IEAHYDRO
The International Energy Agency Technology Collaboration Programme on Hydropower

Improving Performance from Existing Hydropower Facilities

Summary report by Subtask 2 of Task 16: Hidden and Untapped Hydropower Opportunities at Existing Infrastructure

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THE INTERNATIONAL ENERGY AGENCY TECHNOLOGY COLLABORATION PROGRAMME ON HYDROPOWER

The International Energy Agency (IEA) Technology Collaboration Programme on Hydropower (IEA Hydro) is a working group of IEA member countries and others that have a common interest in advancing hydropower worldwide. Current members of IEA Hydro are Australia, Brazil, China, the EU, Finland, Japan, Norway, Switzerland and the USA. Sarawak EB is a sponsor. Member governments either participate themselves or designate an organization in their country to represent them on the Executive Committee (ExCo) and the working groups (Tasks), through which IEA Hydro's work is carried out. Some activities are collaborative ventures between IEA Hydro and other hydropower organizations.

Vision

Through the facilitation of worldwide recognition of hydropower as a well-established and socially desirable energy technology, advance the development of new hydropower and the modernization of existing hydropower.

Mission

To encourage through awareness, knowledge, and support the sustainable use of water resources for the development and management of hydropower.

To accomplish its Mission, the Executive Committee has identified the following programme-based strategy to:

- Apply an interdisciplinary approach to the research needed to encourage the public acceptance of hydropower as a feasible, socially desirable form of renewable energy.
- Increase the current wealth of knowledge on a wide array of issues currently associated with hydropower.
- Explore areas of common interest among international organizations in the continued use of hydropower as a socially desirable energy resource.
- Bring a balanced view of hydropower as an environmentally desirable energy technology to the worldwide debate.
- Encourage technology development.

IEA Hydro is keen to promote its work and to encourage increasing involvement of non-participating countries. All OECD and non-OECD countries are eligible to join. Information about membership and research activities can be found on the IEA Hydro website www.ieahydro.org.

CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

ACKNOWLEDGMENTS

The IEA TCP on Hydropower Task 16 has been implemented since its statement of objectives was approved by the 35th Executive Committee in March 2019. A subtask on the improvement of the performance of existing hydropower has been led by Japan, with the cooperation of the Task 16 members including Australia, the European Union, Switzerland and the United States, and the other related organizations, taking about four years to collect and analyse case histories. This technical report was prepared by the Japanese members of Task 16, Yoichi Miyanaga and Nobuo Hashimoto, and was reviewed by Japan's Domestic Expert Committee and the members of Task 16 expert meeting.

We wish to thank the task manager and the members of Task 16, the Executive Committee Secretary, the members of Japan's Domestic Committee and Expert Committee, the Ministry of Economy, Trade and Industry, the New Energy Foundation and the Japan Electric Power Information Center, for [their guidance and cooperation. We deeply thank Mr. Niels Nielsen, the former Executive Committee Secretary, for his valuable advice and cooperation.

Yoichi Miyanaga

IEA Hydro Task 16: Subtask 2 coordinator

LIST OF ABBREVIATIONS

CA	Concrete Arch (dam type)
CG	Concrete Gravity (dam type)
E-flows	Environmental flows
FIT	Feed in Tariff
HEPCO	Hokkaido Electric Power Company, Inc., Japan
Hidden Hydro	Hidden and untapped hydropower opportunities on existing infrastructure (definition is shown in Section 2.1)
IEA	International Energy Agency
KEPCO	Kansai Electric Power Company, Inc., Japan
MLIT	Ministry of Land, Infrastructure Transport and Tourism, Japan
RF	Rock-fill (dam type)
RPS	Renewable Portfolio Standard
TEPCO	Tokyo Electric Power Company Holdings, Inc., Japan

EXECUTIVE SUMMARY

The IEA Technology Collaboration Programme (TCP) on Hydropower Task 16: Hidden and Untapped Hydropower Opportunities on Existing Infrastructure (hereinafter abbreviated as "Hidden Hydro") aims to provide a framework to enable and support an increased development of "Hidden Hydro" globally. The term "Hidden Hydro" generally refers to hydropower potential that is not included in the current national inventories or that could be used more rationally than in conventional ways. It is an important concept of hydropower potential in consideration of further development of hydropower particularly in the countries where most of economically and technically feasible hydropower projects have been developed.

Task 16 consists of five subtasks as follows:

Subtask 1: Updating hydropower inventories

Subtask 2: Improving performance from existing hydropower facilities

Subtask 3: Adding power to non-power dams and water management facilities

Subtask 4: Hidden storage

Subtask 5: Hydropower technology research and innovation in the context of "Hidden Hydro"

This report describes the results of Subtask 2 activities.

The objective of Subtask 2 is to identify "Hidden Hydro" in the improvement of performance from existing hydropower facilities based on the case history study and thereby to contribute to further performance improvement through future modernization projects.

The Subtask 2 study consists of a review of development methodologies for improving performance from existing hydropower facilities and a case history study of "Hidden Hydro." Data on case histories were collected basically through literature and questionnaire surveys. Japan served as the subtask coordinator, and the study was conducted with the cooperation of Australia, the European Union, Switzerland and the United States.

To identify "Hidden Hydro" related to the improvement of performance from existing hydropower facilities, the following basic requirements have been introduced based on the review of case histories collected in Annex 11: Renewal & Upgrading of Hydropower Plants (2016).

A) Effective use of water resources including unused or overlooked potential in existing facilities

B) Introduction of advanced or improved methodologies to maximize plant performance

C) Enhancement of reliability and flexibility to meet market needs

Furthermore, development methods for "Hidden Hydro" are categorized into three types as follows:

Type I: Renewal/refurbishment

Type II: Expansion/new construction/redevelopment

Type III: Operational improvement

On the basis of the requirements and the categorization of development methods, a total of 113 case histories have been collected systematically covering a wide range of projects from Annex 11 (2016), Annex 15: Decision-making for Maintenance Works and Upgrading of Hydro Facilities (2021) and other literature.

From the analysis of the case histories, major findings on the characteristics of "Hidden Hydro" are summarized as follows:

Type I: Renewal of existing facilities

- Improved methods to improve efficiency and durability of turbine/generator
- Improved methods to reduce cost and period of construction work
- Utilization of unused river flow
- Capacity factor improvement by downsizing turbine/generator
- Response to market needs such as enhancement of peak supply capacity and frequency control function, variable speed operation of pumped storage power plant, etc.
- Improvement of intake and water channel facilities to enhance power plant performance
- Increasing output and power generation by diversion from the other catchment

Type II: Expansion/new construction/redevelopment

- Utilization of various types of unused potential such as environmental flows from the dam, unused river flow, spilled water at the dam, unused water head in existing water channels, etc.
- Response to market needs such as enhancement of peak supply capacity and expansion/new construction of pumped storage power plant

Type III: Operational improvement

- Expansion of flow range for power generation
- Efficient operation of existing power plant by diversion from the other catchment
- Optimization of intake discharge management
- Systematic renewal/expansion considering the operation of cascade power plants
- Optimization of power plant operation through more accurate dam inflow forecasts

The most frequent challenges in the development of "Hidden Hydro" are technical issues and successful solutions are technical innovations. Particularly in type III projects, there is much room for improvement of performance using rapidly progressing technologies such as digital technologies extending the range of power plant operation, integrating meteorological observation, reservoir inflow prediction and dam operation, etc.

Economic efficiency is also a major concern in most projects. The solutions include cost reduction through technical innovations in design, construction and operation and maintenance (O&M). Policy support is expected to enhance such technical innovations.

Most environmental challenges are not significant barriers to development because renewal, expansion and operational improvement projects have less additional environmental impact than new construction projects.

1 INTRODUCTION

1.1 Background

In the countries that are advanced in hydropower development, hydropower resources that can be developed economically have decreased to the extent of resulting in a slowdown in development. In general, hydropower development is planned on the basis of existing hydropower resource inventories. The resources available for development are limited to the theoretical potential by various factors such as the level of technology, the concept of economic evaluation and the harmonization with the natural and social environments. These factors vary with the countries and times involved. There are also unutilized water resources outside the scope of existing resource inventories, such as water resources available at water management facilities that are not designed for hydropower generation. Therefore, when trying to identify further hydropower potential in a country that is advanced in hydropower development, it is important to re-examine the resource inventories used as the basis for planning and evaluate the potential that has not been fully recognized in past surveys.

To address this challenge, Task 16: Hidden and Untapped Hydropower Opportunities on Existing Infrastructure (hereinafter abbreviated as “Hidden Hydro”) was initiated in 2019 under the IEA Technology Collaboration Programme (TCP) on Hydropower. Task 16 consists of five subtasks as follows:

- Subtask 1: Updating hydropower inventories
- Subtask 2: Improving performance from existing hydropower facilities
- Subtask 3: Adding power to non-power dams and water management facilities
- Subtask 4: Hidden storage
- Subtask 5: Hydropower technology research and innovation in the context of “Hidden Hydro”

This report describes the results of Subtask 2 activities.

1.2 Overview of Subtask 2

The objective of Subtask 2 is to identify “Hidden Hydro” in the improvement of performance from existing hydropower facilities based on the case history study and thereby to contribute to further performance improvement through future modernization projects. According to the IEA Hydropower Special Market Report (2021), more than 20% of the global hydropower generation units will be more than 55 years old by 2030 and require modernization. The results of Subtask 2 can help optimize modernization projects globally.

The Subtask 2 study consists of a review of development methodologies for improving performance from existing hydropower facilities and a case history study of “Hidden Hydro.” Data on case histories were collected basically through literature and questionnaire surveys, and, if possible, power plant owners were interviewed.

In the implementation of Subtask 2 activities, Japan served as the subtask coordinator, with the cooperation of other Task 16 members, including Australia, the European Union, Switzerland and the United States. The activities take place from March 2019 to December 2023.

2 STUDY METHOD

2.1 Definition of “Hidden Hydro”

The term “Hidden Hydro” generally refers to hydropower potential that is not included in the current national inventories or that could be used more rationally than in conventional ways.

Specific examples include the following:

- New potential identified through a review of existing hydropower resource inventories
- Potential for use at non-power dams and water management facilities
- New potential for use arising from technical innovations such as the development of low-head hydropower equipment
- Potential for expanded use at existing power plants such as the use of water released from a dam reservoir

This study focuses on “Hidden Hydro” related to the improvement of performance from existing hydropower facilities. In addition to the general definition of “Hidden Hydro,” it is necessary to establish more specific requirements. Therefore, conventional development methods were categorized by the analyses of many cases of improving performance from existing power plants, and more specific requirements for “Hidden Hydro” were introduced.

2.2 Review of the development methodologies for improving performance from existing hydropower facilities

Annex 11: Renewal and Upgrading of Hydropower Plants (2016), of the IEA TCP on Hydropower has collected and analysed 70 case histories related to the renewal and upgrading (R&U) of existing power plants in different countries. Annex 15: Decision-making for Maintenance Works and Upgrading of Hydro Facilities (2021) has also collected various case histories in different countries including the Annex 11 data in a study on decision-making and asset management concerning R&U of hydropower facilities.

In this study, conventional R&U methods are categorized using the Annex 11 data, which cover various cases of R&U. The Annex 15 data are used in the next step to collect case histories of “Hidden Hydro.”

In general, the performance of existing power plants includes those related to i) power output and power generation, ii) reliability and flexibility of power supply, iii) environmental conservation and iv) safety from or resilience against disasters. The objective of R&U projects is mostly the rehabilitation or enhancement of these types of performance.

In this study, we focus on the performance related to i) and ii) because they are thought to be directly related to “Hidden Hydro.”

2.3 Method of case history collection

Case histories of “Hidden Hydro” related to the improvement of performance from existing hydropower facilities are collected, after determining basic requirements (refer to Section 3.2), mainly by data collection from Annex 11, Annex 15, other literature, interviews with power plant owners, and a questionnaire survey of the members of the IEA TCP on Hydropower and cooperating individuals. The case histories thus collected are documented as a summarized table attached to this report as Appendix A.

3 DEVELOPMENT METHODOLOGIES FOR IMPROVING PERFORMANCE FROM EXISTING HYDROPOWER FACILITIES

3.1 Categorization of development methodologies

The method for R&U of existing power plants has been practiced for a long time with the aim of increasing power output or power generation, and there are many case histories of this approach.

Table 1. Case histories of R&U projects collected in Annex 11

Code [*1]	Name of Power Plant	Country	Project Type[*2]	Before the project[*3]		After the project		Output Increase (%)[*4]
				Commissioning Year	Output (MW)	Commissioning Year	Output (MW)	
JP01	Houri No. 2	Japan	NC	—	—	2012	0.035	—
JP02	Kikka	Japan	RD	1956	0.46	2000	0.56	22
JP07	Shin-Kuronagi No. 2	Japan	NC	—	—	2013	1.9	—
JP08	Okutataragi	Japan	Renewal	1998	1932	2019	1932	0
JP10	Shin-Takatsuo	Japan	RD	1918	5.8	1999	14.5	150
JP14	Shiroyama	Japan	Renewal	1965	250	2010	250	0
JP15	Toyomi	Japan	Renewal	1929	56.4	2013	61.8	10
JP16	Tsuchimurokawa	Japan	NC	—	—	1999	0.35	—
JP17	Nishikinugawa	Japan	Renewal	1928	1	1999	1.2	20
JP18	Minakata	Japan	Renewal	1929	24.1	2000	26.7	11
JP19	Himekawa No. 2	Japan	Renewal	1935	14.4	2010	14.4	0
JP20	Oguchi (Channel 1)	Japan	Renewal	1938	11.5	2011	12	4
JP21	Doi	Japan	Renewal	1938	8	2010	8.2	3
JP22	Kamishiiba	Japan	Renewal	1955	90	2010	93.2	4
JP23	Kawabaru E-flows	Japan	NC	—	—	2011	0.15	—
JP24	Tagokura	Japan	Renewal	1961	380	2012	400	5
JP26	Kagehira	Japan	Expansion	1968	46.5	2010	46.65	0
JP27	Shin-Onagatani No.1	Japan	RD	1955	4	2001	7.5	88
JP29	Saikawa	Japan	Renewal	1923	1.7	2003	1.7	0
JP32	Shin-Taishakugawa	Japan	RD	1924	4.4	2006	11	204
JP34	Yusuharagawa No. 3	Japan	Renewal	1930	2.58	2008	2.8	9
JP36	Okutadami/Otori	Japan	Expansion	1960/63	455	2003	742	63
JP36-2	Okutadami E-flows	Japan	NC	—	—	2003	2.7	—
JP39	Okukiyotsu No. 2	Japan	NC	—	—	1996	600	—
JP41	Hanakawa	Japan	RD	1908	0.1	2011	0.13	30
JP44	Maruyama/ Shin-maruyama	Japan	Renewal	1954/71	201	2020	222.4	11
JP45	Kumagawa No. 1	Japan	Renewal	1922	2.4	2015	2.6	8

Table 1. (continued)

Code [*1]	Name of Power Plant	Country	Project Type[*2]	Before the project[*3]		After the project		Output Increase (%)[*4]
				Commissioning Year	Output (MW)	Commissioning Year	Output (MW)	
NW01	Embretsfoss IV	Norway	RD	1921	9	2013	52.5	483
NW02	Hemsil II	Norway	Renewal	1960	82	2006	98	20
NW03	Hemsil III	Norway	NC	—	—	2019	83	—
NW04	Hol 1	Norway	Renewal	1956	186	2012	220	18
NW05	Hunsfos East/West	Norway	RD	1926	15.5	2008	27.5	77
NW06	Iveland II	Norway	NC	—	—	2016	45	—
NW07	Ranasfoss III	Norway	RD	1922	54	2016	81	50
NW08	Kongsvinger	Norway	Expansion	1975	21	2011	43	105
NW09	Rendalen	Norway	Expansion	1971	92	2013	186	102
FI01	Pirttikoski	Finland	Renewal	1959	110	2010	152	38
FR01	Sisteron	France	Renewal	1975	244	2014	256	5
US01	Abiquiu	USA	Expansion	1990	13.8	2012	16.9	22
US02	Boulder Canyon	USA	Renewal	1910	10	2012	5	-50
US03	Cheoah	USA	Renewal	1919/49	144.7	2012	162	12
US04	North Fork	USA	NC	—	—	2013	3.6	—
US05	Fon du Lac	USA	Renewal	1924	12	2013	12	0
NZ01	Benmore	New Zealand	Renewal	1965	540	2012	NA	—
NZ02	Waitaki	New Zealand	Renewal	1934	90	2017	NA	—
SW01	FMHL+	Switzerland	NC	—	—	2016	240	—
AU01	Poatina	Australia	Renewal	1965	360	2010	372	3
AU02	Tungatinah	Australia	Renewal	1955	125	2013	140	12
BR01	Estreito	Brazil	Renewal	1969	1050	2012	1050	0
CH01	Gezhouba	China	Renewal	1981-88	2715	2022	3213	18

*1: The code used in the Annex 11 report

*2: NC=New construction, RD=Redevelopment

*3: For expansion or redevelopment projects, the commissioning year and output capacity in the “Before the project” column are those for the existing power plant, part of which is utilized by the newly constructed power plant.

*4: For R&U or expansion projects, calculated as (post-R&U/expansion output − *3 output) / (*3 output)

*4: For redevelopment projects, calculated as (output of the new plant + post-redevelopment output of the old plant− *3 output) / (*3 output)

Annex 11 has collected a total of 70 case histories of R&U projects, which are thought to cover a wide range of development opportunities. In categorizing and analysing the case histories, Annex 11 pays attention mainly to the trigger causes of R&U, policy background and the technologies involved. In this study, for the purpose of considering “Hidden Hydro,” the case histories are categorized paying attention to development methods for improving performance related to power output and power generation and the reliability and flexibility of power supply. The 70 cases include 50 cases that involve efforts to increase power output and power generation, restore performance, and enhance reliability and flexibility. Table 1 shows these case histories.

First of all, these cases can be categorized into two types: development that aims to enhance performance by renewal of water channel and power generation facilities (Type I) and expansion of existing facilities or construction of new power plants using existing facilities (Type II). Type II also includes "redevelopment" which involves renewing or abolishing existing facilities and constructing new plants using part of existing facilities.

3.1.1 Type I: renewal of existing water channel and power generation facilities

Thirty-five cases fall into the category of Type I. These can be classified, according to performance improvement methods, as shown in Table 2. These methods are largely classified into "renewal of electro-mechanical equipment," "change in intake discharge/hydraulic head" and "renewal of civil engineering facilities."

Table 2. Categories of Type I development (renewal of existing water channel and power generation facilities) and Annex 11 cases falling into each category

Category		Specific Measures	Corresponding Cases	Number of Cases	Output Increase (%)
Renewal of electro-mechanical equipment	Increase in output	Improving turbine/generator efficiency without changing intake discharge/hydraulic head)	JP15, JP17, JP18, JP20, JP21, JP22, JP24, JP34, JP45, FR01, US03, NZ01, AU01, AU02	14	3-20
	Improvement of durability	Improving wear resistance of turbine	JP19, JP45	2	8
		Improving cavitation resistance of turbine	NZ01, BR01	2	—
	Addition of new functions	Upgrading the frequency control function	FI01, AU01	2	3-38
		Improving grid connectivity	NZ01	1	—
		Adding phase adjustment capability	BR01	1	—
		Installing variable speed generator at existing pumped storage power plant	JP08	1	0
	Others	Restoring performance of aged turbine/generator	JP14, US05	2	0
		Downsizing turbine/generator	US02	1	-50
		Repairing turbine/generator	NZ02	1	—
Change in intake discharge/ hydraulic head	Utilization of unused river water	Increasing intake discharge and improving turbine/generator efficiency	NW02, NW04, NW07, FI01, CH01	5	18-50
	Change in intake water level/tailwater level, etc.	Changing turbine installation height	JP02	1	22
		Raising dam height	JP44	1	11
Renewal of civil engineering facilities	Renewal of intake weir	Renewing aged intake weir and shortening intake interruption period	JP29	1	0

The most common method in the Type I category is "renewal of electro-mechanical equipment," which relies solely on the improvement of turbine/generator efficiency. There are 14 cases falling into this category. The improvement of turbine/generator efficiency is achieved mainly by changing the type of turbine or the number of turbines or optimizing turbine design through refined design technologies such as CFD analysis.

The second most common method is "change in intake discharge/hydraulic head," which aims to increase output by increasing the river water intake discharge and improving turbine/generator efficiency. Five cases fall into this category. Three cases in Norway (NW02, NW04 and NW07) and CH01 in China increase intake discharge from the abundant river water. In FI01 in Finland, intake discharge is increased after considering possible adverse effects such as the influence on the operation of other power plants in the same river system and on the river environment.

Other cases include the following: improvement of durability such as the wear resistance and cavitation resistance of turbines (four cases); addition or upgrading of functions such as frequency control, grid connectivity, phase adjustment operation and variable speed generator (five cases); measures to increase hydraulic head such as changing the installation height of turbine or raising dam height (two cases); downsizing of facilities that have become excessively large because of changes in flow regime (US02); and shortening of the intake interruption period by refurbishing aged intake weir (JP29).

3.1.2 Type II: Expansion, new construction and redevelopment

Twenty-one case histories fall into the Type II category. These cases can be classified, as shown in Table 3, into the development either using unused potential or without using unused potential. In this study, “expansion”, “new construction” and “redevelopment” are differentiated as follows:

Expansion: Adding new power generation units to existing plant

New construction: Constructing a new power plant using part of existing plant facilities

Redevelopment: Constructing a new power plant by renewing or abolishing the existing plant and using part of the existing plant facilities

Type II development is an effective opportunity to increase the output and power generation from existing power plants. Development using unused potential provides more options (e.g. equipment, location) than the developments in Type I. The most common methods in Table 3 are the construction of a new power plant using the environmental flows (e-flows) from the intake dam (six cases), the abolishment of the existing power plant with the construction of a new power plant to increase intake discharge/hydraulic head (six cases). Power plants utilizing e-flows, etc. that were not originally designed for power generation are relatively small output facilities usually with restrictions on intake discharge and site location. In contrast, redevelopment involving the construction of new power plants replacing existing plants is thought to facilitate the planning of increases in output and power generation.

The third most common method is the construction of a new power plant using unused river flow and existing facilities (three cases). In all cases, river flow is sufficiently high to allow an increase of intake discharge for power generation using the existing intake dams, headrace channels, etc.

Development without using unused potential includes the new construction of a pumped storage power plant using existing facilities (two cases) and the expansion of the peak supply capacity of the existing conventional hydropower plant (JP36). In NW09 in Norway, a new unit is installed for power supply during the operation interruption period for the repair of the aged existing unit, and two units are used alternately without changing the intake discharge and output. All of these projects contribute to the improvement of the reliability and flexibility of power supply.

Most of the 50 case histories shown in Table 1 can be categorized as Type I or Type II. However, there are also cases, such as JP32, where the renewal of existing facilities and the construction of new power plants using existing facilities were carried out concurrently.

