# Risk analysis and management of K-water overseas programs: Case of floating photovoltaic power plant projects

By

**HAN, Hwayoung**

**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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# ABSTRACT

## Risk analysis and management of K-water overseas programs: Case of floating photovoltaic power plant projects

**By**

**Han, Hwayoung**

In response to the escalating threat of climate change, nations worldwide are increasingly adopting proactive measures to mitigate its impact. Central to these efforts is the establishment of ambitious targets for reducing carbon emissions by 2050. This commitment has been reinforced by significant international agreements such as the Paris Agreement and the UN Climate Summit, which have galvanized global action on climate change. To meet these targets and adapt to evolving energy trends, there is a concerted push towards advancing renewable energy industries, notably solar, wind, and hydrogen. As a result, the eco-friendly energy market is witnessing substantial growth and recognition on the global stage.

However, despite the promise of renewable energy, the sector faces challenges stemming from its relative novelty and lack of a robust track record. This immaturity introduces unforeseen risks and complicates issues related to supply chain integrity and operational safety.

This paper focuses on the current landscape of overseas renewable energy projects, with a particular emphasis on those undertaken by K-water. By analyzing business risk factors associated with floating photovoltaic energy projects, the study aims to categorize risks into Technical, Economic, Social, and Environmental sectors and develop management strategies to mitigate them. Risk reduction strategies were presented based on literature review and project case studies. Methodologically, the Numerical Scale for likelihood. is used to assess the likelihood of a risk event occurring.

Through comprehensive analysis and case studies, this paper seeks to provide practical insights and management plan suggestions for the overseas expansion of renewable energy projects, contributing to the sustainable growth of the renewable energy sector.

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# I. Introduction

Recently, in order to actively respond to climate change occurring around the world, each country is setting a 2050 goal to reduce carbon emissions, and trends are changing due to the shift to renewable energy for security due to the war in Ukraine. In particular, as awareness of climate change has strengthened in the international community, following the Paris Agreement and the UN Climate Summit, 121 countries have joined the Alliance to Raise Climate Goals, set a 2050 carbon neutrality goal, and are making efforts to realize it.

In an effort to reduce carbon emissions, we are setting goals to reduce the use of fossil fuels, developing energy efficiency technologies, and making efforts to develop eco-friendly energy. In response to changes in new and renewable energy trends in oil and natural gas, we are working to develop renewable energy industries such as solar and wind power and increase the value of hydrogen. The eco-friendly energy market is growing as it becomes more prominent.

The renewable energy business is a new energy source and has a short track record, which causes unexpected risks and lacks completeness and safety of the supply chain due to the immaturity of the market. To reduce these risks, global energy companies are pursuing efficiency measures to reduce risks, and a fundamental solar energy traction policy has been introduced. Demand-pull policies from governments around the world include the feed-in Tariffs(FITs) and Renewable Portfolio Standard(RPS) systems.

## 1.1 Research questions

According to the K-water 2023 Sustainability Report, in order to continue to grow in the overseas sector, K-water is upgrading its existing small-scale businesses to win large-scale projects and is directly proposing large-scale official development assistance (ODA) projects requested by developing countries.

Through the establishment of a model that creates value through subsequent business linkages, K-water was able to export a 28.5 billion won water treatment plant to Jakarta, the new capital of Indonesia.

The aim of these efforts is to stabilize the business development system centered on overseas bases, diversify the business model with eco-friendly energy development and energy reduction technologies, and reduce risks through joint business participation.

Although K-water has not yet expanded its floating photovoltaic (FPV) power business overseas, it is the largest public renewable energy company in Korea, with a successful track record of promoting, operating and managing FPV power projects in adverse surface conditions. This paper aims to analysis the expected risks and propose management techniques based on the business model for expanding overseas large-scale FPV power projects.

Since K-water's FPV business is only a test bed and feasibility study, and the business has not gone overseas, this paper analyzes the risks based on the cases of other public enterprises that have entered the plant business and the active development of FPV in China and Korea.

This is a study on risk analysis and management measures for overseas expansion of the renewable energy businesses to create new growth engines for K-water's overseas business. It identifies risk factors through literature research and studies ways to reduce risks. We will present management plan suggestions, conclusions, and future research directions through case studies and analysis of public institution cases.

## 1.2 Methods

The paper explores the risks associated with FPV power projects in the context of public enterprises' overseas expansion. Since there are no existing cases of such expansions, the analysis draws upon overseas business cases of public companies and risks associated with general plant overseas ventures. Additionally, insights are gleaned from the risk factors identified in FPV power projects by K-water in Korea and ongoing research on FPV power in China. To facilitate successful implementation of FPV power projects by public institutions, risks are categorized into four areas: technical, economic, social, and environmental. Risks that may arise during project implementation are analyzed, and risk reduction measures from similar projects are presented. Risk management assessment utilizes the "the Numerical Scale for likelihood," which employs a numerical scale to express the frequency and impact of potential risks. This scale enables risk analysts to quantify and compare the likelihood of various risk events, aiding in the prioritization of risk management efforts and resources. The paper concludes with techniques for mitigating each listed risk factor, providing insights into effective risk management strategies for FPV power projects and compare the likelihood of occurrence of various risk events to effectively prioritize risk management efforts and resources. The paper concludes with techniques on how each of the listed factors can be mitigated.

## II. Case: K-water overseas floating photovoltaic projects

2.1 Overview of global renewable energy

1) Global renewable energy

According to the IEA report, renewable energy is poised to contribute 30% of the total power generation in 2022, with 174 countries setting renewable power targets. However, only 37 of these nations have committed to achieving 100% renewable energy targets. Investment in renewables witnessed a notable growth of +17.2% in 2022, albeit with disparities observed across technologies and geographical regions. Notably, most advancements in augmenting the share of renewables in the energy mix have occurred within the power sector, with renewable sources accounting for nearly one-third (30%) of global electricity production in 2022 (refer to Figure 2 for details).

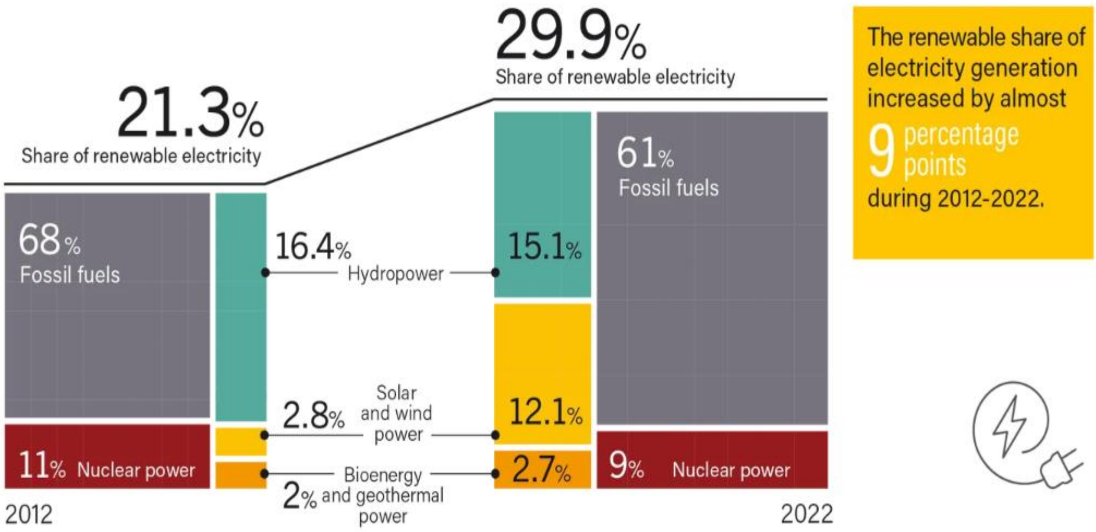


**Fig 1. Share of renewable electricity Generation, by Energy Source (Ren21, 2023)**

In 2023, solar PV alone accounted for three-quarters of the total renewable capacity additions worldwide. Looking ahead, renewable power capacity additions are projected to further escalate over the next five years, with solar PV and wind installations expected to comprise a remarkable 96% of the total. This dominance is attributed to their lower generation costs compared to both fossil and non-fossil alternatives in many countries, coupled with sustained policy support.

Forecasts indicate that solar PV and wind additions will more than double by 2028 compared to 2022, consistently setting new records throughout the forecast period and reaching an impressive total of nearly 710 GW. In 2023, renewable electricity capacity additions surged to an estimated 507 GW, marking a nearly 50% increase from the previous year. This surge was primarily propelled by substantial year-on-year growth in China's solar PV (+116%) and wind (+66%) markets.

