# A Study on the predictors for O&M cost estimation of K-water's overseas hydropower projects

## (Focused on the E&M equipment)

By

**PARK, Seong Soon**

**CAPSTONE PROJECT**

Submitted to

KDI School of Public Policy and Management

In Partial Fulfillment of the Requirements

For the Degree of

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Committee in charge:

Professor Lee, Junesoo, Supervisor ____________________

Professor Byun, Doo Gyoon ____________________

Approval as of May, 2020

**Executive summary**

The overseas investment projects currently carried out by K-water are mainly hydropower projects, and using such experience, the investment in overseas hydropower projects is highly likely to continue in the future. O&M cost is an important factor in the profitability analysis of overseas hydropower projects, but there is no established standard estimation method for it in K-water. This resulted in inconsistent estimations of O&M costs and the continuous repetition of inefficient tasks for it. This study has been conducted for the purpose to propose a method to estimate the appropriate O&M costs of K-water's overseas hydropower projects in order to address these problems.

In this study, the items that make up the O&M cost in overseas hydropower projects were analyzed, and then standard items with high relevance to facility capacity and low sensitivity to local conditions were derived. O&M cost data of K-water's domestic hydropower plants were collected and based on this data, the correlation between facility capacity and O&M unit price was analyzed. As a result, a significant correlation was found between the two factors, and statistically significant regression model equations could be derived from the regression analysis. Therefore, when estimating the O&M project cost of overseas hydropower projects, it may be possible to use partially to estimate standard O&M cost according to facility capacity using the regression model formula derived from this study.

However, the following limitations exist in this study. First, the regression model in this study is not suitable for using to estimate overall O&M costs, as the results of this study are focused on the E&M equipment only. The O&M cost of facilities that are not directly related to the facility capacity, such as civil structures and transmission lines, has been excluded in this study. In addition, the replacement cost of E&M equipment that requires large-scale investment was also excluded, so estimating the overall O&M cost still requires more detailed information and consideration.

Second, in order to practically use the method proposed in this study, prior verification through actual overseas projects is required. When the operation period of K-water's overseas hydropower projects becomes longer, and the number of project countries is expanded, further research will be needed to compare and verify the result of this study through accumulated O&M cost data.

Lastly, this study has been conducted by setting the core predictor of O&M unit cost as facility capacity only. However, there is a possibility that other predictors that can be used for more accurate estimating may exist in addition to the facility capacity because overseas hydropower projects are targeting various countries. Therefore, future research to find better predictors is required as well.

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## 1. Introduction

In order to increase corporate value in the rapidly changing economic environment, public corporations have implemented various strategies. Recently, as one of the representative methods of increasing corporate value and securing competitiveness, they have made efforts to reinforce corporate profitability through successful overseas expansion (Ju, 2013). In the past, public corporations have been able to accumulate core competencies and assets through their business in the monopolistic domestic market, and utilize them to enter foreign markets by establishing partnerships with the private sector or independently. This can not only contribute to the improvement of management performance but also the economic ripple effect through the creation of new employment opportunities (Kwak & Hong, 2010).

K-water, which is a public corporation in charge of water resources management in Korea, has also joined in on this trend. K-water has built and operated many multi-purpose dams for domestic water resource management and stable water supply. In addition, hydropower plants were planned to be constructed together with the dams for efficient use of water and the supply of electric power. As a result, since K-water started commercial operation of the Soyang hydropower plant with a capacity of 200MW in 1973, it has built and operated hydropower plants with a total generating capacity of 1,008MW as of the end of 2018. Excluding pumped-storage power plants, this accounts for about 60.4% of the domestic hydropower capacity (KPX, 2019). The experience and know-how in operating hydropower plants with such large-scale facilities are the foundation for an expansion of K-water's business into the overseas market.

As shown in Figure 1, K-water is currently working on seven overseas investment projects, and five projects out of them are hydropower projects. The hydropower projects have taken the lead over the water supply projects because it is relatively easier to secure profitability in hydropower projects through a power purchase agreement with power purchasers. This trend is expected to continue in K-water overseas business for the time being. Therefore, hydropower projects play an essential role in K-water's overseas business.

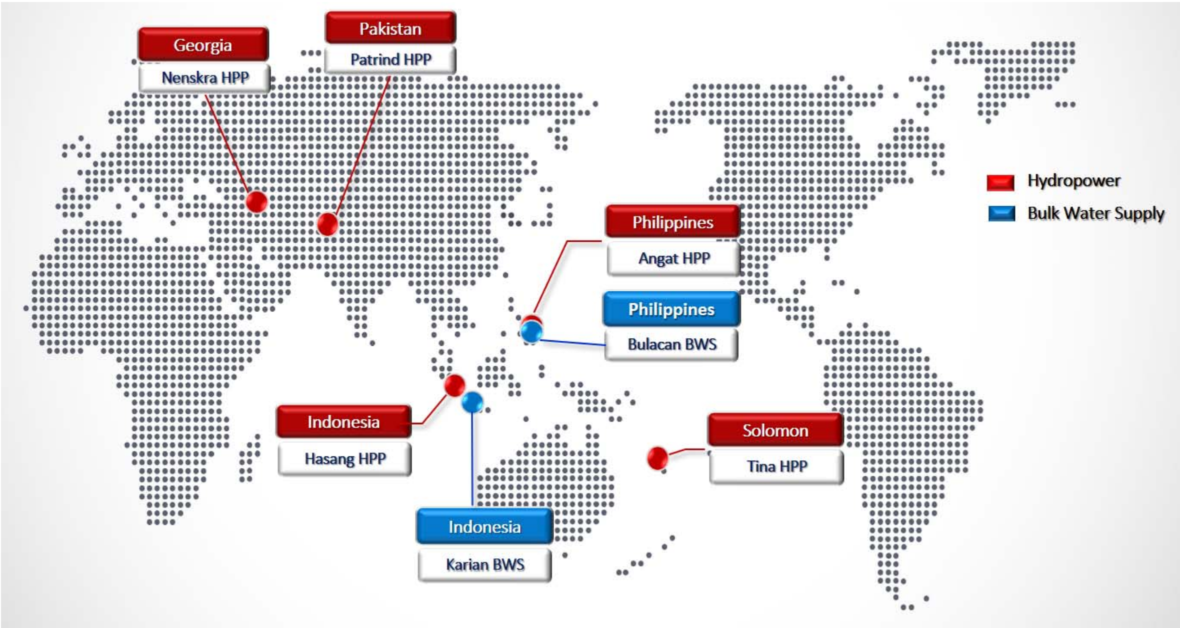



***Figure 1.*** The status of K-water overseas projects (2019)

Overseas projects of public corporations can be justified when they can contribute to the efficient execution of the public corporation's work or increase of profitability (Kwak & Hong, 2010). Therefore, in principle, overseas projects of public corporations should be carried out to generate profitability, unlike their domestic projects. Based on this principle, K-water sets improving profitability through risk reduction as the most important goal when implementing overseas projects.