Table 3. Categories of Type II development (expansion, new construction and redevelopment) and Annex 11 cases falling into each category

Category		Specific Measures	Corresponding Cases	Number of Cases	Output Increase (%)
Development using unused potential	Expansion/new construction	Construction of a new power plant using e-flows, etc. from the dam	JP01, JP16, JP23, JP26, JP36-2, US04	6	—
		Construction of a new power plant using unused river flow and existing facilities	JP07, NW03, NW06	3	—
		Expansion to increase intake discharge of existing power plant	NW08, US01	2	22-105
	Redevelopment	Renewal or abolishment of existing power plant and construction of a new power plant using existing facilities	JP10, JP27, JP32, JP41, NW01, NW05	6	30-483
Development without using unused potential	Expansion/new construction	Expansion to increase peak supply capacity of existing power plant	JP36, JP39, SW01	3	63
		Expansion to enhance flexibility in the operation and maintenance of existing power plant	NW09	1	102

3.2 Identification of “Hidden Hydro”

3.2.1 Characteristics of R&U projects in Annex 11

Some of the R&U projects in Annex 11 improving the performance of existing power plants are found to have achieved an increase in output or power generation through advanced or improved methods. These meet the requirements of the general definition of “Hidden Hydro” in Section 2.1.

In addition, Type I projects utilizing unused river water in Table 2 and Type II projects using unused potential in Table 3 are considered to be the developments using unused potential that is not included in the existing hydropower inventories.

As for the improvement of reliability and flexibility, some cases involve the enhancement of features such as grid stabilization, peak supply capacity and demand-supply balancing. Although these are only part of the important features of hydropower, they are becoming even more important because of the changing conditions in the power market such as the massive introduction of variable renewables. Such changes in the market needs may trigger new types of development.

3.2.2 Importance of operational improvements

Besides R&U projects, it is also necessary to consider the possibility of performance enhancement through operational improvements. Some of the case histories shown in Table 2 and Table 3 include operational improvements. For example, US02, which is classified as the downsizing of turbine/generator in the Type I category, made operation at higher capacity factors possible by downsizing the facilities that had become excessively large due to the change in flow regime. In US01, which is classified as expansion using unused potential in the Type II category, operation at a higher overall utilization rate of river water was made possible by installing additional facilities capable of power generation even when the river flow is lower than the minimum discharge required by existing facilities. Other commonly used operational improvement approaches, though not listed in Table 2 or Table 3, include managing the intake discharge and intake water level, optimizing the operation of cascade reservoirs, and diverting water from other catchments. Since there has been little aggregated information on operational improvements, it would be worthwhile to collect case histories.

3.2.3 Basic requirements and development methods for “Hidden Hydro”

In view of the general definition given in Section 2.1 and the discussions above, basic requirements for “Hidden Hydro” have been introduced, as shown in Table 4, from three points of view: effective use of water resources, advanced or improved methods and response to needs in the market. These requirements can be used as a basis for the systematic collection of case histories of “Hidden Hydro.” It should be noted, however, that because judgment criteria about "advanced or improved methods" and "needs in the market" are not always definite, there is a need for discussions and reviews by experts.

Table 4. Basic requirements for “Hidden Hydro” improving existing hydropower facilities

Basic Requirements	Examples
A) Effective use of water resources including unused or overlooked potential in existing facilities	• Utilization of unused water head at dam • Water diversion from other catchments • Extension of flow range for power generation
B) Introduction of advanced or improved methodologies to maximize plant performance	• Improvement of electro-mechanical equipment • Improvement of civil engineering facilities • Optimization of power plant operation
C) Enhancement of reliability and flexibility to meet market needs	• Addition or improvement of pumped storage power generation function • Upgrading of frequency control function

On the basis of Table 2 and Table 3, and considering operational improvements, development methods of “Hidden Hydro” have been categorized as shown in Table 5.

Table 5. Categorization of "Hidden Hydro" development methods for existing hydropower facilities

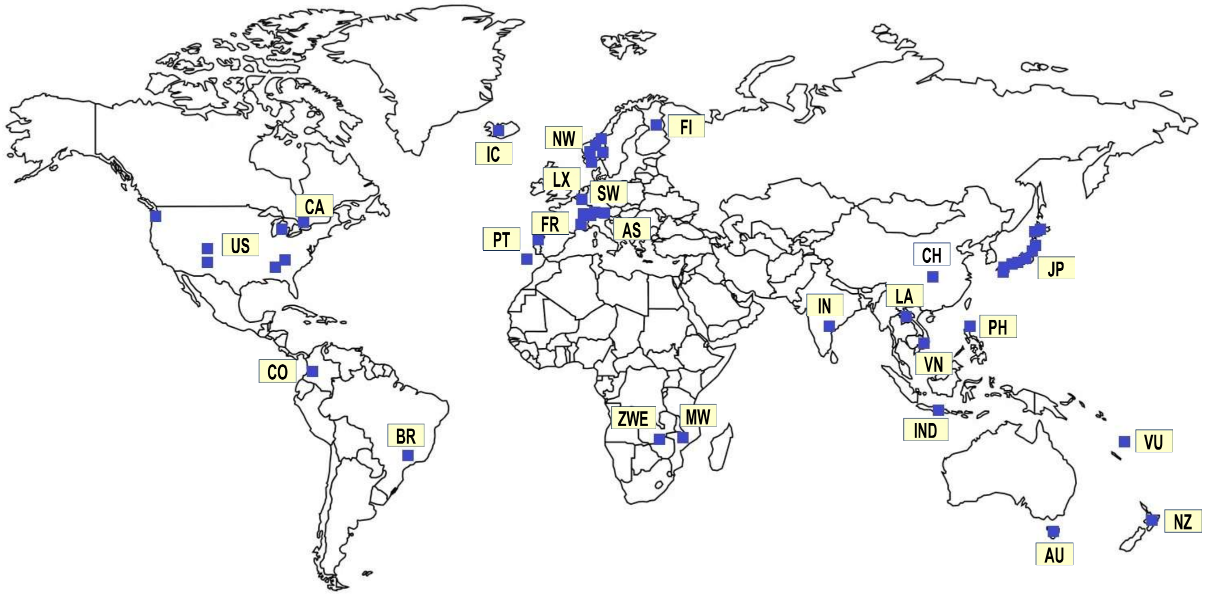
Development Methods		Examples of "Hidden Hydro"
I Renewal of existing facilities		
I-1	Renewal of electro-mechanical equipment without changing intake discharge/hydraulic head	• Improvement of turbine/generator efficiency by advanced or improved method • Shortening the interruption period through the improvement of turbine/generator durability
I-2	Renewal of electro-mechanical equipment changing intake discharge/hydraulic head	• Utilization of unused head or unused river flow
I-3	Renewal of electro-mechanical equipment adding new functions	• Addition or enhancement of functions contributing to reliability and flexibility
I-4	Renewal of civil engineering facilities	• Enhancement of water intake capability by advanced or improved method
II Expansion/new construction/redevelopment		
II-1	Development using unused potential	• Utilization of unused river flow • Utilization of unused water head, e-flows, etc. • Effective use of water resources through diversion from another catchment
II-2	Development without using unused potential	• Enhancement of peak supply capacity • Upgrading of pumped storage power plant
III Operational improvement		
III-1	Optimized operation of electro-mechanical equipment	• Expansion of flow range for power generation
III-2	Optimized operation of reservoir/power plant	• Improvement of power plant operation efficiency by advanced or improved method • Optimized operation of the power plant through diversion from another catchment

4 CASE HISTORIES OF “HIDDEN HYDRO”

4.1 Overview of the case histories

On the basis of the basic requirements shown in Table 4, a total of 113 case histories have been collected from Annex 11, Annex 15 and other literature.

The location of the case histories on the world map is shown in Figure 1. The outline of the case histories is summarized in Table 6(a) to (c). Many cases of power generation using environmental flows (e-flows) from the dam have been found, and they are separately summarized in Table 6(c).



Code	Country	N	Code	Country	N	Code	Country	N	Code	Country	N
AS	Austria	1	AU	Australia	2	BR	Brazil	1	CA	Canada	1
CH	China	1	CO	Colombia	1	FI	Finland	1	FR	France	2
IC	Iceland	2	IN	India	1	IND	Indonesia	1	JP	Japan	65
LA	Laos	1	LX	Luxembourg	1	MW	Malawi	1	NW	Norway	9
NZ	New Zealand	1	PH	Philippines	1	PT	Portugal	4	SW	Switzerland	6
US	USA	6	VN	Vietnam	1	VU	Vanuatu	1	ZWE	Zimbabwe	1

N: Number of the case histories

Figure 1. Location map of the case histories

Table 6(a). Case histories of "Hidden Hydro"
(selected from Annex 11, excluding power generation using e-flows from the dam)

Code[*1]	Name of Power Plant	Country	Project Type[*2]	After the project		Develop-ment Type[*3]	HH Require-ments[*4]
				Commissioning Year	Output (MW)		
JP02	Kikka	Japan	RD	2000	0.56	I-2	A
JP07	Shin-Kuronagi No. 2	Japan	NC	2013	1.9	II-1	A
JP08	Okutataragi	Japan	Renewal	2019	1932	I-3	C
JP10	Shin-Takatsuo	Japan	RD	1999	14.5	II-1	A
JP19	Himekawa No. 2	Japan	Renewal	2010	14.4	I-1	B
JP24	Tagokura	Japan	Renewal	2012	400	I-1	B
JP27	Shin-Onagatani No.1	Japan	RD	2001	7.5	II-1	A
JP29	Saikawa	Japan	Renewal	2003	1.7	I-4	B
JP32	Shin-Taishakugawa	Japan	RD	2006	11	II-1	A
JP36	Okutadami/Otori	Japan	Expansion	2003	742	II-2	C
JP39	Okukiyotsu No. 2	Japan	NC	1996	600	II-2	C
JP41	Hanakawa	Japan	RD	2011	0.13	II-1	A
NW01	Embretsfoss IV	Norway	RD	2013	52.5	II-1	A
NW02	Hemsil II	Norway	Renewal	2006	98	I-2	A
NW03	Hemsil III	Norway	NC	2019	83	II-1	A
NW04	Hol 1	Norway	Renewal	2012	220	I-2	A
NW05	Hunsfos East	Norway	RD	2008	15	II-1	A
NW06	Iveland II	Norway	NC	2016	45	II-1	A
NW07	Ranasfoss III	Norway	RD	2016	81	II-1	A
NW08	Kongsvinger	Norway	Expansion	2011	43	II-1	A
FI01	Pirttikoski	Finland	Renewal	2010	152	I-2, I-3, III-2	A, C
FR01	Sisteron	France	Renewal	2014	256	I-1, III-1	B
SW01	FMHL+	Switzerland	NC	2016	240	II-2	C
US01	Abiquiu	USA	Expansion	2012	16.9	II-1, III-1	A, B
US02	Boulder Canyon	USA	Renewal	2012	5	I-2, III-1	B
US03	Cheoah	USA	Renewal	2012	162	I-1	B
AU01	Poatina	Australia	Renewal	2010	372	I-3	C
BR01	Estreito	Brazil	Renewal	2012	1050	I-1, I-3	B, C
CH01	Gezhouba	China	Renewal	2022	3213	I-2	A

*1: The code used in the Annex 11 report
*2: NC=New construction, RD=Redevelopment
*3: See Table 5.
*4: See Table 4 (HH: Hidden Hydro).

Table 6(b). Case histories of "Hidden Hydro"
(selected from Annex 15 and literature, excluding power generation using e-flows from the dam)

Code*1	Name of Power Plant	Country	Project Type	After the project		Develop-ment Type*2	HH Require-ments*3
				Commissioning Year	Output (MW)		
JP101	Ooigawa	Japan	Renewal	2013	68.2	I-4, III-2	B
JP102	Kawahira No. 2	Japan	NC	2006	0.12	II-1, III-1	A, B
JP103	Yukomanbetsu	Japan	NC	2014	0.69	II-1	A
JP104	Konokidani	Japan	NC	2016	0.2	II-1	A
JP105	Kitanomata No. 3	Japan	NC	2010	0.06	II-1	A
JP106	Okususobana No. 2	Japan	NC	2017	0.98	II-1	A
JP107	Shin-Iwamatsu	Japan	RD	2016	16	II-1	A
JP108	Shimoyama	Japan	Renewal	2005	3.6	I-2, III-1	B
JP109	Shin-Kousa	Japan	RD	2019	7.2	II-1	A
JP110	Yugashima	Japan	Renewal	2012	2	I-2	A
JP111	Sakaigawa	Japan	Renewal	2019	24.2	I-4, III-2	A, B
JP112	Shumarinai	Japan	NC	2013	0.88	II-1, III-2	A, B
JP113	Shirotagawa	Japan	Operation	2016	3.1	III-2	B
JP114	Nakazato	Japan	Operation	2010	0.85	III-2	B
JP115	Kaminojiri No. 2	Japan	NC	2002	13.5	II-1	A, B
JP116	Nakatsugawa No. 2	Japan	NC	2002	1.8	II-1	A
JP117	Yukawa	Japan	RD	1997	17.4	II-1	A
JP118	Yabukami No. 2	Japan	NC	2016	4.5	II-1	A
JP119	Azumi	Japan	Renewal	1999	623	I-4, III-2	A, B
JP120	PS in Kurobe River	Japan	Operation	2019-	—	III-2	A, B
JP121	Akiba No.3 (Large Turbine)	Japan	NC	1991	45.3	II-1	A
JP122	Higashimachi	Japan	Operation	2019	32.8	III-2	A, B
AU102	Tods Corner	Australia	NC	1966	1.7	II-1	A
NZ101	Whakamaru	New Zealand	Renewal	2017	127.2	I-2	C
PT101	Madeira/Socorridos	Portugal	RD	2007	24	II-2	A, C
PT102	Salamonde II	Portugal	NC	2015	224	II-2	C
PT103	Frades II	Portugal	NC	2017	780	II-2	C
PT104	Valeira	Portugal	Operation	NA	246	III-1	A, B
AS101	Obervermuntwerk II	Austria	NC	2018	360	II-2	C
IC101	Burfell	Iceland	Renewal	1999	270	II-1	A
IC102	Burfell II	Iceland	NC	2018	100	II-1	A
LX101	Vianden	Luxembourg	Expansion	2014	1290	II-2	C
FR101	La Centrale de Mathay	France	Expansion	2019	1.5	II-1	A
SW101	Profray	Switzerland	Renewal	2007	0.38	I-2, III-1	B
SW102	Schils	Switzerland	RD	2021	13.5	II-1	A
SW103	Milan	Switzerland	Expansion	2023	4.2	II-1, III-1	A, B
SW104	Glarey	Switzerland	Expansion	2023	2.2	II-1	A
SW105	Farettes	Switzerland	Expansion	2016	22.5	II-1	A
CA101	London Street	Canada	Expansion	2016	6	II-1	A
US101	Ludington	USA	Renewal	2020	2172	I-2	C
US102	Alabama (3plants)	USA	Renewal	2014	503	I-1	B
CO101	Salvajina	Colombia	Renewal	2012	125	I-2	A
LA101	Nam Ngum1	Laos	Expansion	2017	195	II-2	C
PH101	Maris Main Canal 1	Philippines	NC	2017	8.5	II-1	A
VN101	Thac Mo	Vietnam	Expansion	2014	225	II-1	A
IN101	Srisailam Left Bank	India	NC	2003	990	II-2	C
MW101	Tedzani IV	Malawi	NC	2021	19	II-1	A
VU101	Sarakata River	Vanuatu	Expansion	2009	0.6	II-1	A
ZWE101	Kariba South	Zimbabwe	Expansion	2018	1050	II-1	A

*1: The code used in this study, *2: See Table 5, *3: See Table 4 (HH: Hidden Hydro)

Table 6(c). Case histories of "Hidden Hydro"
(related to power generation using e-flows from the dam, selected from Annex 11, Annex 15 and other literature)

Code*1	Name of Power Plant	Country	Project Type	After the project: Commissioning Year	After the project: Output (MW)	Development Type*2	HH Requirements*3
JP01	Houri No. 2	Japan	NC	2012	0.035	II-1	A
JP16	Tsuchimurokawa	Japan	NC	1999	0.35	II-1	A
JP23	Kawabaru E-flows	Japan	NC	2011	0.15	II-1	A
JP26	Kagehira (Unit 2)	Japan	Expansion	2010	0.15	II-1	A
JP36-2	Okutadami E-Flows	Japan	NC	2003	2.7	II-1	A
JP201	Dashidaira	Japan	NC	2014	0.52	II-1	A
JP202	Isawa No. 4	Japan	NC	2012	0.17	II-1	A
JP203	Shin-Tonami	Japan	NC	2011	1.00	II-1	A
JP204	Iino	Japan	NC	2014	0.23	II-1	A
JP205	Shin-Kushihara	Japan	NC	2015	0.23	II-1	A
JP206	Okuwanojiri	Japan	NC	2011	0.48	II-1	A
JP207	Kuttari	Japan	NC	2015	0.47	II-1	A
JP208	Doshi Dam	Japan	NC	2006	0.05	II-1	A
JP209	Azuma No. 2	Japan	NC	2006	0.23	II-1	A
JP210	Koami	Japan	NC	2007	0.13	II-1	A
JP211	Takato Sakura	Japan	NC	2017	0.20	II-1	A
JP212	Aihara	Japan	NC	2014	0.08	II-1	A
JP213	Akiba No.3 (small turbine)	Japan	NC	1991	1.60	II-1	A
JP214	Managawa Dam	Japan	NC	2003	0.49	II-1	A
JP215	Isawa No. 3	Japan	NC	2014	1.50	II-1	A
JP216	Inekoki	Japan	NC	1999	0.51	II-1	A
JP217	Kazunogawa Microhydropower	Japan	NC	2014	0.16	II-1	A
JP218	Ayado	Japan	NC	1998	0.67	II-1	A
JP219	Torao	Japan	NC	2011	0.27	II-1	A
JP220	Kyogoku Meisui No Sato	Japan	NC	2016	0.41	II-1	A
JP221	Akigami	Japan	NC	2016	0.29	II-1	A
JP222	Sakore	Japan	NC	2018	0.385	II-1	A
JP223	Higashigochi	Japan	NC	2001	0.17	II-1	A
JP224	Shin-Okuizumi	Japan	NC	2018	0.32	II-1	A
JP225	Hitotsuse E-flows	Japan	NC	2013	0.33	II-1	A
JP226	Kamishiiba E-flows	Japan	NC	2013	0.33	II-1	A
US04	North Fork	USA	NC	2013	3.6	II-1	A
NW201	Hegsetdammen kraftverk	Norway	NC	2010	0.23	II-1	A
PT201	Castelo do Bode	Portugal	Operation*4	2020-	54	III-2	A, B
IDN201	Wonorejo Dam	Indonesia	NC	2002	0.2	II-1	A

*1: The codes for JP01 and JP26 used in the Annex 11 report, as well as the other codes used in this study.
*2: See Table 5.
*3: See Table 4 (HH: Hidden Hydro).
*4: E-flows from existing power generation facilities and outlet conduits at the dam

Looking at the regional distribution, we notice that 71 cases are in Asia (65 of which are in Japan), 27 in Europe, seven in North America, four in Oceania, and four in other regions (Figure 2).

The category of development methodologies reveals that there are 26 cases of Type I, 83 cases of Type II and 18 cases of Type III. Thus, the number of Type II cases is the largest, and many cases utilize unused potential such as e-flows from the dam (Figure 3).

A comparison of different categories of basic requirements for “Hidden Hydro” reveals that there are 88 cases in the A category, 24 in the B category, and 16 in the C category, indicating that the number of cases in the A category is the largest (Figure 4).

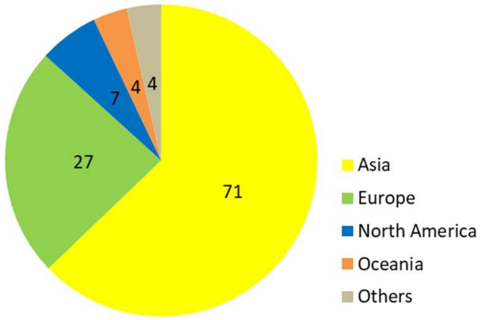


Figure 2. Breakdown by the region

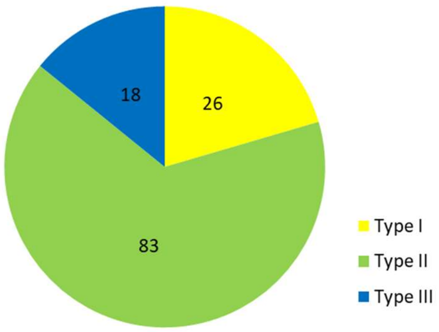


Figure 3. Breakdown by the development type

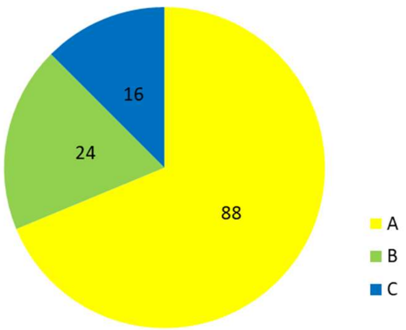


Figure 4. Breakdown by the requirements for “Hidden Hydro”

4.2 Characteristics of “Hidden Hydro”

4.2.1 Type I: Renewal of existing facilities

Table 7 summarizes the characteristics of “Hidden Hydro” in the Type I development categories and the corresponding case histories.

Table 7. Characteristics of “Hidden Hydro” in Type I categories and corresponding cases

Type of Development		Characteristics	Case Histories	Number of cases	Output Increase (%)
I-1	Renewal of electro-mechanical equipment without changing intake discharge/ hydraulic head	A shorter interruption period is achieved by improving turbine/generator durability	JP19, BR01	2	0
		Cost reduction and shorter interruption period achieved by reuse of existing casing and downsizing of equipment	JP24	1	5
		Improvement of partial load efficiency by adopting a unique turbine air supply system	FR01	1	5
		Increase of power generation by improving turbine/generator efficiency	US03, US102	2	0-12
I-2	Renewal of electro-mechanical equipment changing intake discharge/ hydraulic head	Increased output/power generation by using unused river flow	NW02, NW04, FI01, CH01, CO101	5	11-38
		Increased output/power generation by using existing unused regulating reservoir	JP110	1	25
		Increased effective head by changing turbine installation height	JP02	1	22
		Increased peak supply capacity by increasing maximum discharge	NZ101	1	19
		Increased peak supply capacity by increasing maximum discharge at pumped storage power plant	US101	1	8
		Improvement of capacity factor by downsizing turbine/generator	US02, JP108, SW101	3	-64 - -43
I-3	Renewal of electro-mechanical equipment adding new functions	Improvement of flexibility by upgrading frequency control capability	FI01, AU01	2	3-38
		Improvement of flexibility by adding phase adjustment capability	BR01	1	—
		Introduction of variable speed generator at pumped storage power plant	JP08	1	—
I-4	Renewal of civil engineering facilities	Shorter intake interruption period after a high run-off by renovation of aged intake weir	JP29	1	0
		Flow capacity improvement by retrofitting headrace channel for conveying water from multiple rivers	JP101	1	0
		Increased output/power generation of the existing power plant by diversion from another catchment	JP111, JP119	2	0

Type I-1 “renewal of electro-mechanical equipment without changing discharge/hydraulic head” includes widely known methods such as replacement with higher performance turbine/generator based on the sophisticated design technologies through CFD analysis since around 2000. Except for these well-known methods, we selected three cases of “Hidden Hydro,” involving the improvement of the wear resistance and cavitation resistance of turbines to achieve shortening of interruption period; one case involving the reuse of existing plant parts and the downsizing of equipment to achieve cost reduction and performance enhancement; and one case involving the adoption of a unique turbine air supply system to improve partial load efficiency and expand the range of operation. These methods can be regarded as good practices to improve conventional methods and make renewal efforts even more effective in performance improvement.