Renewable power capacity additions are expected to maintain an upward trajectory in the coming years, driven by favorable policy environments in over 130 countries. The global acceleration observed in 2023 underscores the significant shift in the growth trend, with solar PV and wind leading the charge due to their cost competitiveness and continued policy backing.

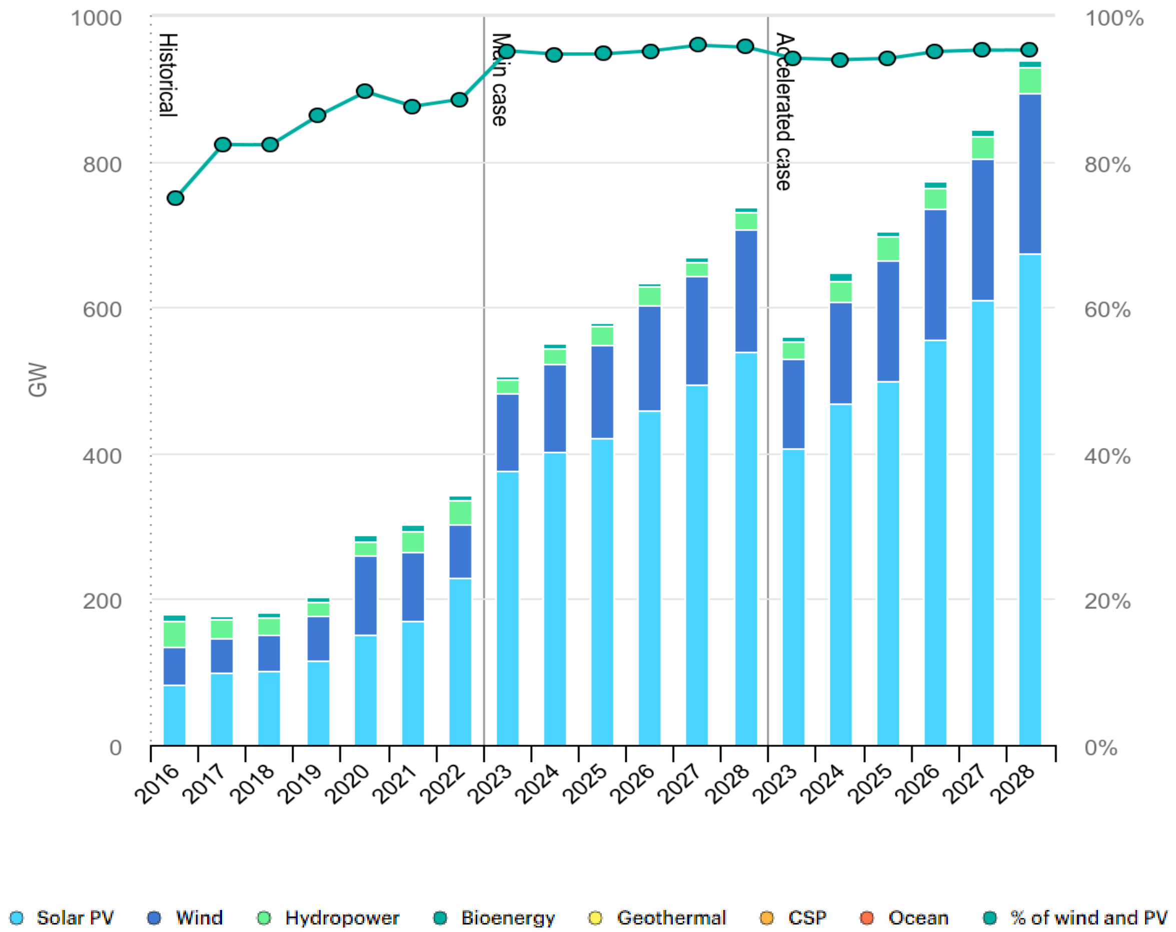


Figure 2. Renewable electricity capacity additions by technology and segment, 2016-2028

(source:https://www.iea.org/data-and-statistics/charts/renewable-electricity-capacity-additions-by-technology-and-segment-2016-2028)

2) Statues of overseas project by public institutions

Public enterprise companies in South Korea have been actively pursuing overseas projects as part of their strategic expansion initiatives. These projects span various sectors, including infrastructure development, energy, construction, telecommunications, and more. Leveraging their expertise, resources, and technological capabilities, South Korean public enterprises have been able to secure contracts and partnerships globally, contributing to economic growth and fostering international cooperation. Notably, these endeavors have been extensive, with a total of 406 projects undertaken by 46 institutions from the 1990s to the present day (KIPF, 2020).

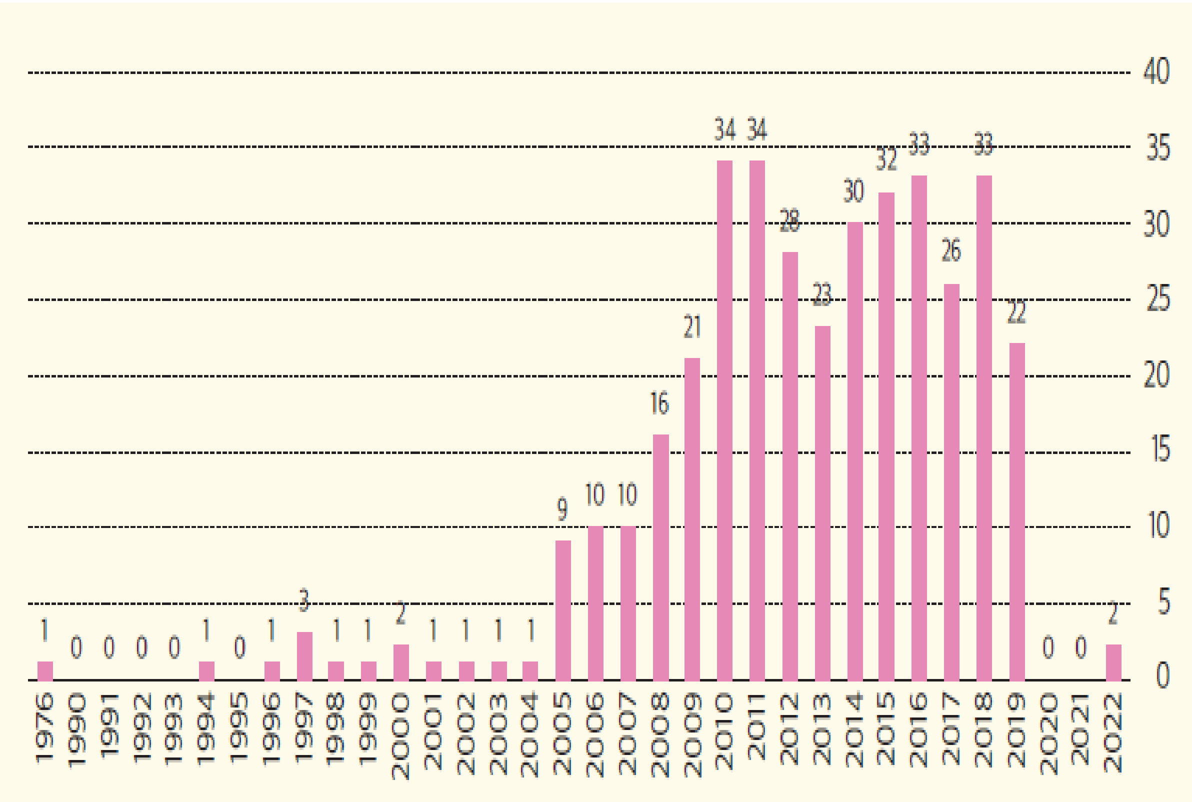


Figure 3. Oversea project of public enterprise company (KIPF, 2020)

According to KIPF report, the field of SOC has a total of 155 overseas projects, accounting for 38.2% of the total. Among these, there are 73 projects related to energy (resource development) and 71 projects related to energy (generation). It is notable that energy projects exhibit a high proportion of direct overseas investment.

Table 1. The status of project type (KIPF, 2020)

| Type | Number | Percent(%) |
|---|---|---|
| SOC | 155 | 38.2 |
| Energy resouce developement | 73 | 18 |
| Energy Power Plant | 71 | 17 |
| Nateion Life | 21 | 5.2 |
| ETC | 87 | 20.2 |
| Sum | 406 | 100.0 |

Examples of joint overseas projects between public power companies and private companies can be found in the joint promotion of large-scale new and renewable energy power generation projects. Private companies and public power generation companies establish project companies through equity investment and raise funds through project financing. In terms of division of work, private companies mainly sign EPC contracts for projects, and public power generation companies sign O&M contracts. In addition to the profits from equity investments in these projects, additional profits can be expected (Korea Energy Economics Institute, 2017). As seen in Table 2, Korea South-East Power participated in hydroelectric power plant projects and was responsible for O&M, while private enterprises mainly handled investment and EPC. Korea East-West Power and Korea West Power Company also managed O&M. This is largely attributed to the extensive utilization of technological advantages from operating power plants domestically. The operational management period ranges from 27 to 30 years, which can be considered as the duration of the power plant's operational years following EPC installation. This not only establishes the investment profit structure but also enables revenue generation through operational management.