The items that make up the costs and benefits of hydropower projects are as follows. The cost of the hydropower project consists of the facility construction cost, the interest cost for external financing, insurance fees for various risks, and Operation and Maintenance (O&M) costs during the operation period. Revenue is from the sales of annual electric power generated according to hydrological conditions. In order to analyze the profitability of hydropower projects at the screening stage of the project, accurate predictions on these items are required.

Annual amounts of power generation or construction costs can be estimated relatively accurately using engineering software. Insurance fees and interest expenses can also be determined by taking into account the rate against the total project cost. However, it is not easy to calculate the annual O&M costs during the operation period because the costs can vary considerably according to the operation and maintenance policies of operating companies. Moreover, in the case of overseas projects, the estimated O&M costs may have very different results according to the local conditions in various countries, special requirements depending on the location of the power plant, and the terms of the contract. Despite these difficulties, inadequate estimates of O&M costs can have a significant impact on the profitability of the project, as these costs continue to be applied for an operating period which is generally set at 30 years. Therefore, estimating appropriate O&M costs is very important in the profitability analysis of projects.

Despite such importance, K-water has no standard for the estimation of overseas hydropower O&M costs yet and has estimated these costs using different methods for each project. Most of the methods for getting O&M cost estimates of new projects were performed by reviewing the relevant costs of similar-sized hydropower plants in Korea, which result in the following problems. First, the result of the O&M cost estimation is not consistent. It may vary according to each O&M cost reviewers. Second, unnecessary tasks similar to ones in the past projects and time-consuming tasks repeat in every project. Third, uncertainty at the review stage may become a risk at the operational stage after construction. Recently, project owners and lenders have been demanding detailed data on the adequacy and basis of O&M cost estimation. Therefore, the need for a consistent standard for estimating O&M costs is increasing.

In this background, this study aimed to suggest a reasonable and objective O&M cost estimation methods for K-water's overseas hydropower projects. To this end, this study was carried out in the following steps. First of all, precedent researches performed by international institutions and organizations about O&M costs estimation methods were investigated through the literature review. Next, I examined the items that make up the O&M cost of the hydropower project, derived items that could be standardized regardless of country, and set them as factors of interest in this study. For the selected items, past O&M cost data of the nine domestic hydropower plants operated by K-water has been collected and analyzed through correlation and regression analysis between installed capacity and O&M unit cost. Finally, the conclusion about the appropriate O&M cost estimation method was drawn. The procedure for this study is shown in Figure 2 below.

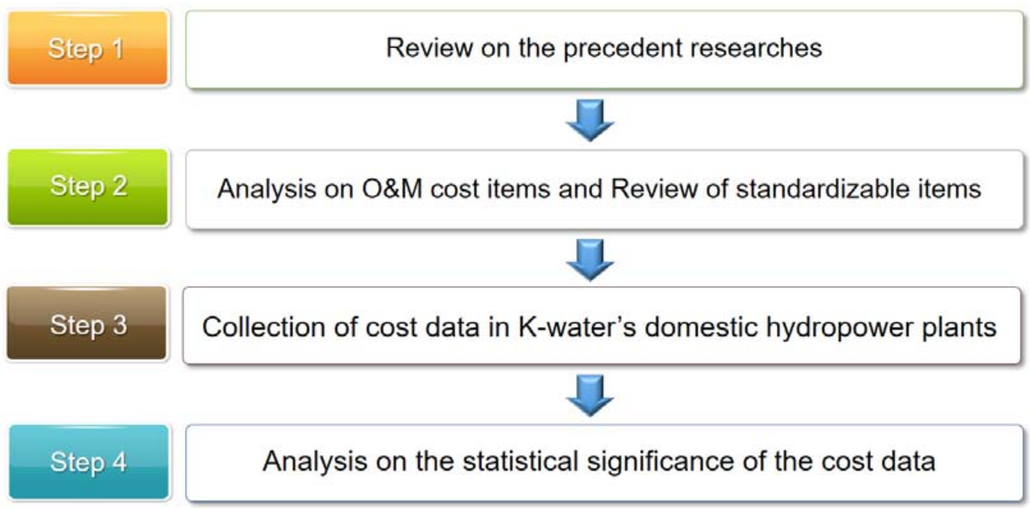



***Figure 2.*** The procedure of this study

## 2. Literature review

The operation and maintenance of hydropower projects are carried out in accordance with internal policies established based on the experience and know-how of the operating organization. So, they may vary with plant operators, and it is difficult to standardize the related O&M costs. Another reason that standardization of O&M costs is difficult is that it is difficult to obtain actual O&M cost data. O&M cost data is a kind of company's confidential business information, which is not readily disclosed to the outside. Even with some disclosures, it is common to present rough values such as the unit cost for unit capacity, rather than specific data. For this reason, precedent studies on O&M costs of hydropower projects were not extensive in number and their contents were often not specific. The contents of significant precedent researches related to O&M costs presented by international institutions are as follows.

In some reports, fixed amounts of unit cost per kilowatt (kW) were suggested as annual O&M costs. Ecofys et al. (2011) indicated that O&M costs for large-scale hydropower projects are 35€ /kW (kilowatt) · year and 40€/kW · year for small-scale hydropower plants. Olson, Schlag, Patel, and Kwok (2014) also recommended O&M cost as fixed unit cost, which is 30 USD/kW·year for large and small hydropower plants in the western United States. Here, fixed O&M costs include labor cost and administrative overhead, and exclude property tax and insurance.