Note that the term “without changing hydraulic head” in this category means no alteration of the installation height of the intake, outlet, and turbine/generator.

In the category of Type I-2 “renewal of electro-mechanical equipment changing discharge/hydraulic head,” there are seven case histories utilizing “Hidden Hydro” of unused river flow, etc., to increase intake discharge and output, and the number of cases of this method is the largest in Type I-2. Two cases of increasing peak supply capacity (conventional hydropower and pumped storage hydropower) contributed to the improvement of reliability and flexibility of power supply. CO101 is a case of increasing discharge and output by utilizing the redundant turbine power allowed in the design and renewing only the generator. US02 and JP108 are cases of capacity factor improvement by downsizing the turbine and generator.

In the category of Type I-3 “renewal of electro-mechanical equipment adding new functions,” case histories are enhancing or adding functional features such as frequency control, phase adjustment operation and variable speed generator in pumped storage power generation, and all cases contribute to the improvement of reliability and flexibility of power supply. Because of the massive introduction of variable renewables in the coming years, these measures for functional enhancement are thought to become even more important.

The phase adjustment operation capability in BR01 involves a compressed air system installed to the draft tube of the Francis turbine to lower the water level so that the units can operate as synchronous condensers.

Type I-4 “renewal of civil engineering facilities” includes a case achieving a shorter interruption period by renovating an old gabion dam, which had been frequently washed out during high run-off, and a case improving flow capacity by retrofitting the headrace channel of a run-of-river type power plant. Both methods helped increase power production.

4.2.2 Type II: Expansion/new construction/redevelopment

Type II-1 "development using unused potential" includes cases involving various forms of utilization of unused potential associated mainly with rivers, release flow from the dam, and water channels.

Although expansion/new construction using unused river flow is a widely practiced method, we selected the cases according to the Category A basic requirements for “Hidden Hydro.” Among these cases, US01 and JP102 also can be categorized in Type III because they utilize river flow lower than the minimum flow required for existing plant operation.

Table 8. Characteristics of “Hidden Hydro” in Type II categories and corresponding cases

Type of Development		Characteristics	Case Histories	Number of cases	Output Increase (%)
II-1	Development using unused potential	Expansion/new construction of power generation facilities using e-flows from the dam, etc.	Cases in Table 6(c) except for PT201	34	—
		Expansion/new construction of power generation facilities using unused river flow	JP07, NW03, NW08, US01, JP102, JP115, VN101, VU101, IC101, IC102, CA101, SW102, SW103, SW104, SW105	15	22-236
		Expansion/new construction of power generation facilities using spilled water at the dam, etc.	NW06, JP106, JP118, JP121, ZWE101, MW101	6	40
		New construction of power generation facilities using the water released for irrigation from the dam	JP112	1	—
		Expansion/new construction of power generation facilities using unused water heads in existing water channels, tributary water intake facilities, fish ways, etc.	JP103, JP104, JP105, AU102, FR101	5	50
		New construction of power generation facilities using unused water head in reregulating reservoir of existing power plant	JP116, PH101	2	—
		Redevelopment using unused river flow and existing facilities to increase output	JP10, JP27, JP41, NW01, NW05, NW07, JP107, JP109, JP117	9	27-483
		Redevelopment using unused water head and existing facilities to increase output	JP32	1	205
II-2	Development without using unused potential	Expansion of existing pumped storage power plant or new construction using existing facilities	JP39, SW01, PT102, PT103, AS101, IN101, LX101	7	18
		Increasing peak supply capacity through expansion using existing reservoir	JP36, LA101	2	26-63
		New construction of the reservoir and addition of pumping capability at the existing power plant using a multipurpose water supply system in the island region	PT101	1	0

The majority of Type II-1 cases involve the utilization of e-flows from a dam or similar types of unused flows. Concerning this type of power generation, Appendix B summarizes the facilities used, the characteristics of the technology involved and the challenges in the development. Most of the “e-flows” plants are small-scale in capacity (1 MW or lower), constrained in location conditions just downstream of the dam, and many types of turbine/generator and construction methods have been adopted to address those challenges.

There are also other development methods using spilled water or the water released for irrigation, unused water heads in facilities such as existing headrace channels or intake facilities in tributaries, or unused water heads in existing reregulating reservoirs. Different forms of development, such as expansion, new construction and redevelopment are implemented according to size considerations and site conditions.

The case of JP32 is a redevelopment project that made it possible to utilize unused water head in the existing power plant while reinforcing the aged intake dam. Although the existing power plant was downsized after the renewal, the combined output of the existing plant and a newly constructed power plant reached 204% of the pre-project level.

In the category of Type II-2, "development without using unused potential," there are cases involving the expansion of existing pumped storage power plants or new construction using existing facilities, which is the majority in this category. The cases in Europe were carried out in or after 2010 to meet the emerging needs in the market.

The case of PT101 involves the addition of pumping facilities to an existing power plant using a multipurpose water supply system in the Portuguese Territory of Madeira Island. The project was carried out to meet electric power demand by making effective use of limited water resources in the island region.

4.2.3 Type III: Operational improvement

Table 9 summarizes the characteristics of "Hidden Hydro" in the Type III development categories and corresponding case histories.

Type III-1, "optimized operation of electro-mechanical equipment," includes cases reducing the lower limit of discharge for power generation and increasing capacity factor by downsizing the turbine and generator according to the flow regime. In PT104, a method for plant operation safely reducing the lower limit of discharge for power generation was developed jointly by Portugal's EDP and GE, and the method was verified at existing plants. US02, JP108 and SW101 demonstrated a higher capacity factor by downsizing the turbine and generator, also shown in the Type I-2 category in Table 7.

In the category of Type III-2, "optimized reservoir/power plant operation," there are cases of the increase in power generation by diversion from another catchments such as JP111 and JP119 which increased total power production of power plants within the same river system by conveying greater amounts of water to the plants with higher-energy-conversion-factor; and JP112 which increased total power production of new and existing plants by installing reverse-pump turbine generator system capable of both pumping and power generation at an irrigation water facility and pumping up river water during the non-irrigation period to an intake reservoir of an existing power plant.

In the optimization of intake discharge management, JP113 developed a system automatically controlling the stopping and resumption of water intake in times of flooding in order to make the intake interruption period shorter and JP114 developed a system keeping the intake discharge within the allowable range to reduce spills from the intake weir. Both projects helped increase power production.

In the systematic renewal/expansion projects considering the operation of cascade power plants, the case of FI01 is one of the R&U projects for six power plants on the Kemijoki River in Finland from 1996 to 2011, considering the operational relationship between the power plants with the aim of improving the operational efficiency as a whole.

In the optimization of power plant operation by improving dam inflow forecasting, JP120 has achieved advanced dam inflow forecasting and optimization of power plant operation by combining weather observation and forecasting technology, snow accumulation and melting models, optimization calculation methods, etc., and JP122 has succeeded in improving the accuracy of dam inflow forecasting during high run-off by using machine learning technology, enabling early restoration of reservoir storage by reducing spilled water from the dam. These technologies are expected to apply to many other sites in the future.

Table 9. Characteristics of “Hidden Hydro” in Type III categories and corresponding cases

Type of Development		Characteristics	Case Histories	Number of cases
III-1	Optimized operation of electro-mechanical equipment	Expansion of flow range for power generation	FR01, US01, JP102, PT104, SW103	5
		Capacity factor improvement by downsizing of turbine/generator	US02, JP108, SW101	3
III-2	Optimized operation of reservoir/power plant	Improvement of operational efficiency of existing power plant by diversion from the other catchment	JP111, JP112, JP119, AU101	4
		Optimization of intake discharge management	JP113, JP114	2
		Improvement of power plant operation by retrofitting headrace channel for conveying water from multiple rivers	JP101	1
		Optimization of e-flows release using existing power generation facilities	PT201	1
		Systematic renewal/expansion considering the operation of cascade power plants	FI01	1
		Optimization of power plant operation by improving dam inflow forecasting	JP120, JP122	2

4.2.4 Improvements of performance through the development of “Hidden Hydro”

As shown in Tables 7-9, the development of "Hidden Hydro" contributes to a wide range of performance improvements of existing hydropower plants, including increased output and power generation, improved equipment durability, improved reliability and flexibility in the power supply, and optimized power plant operations.

As an example of the quantitative performance improvements, the output increase rates for Type I and Type II cases are shown in Figure 5. The output increase rate is defined here as (output increase due to the project implementation) / (maximum output before the project implementation.) Figure 5 shows that the output increase rate was larger for Type II, which has more options for development methods, than for Type I, particularly for small-scale hydropower plants with an output of 10 MW or less. Note that the figure does not include three cases of Type I, in which the water turbines and generators were downsized to improve the capacity factor, and one case of Type II, in which the output increase rate was extremely large (483%, NW01).

Most of the cases with increased output also increased power generation, except for the cases that expanded the pumped storage power plants. The expansion of pumped storage power plants contributed to the improvement of reliability and flexibility, such as securing the peak supply capacity. Even in the cases with no increase in output, power generation was increased due to the improvements in equipment durability and efficiency.

Type III cases contributed to the increased power generation and the improved efficiency through the optimization of power plant and reservoir operations.

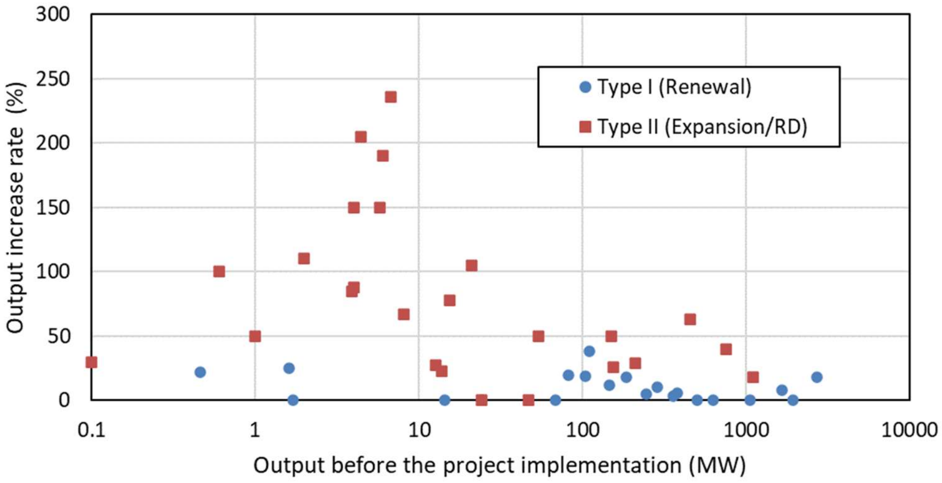


Figure 5. Output increase rate for Type I and Type II cases

(RD=redevelopment. New construction projects in Type II are not included.)

4.3 Development of “Hidden Hydro”: challenges and solutions

In general, there are challenges related to technology, economic efficiency, environment and regulations in hydropower development. The same is true for the development of “Hidden Hydro.” From the collected case histories, specific examples of the solutions to these challenges are summarized in Tables 10 through 12.

4.3.1 Solutions to technical challenges

Solutions to the technological challenges can be divided into two categories: those related to enhancement and improvement of the performance of facilities, which is utilized in the development of “Hidden Hydro,” and those related to the design and construction of civil engineering facilities, as shown in Table 10.

Technological challenges related to the performance of facilities are basically solved through technological improvements and innovations, many of which correspond to the basic requirement B “advanced or improved methods” of “Hidden Hydro.” Concerning electromechanical equipment, noticeable cases are improvements in the efficiency and durability of water turbine (JP19, BR01, FR01, etc.), introduction of new types of water turbine (JP102, JP115, FR101, etc.), addition of pumped storage function (AS101), variable speed turbine and generator (JP08), data monitoring system to expand the range of turbine and generator operation (PT104), automation of water intake control (JP113, JP114), and improved operational planning through more accurate dam inflow forecasts (JP120, JP122). Concerning civil engineering facilities, there has been the introduction of the steel-rubber hybrid gate (JP29), structural reinforcement of aged dams and the enlargement of flood discharge capacity (JP32), among others. Elemental technologies used to improve and enhance the performance of these facilities include CFD analysis and model test of water turbine and channel flows, monitoring and control of equipment using digital technologies, weather observation/forecasting system, and method for predicting dam inflows.

Challenges related to the design and construction of civil engineering facilities are often found in Type II cases including expansion, new construction and redevelopment in a variety of site conditions. Specifically, there are measures to prevent construction work from affecting the operation of existing power plant (NW01, JP109, SW01, PT102, etc.), controlling river flow during construction (NW05, NW08), tunnel and underground cavity excavation technology (JP27, JP39), construction technology at sites with severe topographical and ground constraints (JP103, VU101, SW104, etc.), and drilling of concrete dam body (JP121, JP36, LA101). In these design and construction works, it is important to optimize them while considering safety, economic efficiency, and environmental impacts.

Table 10. Specific solutions to technical challenges in case histories

Specific Solutions to Technical Challenges		Case Histories
Enhancement and improvement of performance of facilities	Improving efficiency/durability of water turbine	JP19, BR01, FR01, etc.
	New types of water turbine	JP102, JP115, FR101, etc.
	Adding pumped storage function	AS101
	Variable speed turbine/generator at PSH plant	JP08
	Data monitoring system for range expansion of turbine/generator	PT104
	Automatic water intake control	JP113, JP114
	Improving power plant operation by more accurate dam inflow forecasts	JP120, JP122
	Steel-rubber hybrid gate	JP29
	Structural reinforcement of aged dam and enlargement of flood discharge capacity	JP32
Design and construction of civil engineering facilities	Preventing construction work from affecting existing power plant operation	NW01, JP109, SW01, PT102
	Controlling river flow during construction	NW05, NW08
	Excavating tunnel and underground cavity	JP27, JP39
	Construction under severe topographical and ground constraints	JP103, VU101, SW104, etc.
	Drilling concrete dam body	JP121, JP36, LA101

Technical challenges of power generation using environmental flows at existing dams and power plants are analysed in Appendix B. Major challenges include simplification of facilities to reduce costs, utilization of existing facilities and construction at locations with severe topographical constraints such as the base of dams.

4.3.2 Solutions to economic challenges

In order to improve the economic efficiency of the project, the main challenges are reducing development costs, minimizing the scale of construction, shortening the construction period, and improving the efficiency of maintenance and management in operation. Solutions to these challenges can be classified into technological methods and policy support, as shown in Table 11.

Technological methods include the use of existing facilities and technological innovations. Specifically, three are examples utilizing existing water intake facilities, headrace channel and penstock (JP02, JP07, JP27, JP41), reducing repair interval by improving the durability of equipment (JP19), optimizing renewal options (JP24), and improving the capacity factor by downsizing equipment (JP115).

For existing facilities, it is possible to reduce the scale of construction work by evaluating their soundness and maximizing their utilization. In improving the durability of equipment, CFD analysis, model experiments and field tests of water turbine and channel flows have been conducted frequently. With future advances in computer performance and CFD analysis technology, costs will be further reduced if experiments and tests can be reduced.

Optimization of renovation options at early design stages also contributes to the project's cost reduction. The RENOVHydro project, although not included in the case histories, has demonstrated a systematic assessment methodology using a hydropower plant simulation model developed by EPFL to identify the most cost-effective civil and hydro-electrical options (Landry, C. et al., 2018).

Table 11. Specific solutions to economic challenges in case histories

Specific Solutions to Economic Challenges		Case Histories
Technological Method	Utilizing existing civil engineering facilities	JP02, JP07, JP27, JP41
	Reducing repair interval by improving the durability of water turbine	JP19
	Optimizing renewal options	JP24
	Improving capacity factor by downsizing equipment	JP115
Policy Support	Subsidies	US01-04, JP02, JP07, JP32, JP41, JP102, JP121
	Electricity certificates	NW01, NW03, NW07
	FIT, RPS	JP01, JP102, JP104-106, JP203, JP207, JP209-212, etc.

Policy support includes subsidies, electricity certificates, RPS (Renewables Portfolio Standard), and FIT (Feed-in-Tariff). Four U.S. examples (US01-US04) were funded by the U.S. Department of Energy under The American Recovery & Reinvestment Act of 2009. Six Japanese projects (JP02, JP07, JP32, JP41, JP102, and JP121) received national funding to support medium and small-scale hydropower development. Three Norwegian cases (NW01, NW03, NW07) have used the Norwegian-Swedish electricity certificate market. In addition, many Japanese examples of environmental flows power generation have used the FIT system introduced in 2012.

4.3.3 Solutions to environmental challenges

Environmental impacts of hydropower development generally include impacts on the natural environment, such as flow regime, water quality, reservoir sedimentation and terrestrial and aquatic ecosystems, as well as impacts on the social environment, such as water use, landscape and livelihoods of residents in the affected area. In the renewal or redevelopment of existing power plants, these additional environmental impacts have to be assessed and minimized. Most of these additional environmental impacts are relatively small compared to those of new greenfield projects and are not significant barriers to the development of “Hidden Hydro.”

As shown in Table 12, major mitigation measures in the collected cases include release of river maintenance/environmental flows (NW03, JP117, JP121, SW104), fish migration and habitat conservation (JP10, NW01, US01, US04, SW102), bird conservation (JP36, JP107, JP116) and landscape conservation (JP32, NW01, JP117, SW105). Effective mitigation measures have been developed and demonstrated for a wide variety of environmental impacts. In the US04 case, an innovative upstream fish passage system has been developed to collect migrating fish at the base of a 72m-high dam and transport them upstream. Note that streamlining the environmental consultation process may be necessary in some cases (JP111, SW103) to avoid delays in development. This is also true for consultations related to non-environmental regulations such as water diversion and land use.

Table 12. Specific solutions to environmental challenges in case histories

Specific Solutions to Environmental Challenges		Case Histories
Natural Environment	Releasing environmental flows	NW03, JP117, JP121, SW104
	Preserving fish migration and habitat	JP10, NW01, US01, SW102
	Preserving birds	JP36, JP107, JP116
Social Environment	Preserving landscape	JP32, NW01, JP117, SW105
	Streamlining environmental consultations	JP111, SW103

5 SUMMARY AND CONCLUSIONS

In this study, we defined the methods to increase output and power generation as well as reliability and flexibility of existing hydropower plants through modernization using unused potential and/or advanced technologies as "Hidden and Untapped Hydropower Opportunities" (Hidden Hydro), and collected 113 case histories globally.

"Hidden Hydro" of existing hydropower plants is important for hydropower development with lower environmental impacts and development costs than alternative greenfield projects, particularly in countries where hydropower development has advanced and the number of suitable sites for the new development has decreased. This study systematically organized methods for performance improvement by project type and "Hidden Hydro" requirements, and compiled data and findings useful for efficient future hydropower development. A summary of the main findings is presented in the "Executive Summary." Detailed information on the case histories is available in the Appendices A and B.

There are technological and economic challenges in the development of "Hidden Hydro." In order to resolve these issues and develop "Hidden Hydro" more efficiently, technological innovation and policy support will continue to be important.

6 REFERENCES

IEA TCP on Hydropower, Annex 16 Hidden Hydro Opportunities, *www.ieahydro.org/work-programme/annex-xvi-hidden-hydro*.

IEA TCP on Hydropower (2016), Renewal & Upgrading of Hydropower Plants, Annex 11 Summary Report.

IEA TCP on Hydropower (2021), Maintenance Works and Decision-making for Hydropower Facilities, Annex 15 Report.

IEA (2021), Hydropower Special Market Report, Analysis and forecast to 2030.

Landry, C. et al. (2018), Renovation of hydraulic power plant: how to select the best technical options? Hydro 2018, Gdansk, Poland.

APPENDIX A
SUMMARY OF CASE HISTORY DATA

This data summary for each case history of "Hidden and Untapped Hydropower Opportunities" includes key information about the project, improvement of performance, main challenges, and characteristics of "Hidden Hydro" development, with the exception of environmental flows power generation, the data of which are summarized in Appendix B.

Definitions and descriptions of the term in the summary

Type of the project:

"Renewal" includes refurbishment, renewal/upgrading, replacement, and retrofitting of existing plant.

"Expansion" is defined as the addition of new power generation units and/or civil structures to existing plants.

"New construction" is defined as the construction of a new power plant using part of existing facilities.

"Redevelopment" includes the construction of a new power plant by renewing or abolishing existing plants, using part of existing facilities.

"Change of power plant operation" includes operations of the power plant and/or water intake system.

Classification of development type

I	Renewal/upgrading of existing facilities
I-1	Renewal of electro-mechanical equipment without changing intake discharge/hydraulic head
I-2	Renewal of electro-mechanical equipment changing intake discharge/hydraulic head
I-3	Renewal of electro-mechanical equipment adding new functions
I-4	Renewal of civil engineering facilities
II	Expansion/new construction/redevelopment
II-1	Development using unused potential
II-2	Development without using unused potential
III	Operational improvement
III-1	Optimized operation of electro-mechanical equipment
III-2	Optimized operation of reservoir/power plant

"Hidden Hydro" requirements

A	Effective use of water resources including unused or overlooked potential in existing facilities
B	Introduction of advanced or improved methodologies to maximize plant performance
C	Improvement of reliability and flexibility to meet market needs

List of data summary for each case history

List of data summary for each case history

Data summary for each case history

Project code	CH01
Name of the project	Renewal of Gezhouba Power Station
Location/country of the project	Yichang City, Hubei Province, China
Implementing body of the project	China Yangtze Power Co., Ltd.
Implementing period	2005 – 2022
Type of the project	Renewal
Specifications (before the project)	
Name of power plant	Gezhouba Power Station (Erjiang PS and Dajiang PS)
Name of river	Yangtze River
Type of power plant	Dam type
Year of commission	1981
Maximum output (MW)	2715MW (Erjiang: 129MW/unit x 7 units, Dajiang: 129MW/unit x 14 units)
Maximum discharge (m3/s)	825/unit
Effective head (m)	18.6
Annual power production (GWh)	15,700
Specifications (after the project)	
Name of power plant	Gezhouba Power Station (Erjiang PS and Dajiang PS)
Name of river	Yangtze River
Type of power plant	Dam type
Year of commission	2022
Maximum output (MW)	3213MW (Erjiang: 153MW/unit x 7 units, Dajiang: 153MW/unit x 14 units)
Maximum discharge (m3/s)	Erjiang: 950.95/unit, Dajiang: 923.39/unit
Effective head (m)	18.6
Annual power production (GWh)	16,400 (estimated)
Overview of the project	Gezhouba Power Station on the Yangtze River has been operating for more than 30 years, and some parts of the units had serious aging phenomena and hidden safety hazards, which affected safe and stable operation. Therefore, China Yangtze Power Co., Ltd. decided to renew and upgrade 129MW units. Targets of the renewal were turbine runners, generator stator cores, stators and rotor winding bars. The renewal was expected to increase maximum output and improve generation efficiency and cavitation erosion resistance.
Improvement of performance	

Increase in output	Maximum output was increased from 129MW/unit to 153MW/unit by using the unused potential.
Increase in power production	An increase in annual power production by 700GWh was expected due to the increase in output.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	N/A
Cost	N/A
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	I-2 Renewal of electro-mechanical equipment changing intake discharge/hydraulic head
Requirement A: Effective use of water resources	Effective utilization of unused potential in the river. Existing generation units were renewed and upgraded by increasing maximum discharge.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History Ch.01_ Gezhouba https://www.ieahydro.org/media/5fb06b0d/ Vol2_Case_History_English(409-598).pdf

Project code	IN101
Name of the project	New construction of Srisailam Left Bank Pumped Storage Power Station
Location/country of the project	Andrha Pradesh (AP), India
Implementing body of the project	AP State Electric Power Board
Implementing period	1988 – 2003
Type of the project	New construction
Specifications (before the project)	
Name of power plant	Srisailam Power Station
Name of river	Krishna River
Type of power plant	Dam and waterway type
Year of commission	1987
Maximum output (MW)	770
Maximum discharge (m3/s)	N/A
Effective head (m)	N/A
Annual power production (GWh)	N/A
Specifications (after the project)	Note: Specifications of the existing Srisailam Power Station are the same as those before the project. Srisailam Left Bank Power Station is newly constructed to expand the existing power station.
Name of power plant	Srisailam Left Bank Power Station (mix-type pumped storage)
Name of river	Krishna River
Type of power plant	Dam and waterway type
Year of commission	2003
Maximum output (MW)	990
Maximum discharge (m3/s)	N/A
Effective head (m)	N/A
Annual power production (GWh)	1465
Overview of the project	Srisailam Power Station with 7 units of 110MW has been operating since 1987 on the Krishna River in Andrha Pradesh State, India, but there was an overflow from the dam. There is Nagarjugasagar Reservoir located downstream of Srisailam Power Station and it was planned to construct a mix-type pumped storage power station using a hydraulic head between Srisailan upper reservoir and Nagarjugasagar lower reservoir. Through this mix-type pumped storage power development, the river flow was effectively utilized. The peak-power supply from the new pumped storage station meets the increasing power demand in Andrha Pradesh State.
Improvement of performance	
Increase in output	Maximum output was increased by the new construction of a mix-type pumped storage power station.