Table 2. Overseas renewable energy project of public enterprise company (KEEI, 2017)

| Company | Project | Capacity | Period | contents |
|---|---|---|---|---|
| Korea South-East Power | Nepal Upper Trishuli-1 Hydroelectric power generation project | 216MW, $5.74 Billion | 2012.02 ~ 2016.01 | O&M : 30years<br>Investment & EPC :<br>Daelim Industrial, Kyeryoung Construction Industrial<br>Syndication: IFC, ADB, FMO, PROPARCO, DEG, CDC |
| | Pakistan Gulpur Hydroelectric power generation project | 102MW, $3.67Billion | 2012.03 ~ 2016.11 | O&M : 30years<br>Investment & EPC :<br>Daelim Industrial, Lotte Construction<br>Syndication: IFC, ADB, K-EXIM, CDC |
| Korea East-West Power | US EWPRC Operating project | | 2010.10 ~ | US Biomass and natural gas internal combustion Power plants Operating |
| Korea West Power | Xe Pian-Xe Namnoy hydro plant | 410MW, $10.2 Billion | 2008.04 ~ | O&M : 27 years<br>Investment & EPC :<br>SK construction<br>Syndication: Export and import Bank of Thailand, Local Bank |

(3) K-water overseas project

K-water has established itself as Korea's representative public infrastructure company while securing 30 years of overseas business experience, and has contributed to the creation of public values through joint ventures with private companies. Since 1993, K-water has carried out 87 projects in 31 countries, starting with the Shanxi Province Bunhe River Basin Research Project. The global competence and expertise of K-water were acknowledged with the signing of the contract with the Ministry of Environment in 2020 on the general management of the overall process in the water field for ODA projects, and projects are currently underway in Indonesia and Uzbekistan, etc. In addition, the business structure was diversified by advancing into the investment business on hydroelectric power projects in Patrind (Pakistan), Angat (Philippines), Nenskra (Georgia), and Tina River (Solomon Islands), etc. As of September 2021, 92 projects from 34 countries were completed, with 23 projects in progress in 10 countries.

Technical cooperation is a method of participating in the design, supervision, and consultation of new and renewable energy plans. The direct investment method secures business rights through securing aid funds, project proposals, and participation in bidding, and recovers investment costs through power sales after constructing power plants.

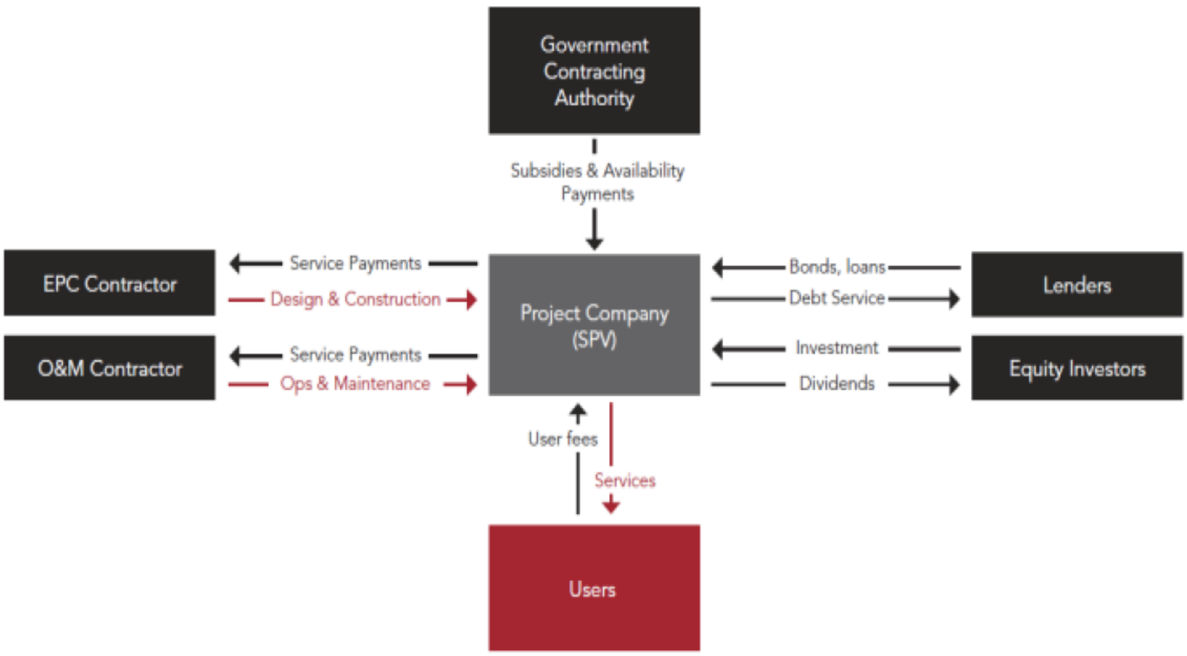


Figure 4. Investment business model(source: https://ppp.worldbank.org/public-private-partnership/finance-structures-ppp)

## 2.2 Status of floating photovoltaic projects

1) Global status of floating photovoltaic project

FPV power plants offer several advantages compared to traditional ground-mounted solar installations. reservoirs, lakes, and ponds, making use of otherwise unused or underutilized water surfaces. This helps to conserve land resources for other purposes like agriculture or development. And reduced land acquisition costs. Sine FPV system utilize water surface, there is typically no need to acquire land for installation, reducing associated costs and potential conflicts over land use. Finally, Enhanced energy efficiency: the cooling effect of water can improve the efficiency of solar panels, and they operate more efficiently at lower temperatures. This can lead to higher energy yields compared to ground-mounted system, especially in hot climates.

Even in China, where solar energy is most widely distributed, existing photovoltaic power plants are ground-based photovoltaic power plants that require more land resources, so, these plants are mainly concentrated in the north-western provinces of China, such as Xinjiang and Gansu. However, in these areas, power supply and demand are often imbalanced, resulting in frequent occurrences of curtailing photovoltaic power and electricity limitations. Conversely, in southern China, where economic industries are well-developed and climate variability is significant, the installed capacity of the power system struggles to meet the demands of daily life due to dense population and limited land resources (Zhou Y, et al, 2020). The dense population in these regions leads to a shortage of land resources for ground-based photovoltaic power plants. Fortunately, there are abundant water areas that can settle the conflict between the development of photovoltaic power projects and strains on land resources so that more and more investors are focusing on the development of FPV power plants

As shown in Fig3, FPV power plants s are usually builted in reservoirs, ponds or lakes, and they are also new photovoltaic power projects with several significant advantages, including high power-generation efficiency, saving land resources and making full use of water resources. Currently, there are 98 000 reservoirs and 20 000 lakes in China, most of which are located in the southern region, providing bright opportunities for the development of FPV power plants. The Chinese government has promulgated relevant policies, such as the 'Notice of National Development and Reform Commission on Matters Concerning the Policies on the

On-grid Tariff for Photovoltaic Power Generation in 2020' and the 'Notice on Further Promoting the Photovoltaic Power Generation Systems', which effectively promote the orderly development of the FPV power-generation industry and reduce the financial burden for investors. Although the natural environment and policy conditions are conducive to developing the FPV power plants, investors face many uncertainties due to the higher investment costs and longer operating period of FPV power plants (Yanli, X., et al., 2021)

Figure 5. floating photovoltaic power plant in china

(Source: State-owned Assets Supervision and Administration Commission of State Council: http://www.sasac.gov.cn/n2588025/n13790238/n16406218/c18732065/content.html).

Although FPV projects are actively developing in China, despite the favorable natural and policy environment, the increasing investment costs and longer operation periods associated with FPV power plants are still causing investors to recognize the risk of uncertainty and conduct research to conduct a comprehensive analysis of the investment risks associated with FPV power plants.

2) K-water floating photovoltaic projects

K-water operates the multi-purpose dam. Multi-purpose dams must provide flood control and clean water. In addition, the dam basin is wide and there is a big change in water level throughout the year. It is very important to consider environmental and structural stability. In order to secure the stability of FPV, demonstrations and tests were carried out step by step. Juam Dam Test Model in 2009 and the 100kW Demonstration Test in Hapcheon Dam in 2011 for the first time in commercialization of 500kW in 2012.