Annual O&M costs are also estimated by a percentage of the total projects cost per kW per year. The values typically range from 1 % to 4 % (International Renewable Energy Agency (IRENA), 2012). The International Energy Agency (IEA, 2010) assumes 2.2 % to 3 % for small hydropower and 2.2 % for large projects, with a global average of about 2.5 %. European Renewable Energy Council (EREC) and Greenpeace (2010) showed that fixed O&M costs could be estimated as around 4 % of the total capital cost. An average value for O&M costs of 2 % to 2.5 % is considered as the standard value for large hydropower projects (Intergovernmental Panel on Climate Change (IPCC), 2011). This usually includes the refurbishment of mechanical and electrical equipment like generator rewinding, turbine overhaul and reinvestments in communication and control systems. The O&M costs presented by each source so far are shown in Table 1.

**Table 1**

*The O&M unit costs in the precedent researches*

| Classification | Organization | Small Hydro | Large Hydro | Year |
|---|---|---|---|---|
| % of the investment cost / kW·year | IEA | 2.2~3% | 2.2% | 2010 |
| | EREC | 4% | | 2010 |
| | IPCC | - | 2~2.5% | 2011 |
| Unit cost (per kW·yr) | Ecofys | 40 Euro | 35 Euro | 2011 |
| | EEE | 30 USD | | 2014 |

On the other hand, there are many studies that pay attention to the relationship between the capacity of hydropower plants and O&M cost or annual O&M unit cost per kW. Engels, Müser, and Möst (2014) suggested that the installed capacity is the most important driver of O&M cost and there is a square root type relationship between installed capacity and O&M cost as shown in Figure 3.

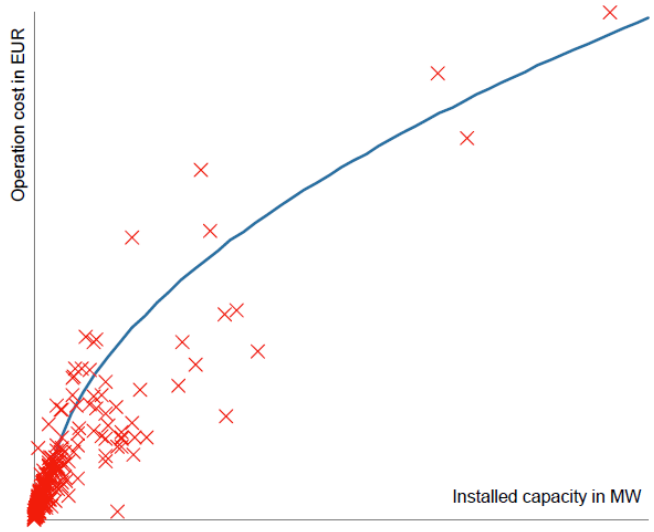
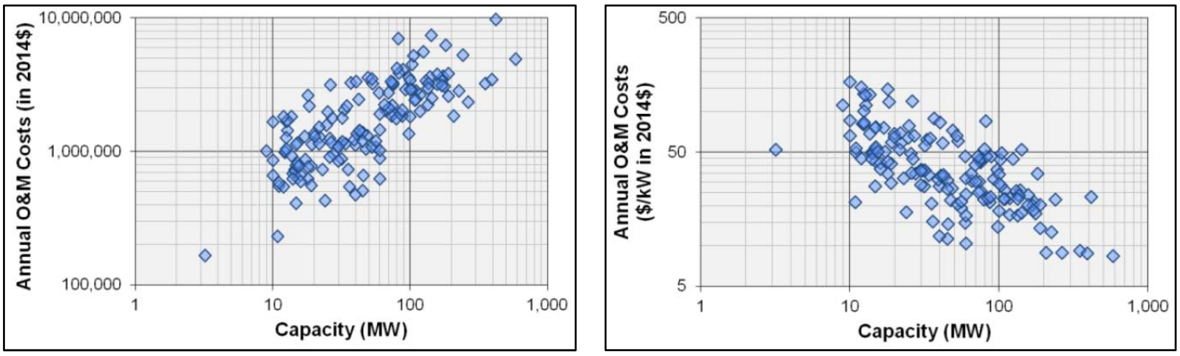



***Figure 3.*** Relationship of installed capacity and O&M cost

O'Connor et al. (2015) analyzed the relationship between O&M costs and installed capacity, and found a clear positive relationship exists between those two factors, while a clear negative relationship between O&M unit cost per kW and installed capacity. These relationships are illustrated in Figure 4 (a) and 4 (b), respectively.




(a) O&M cost vs Capacity (b) O&M Cost ($/kW) vs Capacity

***Figure 4.*** Relationship of O&M cost (O&M unit cost) vs Capacity

Another research also suggests similar findings. Uria-Martinez, Johnson, and O'Connor (2018) argued that the economies of scale with respect to the installed capacity is the single clearest source of variation in O&M cost. The larger the hydropower project is, the lower O&M cost becomes on a relative ($ per kW) basis. Figure 5 shows this relationship by plotting the O&M costs of 451 plants in 2016.