Increase in power production	The increased power output by pumped storage generation and the self-generation using dam inflow increased total annual power production.
Reliability/flexibility	A new mix-type pumped storage power station improved the reliability of the power supply by meeting increasing peak electricity demand.
Others	N/A
Challenges in the project	
Technology	N/A
Cost	The project was funded by ODA loans from the Japan International Cooperation Agency.
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	Effective utilization of overflow discharge and hydraulic head at existing dam
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	Increased peak-power supply by the new construction of a mix-type pumped storage power station improved the reliability and flexibility of the power supply.
Others	N/A
References	[1] India Srisailam Left Bank Power Station Project - JICA https://www.jica.go.jp/english/our_work/evaluation/oda_loan/post/2006/pdf/project35_full.pdf

Project code	**JP02**
Name of the project	Redevelopment of Kikka Power Station
Location/country of the project	Kumamoto Prefecture, Japan
Implementing body of the project	Kumamoto Prefecture, Public Enterprise Bureau
Implementing period	1998 – 2000
Type of the project	Redevelopment
Specifications (before the project)	
Name of power plant	Fukaze Power Station
Name of river	Uchidagawa River and Kuwazurugawa River
Type of power plant	Waterway type
Year of commission	1956
Maximum output (MW)	0.46
Maximum discharge (m3/s)	1.1
Effective head (m)	62
Annual power production (GWh)	2.6
Specifications (after the project)	Note: The existing Fukaze Power Station was renewed and upgraded to Kikka Power Station.
Name of power plant	Kikka Power Station
Name of river	Uchidagawa River and Kuwazurugawa River
Type of power plant	Waterway type
Year of commission	2000
Maximum output (MW)	0.56
Maximum discharge (m3/s)	1.1
Effective head (m)	63.1
Annual power production (GWh)	N/A
Overview of the project	Kikka Power Station is the renewal project of Fukase Power Station, which was built in Kikka town, Kumamoto Prefecture. Fukase Power Staion was decided to implement renewal & upgrade works because the power facilities were too old. The developer was also changed from a local business union to the prefecture enterprise bureau. Renewal & upgrade works consist of the effective utilization of the existing waterway, the adoption of the latest model of turbine/generator and the change of installation position of the turbine center. After the project, maximum output and power production were increased by the increase of effective head.
Improvement of performance	
Increase in output	Maximum output was increased from 460 kW to 560 kW.
Increase in power production	Power production was increased by the increase in output.
Reliability/flexibility	N/A
Others	N/A

Challenges in the project	
Technology	A survey into the soundness of the waterway was conducted before renewal works and it was found that the existing old waterway for Fukase Power Station was available for work with periodic inspection and repair.
Cost	Considering the economic efficiency of the construction of Kikka Power Station, the existing waterway was effectively utilized and a public subsidiary system for hydropower development was utilized.
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	I-2 Renewal of electro-mechanical equipment changing intake discharge/hydraulic head
Requirement A: Effective use of water resources	Effective use of unused potential by increasing effective head
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History Jp.02: Kikka https://www.ieahydro.org/media/860db877/ Vol2_Case_History_English(207-408).pdf [2] Kumamoto prefecture Overview https://www.pref.kumamoto.jp/uploaded/attachment/50286.pdf

Project code	**JP07**
Name of the project	New construction of Shin-Kuronagi No. 2 Power Station
Location/country of the project	Toyama Prefecture, Japan
Implementing body of the project	Kansai Electric Power Co., Inc.
Implementing period	2012 – 2013
Type of the project	New construction
Specifications (before the project)	
Name of power plant	Kuronagi No.2 Power Station
Name of river	Kuronagi River
Type of power plant	Waterway type
Year of commission	1947
Maximum output (MW)	7.6
Maximum discharge (m3/s)	6.2
Effective head (m)	152.55
Annual power production (GWh)	58.6
Specifications (after the project)	Note: Specifications of the existing Kuronagi No.2 Power Station are the same as those before the project.
Name of power plant	Shin-Kuronagi No. 2 Power Station
Name of river	Kuronagi River
Type of power plant	Waterway type
Year of commission	2013
Maximum output (MW)	1.9
Maximum discharge (m3/s)	1.7
Effective head (m)	142.13
Annual power production (GWh)	8.6
Overview of the project	Shin-Kuronagi No.2 Power Station with a maximum output of 1.9MW and annual power production of 8.6GWh was newly constructed on the upstream site adjacent to the existing Kuronagi No. 2 Power Station. In this project, existing power facilities such as an intake weir, headrace tunnel, head tank and penstock were effectively utilized and the surplus waterflow capacity of the waterway (by partial enlargement of tunnel section) made it possible to increase water discharge from 6.2 to 7.9 m3/s. Because the existing facilities were utilized, construction cost could be reduced to about 40% compared to the new construction of a hydropower station of the same scale and type.
Improvement of performance	
Increase in output	Maximum output was increased by 1.9MW.
Increase in power production	Annual power production was increased by 8.6GWh.
Reliability/flexibility	N/A

Others	N/A
Challenges in the project	
Technology	N/A
Cost	Maximum discharge was examined on an appropriate scale from an economical viewpoint. In addition, because the existing power facilities were utilized, construction costs could be reduced to about 40% compared to the case of new construction of hydropower stations of the same scale and type, and a public subsidiary system for hydropower development was utilized.
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	Utilization of existing power facilities and effective utilization of the surplus waterflow capacity of the waterway made it possible to reduce construction cost of the project greatly.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History Jp.07_Shin-Kuronagi https://www.ieahydro.org/media/5fb06b0d/ Vol2_Case_History_English(1-206).pdf

Project code	**JP08**
Name of the project	Renewal of Okutataragi Pumped Storage Power Station
Location/country of the project	Hyogo Prefecture, Japan
Implementing body of the project	Kansai Electric Power Co., Inc.
Implementing period	2008 – 2019
Type of the project	Renewal
Specifications (before the project)	
Name of power plant	Okutataragi Pumped Storage Power Station
Name of river	Upper Reservoir：Ichi River Lower Reservoir：Maruyama River
Type of power plant	Recirculating pumped storage
Year of commission	1998
Maximum output (MW)	generation 303MW, pumping 320MW (Unit No.1-2)
Maximum discharge (m3/s)	94
Effective head (m)	383.4
Annual power production (GWh)	N/A
Specifications (after the project)	Note: The following specifications are the same as those before the project. Unit No.1 and No.2 were upgraded from constant speed type to variable speed type.
Name of power plant	-
Name of river	-
Type of power plant	-
Year of commission	2019
Maximum output (MW)	-
Maximum discharge (m3/s)	-
Effective head (m)	-
Annual power production (GWh)	-
Overview of the project	Frequency control of the electric power system in late night hours has been accomplished by variable speed generator motors of pumped storage power stations and fossil fuel-fired power units, which have AFC (Automatic Frequency Control). In order to secure the frequency control functions, existing No.1 & 2 units of the Okutataragi Pumped Storage Power Station were upgraded from constant speed type to variable speed type by the renewal project.
Improvement of performance	
Increase in output	No
Increase in power production	No
Reliability/flexibility	The frequency control function was improved, which contributed to the improvement of reliability and flexibility of

	the existing pumped storage power station by upgrading the existing constant speed pumped storage system to variable speed system.
Others	N/A
Challenges in the project	
Technology	- Modification to variable speed system by using the existing facilities - Runner with splitter vanes - Securing the widening space by excavation of the existing tunnel - Rationalization of design for rotor coil insulation in terms of high voltage and high mechanical/thermal strength
Cost	N/A
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	I-3 Renewal of electro-mechanical equipment adding new functions
Requirement A: Effective use of water resources	N/A
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	The frequency control function was improved by upgrading the existing constant speed pumped storage system to variable speed system. The reliability and flexibility of the existing pumped storage power station was improved.
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History Jp.08_Okutataragi https://www.ieahydro.org/media/5fb06b0d/ Vol2_Case_History_English(1-206).pdf

Project code	JP10
Name of the project	Redevelopment of Shin-Takatsuo Power Station
Location/country of the project	Wakayama Prefecture, Japan
Implementing body of the project	Kansai Electric Power Co., Inc.
Implementing period	1997 – 1999
Type of the project	Redevelopment
Specifications (before the project)	
Name of power plant	Takatsuo Power Station
Name of river	Hidaka River
Type of power plant	Waterway type
Year of commission	1918
Maximum output (MW)	5.8
Maximum discharge (m3/s)	14.4
Effective head (m)	N/A
Annual power production (GWh)	N/A
Specifications (after the project)	
Name of power plant	Shin-Takatsuo Power Station
Name of river	Hidaka River
Type of power plant	waterway type
Year of commission	1999
Maximum output (MW)	14.5
Maximum discharge (m3/s)	32
Effective head (m)	51
Annual power production (GWh)	N/A
Overview of the project	Shin-Takatsuo Power Station of 14.5MW was constructed by increasing maximum water discharge and utilizing a part of the existing facilities (intake structures, headrace, etc.) along with the abolition of the aged Takatsuo Power Station of 5.8MW. For fish protection, the facility to prevent sweetfish from entering the water intake was installed.
Improvement of performance	
Increase in output	Maximum output was increased from 5.8MW to 14.5MW by increasing maximum discharge.
Increase in power production	Annual power production was increased by the increase in output.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	N/A
Cost	N/A

Environmental conservation	Shin-Takatsuo Power Station is located midstream of the Hidaka River and is one of the most famous sweetfish habitats in Japan. Therefore, the fish way was installed at the intake dam to help sweetfish upstream migration. However, when sweetfish migrates downstream to the river mouth so as to lay eggs, they often enter the water intake of the power station and pass through the turbine, resulting in many fish deaths. For this reason, along with the construction work of Shin-Takatsuo Power Station, the facility to prevent sweetfish from entering the water intake was installed.
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	Effective utilization of unused potential by increasing maximum discharge
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History Jp.10_Shin-Takatsuo https://www.ieahydro.org/media/5fb06b0d/Vol2_Case_History_English(1-206).pdf

Project code	JP19
Name of the project	Renewal of Himekawa No.2 Power Station
Location/country of the project	Nagano Prefecture, Japan
Implementing body of the project	Chubu Electric Power Co., Inc.
Implementing period	2005 – 2010
Type of the project	Renewal
Specifications (before the project)	
Name of power plant	Himekawa No.2 Power Station
Name of river	Hime River, Kusu River, Matsu valley, Oyasawa River, Kurosawa River
Type of power plant	Waterway type
Year of commission	1935
Maximum output (MW)	14.4
Maximum discharge (m3/s)	10.3
Effective head (m)	164.55
Annual power production (GWh)	N/A
Specifications (after the project)	Note: The following specifications are the same as those before the project. The guide vane of the water turbine was upgraded in the project.
Name of power plant	-
Name of river	-
Type of power plant	-
Year of commission	2010
Maximum output (MW)	-
Maximum discharge (m3/s)	-
Effective head (m)	-
Annual power production (GWh)	-
Overview of the project	At Himekawa No. 2 Power Station, turbine parts such as runners and guide vanes were significantly worn out due to the sediment contained in water, and it was necessary to repair turbine parts at a shorter cycle (4 to 6 years) than other power stations. In order to deal with this problem, CFD analysis was used to analyze the flow phenomenon of water including sediment in the turbine (Solid-liquid two-phase flow analysis), and a guide vane shape was developed to reduce wear. The deterioration of turbine performance was reduced, and a repair cycle was extended from the current 6 to 12 years. Repair costs and loss of power production caused by power stoppage were reduced.
Improvement of performance	
Increase in output	No

Increase in power production	Loss of power production caused by power stoppage was decreased by shortening the repair interval of the turbine.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	CFD for solid-liquid two-phase flow was used to analyze the flow phenomenon of water, including sediment in the turbine and the guide vane shape reducing sediment wear was developed.
Cost	Renewal works extended the maintenance/repair cycle, and repair costs and loss of power production were reduced.
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	I-1 Renewal of electro-mechanical equipment without changing intake discharge/hydraulic head
Requirement A: Effective use of water resources	N/A
B: Improved and/or advanced methodologies	Increase in power production due to the reduction of sand abrasion by CFD analysis for solid-liquid two-phase flow, which shortens the downtime by inspection/maintenance leading to a longer operation time.
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History Jp.19_Himekawa#2 https://www.ieahydro.org/media/5fb06b0d/ Vol2_Case_History_English(1-206).pdf

Project code	**JP24**
Name of the project	Renewal of Tagokura Power Station
Location/country of the project	Fukushima Prefecture, Japan
Implementing body of the project	Electric Power Development Co., Ltd.
Implementing period	2004 – 2012
Type of the project	Renewal
Specifications (before the project)	
Name of power plant	Tagokura Power Station
Name of river	Tadami River
Type of power plant	Dam type
Year of commission	1961
Maximum output (MW)	380
Maximum discharge (m3/s)	431.2
Effective head (m)	105
Annual power production (GWh)	N/A
Specifications (after the project)	
Name of power plant	Tagokura Power Station
Name of river	Tadami River
Type of power plant	Dam type
Year of commission	2012
Maximum output (MW)	400
Maximum discharge (m3/s)	420
Effective head (m)	106.8
Annual power production (GWh)	N/A
Overview of the project	Renewal works were conducted in Tagokura Power Station from 2004 to 2012 by refurbishing 4 units one by one, and the maximum output was increased to 400MW. Firstly, the normal head was reviewed based on the examination of the actual operation results (dam water level, power discharge, power output) for 1998 to 2001, and the health of the equipment was diagnosed. The removal of buried parts was minimized for renewal work. Renewal works were conducted through an optimum design of the target parts of renewal by CFD analysis, and this contributed to the improvement of the shape design of the speed ring and runner vane. Furthermore, the optimization of the specific speed of the turbine made it possible to increase rotation speed by one rank and improve maximum efficiency and partial load efficiency of the equipment. Finally, the maximum output was increased by 20MW.
Improvement of performance	

Increase in output	Maximum output was increased by 20MW.
Increase in power production	Annual power production was increased due to the increase in output.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	Before the renewal works, equipment health was diagnosed, and the removal of buried parts was minimized in the concrete surrounding the turbine. The optimum turbine design was performed using CFD, and the rotation speed of the turbine was increased to improve equipment efficiency.
Cost	A comparison of the economic efficiency of the partial refurbishment of aged equipment with that of the whole refurbishment confirmed that the whole refurbishment was more economical.
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	I-1 Renewal of electro-mechanical equipment without changing intake discharge/hydraulic head
Requirement A: Effective use of water resources	N/A
B: Improved and/or advanced methodologies	Not only the turbine runner but also the casing, stay vanes, guide vanes, and draft tube were improved in performance by CFD. Furthermore, maximum efficiency and partial load efficiency were improved by increasing the rotation speed. Those contributed to the increase in maximum output and power production. Compared with the conventional way of renewal, the project was innovative in terms of cost reduction and minimal impact on the operation of existing units.
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History Jp.24_Tagokura https://www.ieahydro.org/media/5fb06b0d/ Vol2_Case_History_English(1-206).pdf

Project code	**JP27**
Name of the project	Redevelopment of Shin-Onagatani No.1 Power Station
Location/country of the project	Toyama Prefecture, Japan
Implementing body of the project	Toyama Bureau of Enterprise
Implementing period	1997 – 2001
Type of the project	Redevelopment
Specifications (before the project)	
Name of power plant	Onagatani No.1 Power Station
Name of river	Ida River
Type of power plant	Waterway type
Year of commission	1955
Maximum output (MW)	4
Maximum discharge (m3/s)	3.25
Effective head (m)	146.61
Annual power production (GWh)	N/A
Specifications (after the project)	
Name of power plant	Shin-Onagatani No.1 Power Station
Name of river	Ida River
Type of power plant	Waterway type
Year of commission	2001
Maximum output (MW)	7.5
Maximum discharge (m3/s)	6
Effective head (m)	152
Annual power production (GWh)	N/A
Overview of the project	Onagatani No.1 Power Station was a run-of-river hydropower station with a maximum output of 4MW developed by Toyama Prefecture in 1955. Forty years have passed since the start of the operation, and facilities such as the headrace tunnel have deteriorated significantly, and redevelopment was conducted. Maximum discharge was changed from 3.25m3/s to 6.0m3/s, a 60-day flow rate, which was the cheapest construction cost per kWh and maximum output was increased from 4MW to 7.5MW. The intake weir was shifted upstream of the existing weir, and most of the power facilities were newly constructed. Existing penstock was used for the spillway tube to reduce construction costs.
Improvement of performance	
Increase in output	An intake weir was constructed upstream of the existing weir to increase the water head and maximum discharge. The maximum output was increased.

Increase in power production	Power production was increased by the increase in output.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	A new method of TBM with integrated excavation and lining was adopted for the small-section tunnel construction, shortening the construction period by approximately 13% compared to the conventional method.
Cost	A new head tank was constructed next to the existing head tank and the existing penstock was used as a new spillway tube to reduce construction costs.
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	Effective utilization of the unused potential. The increase in effective head and maximum discharge increased maximum output.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History Jp.27_Shin-Onagatani #1 https://www.ieahydro.org/media/5fb06b0d/ Vol2_Case_History_English(207-408).pdf

Project code	JP29
Name of the project	Renewal of Saikawa Power Station
Location/country of the project	Nagano Prefecture, Japan
Implementing body of the project	Chubu Electric Power Co., Inc.
Implementing period	2000 – 2003
Type of the project	Refurbishment
Specifications (before the project)	
Name of power plant	Saikawa Power Station
Name of river	Saikawa River
Type of power plant	waterway type
Year of commission	1923
Maximum output (MW)	1.7
Maximum discharge (m3/s)	10.71
Effective head (m)	19.06
Annual power production (GWh)	N/A
Specifications (after the project)	Note: The following specifications are the same as those before the project. The intake dam was refurbished in the project.
Name of power plant	-
Name of river	-
Type of power plant	-
Year of commission	2003
Maximum output (MW)	-
Maximum discharge (m3/s)	-
Effective head (m)	-
Annual power production (GWh)	-
Overview of the project	Before the renovation, the intake weir of Saikawa Power Station had a fixed weir of gabion construction and an aged flushing gate. Since the discharge capacity of the flushing gate was small, many gabions were lost by the overflow at the weir section by floods. Consequently, a portion of the weir and steel gate were removed, and a large-scale steel flap gate with rubber bladders (SR dam) was installed. As a result, the loss of power production during repairing time for gabion weir and the expenses for repairing the lost gabion were reduced.
Improvement of performance	
Increase in output	No
Increase in power production	Loss of power production during repairing time for the gabion weir and the expenses for repairing the lost gabion were reduced.
Reliability/flexibility	N/A
Others	N/A

Challenges in the project	
Technology	SR dam can change weir height according to the river flow and keep water intake for the power operation. This is an advantage over the rubber dam.
Cost	N/A
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	I-4 Renewal of civil engineering facilities
Requirement A: Effective use of water resources	N/A
B: Improved and/or advanced methodologies	Renovation from the existing gabion weir to the SR dam made it possible to reduce the loss of power production during repairing time for the lost gabion by floods.
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History Jp.29_Saikawa https://www.ieahydro.org/media/5fb06b0d/ Vol2_Case_History_English(207-408).pdf

Project code	**JP32**
Name of the project	Redevelopment of Shin-Taishakugawa Power Station
Location/country of the project	Hiroshima Prefecture, Japan
Implementing body of the project	Chugoku Electric Power Co., Inc.
Implementing period	2003 – 2006
Type of the project	Redevelopment
Specifications (before the project)	
Name of power plant	Taishakugawa Power Station
Name of river	Taishakugawa River and Fukumasugawa River
Type of power plant	Waterway type
Year of commission	1924
Maximum output (MW)	4.4
Maximum discharge (m3/s)	5.7
Effective head (m)	95.2
Annual power production (GWh)	N/A
Specifications (after the project)	
Name of power plant	Taishakugawa Power Station
Name of river	Fukumasugawa River
Type of power plant	Waterway type
Year of commission	2006
Maximum output (MW)	2.4
Maximum discharge (m3/s)	3.1
Effective head (m)	95.2
Annual power production (GWh)	N/A
Name of power plant	Shin-Taishakugawa Power Station
Name of river	Taishakugawa River
Type of power plant	Dam & waterway type
Year of commission	2006
Maximum output (MW)	11
Maximum discharge (m3/s)	10
Effective head (m)	129
Annual power production (GWh)	N/A
Overview of the project	Taishakugawa Dam, constructed in 1924, has been used as an intake dam for Taishakugawa Power Station, with a capacity of 4.4MW and tourism resources. However, about 80-year-old dam had become not to meet the recent standards for stability and the discharge capacity of the spillway had been insufficient for the reservoir operation during the flood period. Furthermore,

	there had been unused water head up to about 35m caused by taking in power water from a tank located just downstream of dam and conveying it to the power house through a non-pressured waterway. Therefore, Chugoku Electric Power Company, owner of the power station, implemented a redevelopment project during 2003-2006, including the structural reinforcement of the dam body, the increase of flood discharge capacity and the construction of a new power station "Shin-Taishakugawa Power Station" with a capacity of 11MW using the unused water head of dam along with the renewal of old power station.
Improvement of performance	
Increase in output	Maximum output was decreased by 2MW in Taishakugawa Power Station. In contrast, it was increased by 11MW due to the construction of Shin-Taishakugawa Power Station. The net increase in maximum output was 9MW.
Increase in power production	Annual power production was increased by a net increase in the total maximum output of the two stations.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	Refurbishment of about 80-year-old dam with structural reinforcement and increase in spillway capacity
Cost	N/A
Environmental conservation	Conservation of natural environment and landscape in the national park area
Legal restriction	Legal regulation for the natural environment
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	Utilization of unused water head at the dam through the refurbishment of dam and the construction of a new power station. Existing Taishakugawa Power Station decreased power production, but the total power production of Taishakugawa and Shin-Taishakugawa Power Stations increased.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History Jp.32: Shin-Taishakugawa https://www.ieahydro.org/media/5fb06b0d/Vol2_Case_History_English(207-408).pdf