In December 2017, K-water installed 3000kW at chungju dam. How K-water developed the FPV. Stage 1, the Pilot plant was the first FPV on the surface of Dam whose purpose is to challenge inexperience of design tech and construction. Stage 2, we found the possibility of installing the FPV in dam. Three types of structure were installed to find out what is suitable. Construction costs were over 6000 USD/kW, double price for the land PV at that time. Stage 3. the commercial plant of 500kW was launched whose construction costs are 4300 dollars. 30% reduced just a year.

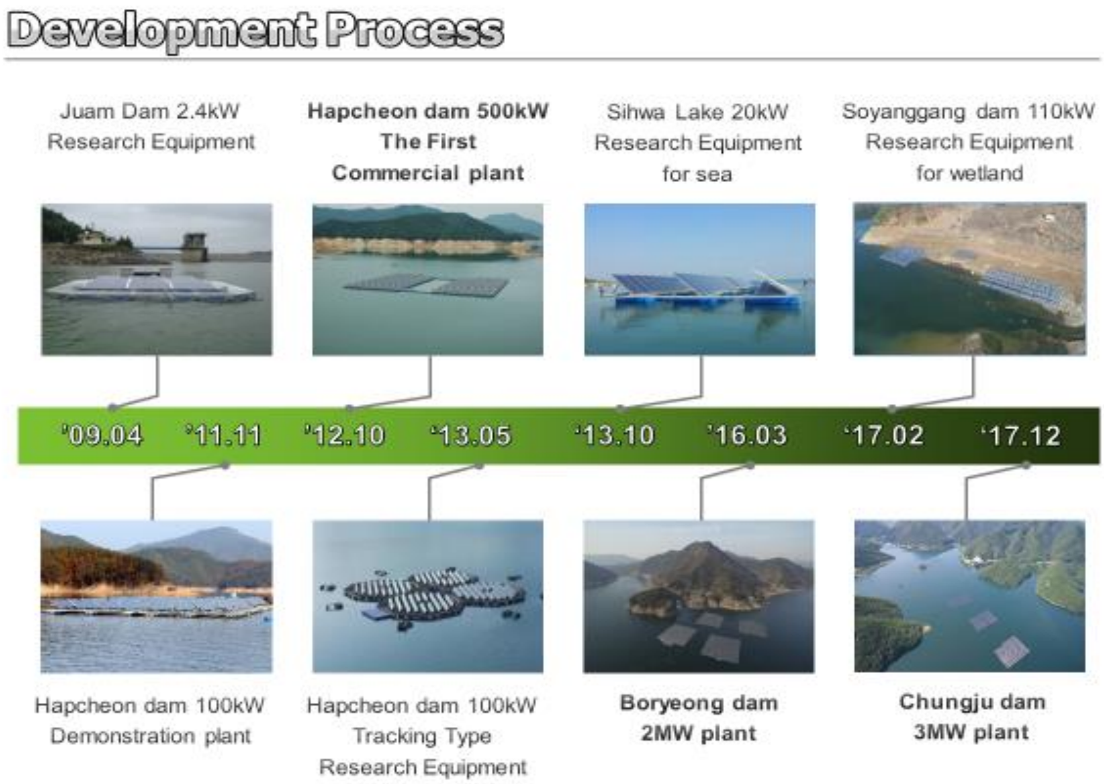


Figure 6. K-water FPV power plants (source:K-water homepage)

## III. Risk analysis of the case

3.1 General overseas Risk Factor

The risk factors identified in both domestic and international literature, including theses, academic papers, research reports, and publications focusing on plant business projects such as overseas construction and plants, encompass business models and significant risks at each stage. Furthermore, they shed light on the prevailing business methods embraced by K-water. Specifically, our analysis delved into and scrutinized risk factors associated with FPV power projects.

While diverse risk factors exist for FPV power projects in each country, our framework defined these factors by drawing upon commonly recognized domestic risk factors and those prevalent in overseas construction projects. The derivation and classification of risk factors by stage for overseas business are detailed in Table 3.

Table 3. Business Model classification (source: editing K-water materials)

| Model | contents |
|---|---|
| ODA | financial resources are clear, relatively low risk as our government directly plans/executes (KOICA) or approves |
| Contract/**EPC** | Separate design and construction according to ordering method (contract)<br>Construction design method (EPC) classification |
| PPP(Spc) | PPP for private capital raising;<br>Procurement of PF from financial companies for business financing<br>High risk relatively |

Additionally, through extensive preliminary research aimed at analyzing risks in renewable energy businesses according to various business models for international business promotion, we identified and examined major potential risk factors associated with different types of overseas business models. To conduct this analysis, we assumed that among the various models, such as ODA, subcontracting/EPC, and PPP (SPC) models, prevalent in overseas construction and power plant projects, K-water primarily promotes investment projects (PPP). This approach entails participating as an investor and engaging in operational activities. This approach entails participating as an investor and engaging in operational activities.

Risk refers to the degree of exposure to uncertainty and refers to all uncertain factors that affect project costs, construction period, quality, profitability, etc. that occur during the project order receiving stage and project execution stage. Among the major risks of the renewable energy business extracted through literature research, the risk factors and guidelines for each business stage are as follows so that K-water can select the management items to focus on.

1) Business Model

At the project order stage, the representative risks that can arise from the business model are differences in the project promotion (ordering and project execution) process due to the classification of aid projects, contracting projects, and investment development projects according to financial resources, and the business ordering method (contracting, EPC, PPP). The business execution process is different depending on the differences. This risk can be managed by determining the corresponding business model through a project discovery and selection process depending on the method of financing and ordering the business.

2) Contract

The main risks of the contract are the possibility of a decrease in the success rate due to excessive competition between domestic companies and the risk (occurrence of foreign exchange loss) due to exchange rate fluctuations. Reduction measures include expansion of joint contracting between companies (between large and medium-sized companies, small and medium-sized companies) and low bidding. There is a way to offset foreign exchange fluctuations by matching the timing of income and expenditure of funds, and in the case of large-scale projects, transfer the risk by signing up for exchange fluctuation insurance with K-Sure.

3) Implementation

At the implementation stage, there are difficulties in organizing an implementation budget including an appropriate rate of return due to a tight budget, and in the case of the KOICA project, there are risks due to rising prices and design changes, and the possibility of excessive construction costs compared to the project budget. Reduction measures include establishing a plan to reduce construction costs through meticulous estimates and utilizing local manpower, strengthening on-site construction management and setting up reserve funds during estimates, and reducing labor and construction costs by utilizing thorough localization strategies.

4) Project Settlement & Monitoring

Risks in the settlement stage include the occurrence of defect repairs, the possibility of a decline in the local image if the project completion level is low, and the occurrence of foreign exchange losses due to exchange rate fluctuations. Countermeasures include establishing a defect repair plan through linkage with the expansion region and maintaining continuous expectations on the government of the recipient country. There is management.

### 3.2 Direction of risk analysis in floating photovoltaic project

FPV power plants have emerged as a promising solution to harness solar energy while mitigating land use conflicts and providing additional benefits for water management and environmental conservation. However, the successful deployment and operation of FPV projects are subject to various risks that can impact their viability and sustainability. Effective risk management strategies are essential to identify, assess, mitigate, and monitor these risks throughout the project lifecycle. This study delves into the risk factors associated with FPV power in the context of overseas projects led by the public institution K-water. Excluded from the scope of risk factors are aspects pertaining to wafer, solar cell, and module technology, as well as considerations of price competitiveness within the industrial development sector. Furthermore, the study does not encompass the broader discussion of universalization technology development in renewable energy through grid parity. Instead, its focus remains strictly within the domain of PV power project development. This paper discusses risk management strategies for FPV power plants, focusing on technical, economic, social, and environmental risks.

1) Technical Risk:

Technical risks encompass challenges related to the design, construction, and operation of FPV systems. These risks include structural integrity, equipment malfunction, electrical failures, and corrosion. Mitigation strategies for technical risks involve implementing robust design principles, conducting thorough engineering analyses, and utilizing high-quality materials and components. Regular maintenance and inspection protocols should be established to detect and address potential technical issues promptly. Collaboration with experienced engineering firms and adherence to industry best practices can enhance the reliability and resilience of FPV systems against technical failures.