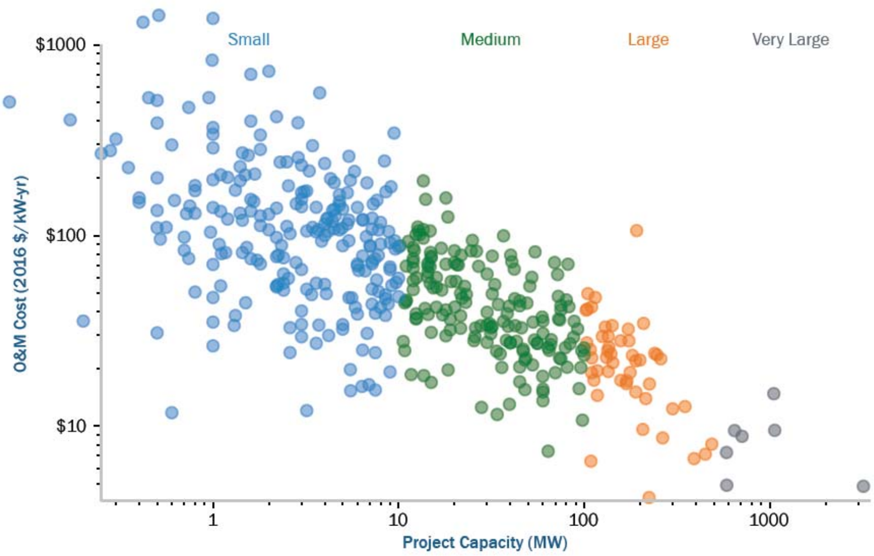



***Figure 5***. 2016 O&M costs for hydropower plants

Although O&M costs of various scales are presented in the precedent researches described above, it is difficult to draw a uniform standard for O&M cost estimation from them. Because the detailed analysis of the costs that constitute the O&M costs is insufficient and the assumptions used to derive the suggested amounts vary in each case. Therefore, the estimate of O&M costs suggested by these researches are difficult to apply to actual projects, and it may be used as a reference value in the early stages of the project where a detailed review is difficult.

On the other hand, some precedent studies showed that there is a strong correlation between the installed capacity and the O&M (unit) cost in hydropower projects. Based on this point, this study focused on analyzing the correlation between power plant capacity and O&M cost and developing a method for using it for K-water's overseas hydropower projects.

## 3. Methods

### 3.1 O&M cost item analysis

O&M costs for hydropower projects include labor, regular maintenance, spare parts, consumables, and insurance. It also includes concession fees, water tolls, or land lease fees, which vary from country to country. O&M costs per kW differ considerably with power plant size and power generation type, and labor cost may be a primary cause of significant differences in O&M costs among countries (International Finance Corporation (IFC), 2015). In addition to these country-specific differences, a variety of design, technical and market factors also contribute to different O&M costs (Uria-Martinez et al., 2018). In this study, O&M costs were classified into six categories as shown in Table 2, and details are as follows.

(1) Maintenance costs

IFC (2015) mentioned that the goal of maintenance work is to ensure the highest availability and reliability of power generation equipment and civil structures at optimum cost. On this basis, maintenance costs can be defined as the costs used for such maintenance work.

**Table 2**

*O&M cost items*

| Item | Description |
|---|---|
| **Maintenance costs** | Cost for the followings;<br>- Replacement<br>- Repair<br>- Consumables<br>- Spare parts<br>- Testing or inspection<br>- Outsourcing for special works |
| **Labor cost** | Wage for operators and maintenance personnel |
| **Overhaul cost** | Cost for disassembling and detail checking of main equipment |
| **Land lease** | Fees for rent of power plant premises |
| **Insurance** | Expenses of insurances for the mitigation of various risks |
| **Water tolls** | Fees for using water for generation from $3^{rd}$ provider or government |

Facilities requiring maintenance include Electric & Mechanical (E&M) equipment, transmission lines, structural facilities such as dams, power plant buildings, and access roads. The O&M cost consists of the following items:

- The replacement cost of equipment that has exceeded its useful life;
- Cost of purchasing parts for repair and spare;
- Cost of consumables such as emergency generator fuel, filters, grease, paints and so on;
- Testing, calibration, and inspection of equipment;
- Outsourcing cost for specialized works.

(2) Labor cost

The operation and maintenance of hydropower plants require skilled personnel with appropriate skills. Labor cost is the wage for these people.

(3) Overhaul cost

Overhaul refers to the work of disassembling and reassembling all the parts in order to perform a detailed inspection and testing after operating the hydropower plant for a certain period of time. This is to find out the failure factors in advance and to maintain the optimal condition of the equipment. K-water generally conducts an overhaul every six years for each unit of turbine-generator. Overhaul cost is mostly due to labor and inspection cost for external experts.

(4) Land lease fee

Some countries do not permit land ownership by foreign companies. In this case, the land for the dam and power plant is rented for an extended period of time and the rent is paid to the government or landowner.

(5) Insurance

In general, overseas businesses need various insurance policies to prepare for possible risks. Such insurances cover the damages from political risks, natural disasters, a default of power purchaser, etc.

(6) Water tolls

In hydropower, water is needed for power generation, which is affected by the water right. If the generating company has a water right, there will be no charge for the water used, but otherwise, a water toll should be paid for the water used for power generation.

### 3.2 Review on standardizable items of O&M costs

(1) Assumptions for standardizable items

As mentioned earlier, O&M costs of overseas hydropower projects are site-specific and can be estimated in various ways depending on the specific conditions of the country, such as labor costs. Therefore, in order to derive K-water's O&M cost estimation method that can be universally applied regardless of the country of the project, it is necessary to select O&M cost items that can be standardized in advance. In this study, it was assumed that these standard items are highly related to the installed capacity and are hardly affected by local conditions. The standard items were decided through the review on these.

(2) Analysis of Relevance with capacity and Sensitivity to local conditions

The capacity of a hydropower plant is determined by the unit capacity and the number of units of power generation equipment in the power plant. The larger the capacity, the larger the unit size and the larger the number of units. In addition, the capacity of transmission and transformation of electric power equipment and auxiliary equipment are also determined by the capacity of power generation equipment. Therefore, the maintenance cost for such E&M equipment increases as the facility capacity increases. On the other hand, the E & M equipment of hydropower plants is mostly made up of the products of global manufacturers who have standardized specifications, so the cost of the same parts can be said to be not much different at home and abroad. Therefore, this item has low sensitivity to local conditions.

Civil structure maintenance costs, on the other hand, include the repair costs to maintain the function of major structures such as dams, spillways, tunnels, and access roads, and the structures of power plants. The size of these structures tends to vary greatly depending on the project condition and scheme rather than the capacity of the power plant. So, it is hard to say that it is necessarily related to facility capacity.