	[2] IEA Hydro (2017) Annex II, Subtask A5 Appendix A2, Collection of Good Practice Reports, Part 1 JP05: Taishakugawa and Shin-Taishakugawa https://www.ieahydro.org/media/6eb4c0b4/AnnexII_STA5_Appendix2_GoodPracticeReports_Part%201_p1-104.pdf

Project code	JP36
Name of the project	Expansion of Okutadami Power Staion and Ohtori Power Station
Location/country of the project	Fukushima Prefecture, Niigata Prefecture, Japan
Implementing body of the project	Electric Power Development Co., Ltd.
Implementing period	1999 – 2003
Type of the project	Expansion
Specifications (before the project)	
Name of power plant	Okutadami Power Station
Name of river	Tadami River
Type of power plant	Dam and waterway type
Year of commission	1960
Maximum output (MW)	360
Maximum discharge (m3/s)	249
Effective head (m)	170
Annual power production (GWh)	N/A
Name of power plant	Ohtori Power Station
Name of river	Tadami River
Type of power plant	Dam type
Year of commission	1963
Maximum output (MW)	95
Maximum discharge (m3/s)	220
Effective head (m)	50.8
Annual power production (GWh)	N/A
Specifications (after the project)	
Name of power plant	Okutadami Power Station
Name of river	Tadami River
Type of power plant	Dam and waterway type
Year of commission	2003
Maximum output (MW)	560
Maximum discharge (m3/s)	387
Effective head (m)	170/164.2
Annual power production (GWh)	N/A
Name of power plant	Ohtori Power Station
Name of river	Tadami River
Type of power plant	Dam type
Year of commission	2003

Maximum output (MW)	182
Maximum discharge (m3/s)	427
Effective head (m)	50.8/48.1
Annual power production (GWh)	N/A
Overview of the project	Expansion of Okutadami and Ohtori Power Stations aimed to increase their peak supply capacity by 287MW (Okutadami; 200MW, Ohtori; 87MW). This was the largest case in Japan in terms of the expansion of a conventional type of hydropower by increasing the peak-power supply capacity of a large-scale reservoir. In the case of Okutadami, one of the new technologies adopted for the construction is a large-sized temporary closing for intake construction without lowering the reservoir water level, which contributed to securing the construction period and reducing construction costs. The construction work was conducted considering the environmental conservation and the operation of existing power units.
Improvement of performance	
Increase in output	Total maximum output was increased by expansion.
Increase in power production	N/A
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	In the construction of the Okutadami water intake, it was necessary not to lower the reservoir water level during the construction period because of the continuous regular operation of the existing power station. Consequently, on the upstream side of the dam, a temporary closing designed for a maximum water depth of 50m (the first construction case of this size in Japan) was installed so that the construction of water intake, boring of a hole into the dam body and installation of the hydraulic steel pipe, intake gate sheet and others were able to be conducted in dry conditions.
Cost	N/A
Environmental conservation	With the view to protect the natural ecosystem including the protection measures for Golden Eagles and Mountain Hawk Eagles, and to continuously minimize the environmental load caused by the expansion construction, the following environmental countermeasures were conducted: ・Protection of rare important birds ・Countermeasures against noise and vibration ・Countermeasures to maintain water quality ・Lighting and color strategy
Legal restriction	N/A
Others	N/A

Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-2 Development without using unused potential
Requirement A: Effective use of water resources	N/A
B: Improved and/or advanced methodologies	In the expansion of Okutadami, a large-sized temporary closing for intake construction without lowering reservoir water level was adopted, which contributed to securing the construction period and reducing construction cost.
C: Improvement of reliability/flexibility corresponding to market needs	The expansion of Okutadami Power Station increased peak-power supply capacity using the existing reservoir (peaking-time revised). It contributed to the improvement of reliability and flexibility of the existing power station.
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History Jp.36_Okutadami_Ohtori https://www.ieahydro.org/media/5fb06b0d/ Vol2_Case_History_English(207-408).pdf

Project code	**JP39**
Name of the project	New construction of Okukiyotsu No. 2 Pumped Storage Power Station
Location/country of the project	Niigata Prefecture, Japan
Implementing body of the project	Electric Power Development Co., Ltd.
Implementing period	1992 – 1996
Type of the project	New construction
Specifications (before the project)	
Name of power plant	Okukiyotsu Pumped Storage Power Station
Name of river	Kassa River
Type of power plant	Recirculating pumped storage
Year of commission	1978
Maximum output (MW)	1000
Maximum discharge (m3/s)	260
Effective head (m)	470
Annual power production (GWh)	N/A
Specifications (after the project)	Note: Specifications of the existing Okukiyotsu Pumped Storage Power Station are the same as those before the project. Okukiyotsu No. 2 Pumped Storage Power Station was newly constructed using the upper and lower pondages of the existing power station.
Name of power plant	Okukiyotsu No. 2 Pumped Storage Power Station
Name of river	Kassa River
Type of power plant	Recirculating pumped storage
Year of commission	1996
Maximum output (MW)	600
Maximum discharge (m3/s)	154
Effective head (m)	470
Annual power production (GWh)	N/A
Overview of the project	Okukiyotsu Pumped Storage Power Station is located in Niigata Prefecture and has a capacity of 1 GW. Kassa Dam for the upper pondage was constructed in the tributary of Kiyotsu River, and Futai Dam for the lower pondage in the main river of Kiyotsu River. Okukiyotsu No.2 Pumped Storage Power Station was constructed as the expanded power station by using the existing pondage of Okukiyotsu Pumped Storage Power Station. The project was developed as the top-priority project for the emergent peak-power supply in order to meet the increase of peak power demand after 1996. Before the project, the peak power generation was able to be conducted for 12 hours with the existing regulating pondage capacity. After the project, even with an additional peak power increase of 600MW, it is possible to generate peak

	power for 7.6 hours by the effective use of the existing regulating pondages.
Improvement of performance	
Increase in output	Maximum output was increased by the construction of a new pumped storage power station using the existing regulating pondage.
Increase in power production	No
Reliability/flexibility	Okukiyotsu and Okukiyotsu No.2 Pumped Storage Power Stations are connected to the power supply grid to the metropolitan area, enabling high-power operation at peak-power demand. Expansion of the power station increased the reliability and flexibility in system operation.
Others	N/A
Challenges in the project	
Technology	In the excavation of the inclined shaft of underground penstock, for the pilot excavation of the upper inclined portion where the bedrock was relatively hard, an Alimak climber was used, and for the lower portion where the bedrock was relatively unstable, a Raise bowler machine was used to improve the work efficiency.
Cost	N/A
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-2 Development without using unused potential
Requirement A: Effective use of water resources	
B: Improved and/or advanced methodologies	
C: Improvement of reliability/flexibility corresponding to market needs	A new pumped storage power station increased the reliability and flexibility of the power supply by enabling high-power operation at peak-power demand.
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History Jp.39_Okukiyotsu #2 https://www.ieahydro.org/media/5fb06b0d/ Vol2_Case_History_English(207-408).pdf [2] Electric Power Development Co., Ltd. Oku Kiyotsu Power Station Overview https://www.jpower.co.jp/okky/about/

Project code	JP41
Name of the project	Redevelopment of Hanakawa Power Station
Location/country of the project	Ibaraki Prefecture, Japan
Implementing body of the project	Tokyo Electric Generation Co., Inc.
Implementing period	2009 – 2011
Type of the project	Redevelopment
Specifications (before the project)	
Name of power plant	Hanakawa Power Station
Name of river	Hanazono River
Type of power plant	waterway type
Year of commission	1908 (abolished in 1971)
Maximum output (MW)	0.1
Maximum discharge (m3/s)	0.78
Effective head (m)	18.17
Annual power production (GWh)	N/A
Specifications (after the project)	
Name of power plant	Hanakawa Power Station
Name of river	Hanazono River
Type of power plant	waterway type
Year of commission	2011
Maximum output (MW)	0.13
Maximum discharge (m3/s)	1
Effective head (m)	17.35
Annual power production (GWh)	N/A
Overview of the project	Hanakawa Power Station was redeveloped from the old hydropower station that had been abolished. Existing power facilities were transferred from Kita-Ibaraki City to Tokyo Electric Generation Co., Ltd. Maximum discharge was increased from 0.78 m3/s to 1.00 m3/s after reviewing the waterflow capacity of the waterway. The maximum output was increased by 30kW. Redevelopment of the abolished power station made it possible to decrease the construction costs by using the existing power facilities.
Improvement of performance	
Increase in output	Maximum output was increased from 0.1MW to 0.13MW.
Increase in power production	Annual power production was increased due to the increase in output.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	

Technology	Maximum discharge was increased by reviewing the possible capacity of the waterway.
Cost	Construction costs were reduced significantly by the utmost utilization of the existing facilities. For penstock, by inserting high-density polyethylene pipe into the existing steel pipe to make it a double pipe, great cost savings were achieved without the removal of the existing pipe and a public subsidiary system for hydropower development was utilized.
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	The abolished power station was redeveloped using unused potential and the existing facilities.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History Jp.41_Hanakawa https://www.ieahydro.org/media/5fb06b0d/ Vol2_Case_History_English(207-408).pdf

Project code	**JP101**
Name of the project	Renewal of Ooigawa Power Station
Location/country of the project	Shizuoka Prefecture. Japan
Implementing body of the project	Chubu Electric Power Co., Inc.
Implementing period	2012 – 2013
Type of the project	Renewal
Specifications (before the project)	
Name of power plant	Ooigawa Power Station
Name of river	Oi River
Type of power plant	Dam and waterway type
Year of commission	1936
Maximum output (MW)	68.2
Maximum discharge (m3/s)	72.35
Effective head (m)	112.73
Annual power production (GWh)	N/A
Specifications (after the project)	Note: Specifications of the existing Ooigawa Power Station are the same as those before the project. The existing waterway was remodeled to increase water flow capacity.
Name of power plant	-
Name of river	-
Type of power plant	-
Year of commission	2013
Maximum output (MW)	-
Maximum discharge (m3/s)	-
Effective head (m)	-
Annual power production (GWh)	-
Overview of the project	At the Sumatagawa Dam of Ooigawa Power Station (dam & waterway type), the water up to 60m3/s supplied from Ooigawa Dam at the main river is conveyed to the dam. The water of a maximum of 72.35m3/s including the water taken from the Sumata River, is conveyed to the power station through a siphon channel and headrace tunnel. This siphon was constructed in 1936, and because of its complicated shape and limited water flow capacity of 43m3/s, it was difficult to take water up to 60m3/s for about 10 days a year. Therefore, in order to increase the water flow capacity of the siphon channel, remodeling work of the headrace junction was carried out from 2012 to 2013 for the increase of power production.
Improvement of performance	
Increase in output	No

Increase in power production	Intake discharge was increased by expanding the flow capacity of the siphon channel and annual power production was increased.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	N/A
Cost	N/A
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	I-4 Renewal of civil engineering facilities III-2 Optimized operation of reservoir/power plant
Requirement A: Effective use of water resources	N/A
B: Improved and/or advanced methodologies	Power production was increased by remodeling the existing siphon channel.
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] Electric Power Civil Engineering, No.367, 2013.9 (In Japanese)

Project code	**JP102**
Name of the project	New construction of Kawahira No.2 Power Station
Location/country of the project	Tottori Prefecture, Japan
Implementing body of the project	Chugoku Electric Power Co., Inc.
Implementing period	2006
Type of the project	New Construction
Specifications (before the project)	
Name of power plant	Kawahira Power Station
Name of river	Hino River
Type of power plant	Waterway type
Year of commission	1931
Maximum output (MW)	1.3
Maximum discharge (m3/s)	17.39
Effective head (m)	9.55
Annual power production (GWh)	N/A
Specifications (after the project)	Note: Specifications of the existing Kawahira Power Station are the same as those before the project. Kawahira No.2 Power Station was newly constructed using the facilities of the existing power station.
Name of power plant	Kawahira No,2 Power Station
Name of river	Hino River
Type of power plant	Waterway type
Year of commission	2006
Maximum output (MW)	0.12
Maximum discharge (m3/s)	1.63
Effective head (m)	9.27
Annual power production (GWh)	0.782
Overview of the project	Kawahira Power Station constructed in 1931, is located in the reduced water section of Shin-Kawahira Power Station upstream, built in 1979 and can operate for only about 70 days a year due to the reduced waterflow with a plant factor of about 10%. Therefore, the Kawahira No.2 Power Station was newly constructed using a smaller amount of water discharge than the Kawahira Power Station. This expansion made it possible to use the river flow effectively and to increase the total power generation of the two power stations.
Improvement of performance	
Increase in output	Maximum output was increased due to the new construction of a power station.
Increase in power production	Annual power production was increased using a small amount of water discharge that the existing power station could not use.

Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	Under water turbine/generator was adopted to reduce the construction cost of civil facilities.
Cost	Renewable Portfolio Standard (RPS) Law was applied for small hydropower development and the construction costs were subsidized by the New Energy and Industrial Technology Development Organization (NEDO) by 30%.
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	Unused waterflow at the existing power station was effectively used by the new construction of a power station using a small water discharge.
B: Improved and/or advanced methodologies	New construction of a small-sized power station to improve power operation and increase annual power production by lowering available water discharge for the turbine.
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] Electric Power Civil Engineering, No.329, 2007.5 (In Japanese)

Project code	JP103
Name of the project	New construction of Yukomanbetsu Power Station
Location/country of the project	Hokkaido, Japan
Implementing body of the project	Hokkaido Electric Power Co., Inc.
Implementing period	2012 – 2014
Type of the project	New Construction
Specifications (before the project)	
Name of power plant	
Name of river	
Type of power plant	
Year of commission	
Maximum output (MW)	
Maximum discharge (m3/s)	
Effective head (m)	
Annual power production (GWh)	
Specifications (after the project)	Note: Yukomanbetsu Power Station was newly constructed using the facilities of the existing Eoroshi Power Station.
Name of power plant	Yukomanbetsu Power Station
Name of river	Yukomanbetsu River
Type of power plant	Waterway type
Year of commission	2014
Maximum output (MW)	0.69
Maximum discharge (m3/s)	1.3
Effective head (m)	66.1
Annual power production (GWh)	4.154
Overview of the project	Yukomanbetsu Power Station was newly constructed with the partially improved water intake facilities of the existing Eoroshi Power Station and a new water tank, penstock, power house and tailrace. The maximum output of the new power station is 690kW, using a maximum discharge of 1.3m3/s and a hydraulic head of 66.1m. It effectively uses the river’s unused water resources.
Improvement of performance	
Increase in output	Maximum output was increased due to the construction of a new power station.
Increase in power production	Annual power production was increased with the increase in output.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	

Technology	Installation of penstock was needed on the steep slope area, and several construction methods were introduced such as the light-weight FRPM pipes for easy installation, the medium-fluidity concrete materials, and the steep slope reinforcement earthwork.
Cost	N/A
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	An unused hydraulic head in the existing Yukomanbetsu waterway was used for power generation.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	MA
References	[1] Hokkaido Electric Power Press Release https://wwwc.hepco.co.jp/hepcowwwsite/info/2014/__icsFiles/afieldfile/2014/06/20/140620.pdf

Project code	JP104
Name of the project	New construction of Konokidani Power Station
Location/country of the project	Fukui Prefecture, Japan
Implementing body of the project	Electric Power Development Co., Ltd.
Implementing period	2014 – 2016
Type of the project	New Construction
Specifications (before the project)	
Name of power plant	-
Name of river	-
Type of power plant	-
Year of commission	-
Maximum output (MW)	-
Maximum discharge (m3/s)	-
Effective head (m)	-
Annual power production (GWh)	-
Specifications (after the project)	Note: Konokidani Power Station was newly constructed using the unused potential in the existing waterway upstream of the Kuzuryu Dam.
Name of power plant	Konokidani Power Station
Name of river	Kuzuryu River
Type of power plant	Waterway type
Year of commission	2016
Maximum output (MW)	0.199
Maximum discharge (m3/s)	3.22
Effective head (m)	7.4
Annual power production (GWh)	1.43
Overview of the project	Konokidani Power Station, with a maximum output of 199kW was constructed using the unused hydraulic head at the Konokidani water injection point, where water is injected from the intake dam around Kuzuryu Dam in the most upstream of Kuzuryu River. This small-scale hydropower station was developed under the Feed-In-Tariff law for renewable energy promotion. An under-water turbine/generator was applied to make installation and maintenance easier. Furthermore, a generator without an accelerator was used as a non-oil type for oil spill prevention in the river.
Improvement of performance	
Increase in output	Maximum output was increased by the construction of a new power station.
Increase in power production	Annual power production was increased by the increase in output.
Reliability/flexibility	N/A

Others	N/A
Challenges in the project	
Technology	The reduction of the maximum output in the planning made it possible to connect the existing power grid and the cost of connection was reduced.
Cost	A case study was conducted on the scale of power generation, and the case of the largest IRR was selected as the optimal plan.
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	The unused hydraulic head at the Konokidani injection point was used for power generation.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] Electric Power Civil Engineering, No.383, 2016.5 and No.393, 2018.1 (In Japanese)

Project code	**JP105**
Name of the project	New construction of Kitanomata No.3 Power Station
Location/country of the project	Iwate Prefecture, Japan
Implementing body of the project	Iwate Prefecture Enterprise Bureau
Implementing period	2009 – 2010
Type of the project	New Construction
Specifications (before the project)	
Name of power plant	-
Name of river	-
Type of power plant	-
Year of commission	-
Maximum output (MW)	-
Maximum discharge (m3/s)	-
Effective head (m)	-
Annual power production (GWh)	-
Specifications (after the project)	Note: Kitanomata No.3 Power Station was newly constructed using the unused potential in the headrace of the existing power station.
Name of power plant	Kitanomata No. 3 Power Station
Name of river	Kitanomata River
Type of power plant	Waterway type
Year of commission	2010
Maximum output (MW)	0.061
Maximum discharge (m3/s)	1.34
Effective head (m)	6.25
Annual power production (GWh)	0.41
Overview of the project	Kitanomata No. 3 Power Station is a small-scale hydropower station using the unused hydraulic head in the headrace that conveys power water from the existing Kitanomata Power Station to the existing Kashiwadai Power Station. The maximum discharge for Kitanomata No.3 is 1.34 m3/s which is part of 4.1 m3/s for Kitanomata. The hydraulic head at the middle of the second headrace (headrace length of about 820 m) of Kashiwadai Power Station is about 6m in an energy-killing basin. Existing facilities were used to the utmost, such as the steel pipe installed in the steep part of the existing headrace as a penstock.
Improvement of performance	
Increase in output	Maximum output was increased by the construction of a new power station.
Increase in power production	Annual power production was increased due to the increase in output.

Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	N/A
Cost	N/A
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	The unused hydraulic head in the waterway of the existing power station was used for power generation.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] 98th Practical Workshop on Small and Medium-sized Hydroelectric Power Generation Technology, NEF, No.1 2013 (In Japanese).

Project code	**JP106**
Name of the project	New Construction of Okususobana No.2 Power Station
Location/country of the project	Nagano Pref. Japan
Implementing body of the project	Nagano Prefecture, Public Enterprise Bureau
Implementing period	2015 - 2017
Type of the project	New Construction
Specifications (before the project)	
Name of power plant	Okususobana Power Station
Name of river	Susobana River
Type of power plant	Dam type
Year of commission	1979
Maximum output (MW)	1.70
Maximum discharge (m3/s)	4
Effective head (m)	53.68
Annual power production (GWh)	N/A
Specifications (after the project)	Note: Specifications of the existing Okususobana Power Station are the same as those before the project. Okususobana No.2 Power Station was newly constructed using the facilities of the existing power station.
Name of power plant	Okususobana No.2 Power Station
Name of river	Susobana River
Type of power plant	Dam type
Year of commission	2017
Maximum output (MW)	0.98
Maximum discharge (m3/s)	2.53
Effective head (m)	48.17
Annual power production (GWh)	5.067
Overview of the project	Spring snowmelt water was not available at the existing Okususoobana Power Station and was discharged from the Okususobana Dam. The spilled snowmelt water and unused water discharge from the valve during low river flow in summer were effectively used by the newly constructed Okususobana No.2 Power Station without constructing new intake facilities. Existing intake and a part of the penstock of the existing Okususobana Power Station were commonly used.
Improvement of performance	
Increase in output	Maximum output was increased by the construction of a new power station.
Increase in power production	Annual power production was increased by the increase in output.
Reliability/flexibility	N/A

Others	N/A
Challenges in the project	
Technology	N/A
Cost	In order to ensure economic efficiency, the existing intake and penstock were commonly used in the new power station.
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	A small-scale hydropower station was newly constructed using the unused spilled water from the dam.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] Nagano Prefecture home page https://www.pref.nagano.lg.jp/kigyo/infra/suido-denki/denki/koei/ichiran/okususobana-02.html

Project code	**JP107**
Name of the project	Redevelopment of Shin-Iwamatsu Power Station
Location/country of the project	Hokkaido, Japan
Implementing body of the project	Hokkaido Electric Power Co., Inc.
Implementing period	2013 – 2016
Type of the project	Redevelopment
Specifications (before the project)	
Name of power plant	Iwamatsu Power Station
Name of river	Tokachi River
Type of power plant	Dam and waterway type
Year of commission	1942
Maximum output (MW)	12.6
Maximum discharge (m3/s)	37.5
Effective head (m)	41.55
Annual power production (GWh)	79.9
Specifications (after the project)	
Name of power plant	Shin-Iwamatsu Power Station
Name of river	Tokachi River
Type of power plant	Dam and waterway type
Year of commission	2016
Maximum output (MW)	16
Maximum discharge (m3/s)	45
Effective head (m)	40.3
Annual power production (GWh)	90.5
Overview of the project	Shin-Iwamatsu Power Station, with a maximum output of 16MW was re-developed for the existing aged Iwamatsu Power Station, which was constructed in 1942, with a maximum output of 12.6MW. The penstock, powerhouse, and tailrace channel were newly built and the existing intake weir, headrace and surge tank were used without change.
Improvement of performance	
Increase in output	Maximum output was increased from 12.6MW to 16MW by the redevelopment.
Increase in power production	Annual power production was increased by 10.6GWh due to the increase in output.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	

Technology	Additional works such as curing sheets, embankments, and ground anchors were constructed due to the deformation of the earth retaining wall caused by frost heaving.
Cost	N/A
Environmental conservation	The construction of a long tailrace using the shield tunneling method was not adopted, considering the environmental impact.
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	Effective utilization of unused potential in river water
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] Electric Power Civil Engineering, No.377, 2015.5. (In Japanese)