2) Economic Risk:

Economic risks associated with FPV projects include cost overruns, fluctuations in equipment prices, changes in financing terms, and revenue uncertainties. To mitigate economic risks, project developers should conduct comprehensive financial feasibility studies to assess project economics and identify potential cost drivers and revenue streams. Implementing cost-control measures, such as competitive procurement processes and project optimization strategies, can help manage project expenses and improve financial performance. Diversifying revenue sources, such as selling excess energy to local utilities or participating in renewable energy incentive programs, can also mitigate revenue uncertainties and enhance project profitability.

3) Social Risk:

Social risks refer to potential adverse impacts on local communities, stakeholders, and indigenous populations. These risks may include land tenure disputes, cultural heritage concerns, community opposition, and stakeholder conflicts. Effective stakeholder engagement and consultation processes are essential to identify and address social risks early in the project development phase. Establishing transparent communication channels, conducting community outreach initiatives, and incorporating stakeholder feedback into project planning and decision-making can build trust and mitigate social tensions. Respecting local customs, traditions, and land-use practices is crucial to fostering positive relationships with host communities and minimizing social risks associated with FPV projects.

4) Environmental Risk:

Environmental risks associated with FPV installations include habitat disruption, water quality impacts, ecological disturbances, and potential harm to aquatic ecosystems. Comprehensive environmental impact assessments should be conducted to evaluate the potential environmental effects of FPV projects and identify mitigation measures to minimize adverse impacts. Implementing best management practices, such as habitat restoration efforts, water quality monitoring programs, and pollution prevention measures, can help mitigate environmental risks and enhance the ecological sustainability of FPV installations. Collaboration with environmental experts, regulatory agencies, and conservation organizations is essential to ensure compliance with environmental regulations and promote responsible stewardship of natural resources.

### 3.3 Risk factors analysis in floating photovoltaic project

1) Technical risk

A) Site condition

Site condition is a key part of the development of FPV power plants. The site-selection involved many processes, such as sunshine duration, irradiance, insolation, hydrological environment, etc. The unreasonable site will not only have a negative impact on the economic benefits of the projects, but may also cause the projects to fail to meet the requirements (Nazir CP, 2018).

Generally, solar radiation data is provided through resource mapping, as is the case in countries. Site selection and orientation have a significant impact on the efficiency of power generation. Additionally, due to the nature of installation on water bodies, it is crucial to select areas that can be designed according to weather conditions such as typhoons. In terms of countries, relatively small land area countries such as South Korea, Japan, Taiwan, the United Kingdom, and the Netherlands have seen a lot of construction. The regions in China with the highest number of installations largely represent areas with significant domestic development.

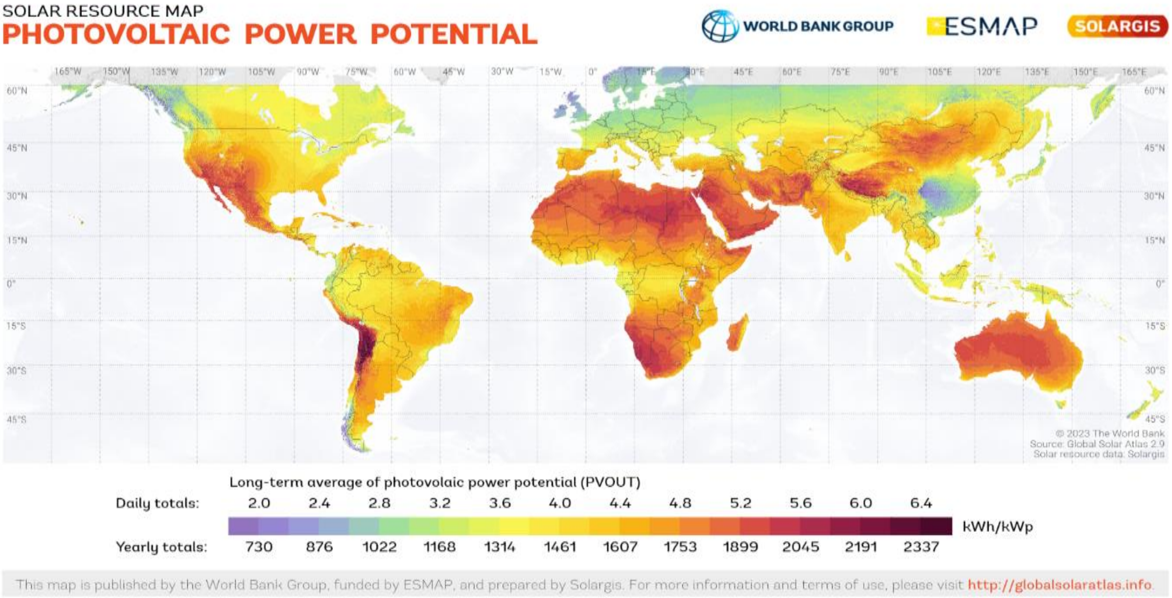


Figure 7. photovoltaic power potential (World Bank, 2020)

B) Structural design

The structural design of photovoltaic power plants includes the photovoltaic panel size, the distance between the photovoltaic panels, inclination angle (Dhimish M, et al. 2019), anchoring system, etc.

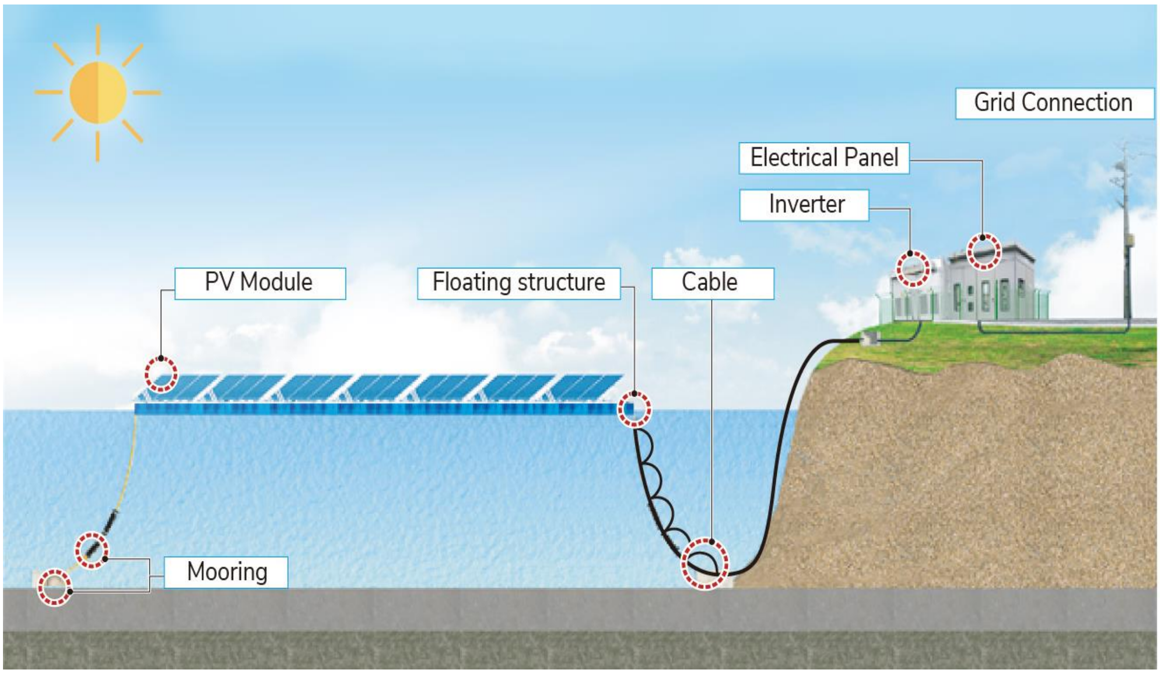


Figure 8. mooring system of hapcheon FV power plant (source:hapcheon SPC homepage)

The structural design of FPV systems involves several key components and considerations to ensure stability, durability, and efficiency. While specific designs may vary depending on factors such as site conditions, water body characteristics, and project requirements, the following elements are commonly incorporated in the structural design of FPV systems. Especially, An anchoring system is used to moor the FPV system in place and prevent it from drifting or moving with wind and water currents. Anchors may be attached to the bottom of the water body using cables, chains, or other tethering mechanisms. The anchoring system must be designed to provide sufficient stability and withstand the forces exerted on the floating platform.

The design of mooring systems and flotation devices is a pivotal consideration for ensuring the structural stability of FPV power installations, given their inherent placement on water. As illustrated by the yamakura dam incident detailed in Figure 9, a storm boasting average wind speeds of 41 m/s and gusts reaching 57.5 m/s (207 km/h) triggered a chain of events, leading to the destruction of approximately two-thirds of the facility and causing certain sections to ignite. This example underscores the critical importance of developing mooring lines and anchor technologies capable of withstanding natural disasters, such as storms, which pose significant risks to such installations.