The maintenance cost of a transmission line to transmit electricity from a power plant to a nearby substation is more affected by the length of the transmission line depending on the location of the plant than the capacity of the power plant. In addition, in the case of overseas projects, the relevant government or electric power purchasers are often in charge of the construction and operation of transmission lines, so it is not desirable to select transmission line maintenance costs as standard cost items.

Overhaul cost is related to facility capacity in terms of work scope, but the labor cost of professional inspectors who participate in the overhaul makes up the most significant portion, so it is affected by local conditions such as local supply and labor cost for such personnel.

Labor cost is determined by the number of people and the unit cost of labor. First, in the case of unit labor cost, the operating staff of overseas projects is mostly composed of local people, and unit labor cost is usually different from country to country, so it is challenging to standardize it. In addition, K-water's overseas projects are mostly located in developing countries, where the hydropower project is often the only source of employment for local people so staffing might include several deputy managers, facility cleaners, unskilled laborers, administrative staff, tea servers, gardeners, drivers, and security personnel. So, a project of the same size in a developing country that has high unemployment might employ 3 to 10 times the number of employees in developed countries despite modern technologies, remote control and monitoring (IFC, 2015). So, labor cost is greatly affected by local conditions.

Insurance fees vary depending on the credit and political stability of the country, the frequency of natural disasters, and the risks of the project itself. Therefore, it has low relevance to facility capacity and is sensitive to local conditions.

Land lease fee and water toll are determined by local policies of the countries or power purchase agreements. So they also have a weak association with facility capacity and are deeply related to local conditions.

So far, the main items of O&M costs have been reviewed in relevance to facility capacity and sensitivity to local conditions and the results are shown in Table 3. Based on the review, it was determined that repair, replacement, consumable, and spare parts items corresponding to maintenance costs could be standardized. However, based on the aforementioned reasons, maintenance costs for civil structures and transmission lines were excluded.

**Table 3**

*Selection of standard cost items*

| Cost items | Relevance with Capacity | | Sensitivity to Local conditions | |
|---|---|---|---|---|
| | Relevant | Irrelevant | High | Low |
| Repair* | ⦿ | | | ⦿ |
| Replacement* | ⦿ | | | ⦿ |
| Consumable* | ⦿ | | | ⦿ |
| Spare parts* | ⦿ | | | ⦿ |
| Overhaul | ⦿ | | ○ | |
| Labor cost | ○ | | ⦿ | |
| Insurance | | ⦿ | ⦿ | |
| Land lease | | ⦿ | ⦿ | |
| Water toll | | ⦿ | ⦿ | |

Note. * For E&M equipment only, excluding civil structure and transmission line

### 3.3 Analysis of O&M cost data of K-water

(1) Methodology

As mentioned above, K-water has been developing and operating hydropower projects in Korea for about 47 years and based on its abundant experience, K-water has prescribed and applied the necessary tasks for operation and maintenance. This includes methods and cycles of regular inspections, recommended cycles of major equipment replacement, appropriate quantities of spare parts, and various tests. Compliance with such regulations is essential for K-water's overseas business as well as domestic business. This is because whether the internal policy was applied should be verified at various stages of decision-making, such as technical examination or investment appraisal.

The O&M costs of domestic hydropower plants operated by K-water can be said to reflect comprehensively such operational policies of K-water. Therefore, based on domestic O&M cost data, the analytical data on the standard items of O&M cost, which have been previously reviewed, can be applied to K-water's overseas hydropower projects. Based on this methodology, O&M cost data of K-water's domestic hydropower plant has been collected and analyzed as follows.

(2) Collecting and processing of Data

The data to be investigated are budget execution data used in nine large hydropower plants (Table 4) operated by K-water with regard to the previously selected standard items. According to K-water's budget classification criteria, the categories of power generation and other machinery equipment construction in progress, power generation maintenance, and major facility maintenance are included in these data. The target period is 10 years from 2009 to 2018, and data was collected through K-water's Financial Management System as shown in Figure 6. 10% Value added Tax (VAT) was excluded to eliminate the difference in O&M costs due to differences in VAT across countries.

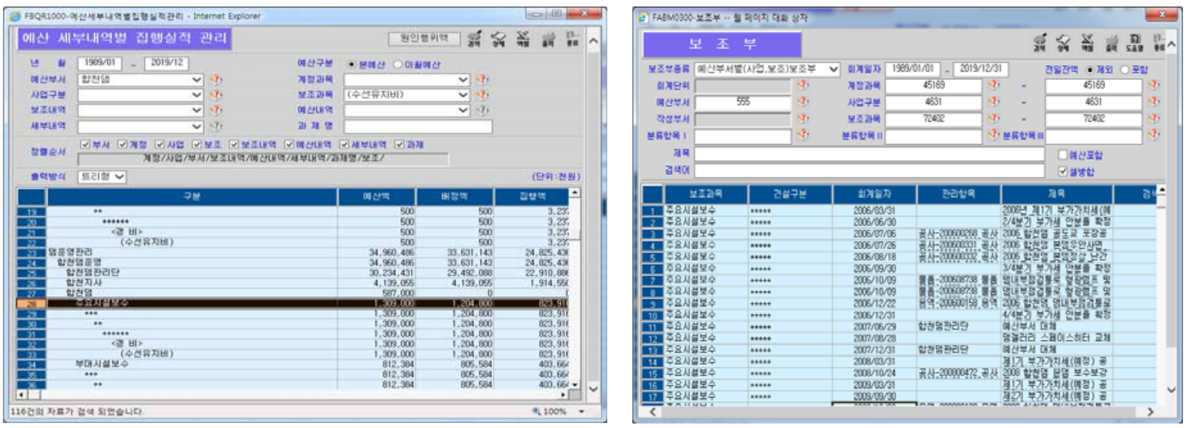
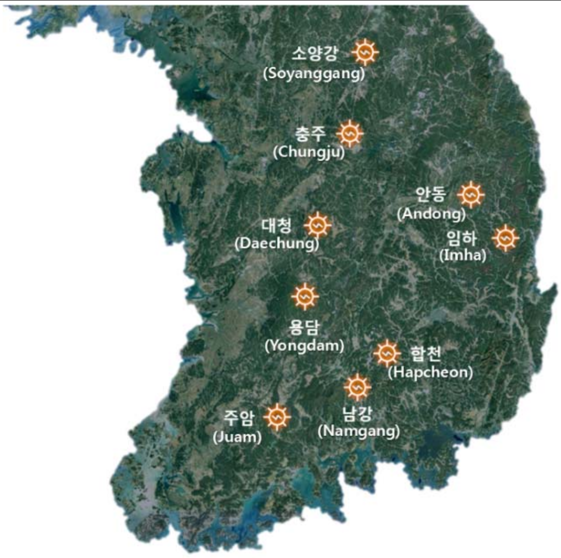