Project code	**JP108**
Name of the project	Renewal of Shimoyama Power Station
Location/country of the project	Hiroshima Prefecture, Japan
Implementing body of the project	Chugoku Electric Power Co., Inc.
Implementing period	2004 - 2005
Type of the project	Renewal
Specifications (before the project)	
Name of power plant	Shimoyama Power Station
Name of river	Takiyama River and Oosa River
Type of power plant	Waterway type
Year of commission	1934
Maximum output (MW)	10
Maximum discharge (m3/s)	14.32
Effective head (m)	85.5
Annual power production (GWh)	N/A
Specifications (after the project)	
Name of power plant	Shimoyama Power Station
Name of river	Oosa River
Type of power plant	Waterway type
Year of commission	2005
Maximum output (MW)	3.6
Maximum discharge (m3/s)	5
Effective head (m)	86.27
Annual power production (GWh)	N/A
Overview of the project	Shimoyama Power Station was commissioned in 1934 with an output of 10MW. In 1959, the Takiyamagawa Power Station, with an output of 51.5MW ,was commissioned to take water from upstream of Shimoyama Power Station. Therefore, the capacity factor of Shimoyama Power Station was decreased significantly due to small water discharge against maximum output. The renewal of Shimoyama Power Station was implemented from the viewpoint of an economical scale. Two units were replaced by one unit, and maximum discharge decreased from 14.32m3/s to 5.0m3/s. In addition, safety measures were taken for the spillway when the generator suddenly stopped and the spilled water discharged into the river.
Improvement of performance	
Increase in output	No
Increase of power production	No

Reliability/flexibility	N/A
Others	Downsizing of the turbine/generator improved the capacity factor of the power station. Renewal of spillway improved the safety of power station.
Challenges in the project	
Technology	In the renewal of the spillway, the existing penstock was used for the spillway pipe, and an energy-dissipation facility was installed in the power house to secure safety.
Cost	N/A
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	I-2 Renewal of electro-mechanical equipment changing intake discharge/hydraulic head III-1 Optimized operation of electro-mechanical equipment
Requirement A: Effective use of water resources	N/A
B: Improved and/or advanced methodologies	Downsizing to the optimal scale of the generation facility increased the capacity factor of the power station.
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] Electric Power Civil Engineering, No.323, 2006.5. (In Japanese)

Project code	**JP109**
Name of the project	Redevelopment of Shin-Kousa Power Station
Location/country of the project	Kumamoto Prefecture, Japan
Implementing body of the project	Kyushu Electric Power Co., Inc.
Implementing period	2012 – 2019
Type of the project	Redevelopment
Specifications (before the project)	
Name of power plant	Kousa Power Station
Name of river	Midori River
Type of power plant	Waterway type
Year of commission	1951
Maximum output (MW)	3.9
Maximum discharge (m3/s)	19.3
Effective head (m)	25.1
Annual power production (GWh)	24
Specifications (after the project)	
Name of power plant	Shin-Kousa Power Station
Name of river	Midori River
Type of power plant	Waterway type
Year of commission	2019
Maximum output (MW)	7.2
Maximum discharge (m3/s)	35
Effective head (m)	24.46
Annual power production (GWh)	30
Overview of the project	Kousa Power Station is located downstream of Funatsu Dam in the middle of the Midori River and started operation in 1951. It has been 64 years since the commissioning, and the renewal was required because of significant deterioration. Since the maximum discharge of the upstream power station exceeds that of the Kousa Power Station, the water from intake weir was spilled for about 180 days a year. Therefore, the Shin-Kousa Power Station was constructed to install a turbine and generator using a larger amount of water discharge along with the abolition of the existing power station.
Improvement of performance	
Increase in output	Maximum output was increased from 3.9MW to 7.2MW by increasing maximum discharge.
Increase in power production	Annual power production was increased by 6 GWh due to the increase in output.
Reliability/flexibility	N/A

Others	N/A
Challenges in the project	
Technology	Construction of civil facilities such as new headrace tunnel was conducted in parallel with the operation of the existing power station.
Cost	N/A
Environmental conservation	Environmental conservation was carried out by the transplantation of rare plants and the confirmation of change in the mountain water stream due to the tunnel construction.
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	Effective utilization of unused potential in the river. The increased water discharge by the redevelopment increased maximum output and annual power production.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] Electric Power Civil Engineering, No.372, 2014.7. (In Japanese)

Project code	JP110
Name of the project	Renewal of Yugashima Power Station
Location/country of the project	Shizuoka Prefecture, Japan
Implementing body of the project	Tokyo Electric Generation Company
Implementing period	2011 - 2012
Type of the project	Renewal
Specifications (before the project)	
Name of power plant	Yugashima Power Station
Name of river	Kano River
Type of power plant	Waterway type
Year of commission	1930
Maximum output (MW)	1.6
Maximum discharge (m3/s)	1.61
Effective head (m)	134.99
Annual power production (GWh)	5.28
Specifications (after the project)	
Name of power plant	Yugashima Power Station
Name of river	Kano River
Type of power plant	Waterway type
Year of commission	2012
Maximum output (MW)	2.0
Maximum discharge (m3/s)	1.9
Effective head (m)	132.17
Annual power production (GWh)	6.6
Overview of the project	Yugashima Power Station started operation in 1930. The renewal and upgrade of the aged power station was carried out in 2011 - 2012 by replacing the existing Francis turbine 0.8MW (2 units) with a Turgo impulse turbine 2MW (1 unit) and increasing maximum discharge to use the existing regulating pondage effectively. The existing spillway was abolished to reduce the risk of public disasters, and the deflector of the Turgo turbine controlled the spilled water during the shutdown of the power operation.
Improvement of performance	
Increase in output	Maximum output was increased from 1.6 MW to 2.0 MW by the increase of maximum discharge.
Increase in power production	Annual power production was increased with the increase in output.
Reliability/flexibility	N/A
Others	N/A

Challenges in the project	
Technology	The existing spillway was abolished to reduce the risk of public disasters, and the deflector of the Turgo turbine controlled the spilled water during the shutdown of the power operation.
Cost	N/A
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	I-2 Renewal of electro-mechanical equipment changing intake discharge/hydraulic head
Requirement A: Effective use of water resources	Effective utilization of unused potential in the river. The increase of maximum discharge by renewal increased maximum output and annual power production.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] Practical Workshop on Small and Medium-sized Hydroelectric Power Generation Technology, NEF. (In Japanese)

Project code	**JP111**
Name of the project	Operational change of Sakaigawa Power Station
Location/country of the project	Toyama Prefecture, Japan
Implementing body of the project	Kansai Electric Power Co., Inc.
Implementing period	2019
Type of the project	Change of power plant operation Water diversion
Specifications (before the project)	
Name of power plant	Sakaigawa Power Station
Name of river	Sakai River
Type of power plant	Dam and waterway type
Year of commission	1993
Maximum output (MW)	24.2
Maximum discharge (m3/s)	13
Effective head (m)	216.7
Annual power production (GWh)	73
Specifications (after the project)	Note: Specifications of the existing Sakaigawa Power Station are the same as those before the project except for annual power production. The construction of a new diversion tunnel upstream increased the inflow to the power station.
Name of power plant	-
Name of river	-
Type of power plant	-
Year of commission	-
Maximum output (MW)	-
Maximum discharge (m3/s)	-
Effective head (m)	-
Annual power production (GWh)	96
Overview of the project	Sakaigawa Power Station is located on the Sakai River, a tributary of the Sho River, with a maximum discharge of 13.0 m3/s and a maximum output of 24.2MW. The plan for water withdrawal from the Kasura River, another tributary of the Sho River, included installation of an intake weir on the Kasura River and construction of a new headrace tunnel with a length of about 1.2km to take 5.6m3/s from the river and convey it to the Sakaigawa Dam upstream of the Sakaigawa Power Station. Although the maximum output of the power station did not change, the amount of water available for power generation increased due to the water diversion, and annual power production at the Sakaigawa Power Station increased. On the other hand, at the existing two power stations on the Sho River, annual power production decreased due to the water diversion. Since the ratio of output to discharge at

	Sakaigawa Power Station is about four times higher than those at two power stations on the Sho River, the total annual power production of three power stations increased by about 17GWh after the water diversion.
Improvement of performance	
Increase in output	No
Increase in power production	Annual power production was increased by the water diversion from another river basin.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	N/A
Cost	N/A
Environmental conservation	N/A
Legal restriction	It took more than a year for preliminary consultation with Gifu Prefecture on the application for the release of safety forests related to the construction work due to the lack of clear criteria.
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	I-4 Renewal of civil engineering facilities III-2 Optimized operation of reservoir/power plant
Requirement A: Effective use of water resources	The water taken from another river basin was effectively used at the existing power station.
B: Improved and/or advanced methodologies	The water was taken from another river basin for the power station, which had a higher ratio of output to discharge to increase the total annual power production of three existing power stations in the river system.
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] Kansai Electric Power Co., Inc. Press Release Dec. 2nd 2019. [2] Practical Workshop on Small and Medium-scale Hydropower Generation Technology, No.110, NEF, 2017. (In Japanese)

Project code	**JP112**
Name of the project	New Construction of Shumarinai Power Station
Location/country of the project	Hokkaido, Japan
Implementing body of the project	Hokkaido Electric Power Co., Inc.
Implementing period	2013
Type of the project	New Construction Change of power plant operation
Specifications (before the project)	
Name of power plant	
Name of river	
Type of power plant	
Year of commission	
Maximum output (MW)	
Maximum discharge (m3/s)	
Effective head (m)	
Annual power production (GWh)	
Specifications (after the project)	Note: Shumarinai Power Station was newly constructed using the existing pumping facilities to the intake reservoir of the existing Uryu Power Station.
Name of power plant	Shumarinai Power Station
Name of river	Uryu River
Type of power plant	Dam type
Year of commission	2013
Maximum output (MW)	1.12
Maximum discharge (m3/s)	4.36
Effective head (m)	32.2
Annual power production (GWh)	N/A
Overview of the project	Shumarinai Power Station was constructed using the existing facility to pump water from the Mitsumata Intake Weir on the Uryu River to the Uryu Dam Reservoir. A new pump-turbine generator was installed for both pumping and generation functions. During the non-irrigation season (September to April), the water of 2.75 m3/s is pumped up to the Uryu Dam and used for power generation at the existing Uryu Power Station. In the irrigation season, the water of 4.36 m3/s is discharged reversely through Shumarinai Power Station for both power generation and irrigation.
Improvement of performance	
Increase in output	A small-scale hydropower station using irrigation water was newly constructed by remodeling the pumping facility to pump-turbine and generator.

Increase in power production	Annual power production was increased by a new power station using the unused potential.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	N/A
Cost	N/A
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential III-2 Optimized operation of reservoir/power plant
Requirement A: Effective use of water resources	River water was effectively used in both irrigation and non-irrigation periods by remodeling the existing pumping facility.
B: Improved and/or advanced methodologies	Annual power production was increased by adding a generation function to the existing pumping facility.
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] Journal of Turbomachinery Society of Japan, Vol.42, No.7. (In Japanese) [2] Journal of Smart Processing Society for Materials, Vol.3, No.2, 2014. (In Japanese) [3] Ebara Jihou, No.247, 2015.4. (In Japanese)

Project code	JP113
Name of the project	Operational change of Shirotagawa Power Station
Location/country of the project	Shizuoka Prefecture, Japan
Implementing body of the project	Tokyo Electric Generation Co., Inc.
Implementing period	2016
Type of the project	Change of power plant operation
Specifications (before the project)	
Name of power plant	Shirotagawa Power Station
Name of river	Shirota River, Kawakubo River
Type of power plant	Waterway type
Year of commission	2015
Maximum output (MW)	3.1
Maximum discharge (m3/s)	2.07
Effective head (m)	181.46
Annual power production (GWh)	N/A
Specifications (after the project)	Note: Specifications of the existing Shirotagawa Power Station are the same as those before the project except for annual power production. The amount of water intake was increased by improving intake control.
Name of power plant	-
Name of river	-
Type of power plant	-
Year of commission	2016
Maximum output (MW)	-
Maximum discharge (m3/s)	-
Effective head (m)	-
Annual power production (GWh)	0.144
Overview of the project	Shiratagawa Power Station started operation in 1927. It was renewed in 2015 with a maximum output of 3.1MW and without changing maximum discharge of 2.07m3/s. The intake resume after the flood was operated manually, and in order to reduce man-power and increase power production, an automatic resume of water intake was added to the existing water intake control system in 2016. It can shorten the water intake stop time during floods and increase annual power production.
Improvement of performance	
Increase in output	No
Increase in power production	Annual power production was increased due to the improvement of intake operation.
Reliability/flexibility	N/A
Others	N/A

Challenges in the project	
Technology	Automatic control of sand-flushing gate of weir and intake gate
Cost	N/A
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	III-2 Optimized operation of reservoir/power plant
Requirement A: Effective use of water resources	N/A
B: Improved and/or advanced methodologies	Technically, water intake control was improved, and annual power production was increased.
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	N/A

Project code	**JP114**
Name of the project	Operational change of Nakazato Power Station
Location/country of the project	Ibaraki Prefecture, Japan
Implementing body of the project	Tokyo Electric Generation Co., Inc.
Implementing period	2017
Type of the project	Change of power plant operation
Specifications (before the project)	
Name of power plant	Nakazato Power Station
Name of river	Sato River
Type of power plant	Waterway type
Year of commission	2010
Maximum output (MW)	0.85
Maximum discharge (m3/s)	3.06
Effective head (m)	34.3
Annual power production (GWh)	N/A
Specifications (after the project)	Note: Specifications of the existing Nakazato Power Station are the same as those before the project except for annual power production. The amount of water intake was increased by improving intake control.
Name of power plant	-
Name of river	-
Type of power plant	-
Year of commission	2017
Maximum output (MW)	-
Maximum discharge (m3/s)	-
Effective head (m)	-
Annual power production (GWh)	0.051
Overview of the project	Nakazato Power Station started operation in 1908. It was renewed in 2010 with a maximum output of 0.85MW and without changing maximum discharge of 3.06m3/s. The water intake discharge for power generation must be operated below the maximum approved value, and the intake gate adjusts the water intake to keep the water intake level below the maximum approved value. In the current gate control, the constant level control is performed based on the monitoring of channel water level corresponding to the upper and lower limit. Because the width between the upper and lower limits is set to have a margin, an overflow from intake weir is allowed, resulting in energy loss. Therefore, advanced water intake control was introduced in the Nakazato Power Station to reduce overflow and increase annual power production.

Improvement of performance	
Increase in output	No
Increase in power production	Annual power production was increased due to the improvement of intake operation.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	Advanced and automated intake gate control
Cost	N/A
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	III-2 Optimized operation of reservoir/power plant
Requirement A: Effective use of water resources	N/A
B: Improved and/or advanced methodologies	Technically, water intake control was improved, and annual power production was increased.
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] Patent No. 6586480 "Water Volume Control Controllers and Systems" September 30, 2019. (Japan)

Project code	JP115
Name of the project	New construction of Kaminojiri No.2 Power Station
Location/country of the project	Fukushima Prefecture, Japan
Implementing body of the project	Tohoku Electric Power Co., Inc.
Implementing period	2002
Type of the project	New Construction
Specifications (before the project)	
Name of power plant	-
Name of river	-
Type of power plant	-
Year of commission	-
Maximum output (MW)	-
Maximum discharge (m3/s)	-
Effective head (m)	-
Annual power production (GWh)	-
Specifications (after the project)	Note: Kaminojiri No.2 Power Station was newly constructed to expand the existing Kaminojiri Power Station.
Name of power plant	Kaminojiri No.2 Power Station
Name of river	Agano River
Type of power plant	Dam type
Year of commission	2002
Maximum output (MW)	13.5
Maximum discharge (m3/s)	100
Effective head (m)	15.54
Annual power production (GWh)	44.4
Overview of the project	Power stations installed in a cascade in the Agano River System make the best use of abundant water volume and hydraulic head. However, there was an imbalance in the scale of power generation facilities due to the difference in development year. Kaminojiri No.2 Power Station was newly constructed using effectively the unused water at the existing Kaminojiri Power Station. Kaminojiri No.2 is a dam-type power station (maximum discharge 100m3/s, effective head 15.54m, maximum output 13.5MW) and has a vertical bulb turbine installed at the place with less topographical restrictions and reduced civil work. This new type of turbine is applicable to effectively utilize river water and increase power output at other sites.
Improvement of performance	
Increase in output	Maximum output was increased by the construction of a new power station.

Increase in power production	Annual power production was increased by the increase in output. The power stations downstream increased power production due to high water level operations.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	A vertical bulb turbine with a big runner radius and decreased runner blades was developed. The vortex protection measures were taken against the suction vortex at the entrance of the turbine.
Cost	The adoption of a vertical bulb turbine reduced civil work and maintenance costs.
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	Effective utilization of unused potential in the river
B: Improved and/or advanced methodologies	By matching the maximum discharge of upstream and downstream power stations, the imbalance of water discharge was eliminated. Downstream regulating pondage was able to operate at high water levels to increase power production.
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] Electric Power Civil Engineering, No.286, 2000.3 and No.301, 2002.9. (In Japanese) [2] Overview of Kaminojiri No.2 Power Station, https://www.tohoku-epco.co.jp/whats/news/2002/20606a.htm

Project code	**JP116**
Name of the project	Expansion of Nakatsugawa No.2 Power Station
Location/country of the project	Niigata Prefecture, Japan
Implementing body of the project	Tokyo Electric Power Co. Holdings, Inc.
Implementing period	2001 – 2002
Type of the project	Expansion
Specifications (before the project)	
Name of power plant	Nakatsugawa No.2 Power Station (Unit 1)
Name of river	Nakatsu River
Type of power plant	Dam type
Year of commission	1994
Maximum output (MW)	20.7
Maximum discharge (m3/s)	13.91
Effective head (m)	171.25
Annual power production (GWh)	N/A
Specifications (after the project)	Note: Specifications of the existing Nakatsugawa No.2 Power Station (Unit 1) are the same as those before the project. Unit 2 of the power station was newly constructed.
Name of power plant	Nakatsugawa No.2 Power Station (Unit 2)
Name of river	Nakatsu River
Type of power plant	Dam type
Year of commission	2002
Maximum output (MW)	1.8
Maximum discharge (m3/s)	12.66
Effective head (m)	17.54
Annual power production (GWh)	7.6
Overview of the project	Nakatsugawa No.2 Power Station, located in the southern part of Niigata prefecture, started operation in 1922. It was renewed in 1994 with a maximum output of 20.7MW and a maximum discharge of 13.91m3/s. Expansion of Nakatsugawa No.2 Power Station was implemented in 2001 - 2002 to increase maximum output by 1.8MW by utilizing the unused hydraulic head of 19.47m between the existing Ketto regulating pondage and energy-dissipation basin in the middle of the waterway of Nakatsugawa No.2 Power Station. Ketto dam re-regulates the generated water from unit 4 of the existing Nakatsugawa Power Station, and the water from units 1 to 3 goes directly into the headrace of Nakatsugawa No.2 Power Station. Newly installed unit 2 of Nakatsugawa No.2 also has a role in adjusting water supply to the power station.
Improvement of performance	

Increase in output	Maximum output was increased by the newly installed turbine and generator using the unused potential at the existing re-regulating dam.
Increase in power production	Annual power production was increased by the increase in output.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	
Cost	
Environmental conservation	Countermeasures against the noise from construction work were conducted to consider the birds of prey.
Legal restriction	
Others	Construction work was conducted to consider the operation of the existing power station.
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	Unused hydraulic heads and discharge at the existing re-regulating dam were effectively used.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] Electric Power Civil Engineering, No.306, 2003.7. (In Japanese)

Project code	JP117
Name of the project	Redevelopment of Yukawa Power Station
Location/country of the project	Nagano Prefecture, Japan
Implementing body of the project	Tokyo Electric Power Co. Holdings, Inc.
Implementing period	1994 – 1997
Type of the project	Redevelopment
Specifications (before the project)	
Name of power plant	Yukawa Power Station
Name of river	Sai River, Yukawa River, Hannokizawa River, Sepa River and Kurahorasawa River
Type of power plant	Waterway type
Year of commission	1928
Maximum output (MW)	6
Maximum discharge (m3/s)	3.45
Effective head (m)	222.12
Annual power production (GWh)	47
Specifications (after the project)	
Name of power plant	Yukawa Power Station
Name of river	Sai River, Yukawa, Hannokizawa River and Sepa River
Type of power plant	Waterway type
Year of commission	1997
Maximum output (MW)	17.4
Maximum discharge (m3/s)	9
Effective head (m)	227.57
Annual power production (GWh)	60
Overview of the project	The redevelopment of Yukawa Power Station increased the maximum output from 6MW to 17.4 MW by increasing the intake of water from the mountain stream and expanding the capacity of Sepa regulating pondage. Maximum discharge was increased from 3.45m3/s to 9.0m3/s. Because the project site was located in the national park area, the existing power facilities such as the intake weir were utilized as much as possible and the existing exposed penstock and power house were replaced at their current sites to minimize environmental impacts,
Improvement of performance	
Increase in output	Maximum output was increased by utilizing the unused potential in the river.
Increase in power production	Annual power production was increased by the increase in output.
Reliability/flexibility	N/A

Others	N/A
Challenges in the project	
Technology	N/A
Cost	N/A
Environmental conservation	Forest conservation, Landscape consideration and ecological flow release
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	Increase in water discharge by using unused mountain stream waterflow.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] Electric Power Civil Engineering, No.258, 1995.7. (In Japanese)

Project code	JP118
Name of the project	New construction of Yabukami No.2 Power Station
Location/country of the project	Niigata Prefecture, Japan
Implementing body of the project	Tohoku Electric Power Co.,Inc.
Implementing period	2013 - 2016
Type of the project	New Construction
Specifications (before the project)	
Name of power plant	-
Name of river	-
Type of power plant	-
Year of commission	-
Maximum output (MW)	-
Maximum discharge (m3/s)	-
Effective head (m)	-
Annual power production (GWh)	-
Specifications (after the project)	Note: Yabukami No.2 Power Station was newly constructed to expand the existing Yabukami Power Station.
Name of power plant	No.2 Yabukami Power Station
Name of river	Aburuma River
Type of power plant	Dam type
Year of commission	2016
Maximum output (MW)	4.5
Maximum discharge (m3/s)	30
Effective head (m)	17.85
Annual power production (GWh)	18.25
Overview of the project	Yabukami No.2 Power Station was a dam-type hydropower station newly constructed on the right bank of Yabukami Dam, which is an intake dam of the existing Yabukami Power Station using a maximum discharge of 30m3/s. Because the maximum discharge of the upstream existing Kuromatagawa No.1 Power Station was 42.4m3/s, the water overflowed at Yabukami Dam for more than 300 days a year. Yabukami No.2 Power Station was expected to use this unused overflow for power generation.
Improvement of performance	
Increase in output	Maximum output was increased by the construction of a new power station using the overflow water from the existing dam.
Increase in power production	Power production was increased by the increase in output.
Reliability/flexibility	N/A
Others	N/A

Challenges in the project	
Technology	N/A
Cost	N/A
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	Utilization of the unused spilled water at the existing dam
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] Tohoku Electric Power Co., Inc. Press Release https://www.tohoku-epco.co.jp/pastnews/normal/1192130_1049.html https://www.tohoku-epco.co.jp/pastnews/normal/__icsFiles/afieldfile/2016/06/23/b1192130.pdf

Project code	**JP119**
Name of the project	Renewal of Azumi Power Station
Location/country of the project	Nagano Prefecture, Japan
Implementing body of the project	Tokyo Electric Power Co. Holdings, Inc.
Implementing period	1992
Type of the project	Renewal
Specifications (before the project)	
Name of power plant	Azumi Power Station
Name of river	Azusa River
Type of power plant	Dam type (Unit 1 & 2) Dam and Conduit type (Unit 3 to 6)
Year of commission	1969
Maximum output (MW)	623 (412MW for pumped storage generation by Unit 3 to 6) (211MW for natural flow generation by Unit 1&2)
Maximum discharge (m3/s)	540 (27m3/s for natural flow generation by Unit 1&2)
Effective head (m)	135.78 for Unit 1&2/ 134.86 for Unit 3 to 6
Annual power production (GWh)	N/A
Specifications (after the project)	Note: Specifications of the existing Azumi Power Station are the same as those before the project except annual power production. The amount of intake water was increased by water diversion from the Midono River.
Name of power plant	-
Name of river	-
Type of power plant	-
Year of commission	-
Maximum output (MW)	-
Maximum discharge (m3/s)	-
Effective head (m)	-
Annual power production (GWh)	Increased by 12GWh
Overview of the project	Azumi Power Station is a mixed-type pumped storage power station using Nagawado Dam as upper reservoir and Midono Dam as lower reservoir, consisting of two types of units: dam type (unit 1 and 2 for natural flow power generation of 211MW) and dam and waterway type (unit 3 to 6 for pumped storage power generation of 412MW). In 1992, a new intake weir was constructed upstream of Midono River, which flows into Midono Dam, to divert water to Nagawado Dam. This diversion increased water discharge used at the Azumi Power Station for natural flow power generation without affecting power generation at the downstream Midono Power Station.