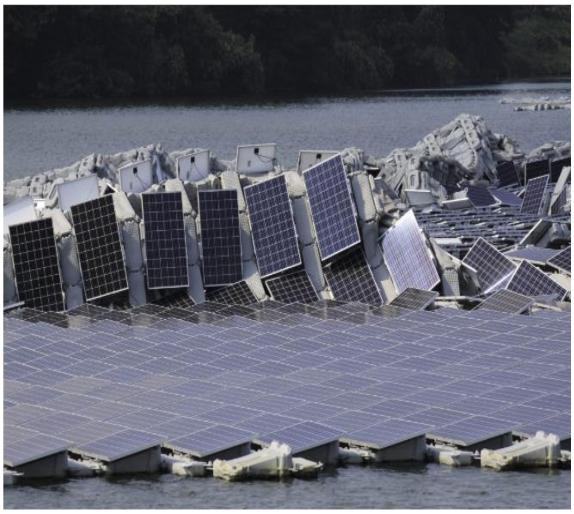

Figure 9. the yamakura dam incident

(*Solar Power Plant Business / Nikkei Business Publications, 2019)*

C) Difficulty of integrating into the grid

Many investors rely on grid-connected power transmission for their investment income. However, FPV power plants are often planned in regions with underdeveloped power-distribution network facilities. Furthermore, photovoltaic power generation exhibits characteristics such as instability, intermittency, and uncontrollability. These factors collectively contribute to significant challenges and risks in grid connection. The inherent variability of renewable energy sources, such as solar or wind power, which depend on natural factors like sunlight or wind, complicates the maintenance of a consistent electricity supply to meet real-time demand. Achieving grid stability entails a delicate balance between energy supply and demand. The intermittent output of renewable energy sources can disrupt this equilibrium, potentially resulting in grid instability, voltage fluctuations, and frequency deviations that undermine the reliability of the power supply. Integrating large-scale renewable energy projects often mandates substantial upgrades to the existing grid infrastructure, necessitating investments in transmission lines, substations, and grid management technologies. Such enhancements are essential to accommodate the variable nature of renewable energy generation and ensure efficient and reliable electricity distribution.

D) Construction risk

Construction risk encompasses the potential uncertainties and obstacles inherent in the physical construction phase of a project. These risks can manifest in various forms, including delays in project completion, exceeding budgetary constraints, or failing to meet the specified output requirements set by regulatory authorities. Such risks can result in adverse consequences such as reduced service delivery to the state or stakeholders, ultimately impacting project success. This risk is pervasive across diverse sectors, spanning real estate development, infrastructure undertakings, and renewable energy ventures like FPV installations.

**2) Economic risk**

Economic risks entail several key factors. Firstly, there is a notable disparity in costs compared to onshore solar power, with FPV projects often incurring higher expenses. Secondly, there exists a financial risk concerning the acquisition of investments necessary for project implementation. Lastly, the potential for national subsidy risks adds another layer of uncertainty, as these incentives can vary significantly between countries.

A) Cost risk

Initial investment costs for FPV power plants are relatively high, approximately 12% higher than ground-based photovoltaic power stations (Bey M, et al. 2021). FPV require unique components specifically designed to withstand aquatic environments, such as corrosion-resistant materials for floating platforms, anchoring systems, and electrical components. These specialized equipment and materials often come at a premium compared to standard solar panels and mounting structures used in onshore installations. The operation and maintenance phases face more risks than anticipated. this risk includes battery-replacement costs, external power-supply costs, dust-removal costs, as well as high maintenance costs due to the impact of the pond environment on the floating frame.

B) Financing risk

The FPV power plants are gradually increasing worldwide, but the consumer market for water-based power plant is not mature. There is great uncertainty in the future income. Therefore, banks and other financial institutions are unwilling to take high risks to provide funds for their project construction, meaning that investors face difficulties in finances. Due to the relatively recent emergence of FPV technology, there may be a limited track record of successful projects and operational performance data available to investors. This lack of historical data can make it challenging for investors to assess the risks associated with FPV projects accurately

C) Subsidy mechanism

The global subsidy mechanism refers to various incentive programs, financial support, and subsidies provided by governments, international organizations, or other entities to promote the adoption and development of renewable energy technologies, such as solar, wind, hydroelectric, and geothermal power. These subsidies are often aimed at reducing the costs associated with renewable energy projects, encouraging investment, stimulating innovation, and accelerating the transition to a low-carbon economy. Subsidies may take different forms, including:

- Feed-in Tariffs (FITs): These are long-term contracts that guarantee a fixed price for renewable energy generation, providing stability and predictability for project developers.
- Investment Tax Credits (ITCs): Tax incentives that allow renewable energy project developers to deduct a percentage of their investment costs from their tax liabilities, reducing the overall project costs. Production Tax Credits (PTCs): Similar to ITCs, PTCs provide tax credits based on the amount of renewable energy generated, incentivizing

renewable energy production.

- Renewable Energy Certificates (RECs): Tradable certificates representing the environmental attributes of renewable energy generation, which can be sold or traded to entities seeking to meet renewable energy targets or offset their carbon emissions.
- Grants and Rebates: Direct financial assistance provided by governments or agencies to support renewable energy projects, often covering a portion of the project costs.
- Low-interest Loans and Loan Guarantees: Financial instruments offered by governments or financial institutions to facilitate access to affordable financing for renewable energy projects, reducing borrowing costs and mitigating financial risks.

The effectiveness and implementation of subsidy mechanisms vary across countries and regions, influenced by factors such as government policies, market conditions, technological advancements, and budget constraints. While subsidies have played a crucial role in driving renewable energy deployment and market growth, they have also faced criticism for distorting market dynamics, inefficient allocation of resources, and budgetary burdens on taxpayers.
In recent years, there has been a trend towards phasing out or reforming traditional subsidy mechanisms in favor of more market-based approaches, such as competitive auctions, carbon pricing, and renewable energy portfolio standards. These approaches aim to promote cost-competitiveness, enhance market efficiency, and foster sustainable growth in the renewable energy sector. However, the transition away from subsidies poses challenges for industry stakeholders and requires careful planning and policy coordination to ensure a smooth and equitable transition towards a sustainable energy future.

### 3) Social risk

A) Complicated approval procedures

Unlike typical photovoltaic power projects, the administrative approval process for FPV plants involves additional steps related to extensive land use and environmental assessments, including consideration of local development. As a result, this complex approval process is lengthy and multifaceted. Lack of social consensus among local residents and stakeholders makes it difficult to move through the administrative process smoothly, and there have been several cases in Korea where FPV power plant projects have been halted due to lack of social consensus among local governments.

B) The unreceptivity to renewable(FPV) energy demand

In the context of FPV projects, a potential risk stems from the societal perception that FPV is less efficient than conventional power systems. This perception stems from the off-grid nature of the regions where FPV is implemented, which requires significant infrastructure investment. There are also challenges in gaining broad social acceptance for large-scale development of distributed renewable energy sources such as FPV.

C) Public opposition

Public opposition can have significant implications for project development, regulatory approval processes, and public policy decisions. It can delay or derail projects, increase costs, damage reputations, and lead to legal disputes or regulatory interventions. Emotional effects such as anger, frustration, fear, and distrust may be heightened when stakeholders perceive that their voices are not being heard, their concerns are being dismissed, or their interests are being disregarded by project proponents or decision-makers.

Public opposition often emerges when projects are believed to jeopardize public health and safety. Concerns may revolve around potential air or water pollution, noise pollution, traffic congestion, or the risk of accidents or disasters. Communities residing near proposed project sites often voice apprehensions regarding the potential adverse effects on their overall well-being and quality of life. Furthermore, development initiatives that pose a threat to cultural heritage sites, sacred lands, or traditional ways of life can provoke opposition from indigenous communities, cultural preservationists, and historians. These stakeholders advocate for the safeguarding and preservation of cultural identity and heritage resources.

4) Environmental risk

A) Severe weather conditions

FPV power plants are confronted with challenging weather conditions, encompassing strong winds, persistent rainfall, limited sunlight exposure, and more. These adverse climatic factors have the potential to disrupt the functionality of photovoltaic modules. For instance, during the rainy season, the battery operation often necessitates lower power output, leading to accelerated wear and tear on the battery (Cazzaniga R, et al. 2021).