***Figure 6.*** Data collection from Financial Management System

**Table 4**

*9 Hydropower plants operated by K-water*

| Power plant | Capacity | Location |
|---|---|---|
| Chungju | 400.0 |   |
| Soyanggang | 200.0 | |
| Hapcheon | 100.0 | |
| Daechung | 90.0 | |
| Andong | 90.0 | |
| Imha | 50.0 | |
| Juam | 22.5 | |
| Yongdam | 22.1 | |
| Namgang | 14.0 | |

*Note. From the Power generation business statistics (K-water)*

The operation period under the Power Purchase Agreement (PPA) of the overseas hydropower plant project currently being carried out by K-water is generally 30 years or more, and future projects will not be different from the existing projects, either. Meanwhile, according to Standards for Operation and Management of Hydropower plants which is K-water's internal operation policy, recommended replacement cycles of some equipment are presented for more than 20 years and less than 30 years. If we assume the operating period as 30 years, this equipment may need to be replaced before the end of the operating period for the stable operation of a power plant. Among them, for the equipment that requires a high project cost of more than 100 million Won per one unit, it is advisable to comprehensively review cost per unit, number of equipment, the necessity of replacement, and the number of replacements and then apply those cost in the O&M cost separately. Therefore, equipment with a replacement cycle of shorter than 30 years and the expected replacement cost of more than 100 million won were excluded from budget execution data, and the list of such equipment is shown in Table 5.

**Table 5**

*Excluded equipment from the budget execution data*

| Equipment | Replacement Cost * (Thousand KRW) | Service life | Source of service life |
|---|---|---|---|
| AVR | 226,504 | 20 years | SOMH** |
| Metering Outfit | 131,439 | 15 years | Standards for Operation and Management of Water supply facilities and lands (K-water) |
| GIS | 3,609,632 | 20 years | SOMH |
| Main Transformer | 2,404,690 | 25 years | SOMH |
| Main Switchgear | 414,838 | 20 years | SOMH |
| Governor | 528,790 | 25 years | SOMH |
| Protective relay | 157,844 | 20~25 years | SOMH |
| Excitation system | 458,465 | 20~40 years | SOMH |
| PLC | 230,503 | 9 years | Standards for Operation and Management of Water supply facilities and lands (K-water) |

*Note.*

* *Replacement costs are arithmetic averages of the entire data and may vary according to their types and unit capacity.*

** *Standards for Operation and Management of Hydropower plants (K-water)*

Figure 7 shows the raw data collected for data analysis through this process.

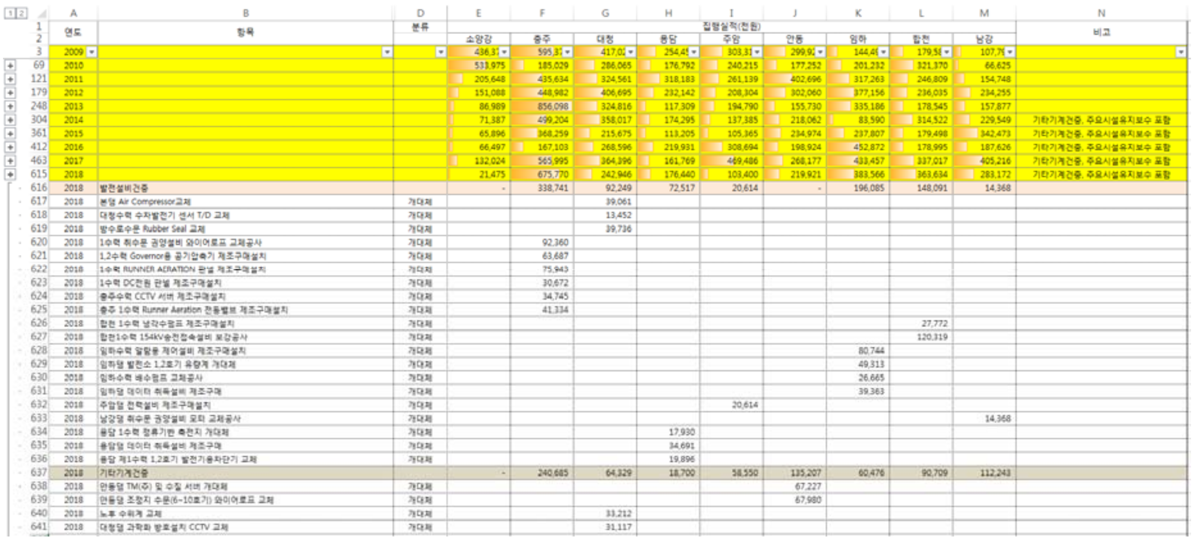


***Figure 7.*** Screenshot of raw data set

The data investigated for each year was converted into the amount as of 2018. In this process, the Consumer Price Index (Table 6) from the Monthly economic indicators published by the Ministry of Economy and Finance in August 2016 and January 2019 has been used in order to remove the effect of value change of money over time.

**Table 6**

*Consumer Price Index from 2009 to 2018*

| Item | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|
| Consumer price index | 97.1 | 100 | 104.0 | 106.3 | 107.7 | 109.0 | 109.8 | 110.9 | 113.0 | 114.7 |

*Source: Ministry of Economy and Finance (2019).*

The analyzed O&M unit costs per MW · year of the nine K-water hydropower plants are shown in Table 7. The final unit cost was calculated by dividing the average value for 10 years by the capacity of each plant.