Improvement of performance	
Increase in output	No
Increase in power production	Annual power production was increased by diverting river water from another river basin.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	N/A
Cost	N/A
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	I-4 Renewal of civil engineering facilities III-2 Optimized operation of reservoir/power plant
Requirement A: Effective use of water resources	Increase of water discharge by diverting river water from another river basin
B: Improved and/or advanced methodologies	Water diversion from another river basin increased water discharge used at the power station without affecting power generation at the downstream power station.
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] Tunnel Engineering Study Group Presentation, Papers and Reports, Vol.1, 1991.12.

Project code	JP120
Name of the project	Operational change of power stations in Kurobe River basin
Location/country of the project	Toyama Prefecture, Japan
Implementing body of the project	Kansai Electric Power Co., Inc.
Implementing period	2019 -
Type of the project	Change of power plant operation
Specifications (before the project)	
Name of power plant	Power stations in the Kurobe River basin
Name of river	Kurobe River
Type of power plant	-
Year of commission	1936 – 2015
Maximum output (MW)	906.7 (Total of 12 PS with 0.5MW - 335MW)
Maximum discharge (m3/s)	1.7 - 74.0
Effective head (m)	34.5 - 545.5
Annual power production (GWh)	3470 (Total of 12 PS averaged in 2015 - 2016)
Specifications (after the project)	Note: Specifications of the existing 12 power stations in the Kurobe River basin are the same as those before the project except for annual power production. Improvements in the power station operations were investigated and verified in 2019.
Name of power plant	-
Name of river	-
Type of power plant	-
Year of commission	2019 -
Maximum output (MW)	-
Maximum discharge (m3/s)	-
Effective head (m)	-
Annual power production (GWh)	An increase by more than 1% (40 GWh) is expected.
Overview of the project	With the aim of increasing the power generation of existing hydropower stations by optimizing their operations, technological development has been conducted to improve dam inflow forecasting and optimize power station operations by combining weather observation and forecasting technology, snow accumulation and snowmelt models, rainfall-runoff prediction models, information network technology, and optimization calculation methods. These technologies were verified using the Kurobe River basin, where 12 power stations are located and snowfall accounts for more than half of the annual precipitation, as a model site, and the results showed that it is possible to increase annual power generation by more than 1% (40 GWh). This project was adopted by the New Energy and Industrial Technology

	Development Organization (NEDO), a national research and development corporation, as a publicly solicited project.
Improvement of performance	
Increase in output	No
Increase in power production	It is possible to increase annual power generation by more than 1% (40 GWh) by optimizing power station operations.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	Technological development has been conducted to improve dam inflow forecasting and optimize power station operations by combining weather observation and forecasting technology, snow accumulation and snowmelt models, rainfall-runoff prediction models, information network technology, and optimization calculation methods.
Cost	This project was adopted by the New Energy and Industrial Technology Development Organization (NEDO) as a publicly solicited project.
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	III-2 Optimized operation of reservoir/power plant
Requirement A: Effective use of water resources	Decrease of spilled water at dams and effective use of water for power generation by optimizing power station operations in river basin
B: Improved and/or advanced methodologies	Technological development has been conducted to improve dam inflow forecasting and optimize power station operations by combining weather observation and forecasting technology, snow accumulation and snowmelt models, rainfall-runoff prediction models, information network technology, and optimization calculation methods.
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] Kansai Electric Power Press Release https://www.kepco.co.jp/corporate/pr/2018/0918_2j.html [2] Electric Power Civil Engineering, No.409., 2020.9. (In Japanese)

Project code	**JP121**
Name of the project	New construction of Akiba No.3 Power Station
Location/country of the project	Shizuoka Prefecture, Japan
Implementing body of the project	Electric Power Development Co., Ltd.
Implementing period	1988 - 1991
Type of the project	New Construction
Specifications (before the project)	
Name of power plant	-
Name of river	-
Type of power plant	-
Year of commission	-
Maximum output (MW)	-
Maximum discharge (m3/s)	-
Effective head (m)	-
Annual power production (GWh)	-
Specifications (after the project)	Note: Akiba No.3 Power Station was newly constructed to expand the existing Akiba No.1 and No.2 Power Stations.
Name of power plant	Akiba No.3 Power Station
Name of river	Tenryu River
Type of power plant	Dam and waterway type
Year of commission	1991
Maximum output (MW)	45.3 (Large turbine) 1.6 (Small turbine for river ecological flow power generation)
Maximum discharge (m3/s)	110 (Large turbine 6 (Small turbine))
Effective head (m)	47.1 (Large turbine) 32.9 (Small turbine)
Annual power production (GWh)	96 (Total of large and small turbines)
Overview of the project	The amount of water flowing into the existing Akiba Dam exceeded the total amount of water used by the existing Akiba No.1 and No.2 power stations (both started operation in 1958), which took water from the Akiba Dam, resulting in an overflow from the dam about 100 days per year. In order to utilize this spilled water for power generation effectively, the Akiba No.3 power station was newly constructed in 1991. The water intake for the No.3 power station uses the water intake facilities of the existing No.1 power station located on the right bank of the Akiba Dam, and the penstock was installed in the dam body after concrete excavation by drilling. The power house was constructed just below the dam. The water intake is divided into a large turbine (110 m3/s) and a small turbine (6 m3/s) for the ecological flows power generation. The water used by the large turbine is discharged through a 3.6km long tailrace tunnel to an existing regulating reservoir downstream.

	At the same time, the water used by the small turbine is discharged just below the dam.
Improvement of performance	
Increase in output	Maximum output was increased by the construction of a new power station.
Increase in power production	Annual power production was increased by 96GWh due to the increase in output.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	An intake facility was constructed in the dam body after concrete excavation by drilling.
Cost	Received subsidy for 10% of construction cost.
Environmental conservation	Ecological flow discharge from the dam was minimized within the acceptable limits in the negotiation with the river management administrator from an economic viewpoint.
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	The new power station utilizes the spilled water from dam effectively by the large turbine and the ecological flow discharge by the small turbine.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] Electric Power Civil Engineering, No.215, 1963.7 (In Japanese) [2] Electric Power Civil Engineering, No.221, 1989.7 (In Japanese)

Project code	**JP122**
Name of the project	Operational change of Asaida Dam for power generation
Location/country of the project	Gifu Prefecture, Japan
Implementing body of the project	Hokuriku Electric Power Co., Ltd.
Implementing period	2019 -
Type of the project	Change of power plant operation
Specifications (before the project)	
Name of power plant	Higashimachi Power Station
Name of river	Jinzuu River
Type of power plant	Dam & waterway type
Year of commission	1942
Maximum output (MW)	32.8
Maximum discharge (m3/s)	47
Effective head (m)	80.5
Annual power production (GWh)	N/A
Specifications (after the project)	Note: Specifications of the existing Higashimachi Power Station are the same as those before the project except for annual power production. Improvement of the intake dam operation has been implemented since 2019.
Name of power plant	-
Name of river	-
Type of power plant	-
Year of commission	2019 -
Maximum output (MW)	-
Maximum discharge (m3/s)	-
Effective head (m)	-
Annual power production (GWh)	Increased by about 3% (5GWh)
Overview of the project	In order to optimize hydropower plant operation, Hokuriku Electric Power Company has developed a prediction model for the inflow to a dam reservoir in collaboration with JFE Engineering Corporation. The model is constructed based on the learning of meteorological and hydrological data observed at the dam using the artificial intelligence software developed by JFE Engineering Corporation. Since 2019, Hokuriku Electric Power Company has introduced the model at Asaida Dam in Jinzuu River, which is an intake dam for Higashimachi Power Station with a capacity of 32.8MW. It was confirmed that the inflow to the dam could be predicted with high accuracy compared with the traditional physical prediction model. The new prediction model makes it possible to recover water elevation at the dam more quickly after the high run-off by saving water release from the dam and increasing annual power production by about 3% (5GWh).

Improvement of performance	
Increase in output	No
Increase in power production	Annual power production was increased by optimizing water release from the dam.
Reliability/flexibility	Inflow prediction model using AI technology can improve its reliability by additional learning of meteorological and hydrological data observed at the dam after its commencement of operation.
Others	N/A
Challenges in the project	
Technology	The river flow prediction model using artificial intelligence technology has been verified at many sites in Japan. However, the prediction of inflow to hydropower reservoir and the optimization of power station operation is a challenge. For further application, this model should improve its reliability for longer-term prediction and be applied to a series of power plants in the river system.
Cost	N/A
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	III-2 Optimized operation of reservoir/power plant
Requirement A: Effective use of water resources	Annual power production was increased by optimizing water release from the dam.
B: Improved and/or advanced methodologies	Optimization of hydropower dam operation and increase of annual power production by introducing an inflow prediction model with high accuracy using artificial intelligence technology.
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] Hokuriku Electric Power Company and JFE Engineering Corporation: News Release, 12 June, 2020. http://www.rikuden.co.jp/press/attach/200612001.pdf [2] JFE Engineering Corporation: Real-time Flood Forecasting System Using AI Technology “WinmuSe(R) Caesar”,Feb. 2011. https://www.jfe-steel.co.jp/research/giho/027/pdf/027-20-2.pdf [3] Electric Power Civil Engineering, No.422, 2022.11 (In Japanese)

Project code	LA101
Name of the project	Expansion of Nam Ngum 1 Power Station
Location/country of the project	Vientiane Province, Laos
Implementing body of the project	Électricité du Laos
Implementing period	2017 – 2021
Type of the project	Expansion
Specifications (before the project)	
Name of power plant	Nam Ngum 1 Power Station
Name of river	Nam Ngum River
Type of power plant	Dam type
Year of commission	1971
Maximum output (MW)	155
Maximum discharge (m3/s)	462.1
Effective head (m)	37
Annual power production (GWh)	NA
Specifications (after the project)	
Name of power plant	Nam Ngum 1 Power Station
Name of river	Nam Ngum River
Type of power plant	Dam type
Year of commission	2021
Maximum output (MW)	195
Maximum discharge (m3/s)	573.3
Effective head (m)	40
Annual power production (GWh)	NA
Overview of the project	A new 40MW unit was added to the existing Nam Ngum 1 Power Station to meet the rapidly increasing electricity demand in Laos. Expansion construction includes the intake facility that was installed by drilling a hole in the concrete-gravity dam body of Nam Ngum Dam and an additional unit was installed in the expanded power station. The expansion increased the peak-power supply and improved the reliability and flexibility of the existing power station.
Improvement of performance	
Increase in output	Maximum output was increased by the expansion of power unit.
Increase in power production	No
Reliability/flexibility	Peak power supply was increased with the increase of maximum output.
Others	NA

Challenges in the project	
Technology	An intake facility and penstock was installed by drilling a hole in the concrete-gravity dam body.
Cost	NA
Environmental conservation	NA
Legal restriction	NA
Others	NA
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-2 Development without using unused potential
Requirement A: Effective use of water resources	NA
B: Improved and/or advanced methodologies	NA
C: Improvement of reliability/flexibility corresponding to market needs	Increased peak-power supply meets the needs of the power market and improves the reliability and flexibility of the existing power station.
Others	NA
References	[1] Electric Power Civil Engineering, No.391, 2017.9. (In Japanese)

Project code	PH101
Name of the project	New construction of Maris Main Canal 1 Power Station
Location/country of the project	Isabela, Philippines
Implementing body of the project	SN Aboitiz Power-Magat, Inc.
Implementing period	2016 – 2017
Type of the project	New Construction
Specifications (before the project)	
Name of power plant	-
Name of river	-
Type of power plant	-
Year of commission	-
Maximum output (MW)	-
Maximum discharge (m3/s)	-
Effective head (m)	-
Annual power production (GWh)	-
Specifications (after the project)	Note: Maris Main Canal 1 Power Station was newly constructed using the re-regulating dam for the existing Magat Power Station.
Name of power plant	Maris Main Canal 1 Power Station
Name of river	Maris River
Type of power plant	Dam type
Year of commission	2017
Maximum output (MW)	8.5
Maximum discharge (m3/s)	NA
Effective head (m)	12.05
Annual power production (GWh)	45
Overview of the project	Maris Power Station was newly constructed at Maris re-regulating dam for the existing Magat Power Station. It uses the unused generated flow from Magat Power Station and the hydraulic head from Maris Dam to Maris Irrigation Canal. Two units of Kaplan turbines (4.25MW/unit) were installed.
Improvement of performance	
Increase in output	Maximum output was increased by the construction of a new power station.
Increase in power production	Annual power production was increased due to the increase in output.
Reliability/flexibility	NA
Others	NA
Challenges in the project	
Technology	NA
Cost	NA

Environmental conservation	NA
Legal restriction	NA
Others	NA
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	Effective utilization of the unused discharge and hydraulic head at the existing re-regulating dam
B: Improved and/or advanced methodologies	NA
C: Improvement of reliability/flexibility corresponding to market needs	NA
Others	NA
References	[1] SN Power Maris Canal https://www.snpower.com/our-markets/philippines/ maris-canal/ [2] Aboitiz Power 2017 https://aboitizpower.com/history/2017/

Project code	**VN101**
Name of the project	New construction of Thac Mo Power Station
Location/country of the project	Binh Phouc, Vietnam
Implementing body of the project	Vietnam Electricity
Implementing period	2006 – 2014
Type of the project	New Construction
Specifications (before the project)	
Name of power plant	Thac Mo Power Station
Name of river	Be River
Type of power plant	Dam and waterway type
Year of commission	1995
Maximum output (MW)	150
Maximum discharge (m3/s)	186
Effective head (m)	90
Annual power production (GWh)	689
Specifications (after the project)	
Name of power plant	Thac Mo Power Station
Name of river	Be River
Type of power plant	Dam and waterway type
Year of commission	2014
Maximum output (MW)	225
Maximum discharge (m3/s)	279
Effective head (m)	90
Annual power production (GWh)	741
Overview of the project	Thac Mo Power Station was commissioned in 1995 with a maximum output of 150MW. However, the actual inflow into the dam was larger than estimated at the time of planning, so a new intake facility from the existing dam, penstock, powerhouse, and tailrace were constructed, and a 75MW generating unit was added.
Improvement of performance	
Increase in output	Maximum output was increased by expansion.
Increase in power production	Annual power production was increased by the increased output.
Reliability/flexibility	NA
Others	NA
Challenges in the project	
Technology	NA
Cost	NA

Environmental conservation	NA
Legal restriction	NA
Others	NA
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	Effective utilization of the unused inflow at the existing intake dam by expansion
B: Improved and/or advanced methodologies	NA
C: Improvement of reliability/flexibility corresponding to market needs	NA
Others	NA
References	[1] Electric Power Civil Engineering, No.382, 2016.3, No.388, 2017.3 and No.393, 2018.1. (In Japanese)

Project code	**AS101**
Name of the project	New construction of Obervermuntwerk II Pumped Storage Power Station
Location/country of the project	Gaschurn, Austria
Implementing body of the project	Illwerke Vkw AG
Implementing period	2014 – 2019
Type of the project	New construction
Specifications (before the project)	
Name of power plant	Obervermuntwerk I Power Station
Name of river	N/A
Type of power plant	Dam & waterway type
Year of commission	1943
Maximum output (MW)	30
Maximum discharge (m3/s)	N/A
Effective head (m)	291
Annual power production (GWh)	N/A
Specifications (after the project)	Note: Specifications of the existing Obervermuntwerk I Power Station are the same as those before the project.
Name of power plant	Obervermuntwerk II Pumped Storage Power Station
Name of river	N/A
Type of power plant	Pumped Storage
Year of commission	2019
Maximum output (MW)	360
Maximum discharge (m3/s)	150
Effective head (m)	291
Annual power production (GWh)	N/A
Overview of the project	Obervermuntwerk II Pumped Storage Power Station in Gaschurn, Austria uses a hydraulic head between Lake Silvretta, where the exisitng Obervermuntwerk I Power Station (reservoir-type hydropower station) is located and Lake Vermunt. A new waterway and power house were constructed underground considering landscape protection. Penstock for Obervermuntwerk I had been installed on the ground, but it was shifted underground and connected to new penstock at the time of construction of Obervermuntwerk II. It is expected that the new pumped storage power station will play a role in increasing peak power supply and stabilizing the power system.
Improvement of performance	
Increase in output	Maximum output was increased by the construction of a new pumped storage power station.

Increase in power production	No
Reliability/flexibility	Reliability and flexibility of the operation of the power station was improved by the new construction of a pumped storage power station.
Others	N/A
Challenges in the project	
Technology	The new pumped storage power station is classified as a "turnary system type" in which turbine, clutch, generator/electric motor, torque converter and pump are connected on the same axis, and "hydraulic short circuit" switches from pumping mode to generation mode and vice versa smoothly. It contributes to the stabilization of the power system.
Cost	N/A
Environmental conservation	A new waterway and power house were constructed underground considering landscape protection.
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-2 Development without using unused potential
Requirement A: Effective use of water resources	N/A
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	Peak supply capacity was increased and reliability and flexibility for market needs were improved by the new construction of a pumped storage power station.
Others	N/A
References	[1] illwerke vkw https://www.illwerkevkw.at/obervermuntwerk-ii.htm

Project code	AU01
Name of the project	Renewal of Poatina Power Station
Location/country of the project	Tasmania, Australia
Implementing body of the project	Hydro Tasmania
Implementing period	2006 – 2010
Type of the project	Renewal
Specifications (before the project)	
Name of power plant	Poatina Power Station
Name of river	Great Lake
Type of power plant	Dam & waterway type
Year of commission	1965
Maximum output (MW)	360
Maximum discharge (m3/s)	50
Effective head (m)	820
Annual power production (GWh)	N/A
Specifications (after the project)	
Name of power plant	Poatina Power Station
Name of river	Great Lake
Type of power plant	Dam & waterway type
Year of commission	2010
Maximum output (MW)	372
Maximum discharge (m3/s)	50
Effective head (m)	820
Annual power production (GWh)	N/A
Overview of the project	Hydro Tasmania modernized units at Poatina Power Station to improve generation efficiency and significantly improve plant performance, achieving a start reliability of 98% and an availability of 95%. This made it possible to increase maximum output by 12 MW (4 MW per unit x 3 units) without increasing maximum discharge and improve the frequency control function.
Improvement of performance	
Increase in output	Maximum output was increased by the renewal of the turbine and generator without increasing maximum discharge.
Increase in power production	No
Reliability/flexibility	Ancillary service of frequency control was provided by the renewal of the control device.
Others	N/A
Challenges in the project	

Technology	Improved inlet valve control and protection system reduced the risk of serious penstock hydraulic risk.
Cost	N/A
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	I-3 Renewal of electro-mechanical equipment adding new functions
Requirement A: Effective use of water resources	N/A
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	The frequency control function was improved by the renewal of the control device, which contributed to the reliability and flexibility of the power station.
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History Au.01_Poatina https://www.ieahydro.org/media/5fb06b0d/ Vol2_Case_History_English(409-598).pdf

Project code	AU102
Name of the project	New construction of Tods Corner Power Station
Location/country of the project	Tasmania, Australia
Implementing body of the project	Hydro Tasmania
Implementing period	1966
Type of the project	New construction
Specifications (before the project)	
Name of power plant	-
Name of river	-
Type of power plant	-
Year of commission	-
Maximum output (MW)	-
Maximum discharge (m3/s)	-
Effective head (m)	-
Annual power production (GWh)	-
Specifications (after the project)	Note: Tods Corner Power Station was newly constructed using the unused potential in the existing waterway.
Name of power plant	Tods Corner Power Station
Name of river	N/A
Type of power plant	Waterway type
Year of commission	1966
Maximum output (MW)	1.7
Maximum discharge (m3/s)	N/A
Effective head (m)	41
Annual power production (GWh)	8
Overview of the project	Arthurs Lake was created in the 1920s to increase the water available at Great Lake which is the largest lake in Tasmania and is used for power generation. Water is pumped up 140m from Arthurs Lake to a 5km flume. Tods Corner Power Station (1.7 MW) was commissioned in 1966 using the unused hydraulic head in the flume. It was intended to recover part of the energy used in pumping the water.
Improvement of performance	
Increase in output	Maximum output was increased by the construction of a new power station.
Increase in power production	Annual power production was increased due to the increase in output.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	N/A

Cost	MA
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	A small-scale hydropower station was newly constructed to effectively use the unused potential in the waterway for pumped-up water from Arthurs Lake to Great Lake.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] Hydropower & Dams Issue Three, 2003 [2] The power of nature, Hydro Tasmania

Project code	BR01
Name of the project	Renewal of Estreito Power Station
Location/country of the project	Pedregulho, São Paulo, Brazil
Implementing body of the project	ELETROBRAS FURNAS
Implementing period	2007 – 2012
Type of the project	Renewal
Specifications (before the project)	
Name of power plant	Estreito Power Station
Name of river	Tocantins River
Type of power plant	Dam type
Year of commission	1969
Maximum output (MW)	1,050
Maximum discharge (m3/s)	306.6
Effective head (m)	65
Annual power production (GWh)	N/A
Specifications (after the project)	Note: Specifications of the existing Estreito Power Station are the same as those before the project.
Name of power plant	-
Name of river	-
Type of power plant	-
Year of commission	-
Maximum output (MW)	-
Maximum discharge (m3/s)	-
Effective head (m)	-
Annual power production (GWh)	N/A
Overview of the project	FURNAS renewed the Estreito Power Station during 2007 - 2012 because of the recurrence of malfunctions in units and auxiliary systems due to degradation and aging. FURNAS studied new materials and processes to repair the cavitation in Francis turbine blades and repaired them using the material "Cavitalloy". The cost of "Cavitalloy" is 30% greater than that of the stainless steel traditionally used. However, it was expected to improve the performance of units by increasing the resistance of cavitation and therefore reducing maintenance costs. A “pressurized air system” was implemented to lower the draft tube level, so that the units could operate as synchronous condensers, contributing to the stabilization of the power system,
Improvement of performance	
Increase in output	No