B) Risk of water corrosion to equipment

The current life cycle of photovoltaic power stations typically spans 20 to 25 years. However, the prolonged exposure of floating body frames or pile foundations to water can lead to corrosion caused by microorganisms, harmful chemicals, and fluctuations in water quality, thereby increasing the risk of premature decommissioning (Zhang H, Xu Z, Zhou Y, et al. 2021). Water corrosion occurs when metal equipment reacts chemically with moisture or water over time, resulting in rust or corrosion on the metal surface. This process compromises the structural integrity of the equipment, diminishing its efficacy and longevity. Water corrosion poses a significant threat to various components of the system, notably metallic structures such as floating platforms, support frames, and anchoring systems

C) Water ecological environment destruction

In the development process of FPV plants, it will inevitably have a certain impact on the surrounding ecological environment (Wu Y, et al, 2020). For example, in the fishing and light complementary project, it will cause problems such as the inconvenience of fishing, cumbersome feed management and difficulty in dredging and disinfection, which will affect the development of the fishery. The environmental impacts associated with FPV systems raise some concerns. Firstly, these facilities provide shade over the water surface and the possibility of changing lighting levels. Second, there is the potential for leaks from solar panels or electrical components during various stages of an FPV project, including construction, operation, and maintenance, and finally, impacts from runoff from clean-up activities associated with FPV installation.

# IV. Risk management of the case

## 4.1 Challenges of K-water overseas floating photovoltaic project

The purpose of the risk summary is to provide decision makers with a clear understanding of the potential risks associated with FPV power plants. By identifying and summarizing technical, economic, social and environmental risks, the purpose of the summary is to help stakeholders make informed decisions when planning, financing and implementing FPV projects. Ultimately, the goal is to enable decision makers to assess their overall risk environment and develop effective strategies to mitigate and manage these risks throughout the project life cycle. As illustrated in Table 4, addressing technical risks involves implementing robust technical management practices to guarantee quality assurance and mitigate technical risks throughout the project lifecycle. Strategies to mitigate economic risks encompass the adoption of internal cost control mechanisms to manage expenditures, alongside a continual pursuit of technological advancements and innovations aimed at optimizing project costs and returns. Addressing social risks may involve resorting to international arbitration to resolve disputes or engaging in negotiations with stakeholders to address concerns and foster positive relationships. Meanwhile, mitigating environmental risks entails the enforcement of stringent environmental management protocols, the formulation of diverse plans to mitigate potential environmental impacts, and collaboration with pertinent stakeholders to ensure environmental sustainability and compliance with regulations.

Table 4. Risk summary (source: author)

| Risk Code | Name | Mitigation Method |
|---|---|---|
| Risk 1 | Technical Risk | Quality Assurance<br>Technology management |
| Risk 2 | Economic Risk | Internal Cost Control Mechanism<br>Technical Improvement and Innovation |
| Risk 3 | Social Risk | International Arbitration<br>Negotiation |
| Risk 4 | Environmental Risk | Environmental Management<br>Various Plan<br>Guarantees and Collaborations. |

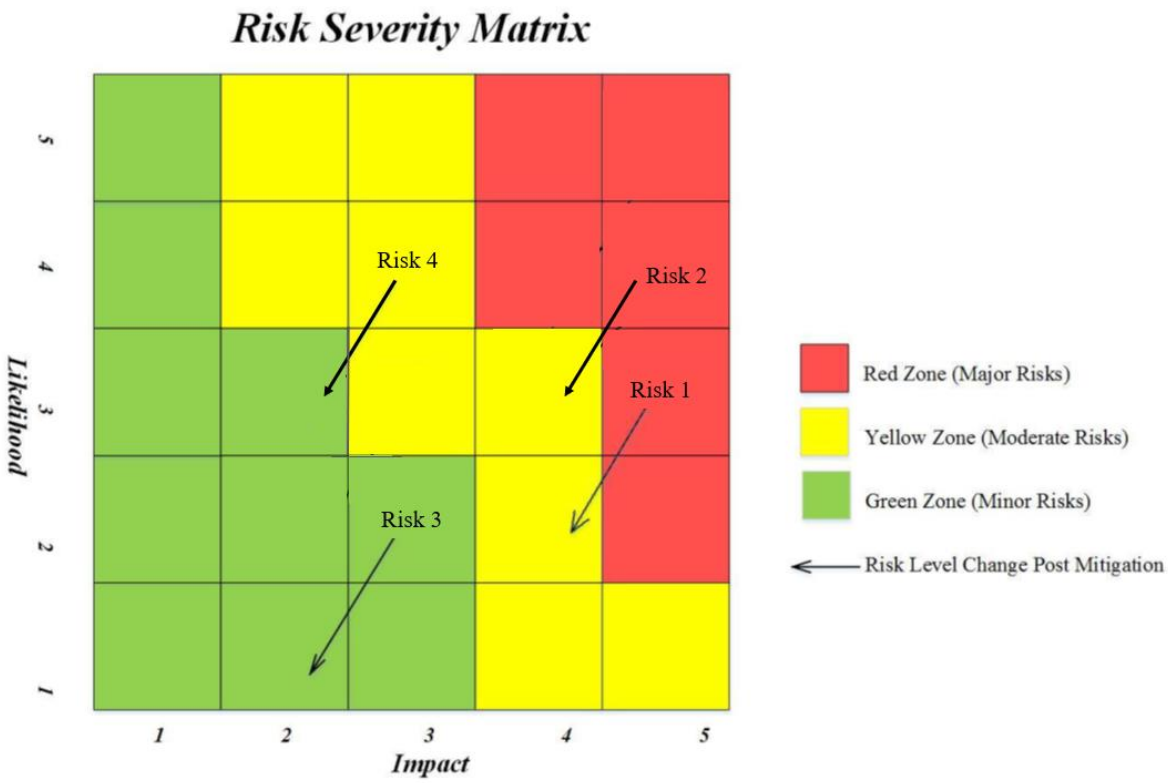


Figure 10. Risk Matrix (source: author)

| Numerical Scale | Definition | Probability |
|---|---|---|
| 5 | Event is expected to occur in most circumstances | 91-100% |
| 4 | Event will probably occur in most circumstances | 61-90% |
| 3 | Event should occur at some time | 41-60% |
| 2 | Event could occur at some time | 10-40% |
| 1 | Event will on occur in exceptional circumstances | 0-10% |

Figure 11. Numerical Scale for Likelihood (source: Larson et al. (2015))

The Numerical Scale for likelihood is a tool used in risk management to quantify the probability or likelihood of a risk event occurring. It typically involves assigning numerical values to represent the likelihood of the risk event happening, usually on a scale from low to high probability. This scale helps risk analysts to assess and compare the likelihood of different risk events, facilitating the prioritization of risk management efforts and resources effectively.

In Figure 10, Risk 1 and Risk 2 were identified as Red Zone (Major Risks). Risk 1, pertaining to the technical risks associated with FPV energy compared to stable ground-mounted solar, was deemed to have a higher likelihood of occurrence and a significant impact. Risk 2, concerning economic risks, was assessed to have a high influence and probability across all project business models.

For projects acquired overseas, it was observed that most of them were undertaken under the auspices of government-led initiatives, ensuring social consensus and environmental safety. Therefore, the risk associated with these projects was considered relatively low.

### 4.2 Policy recommendations for the challenges

Conducting risk management for FPV power plants involves several key steps to identify, assess, mitigate, and monitor risks throughout the project lifecycle.

The risk definition has already been presented, and reduction methods are devised after assessment and evaluation for each individual project. So, the reduction measures for each major risk are required as follows.

1)Technical risk

Mitigating technical risk involves implementing measures to address potential challenges or uncertainties related to the technical aspects of a project. In the context of FPV power plants, technical risk mitigation strategies aim to ensure the reliable performance, efficiency, and safety of the solar installations.

Conduct thorough site assessments to evaluate factors such as water depth, wave conditions, wind patterns, and environmental conditions. This information helps in selecting suitable locations for FPV installations and designing appropriate structural configurations to withstand site-specific challenges. Implement robust structural design practices to ensure the stability and durability of FPV systems. This includes designing floating platforms, support structures, anchoring systems, and electrical components to withstand environmental stresses, such as wind, waves, and currents. Use high-quality materials and components that are resistant to corrosion, degradation, and environmental degradation. This includes selecting corrosion-resistant materials for floating platforms, corrosion protection coatings, and durable electrical components to minimize the risk of equipment failure or degradation over time. Establish comprehensive monitoring and maintenance protocols to regularly assess the performance and condition of FPV systems. This includes periodic inspections, performance monitoring, and preventive maintenance to identify and address potential issues before they escalate into major problems. Embrace technological innovations and advancements in FPV technology to improve system efficiency, reliability, and safety. This may include adopting new materials, design techniques, monitoring systems, and control algorithms to enhance the performance and resilience of FPV installations. Develop contingency plans and emergency response procedures to address unexpected technical failures or emergencies. This includes having backup systems, emergency shutdown procedures, and response protocols in place to mitigate the impact of technical failures and ensure the safety of personnel and equipment.