**Table 7**

*The O&M unit costs of K-water hydropower plants*

| Classification | Namgang | Yongdam | Juam | Imha | Andong | Daechung | Hapcheon | Soyang | Chungju | Remark |
|---|---|---|---|---|---|---|---|---|---|---|
| Capacity (MW) | 14 | 22.1 | 22.5 | 50 | 90 | 90 | 100 | 200 | 400 | |
| 2009 | 107,791 | 254,455 | 303,310 | 144,497 | 299,928 | 417,020 | 179,581 | 436,379 | 595,374 | |
| 2010 | 66,625 | 176,792 | 240,215 | 201,232 | 177,252 | 286,065 | 321,370 | 533,975 | 185,029 | |
| 2011 | 154,748 | 318,183 | 261,139 | 317,263 | 402,696 | 324,561 | 246,809 | 205,648 | 435,634 | |
| 2012 | 234,255 | 232,142 | 208,304 | 377,156 | 302,060 | 406,695 | 236,035 | 151,088 | 448,982 | |
| 2013 | 157,877 | 117,309 | 194,790 | 335,186 | 155,730 | 324,816 | 178,545 | 86,989 | 856,098 | |
| 2014 | 229,549 | 174,295 | 137,385 | 83,590 | 218,062 | 358,017 | 314,522 | 71,387 | 499,204 | |
| 2015 | 342,473 | 113,205 | 105,365 | 237,807 | 234,974 | 215,675 | 179,498 | 65,896 | 368,259 | |
| 2016 | 187,626 | 219,931 | 308,694 | 452,872 | 198,924 | 268,596 | 178,995 | 66,497 | 167,103 | |
| 2017 | 405,216 | 161,769 | 469,486 | 433,457 | 268,177 | 364,396 | 337,017 | 132,024 | 565,995 | |
| 2018 | 283,172 | 176,440 | 103,400 | 383,566 | 219,921 | 242,946 | 363,634 | 21,475 | 675,770 | |
| Total (10 years) | 2,283,170 | 2,099,472 | 2,507,892 | 3,143,651 | 2,666,306 | 3,456,100 | 2,707,108 | 1,978,638 | 5,125,284 | CPI applied |
| Average (10 years) | 228,317 | 209,947 | 250,789 | 314,365 | 266,631 | 345,610 | 270,711 | 197,864 | 512,528 | |
| **Cost / MW·year** | **16,308** | **9,500** | **11,146** | **6,287** | **2,963** | **3,840** | **2,707** | **989** | **1,281** | Thousand KRW |

*Note. Year 2018 basis.*

## 4. Statistical analysis and Findings

In this step, the correlation and statistical significance between facility capacity and O&M unit cost will be analyzed using O&M unit cost data of K-water's domestic hydropower plant.

First, a correlation analysis was conducted to find out whether the capacity of the hydropower plant is related to the O&M Unit cost. The null hypothesis ($H_0$) and the alternative hypothesis ($H_1$) used in the correlation analysis are as follows.

$H_0$: There is no relationship between power plant capacity and O&M unit cost.

$H_1$: Power plant capacity is associated with O&M unit cost

Statistical analysis program SPSS was used for correlation analysis, and the result of the analysis is as shown in Table 8 below. As the p-value was 0.047, which is lower than the significance level of 0.05, it can be concluded that the facility capacity and O&M unit cost are associated at the significance level of 95%.

**Table 8**

*The result of correlation analysis*

| | | Capacity | Unit cost |
|---|---|---|---|
| Capacity | Pearson Correlation | 1 | -.672* |
| | Sig. (2-tailed) | | .047 |
| | N | 9 | 9 |
| Unit cost | Pearson Correlation | -.672* | 1 |
| | Sig. (2-tailed) | .047 | |
| | N | 9 | 9 |

*Note. Correlation is significant at the 0.05 level (2-tailed).*

Next, a regression analysis was performed between the two factors and the relationship model was derived. In regression analysis, the independent variable is power plant capacity, and the dependent variable is O&M unit cost. The null hypothesis ($H_0$) and the alternative hypothesis ($H_1$) used in the regression analysis are as follows.

$H_0$: Power plant capacity does not affect O&M unit cost.

$H_1$: Power plant capacity affects O&M unit cost.

As with correlation analysis, SPSS was used for regression analysis, and the method used is a curve estimation. The results of the regression analysis are shown in Tables 9, 10, and 11 and Figure 8 below. The results of the analysis show that the p-value is almost 0, which is much less than the level of significance at $\alpha = 0.05$ (5%). Therefore, I rejected the null hypothesis and adopted the alternative hypothesis. In other words, it is possible to conclude that power plant capacity affects O&M unit cost. The R-square value of this model is 0.938, which is a fairly high value, and it means that 93.8% of the variation is explained by this equation.

$$\text{O\&M unit cost} = 147457.746 \times \text{Capacity}^{-0.849}$$

**Table 9**

*Model summary*

| R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|
| .968 | .938 | .929 | .257 |

The independent variable is Capacity.

**Table 10**

*The result of ANOVA*

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Regression | 6.982 | 1 | 6.982 | 105.482 | .000 |
| Residual | .463 | 7 | .066 | | |
| Total | 7.446 | 8 | | | |

The independent variable is Capacity.

**Table 11**

*Coefficient of regression analysis*

| | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|
| | B | Std. Error | Beta | | |
| ln(Capacity) | -.849 | .083 | -.968 | -10.270 | .000 |
| (Constant) | 147457.746 | 52569.148 | | 2.805 | .026 |

The dependent variable is ln(Unit cost).

