O strategy, which was found to have a final importance of

Table 4 Combination matrix of first class

		S	W	O	T
		0.275	0.220	0.254	0.250
S	0.275		0.495	0.529	0.525
W	0.220	0.495		0.475	0.471
O	0.254	0.529	0.475		0.505
T	0.250	0.525	0.471	0.505	

Table 5 Combination matrix of second class

		S1	S2	W1	W2	O1	O2	T1	T2
		0.123	0.151	0.113	0.108	0.150	0.104	0.083	0.167
S1	0.123		0.275	0.236	0.231	0.274	0.227	0.207	0.290
S2	0.151	0.275		0.264	0.259	0.302	0.255	0.235	0.318
W1	0.113	0.236	0.264		0.220	0.263	0.217	0.196	0.280
W2	0.108	0.231	0.259	0.220		0.258	0.211	0.191	0.275
O1	0.150	0.274	0.302	0.263	0.258		0.254	0.234	0.317
O2	0.104	0.227	0.255	0.217	0.211	0.254		0.187	0.271
T1	0.083	0.207	0.235	0.196	0.191	0.234	0.187		0.250
T2	0.167	0.290	0.318	0.280	0.275	0.317	0.271	0.250	

0.529. The second-most important strategy is the S-T strategy, with a weight of 0.525. The other suitable strategy, which is scored as the third-highest ranking, is the O-T strategy, which was set at 0.505. However, this O-T strategy shows a gap compared to the other two strategies. As a result, the future planning of floating solar PV should be designed with the direction of amplifying the internal and external advantages while minimizing and properly reacting to the external negative factors.

The total of 36 combinations were derived from the matrix of the second class (See Table 5). In our matrix, two possible strategies were found to be the most suitable considering the subfactors in the second class. The S2-T2 strategy scored the first ranking with 0.318, while O1-T2 was second with 0.317. Although there is a gap, the S2-O1 strategy also shows a high score with 0.302. While considering the ranking of possible strategies, we should examine the following two strategies closely:

S2-T2 strategy (Emphasizing the reduced harmfulness of floating solar PV and dealing with local conflict). To enhance and lead the development of floating solar PV, the government should expand support, such as offering more weight in the regime of RPS, or practicing more aggressive public investment in floating solar PV while continually checking its environmental impact to ensure that the materials do not harm the eco-system or human health. Further, continuous communication and education, particularly aimed at local residents, are imperative. Many residents do not know the exact principles of production, and they do not have sufficient knowledge of the materials used in solar panels. As a result, they have a vague fear, which leads to opposition to floating solar PV. It is the government's duty and responsibility to let people know exactly what floating solar PVs are, and what environmental consequences can be expected.

O1-T2 strategy (Expanding government support and dealing with local conflict). The other suitable strategy is to deal with local conflict by diversifying and reinforcing government support. In fact, according to an internal report by K-water, this public enterprise plans for the participation of local residents as loan investors of floating solar PV, so that they can secure annual interest from 4% to 10% (K-water 2020). This sort of idea can be a feasible alternative for resolving the private-public conflict.

6. Conclusions

This study identified the priorities in the development of floating solar PV and suggests possible strategies by adopting a mixed perspective of quantitative and qualitative methodologies, SWOT-AHP. Our study first analyzed the priorities in planning the future solar PV strategies based on the opinions of 27 experts. As a result, the strengths factor was found to be more important than the other factors of SWOT in the first class. In the second class, conflict with local residents (T2) ranked first, followed by less environmental damage (S2, 0.1515) and government support (O, 0.1504). The other subfactors remained below the inflection point, meaning they were less important. In the next step, we suggested possible strategies based on the combination matrix of the first and second classes. At the macro level, S-O strategy (ranked first with 0.529) and the S-T strategy (ranked second, 0.525) were recommended for future planning. At the micro level, the S2-T2 strategy and the O1-T2 strategy were highly recommended. In other words, the government should expand governmental support while emphasizing the benefits of floating solar PV in that it causes less environmental damage than onshore solar PV. In addition, the government should properly deal with the public-private conflict regarding the installation of floating solar PV.

Although this study suggested several practical implications, some limitations should also be noted. Since this research used the qualitative methodology of SWOT analysis, it cannot be free from the problem of inter-subjectivity. Another limitation is the bounded choice between the first and the second class in the hierarchy structure of AHP. According to the AHP methodology, the evaluations of second class factors in different categories cannot be directly compared. In other words, only S1 and S2 or W1 and W2 can be compared in a pairwise manner, meaning that S1 and W1 cannot be directly compared in the AHP analysis. This bounded choice sometimes causes biased choices by the experts. Further research should carefully consider these methodological limitations.

A fierce debate continues about whether solar PV, including onshore and offshore facilities, should be the major source of renewable energy in the Korean peninsula. Floating solar PV by itself has not reached technological and institutional maturity due to its short R&D history. Nevertheless, it could be an option or alternative for saturated onshore solar PV facilities in Korea, where the population density is high, and where there is very little unused land. Several environmental issues remain, such as the long-term environmental impact of floating solar PV on the water eco-system. For achieving the sustainable growth of floating solar PV, the government and researchers should continuously monitor and control the latent environmental impact of floating solar PV facilities.

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