2) Economic risk

Mitigating economic risk involves implementing strategies to minimize the financial uncertainties and challenges associated with a project. In the context of FPV power plants, economic risk mitigation aims to ensure the financial viability and sustainability of the project over its lifecycle. Here are some strategies to mitigate economic risk in FPV projects.

Conduct thorough cost-benefit analyses and optimize project costs to maximize returns on investment. This includes identifying cost-saving opportunities, negotiating favorable contracts with suppliers and contractors, and minimizing unnecessary expenses without compromising on quality or performance. Develop robust financial plans and forecasts to estimate project costs, revenues, and cash flows accurately. This involves conducting sensitivity analyses and scenario planning to assess the potential impact of various economic factors, such as changes in interest rates, currency fluctuations, and market conditions, on project economics.

Explore opportunities to diversify revenue streams and mitigate reliance on a single source of income. This may include selling excess electricity generated by FPV systems to the grid, entering into power purchase agreements (PPAs) with utility companies, or exploring alternative revenue streams, such as carbon credits or renewable energy certificates. Implement risk hedging strategies, such as financial derivatives or insurance products, to protect against adverse financial outcomes caused by market volatility, currency fluctuations, or unforeseen events. This may involve hedging against changes in commodity prices, interest rates, or exchange rates to minimize financial losses and stabilize project revenues. Stay abreast of regulatory requirements and ensure compliance with relevant laws, regulations, and permits governing FPV projects. Non-compliance with regulatory requirements can result in fines, penalties, or project delays, leading to additional costs and financial risks. Develop contingency plans and risk mitigation strategies to address potential economic challenges or disruptions. This includes having contingency funds, reserve budgets, or emergency financing options in place to cover unexpected expenses, mitigate revenue shortfalls, or address adverse economic conditions.

3) Social risk

Mitigating social risk involves addressing concerns and mitigating potential negative impacts on stakeholders, communities, and society at large. In the context of FPV power plants, social risk mitigation aims to foster positive relationships with local communities, minimize social conflicts, and ensure the project's acceptance and support. Here are some strategies to mitigate social risk in FPV projects.

Engage with stakeholders, including local communities, government authorities, non-governmental organizations (NGOs), and other relevant parties, throughout the project lifecycle. Establish open channels of communication, listen to concerns, and solicit feedback to address social issues and build trust and consensus. Conduct comprehensive community consultations to understand local priorities, preferences, and concerns regarding the FPV project. Involve community members in decision-making processes, seek their input on project design and implementation, and incorporate their feedback into project planning and management. Conduct a thorough social impact assessment to identify potential social risks, assess their significance, and develop appropriate mitigation measures. This may involve evaluating the project's potential effects on livelihoods, cultural heritage, land use, public health, and quality of life in surrounding communities. Develop equitable benefit-sharing mechanisms and compensation schemes to ensure that local communities derive tangible benefits from the FPV project. This may include providing employment opportunities, skills development programs, infrastructure improvements, or financial compensation for land use or resource extraction. Respect and preserve local cultural heritage, traditions, and customs in project planning and implementation. Consult with indigenous communities and cultural stakeholders to ensure that the project's activities and operations are culturally sensitive and do not infringe upon sacred sites or traditional practices. Establish transparent and accessible grievance mechanisms to address community concerns, complaints, or grievances in a timely and effective manner. Provide channels for stakeholders to raise issues, seek redress, and receive feedback on their concerns, and ensure that grievances are handled impartially and resolved satisfactorily. Invest in capacity-building initiatives and community empowerment programs to enhance local skills, knowledge, and capabilities. This may involve training programs, education initiatives, and capacity-building workshops aimed at empowering local communities to participate in project decision-making, management, and oversight.

4) Environmental risk

Mitigating environmental risk in the context of FPV power plants involves implementing strategies to minimize adverse impacts on the natural environment and ecosystems. Here are some key approaches to mitigate environmental risk in FPV projects.

Conduct a comprehensive environmental impact assessment to identify, evaluate, and mitigate potential environmental risks associated with the FPV project. Assess the project's potential effects on water quality, aquatic habitats, biodiversity, air quality, soil integrity, and other environmental factors. Develop mitigation measures to minimize adverse impacts and enhance environmental sustainability. Identify sensitive habitats, critical ecosystems, and protected areas within the project site and implement measures to protect and preserve them. Designate buffer zones, conservation areas, and wildlife corridors to minimize disturbance to natural habitats and support ecosystem resilience. Implement habitat restoration and conservation initiatives to enhance biodiversity and ecosystem health in project-affected areas. Implement effective water management practices to minimize the risk of water pollution and contamination from FPV operations. Implement sedimentation and erosion control measures to prevent soil erosion and sediment runoff into water bodies. Implement stormwater management strategies to capture, treat, and mitigate runoff from construction sites and project facilities. Implement pollution prevention measures to minimize the release of hazardous chemicals, pollutants, and contaminants into the environment. Implement measures to mitigate impacts on local biodiversity and ecosystems by preserving natural habitats, protecting endangered species, and promoting biodiversity conservation measures. Implement habitat enhancement initiatives, such as the creation of artificial reefs, wetlands, and wildlife corridors, to compensate for habitat loss and fragmentation caused by FPV development. Monitor and assess the effectiveness of biodiversity conservation measures and adapt management practices as needed to achieve conservation objectives. Establish robust environmental monitoring programs to assess the effectiveness of mitigation measures, track environmental indicators, and ensure compliance with environmental regulations and permit requirements. Monitor water quality, air quality, noise levels, wildlife populations, and habitat conditions to detect any adverse impacts and implement corrective actions as needed to mitigate risks and protect the environment.

## V. Conclusion and future research

This paper explained the background of public institutions' overseas expansion and the current status of K-water's overseas business. Like other public institutions, K-water has been carrying out overseas projects related to its main business, and in the case of recent investment projects, it is fostering renewable energy-related industries. As the global market is expanding due to the global renewable energy conversion caused by climate change, K-water needs to further activate the overseas expansion of the renewable energy industry. In addition, as the government's direct support policy for overseas expansion is actively under way, it is expected that it will serve as an opportunity to promote overseas business internally and help expand the business area in terms of creating new growth engines. However, although not described in this report, there are negative views on overseas projects by public institutions because there are various risks in the process of implementation.

The development of FPV power plants presents several technical, economic, social, and environmental risks that must be carefully managed to ensure project success. Cite conditions play a crucial role in determining the feasibility and performance of FPV projects, and inadequate site selection can lead to suboptimal economic outcomes and project failure. Furthermore, structural design flaws may result in reduced power production and efficiency, while difficulties in grid integration pose challenges to project viability. Economically, high initial investment costs and ongoing operation and maintenance expenses pose significant financial risks to investors. Uncertainty surrounding future income streams and the lack of mature consumer markets for water-based power plants further exacerbate financing risks. Additionally, imperfect subsidy mechanisms and complex approval procedures increase business uncertainty and hinder investment attractiveness. Social risks include complications in administrative approval processes, insufficient electricity demand, and potential public opposition to new technology implementations. These factors can delay project timelines, increase costs, and ultimately impact project viability. Environmental risks such as severe weather conditions, water corrosion to equipment, and ecological environment destruction highlight the importance of considering the long-term sustainability and environmental impact of FPV projects. Addressing these risks requires robust risk management strategies, stakeholder engagement, and adherence to environmental regulations and best practices.

Overall, successful development and operation of FPV power plants require comprehensive risk assessment, effective risk mitigation measures, and proactive stakeholder engagement to address challenges and ensure project resilience and sustainability. By carefully managing these risks, stakeholders can maximize the potential benefits of FPV technology while minimizing adverse impacts on the environment, society, and financial viability. The utilization of risk summaries plays a pivotal role in providing decision-makers with a comprehensive understanding of the potential risks inherent in projects. Through the utilization of these summaries, decision-makers gain the ability to assess the entirety of their risk environment and devise effective strategies aimed at mitigating and managing these risks throughout the project's lifecycle. This study provides a comprehensive overview of diverse risk management measures and offers recommendations for achieving efficacious risk mitigation. Nonetheless, forthcoming research endeavors aim to devise a specialized risk evaluation instrument through expert evaluation and discourse. Such tools are designed to enable a nuanced and meticulous appraisal of risk, thereby empowering stakeholders to enhance management strategies via an informed and participatory decision-making framework. Consequently, further academic inquiry holds promise for substantially augmenting the effectiveness of risk analysis and management methodologies pertinent to FPV projects.

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