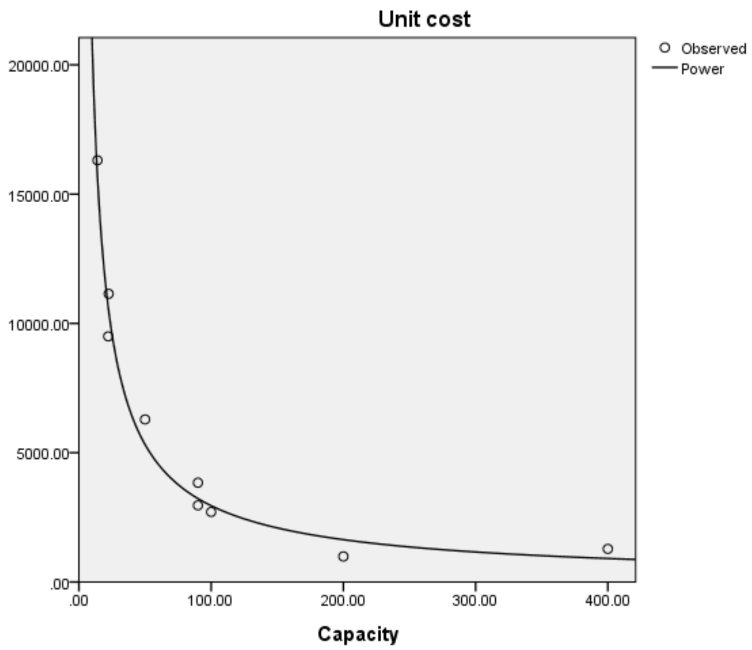



***Figure 8.*** The plot of Capacity vs O&M unit cost

## 5. Conclusion

O&M costs of overseas hydropower projects vary depending on various factors such as country, project design scheme, and project size, so it is not practically easy to derive generalized or standardized methods of the project O&M costs estimation. In the literature reviewed in this study, the annual O&M cost was presented at a very rough level such as % of total investment cost or unit cost per kW, and thus it was confirmed that there is a limit to using it in real business.

Meanwhile, several precedent studies have presented an association between power plant capacity and O&M cost, and based on this point, this study has been conducted. In this study, the items that make up the O&M cost in overseas hydropower projects were analyzed, and then standard items with high relevance to facility capacity and low sensitivity to local conditions were derived. O&M cost data of K-water's domestic hydropower plants were collected and based on this data, the correlation between facility capacity and O&M unit price was analyzed. As a result, a significant correlation was found between the two factors, and statistically significant regression model equations could be derived from the regression analysis. Therefore, when estimating the O&M project cost of overseas hydropower projects, it may be possible to use partially to estimate standard O&M cost according to facility capacity using the regression model formula derived from this study.

However, the following limitations exist in this study. First, the regression model in this study is not suitable for using to estimate overall O&M costs, as the results of this study are focused on the E&M equipment only. It is difficult to make standardized tools for overseas projects because many conditions vary depending on the local conditions of the target country. Given these difficulties, this study focused on identifying the items that can be standardized and establishing a method for appropriate estimation of the O&M cost of E&M equipment which is correlated with facility capacity. Therefore, the O&M cost of facilities that are not directly related to the facility capacity, such as civil structures and transmission lines, has been excluded in this study. In addition, the replacement cost of E&M equipment that requires large-scale investment was also excluded, so estimating the overall O&M cost still requires more detailed information and consideration.

Second, in order to practically use the method proposed in this study, prior verification through actual overseas projects is required. As of 2019, K-water is operating two overseas hydropower plants, the Patrind project in Pakistan and the Angat in the Philippines. However, it was difficult to obtain and verify O&M cost data for these power plants, as sufficient data did not exist due to short-term operation and accessing accounting information was not allowed due to the K-water's low share of the equity. Therefore, if the operation period of K-water's overseas hydropower projects becomes longer and the number of project countries is expanded, further research will be needed to compare and verify the result of this study through accumulated O&M cost data.

Lastly, this study has been conducted by setting the core predictor of O&M unit cost as facility capacity only. However, there is a possibility that other predictors that can be used for more accurate estimating may exist in addition to the facility capacity because overseas hydropower projects are targeting various countries. Therefore, future research to find better predictors is required as well.

## References


Ecofys, Fraunhofer ISI, TU Vienna EEG and Ernst & Young. (2011). *Financing Renewable Energy in the European Energy Market: Final Report*, Ecofys, Utrecht.

Engels, K., Müser, C., & Möst, B. (2014, September). *Benchmarking of Hydropower Plants*. Paper presented at the VGB Conference, Hamburg, Germany.

European Renewable Energy Council (EREC) and Greenpeace. (2010). *Energy Revolution.*

Intergovernmental Panel on Climate Change (IPCC). (2011). *Special Report Renewable Energy Sources and Climate Change Mitigation*, Working Group III-Mitigation of Climate Change, IPCC.

International Energy Agency (IEA). (2010). *Energy Technology Perspectives 2010.*

International Finance Corporation. (2015). *Hydroelectric power: A guide for developers and investors*. World Bank.

International Renewable Energy Agency (IRENA). (2012). *Renewable energy technologies: Cost analysis series (IRENA Working paper), Volume 1: Power sector (3/5).*

Ju, S. H. (2013). The Status and Policy challenges of Overseas Business in State-Owned Enterprises - Focused on Korea Westernpower Overseas Projects -. *Korean Journal of Local Government & Administration Studies,* 27(1), 335-358.

Korea Power Exchange (KPX). (2019). *2018 the status of electric power generating facilities*. https://www.kpx.or.kr/www/selectBbsNttView.do?key=100&bbsNo=8&nttNo=19326

Kwak, C. G., & Hong, G. P. (2010). Policy issues for successful overseas projects by public institutions. *Journal of Korea Society of Public Enterprise Academic Conference*, 1-27.

Ministry of Economy and Finance. (2019). *Monthly Economic Indicators*. https://www.moef.go.kr/st/ecnmyidx/TbEconomyIndicatorList.do?bbsId=MOSFBBS_000000000046&menuNo=6010300

O'Connor, P. W., Zhang, Q. F., DeNeale, S. T., Chalise, D. R., Centurion, E., & Maloof, A. (2015). Hydropower Baseline Cost Modeling Version 2. *ORNL/TM-2015/471, Oak Ridge National Laboratory, Oak Ridge, TN*.

Olson, A., Schlag, N., Patel, K., & Kwok, G. (2014). Capital cost review of power generation technologies. *Prepared for the Western Electric Coordinating Council*.

Uria-Martinez, R., Johnson, M. M., & O'Connor, P. (2018). 2017 hydropower market report. *Oak Ridge National Laboratory, Oak Ridge, TN*.