Increase in power production	No
Reliability/flexibility	The reliability and flexibility of the power station was improved by the implementation of a “pressurized air system” to operate the units as synchronous condensers.
Others	N/A
Challenges in the project	
Technology	The new material "Cavitalloy" was adopted for cavitation repair as the alternative material of stainless steel. The introduction of a "pressurized air system" can also reduce cavitation in the turbine by avoiding the “speed no load” mode operation.
Cost	N/A
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	I-1 Renewal of electro-mechanical equipment without changing intake discharge/hydraulic head I-3 Renewal of electro-mechanical equipment adding new functions
Requirement A: Effective use of water resources	N/A
B: Improved and/or advanced methodologies	The new material "Cavitalloy" was adopted for cavitation repair as the alternative material of stainless steel.
C: Improvement of reliability/flexibility corresponding to market needs	A “pressurized air system” was implemented to lower the draft tube level, so that the units could operate as synchronous condensers, contributing to the stabilization of the power system,
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History Br.01_Estreito https://www.ieahydro.org/media/5fb06b0d/Vol2_Case_History_English(409-598).pdf

Project code	**CA101**
Name of the project	Expansion of London Street Power Station
Location/country of the project	Ontario, Canada
Implementing body of the project	Peterborough Utilities Inc.
Implementing period	2014 – 2016
Type of the project	Expansion
Specifications (before the project)	
Name of power plant	London Street Power Station
Name of river	Otonabee River
Type of power plant	Dam type
Year of commission	1921
Maximum output (MW)	4
Maximum discharge (m3/s)	N/A
Effective head (m)	N/A
Annual power production (GWh)	N/A
Specifications (after the project)	
Name of power plant	London Street Power Station
Name of river	Otonabee River
Type of power plant	Dam type
Year of commission	2016
Maximum output (MW)	10
Maximum discharge (m3/s)	N/A
Effective head (m)	N/A
Annual power production (GWh)	16 (additional)
Overview of the project	London Street Power Station was constructed in 1921 with a total capacity of 4MW by three Francis turbine units. Peterborough Utilities Inc. acquired the facility in 1975 and conducted an expansion of the existing power station by using the unused outflow from the intake dam in 2016. Two new Kaplan turbine units for a total capacity of 6MW were installed adjacent to the existing facilities, producing additional 16GWh annually.
Improvement of performance	
Increase in output	Maximum output was increased by an expansion of the existing power station.
Increase in power production	Annual power production was increased by the increase in output.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	

Technology	N/A
Cost	Feed-in-tariff has been applied.
Environmental conservation	Construction of new facilities was conducted considering the avian nesting activity on the island where the power station is located and the appropriate timing for tree removal was determined along with documentation of the occurrence of avian nesting.
Legal restriction	
Others	
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	New generation units were installed to effectively use the unused potential at the existing intake dam. Increase in power discharge increased maximum output and annual power production.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] London Street Generating Station Expansion https://pub-peterborough.escribemeetings.com/filestream.ashx?DocumentId=19178

Project code	CO101
Name of the project	Renewal of Salvajina Power Station
Location/country of the project	Cauca, Colombia
Implementing body of the project	Celsia S.A. E.S.P.
Implementing period	2017
Type of the project	Renewal
Specifications (before the project)	
Name of power plant	Salvajina Power Station
Name of river	Cauca River
Type of power plant	Dam Type
Year of commission	1985
Maximum output (MW)	285
Maximum discharge (m3/s)	300
Effective head (m)	N/A
Annual power production (GWh)	N/A
Specifications (after the project)	
Name of power plant	Salvajina Power Station
Name of river	Cauca River
Type of power plant	Dam Type
Year of commission	2017
Maximum output (MW)	315
Maximum discharge (m3/s)	350
Effective head (m)	N/A
Annual power production (GWh)	N/A
Overview of the project	The aged No.1 unit of Salvajina Power Station in Colombia was renewed in 2017 to increase maximum output by increasing maximum discharge. The existing water turbine had been designed for overload operation, but the generator and transformer had insufficient capacity. In addition, the generator was aging, causing frequent earth fault failures. Therefore, the generator, exciter and transformer were renewed.
Improvement of performance	
Increase in output	Maximum output was increased by the renewal of existing power station.
Increase in power production	Annual power production was increased by the increase in output.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	

Technology	N/A
Cost	N/A
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	I-2 Renewal of electro-mechanical equipment changing intake discharge
Requirement A: Effective use of water resources	The existing unit was renewed to effectively use the unused potential in the river by increasing maximum discharge.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] Repotenciación de la Unidad 1 de la central hidráulica Salvajina de la empresa Celsia E.S.P. https://educacion.aciem.org/CIMGA/2018/Trabajos/2018-063%20TRA_COL_L_ARBOLEDA_CIMGA2018.pdf

Project code	FI01
Name of the project	Renewal of Pirttikoski Power Station
Location/country of the project	Rovaniemi district, Finland
Implementing body of the project	Kemijoki Oy
Implementing period	2009 – 2010
Type of the project	Renewal
Specifications (before the project)	
Name of power plant	Pirttikoski Power Station
Name of river	Kemijoki River
Type of power plant	Dam & waterway type
Year of commission	1956
Maximum output (MW)	110
Maximum discharge (m3/s)	750
Effective head (m)	N/A
Annual power production (GWh)	551
Specifications (after the project)	
Name of power plant	Pirttikoski Power Station
Name of river	Kemijoki River
Type of power plant	Dam & waterway type
Year of commission	2010
Maximum output (MW)	152
Maximum discharge (m3/s)	1050
Effective head (m)	N/A
Annual power production (GWh)	581
Overview of the project	The power stations along the main channel of the Kemijoki River have been operated in close coordination with each other. The Pirttikoski Power Station is one of them and was constructed in 1959. The upgrading of the power stations on the Kemijoki River started in 1996, and at the Pirttikoski Power Station, turbine and generators, automatic control, protection and hydraulic control systems, etc. were upgraded in 2009-2010. The maximum discharge used by the turbine was increased, and the maximum output was significantly increased. The frequency control reserve was also improved. The upgrading has optimized the operation of river system and power station.
Improvement of performance	
Increase in output	Maximum output was increased by the renewal and upgrade.
Increase in power production	Power production was increased by the increase in power output.
Reliability/flexibility	The frequency control reserve was improved.

Others	N/A
Challenges in the project	
Technology	N/A
Cost	N/A
Environmental conservation	Environmentally friendly oil-free runner hubs were adopted in the new turbines.
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	I-2 Renewal of electro-mechanical equipment changing intake discharge I-3 Renewal of electro-mechanical equipment adding new functions III-2 Optimized operation of reservoir/power plant
Requirement A: Effective use of water resources	The existing unit was renewed and upgraded to effectively use the unused potential in the river by increasing maximum discharge.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	Reliability and flexibility were improved by increasing the frequency adjustment ability for the stabilization of the power system.
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History Fi.01_Pirttikoski https://www.ieahydro.org/media/5fb06b0d/Vol2_Case_History_English(409-598).pdf

Project code	FR01
Name of the project	Renewal of Sisteron Power Station
Location/country of the project	France
Implementing body of the project	EDF
Implementing period	2011 – 2014
Type of the project	Renewal
Specifications (before the project)	
Name of power plant	Sisteron Power Station
Name of river	Durance River
Type of power plant	Dam and waterway type
Year of commission	1975
Maximum output (MW)	244
Maximum discharge (m3/s)	N/A
Effective head (m)	110
Annual power production (GWh)	N/A
Specifications (after the project)	Note: Specifications of the existing Sisteron Power Station are the same as those before the project except annual power production.
Name of power plant	Sisteron Power Station
Name of river	Durance River
Type of power plant	Dam and waterway type
Year of commission	2014
Maximum output (MW)	244
Maximum discharge (m3/s)	N/A
Effective head (m)	110
Annual power production (GWh)	11.7 (additional)
Overview of the project	Sisteron Power Station on the Durance River in south-east France was commissioned in 1975 with a total capacity of 244MW by two Francis turbine units. After 35 years of operation, hydro-mechanical equipment showed serious signs of chronic problems that made plant operation restrictive and risky. Therefore, general refurbishment was carried out in 2009-2014 to secure plant operation. A new runner was designed by CFD analysis, and the operation range of the turbine was extended by adopting an axial air supply system to the runner to increase annual power production.
Improvement of performance	
Increase in output	No
Increase in power production	Annual power production was increased by the renewal.
Reliability/flexibility	N/A
Others	N/A

Challenges in the project	
Technology	An axial air supply system to the runner was adopted to reduce pressure fluctuation of the draft tube at partial load operation and to extend the operation range of the turbine.
Cost	In order to minimize the loss of power generation during construction, the period of on-site works was managed to be shortened.
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	I-1 Renewal of electro-mechanical equipment without changing intake discharge/hydraulic head
Requirement A: Effective use of water resources	N/A
B: Improved and/or advanced methodologies	A new runner was designed by CFD analysis, and the operation range of the turbine was extended by adopting an axial air supply system to the runner to increase annual power production.
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History FR01: Sisteron https://www.ieahydro.org/media/5fb06b0d/Vol2_Case_History_English(409-598).pdf

Subtask 2 case history data summary

Project code	FR101
Name of the project	Expansion of La Centrale de Mathay Power Station
Location/country of the project	Bourgogne-Franche-Comté, France
Implementing body of the project	Hydrocop
Implementing period	2018 – 2019
Type of the project	Expansion
Specifications (before the project)	
Name of power plant	Mathay Power Station
Name of river	Doubs River
Type of power plant	Dam type
Year of commission	1912
Maximum output (MW)	1
Maximum discharge (m3/s)	N/A
Effective head (m)	N/A
Annual power production (GWh)	4.8
Specifications (after the project)	
Name of power plant	Mathay Power Station
Name of river	Doubs River
Type of power plant	Dam type
Year of commission	2019
Maximum output (MW)	1.5
Maximum discharge (m3/s)	15.8 (expanded unit)
Effective head (m)	4.0 (expanded unit)
Annual power production (GWh)	6.1
Overview of the project	Mathay Power Station was commissioned in 1912 and has been repaired and remodeled many times to date. In 2019, a fish way was constructed at the existing intake dam and a new power unit of 500kW was installed at the fish way to increase power production.
Improvement of performance	
Increase in output	Maximum output was increased by the expansion of the existing power station using a fish way.
Increase in power production	Annual power production was increased due to the increase in output.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	A low-head turbine was installed on the fish way.
Cost	N/A

Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	Effective utilization of unused potential in the fish way of existing intake dam.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] Hydrocop_Augmentation de puissance centrale de Mathay et confortement du barrage. http://www.hydrocop.fr/m-120-augmentation-de-puissance-centrale-de-mathay-et-confortement-du-barrage-25-mathay-.html [2] MJ2 Technologies News Letter No. 72 May 2019 http://www.vlh-turbine.com/wp-content/uploads/2019/06/17NL_interattivo_72dpi.pdf

Project code	**IC101**
Name of the project	Renewal of Búrfell Power Station
Location/country of the project	Búrfellsstöð, Iceland
Implementing body of the project	Landsvirkjun
Implementing period	1997 – 1999
Type of the project	Renewal
Specifications (before the project)	
Name of power plant	Búrfell Power Station
Name of river	Thjórsá river
Type of power plant	Dam and waterway type
Year of commission	1972
Maximum output (MW)	210
Maximum discharge (m3/s)	N/A
Effective head (m)	115
Annual power production (GWh)	N/A
Specifications (after the project)	
Name of power plant	Búrfell Power Station
Name of river	Thjórsá River
Type of power plant	Dam and waterway type
Year of commission	1999
Maximum output (MW)	270
Maximum discharge (m3/s)	260
Effective head (m)	115
Annual power production (GWh)	2300
Overview of the project	Burfell Power Station is located in South Iceland and was commissioned in 1972 with a total capacity of 210MW by six Francis turbines. All of the turbines were upgraded in 1997-98 to increase the total capacity by 60MW by increasing maximum discharge and reducing the amount of ice flowing into the intake reservoir.
Improvement of performance	
Increase in output	Maximum output was increased by the renewal of the existing power station.
Increase in power production	Annual power production was increased due to the increase in output.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	N/A
Cost	N/A

Environmental conservation	N/A
Legal restriction	N/A
Others	Prevention of ice inflow into the intake reservoir
Characteristics regarded as "Hidden Hydro"	
Classification of development type	I-2 Renewal of electro-mechanical equipment changing intake discharge
Requirement A: Effective use of water resources	Effective utilization of unused potential in the river by increasing maximum discharge and reducing the amount of ice flowing into the intake reservoir.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] Búrfell Power Station https://www.landsvirkjun.com/ company/powerstations/burfellpowerstation [2] Búrfell Hydropower Station https://www.landsvirkjun.com/ media/enska/operations/Additional%20Information.pdf

Project code	**IC102**
Name of the project	New construction of Búrfell II Power Station
Location/country of the project	Búrfellsstöð, Iceland
Implementing body of the project	Landsvirkjun
Implementing period	2016 – 2018
Type of the project	New construction
Specifications (before the project)	
Name of power plant	Búrfell Power Station
Name of river	Thjórsá River
Type of power plant	Dam and waterway type
Year of commission	1999
Maximum output (MW)	270
Maximum discharge (m3/s)	260
Effective head (m)	115
Annual power production (GWh)	2300
Specifications (after the project)	Note: Specifications of the existing Búrfell Power Station are the same as those before the project.
Name of power plant	Búrfell II Power Station
Name of river	Thjórsá River
Type of power plant	Dam and waterway type
Year of commission	2018
Maximum output (MW)	100
Maximum discharge (m3/s)	92
Effective head (m)	120.7
Annual power production (GWh)	300
Overview of the project	Búrfell Power Station in South Iceland was commissioned in 1972 and upgraded in 1999 with a total capacity of 270MW by increasing the maximum discharge up to 260 m3/s. However, even after the upgrading, river flows still far exceeded the power plant's maximum discharge, so a new 100MW Búrfell II Power Station was constructed in 2018 to utilize unused river water at the existing intake dam.
Improvement of performance	
Increase in output	Maximum output was increased by the construction of a new power station.
Increase in power production	Annual power production was increased due to the increase in output.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	N/A

Cost	N/A
Environmental conservation	The powerhouse was built underground to minimize environmental impacts.
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	A new power station was constructed to effectively use the unused potential at the existing intake dam.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] Búrfell II Power Station https://www.landsvirkjun.com/company/powerstations/burfell-ii-power-station/ [2] Andritz News on HPP Búrfell, Iceland https://www.andritz.com/hydro-en/hydronews/hy-hydro-news-30/hy-news-30-12-burfell-extension-iceland-hydro/pac-received-hpp-burfell

Project code	**LX101**
Name of the project	Expansion of Vianden Pumped Storage Power Station
Location/country of the project	Vianden, Luxembourg
Implementing body of the project	Societe Electrique de l'Our
Implementing period	2010 – 2014
Type of the project	Expansion
Specifications (before the project)	
Name of power plant	Vianden Pumped Storage Power Station
Name of river	Our River
Type of power plant	Pumped storage type
Year of commission	1962
Maximum output (MW)	1096
Maximum discharge (m3/s)	432.5
Effective head (m)	280
Annual power production (GWh)	N/A
Specifications (after the project)	
Name of power plant	Vianden Pumped Storage Power Station
Name of river	Our River
Type of power plant	Pumped storage type
Year of commission	2014
Maximum output (MW)	1291
Maximum discharge (m3/s)	510.7
Effective head (m)	280
Annual power production (GWh)	N/A
Overview of the project	Vianden Pumped Storage Power Station is located in Vianden, Luxembourg, and serves as a peak power plant. The first nine units were commissioned in 1964 with a total output of 900MW, and a 10th unit of 196MW was installed in 1976. To meet the increasing demand for peak energy, the plant capacity was further expanded in 2015 by installing an 11th unit of 195MW along with increasing the storage capacity of the existing upper and lower reservoirs by 500,000m3.
Improvement of performance	
Increase in output	Maximum output was increased by the expansion of the existing power station.
Increase in power production	No
Reliability/flexibility	The peak power supply was increased to improve the reliability and flexibility of the power station.
Others	N/A

Challenges in the project	
Technology	N/A
Cost	N/A
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-2 Development without using unused potential
Requirement A: Effective use of water resources	N/A
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	The peak power supply was increased to improve the reliability and flexibility of the power station.
Others	
References	[1] Societe electrique de l'Our http://www.seo.lu/fr/Activites-principales/PSW-Vianden/Installations [2] Pumped-storage power plant, Vianden https://benelux.rwe.com/en/locations/vianden-pumped-storage-power-plant/

Project code	MW101
Name of the project	New construction of Tedzani IV Power Station
Location/country of the project	Blantyre Province, Malawi
Implementing body of the project	Electricity Generation Company Malawi Limited
Implementing period	2014 – 2021
Type of the project	New construction
Specifications (before the project)	
Name of power plant	-
Name of river	-
Type of power plant	-
Year of commission	-
Maximum output (MW)	-
Maximum discharge (m3/s)	-
Effective head (m)	-
Annual power production (GWh)	-
Specifications (after the project)	Note: Tedzani IV Power Station was newly constructed using the unused potential at the existing dam.
Name of power plant	Tedzani IV Power Station
Name of river	Shire River
Type of power plant	Waterway type
Year of commission	2021
Maximum output (MW)	19
Maximum discharge (m3/s)	58.5
Effective head (m)	37
Annual power production (GWh)	N/A
Overview of the project	In Malawi's Shire River, hydropower stations have been developed in stages since the Tedzani I Power Station of 20MW was completed in 1973. The 4th, Tedzani IV, was built in 2021 as a new 18MW power station using the overflow from the intake dam of the existing power stations.
Improvement of performance	
Increase in output	Maximum output was increased by the construction of a new power station.
Increase in power production	Annual power production was increased due to the increase in output.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	N/A
Cost	The project was funded by the Japan International Cooperation Agency and the Government of Malawi.

Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	A new power station was constructed to effectively use the unused potential at the existing dam.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] JICA ODA, The Project for Expansion of Tedzani Electricity Hydropower Station https://www.jica.go.jp/oda/project/1460570/index.html

Project code	**NW01**
Name of the project	Redevelopment of Embretsfoss IV Power Station
Location/country of the project	Buskerud County, Norway
Implementing body of the project	EB Kraftproduksjon AS
Implementing period	2010 – 2013
Type of the project	Redevelopment
Specifications (before the project)	
Name of power plant	Embretsfoss II Power Station
Name of river	Drammen River
Type of power plant	Dam type
Year of commission	1921 (abolished in 2013)
Maximum output (MW)	9
Maximum discharge (m3/s)	75
Effective head (m)	16.3
Annual power production (GWh)	110
Specifications (after the project)	
Name of power plant	Embretsfoss IV Power Staion
Name of river	Drammen River
Type of power plant	Dam type
Year of commission	2013
Maximum output (MW)	52.5
Maximum discharge (m3/s)	N/A
Effective head (m)	16.3
Annual power production (GWh)	N/A
Overview of the project	There were two parallel power stations (Embretsfoss II and Embretsfoss III) at Embretsfoss, utilizing the same intake pond, and both had heads of approximately 16m. A dam across the river increased the natural head, and provided for a small intake pond. Embretsfoss II has been condemning the failures of civil facilities since 1921, and mechanical and electrical equipment had been worn with low efficiency. Embretsfoss III has been running since 1954, and it is still operating well and producing enough satisfaction. The owner, therefore, decided to build a new power station, Embretsfoss IV, to substitute Embretsfoss II, and maximum output was increased by utilizing the unused water resources. Regarding Embretsfoss III, it keeps its operation continuously.
Improvement of performance	
Increase in output	Maximum output was increased by the redevelopment of the abolished power station using the unused water resources.

Increase in power production	Power production was increased due to the increase in output.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	A new power station (Embretsfoss IV) was constructed parallel with the operation of two existing power stations.
Cost	There was a requirement to secure profits for the effective utilization of river flow. The Norwegian- Swedish Electricity Certificate Market was introduced, which contributed to an incentive for the development of new renewable energy.
Environmental conservation	The Landscape and fish were preserved. Regarding fish, the conditions were improved through the establishment of adequate fish passages.
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	The abolished power station was redeveloped using unused potential.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History Nw.01_Embretsfoss #4 https://www.ieahydro.org/media/5fb06b0d/ Vol2_Case_History_English(207-408).pdf

Project code	**NW02**
Name of the project	Renewal of Hemsil II Power Station
Location/country of the project	Buskerud County, Norway
Implementing body of the project	E-CO Energi AS
Implementing period	2005 – 2006
Type of the project	Renewal/upgrading
Specifications (before the project)	
Name of power plant	Hemsil II Power Station
Name of river	Hemsil River
Type of power plant	Dam and waterway type
Year of commission	1959
Maximum output (MW)	82
Maximum discharge (m3/s)	28
Effective head (m)	370
Annual power production (GWh)	503
Specifications (after the project)	
Name of power plant	Hemsil II Power Station
Name of river	Hemsil River
Type of power plant	Dam and waterway type
Year of commission	2006
Maximum output (MW)	98
Maximum discharge (m3/s)	31
Effective head (m)	370
Annual power production (GWh)	537
Overview of the project	The turbines and generators of Hemsil II Power Station were renewed and upgraded. Renewal of turbines and generators was decided due to their aging. In addition to the efficiency increase by the renewal, maximum output was increased by increasing maximum discharge by 3m3/s within the acceptable range with minor environmental impact. After the renewal, annual power production was increased from 503 GWh to 537GWh.
Improvement of performance	
Increase in output	Maximum output was increased due to the increase of efficiency by renewal and the increase of maximum discharge.
Increase in power production	Annual power production was increased due to the increase in output.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	

Technology	N/A
Cost	N/A
Environmental conservation	N/A
Legal restriction	Maximum discharge was increased within the scope of current permission considering the environmental impact.
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	I-2 Renewal of electro-mechanical equipment changing intake discharge/hydraulic head
Requirement A: Effective use of water resources	Effective utilization of unused potential by renewal & upgrade of the existing power station.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History Nw.02_Hemsil #2 https://www.ieahydro.org/media/5fb06b0d/ Vol2_Case_History_English(207-408).pdf

Project code	**NW03**
Name of the project	New construction of Hemsil III Power Station
Location/country of the project	Buskerud County, Norway
Implementing body of the project	E-CO Energi AS
Implementing period	2016 – 2019
Type of the project	New construction
Specifications (before the project)	
Name of power plant	Hemsil II Power Station
Name of river	Hemsil River
Type of power plant	Dam and waterway type
Year of commission	2006
Maximum output (MW)	98
Maximum discharge (m3/s)	31
Effective head (m)	370
Annual power production (GWh)	537
Specifications (after the project)	Note: Specifications of the existing Hemsil II Power Station are the same as those before the project. Hemsil III Power Station is newly constructed as an expansion of the existing power station.
Name of power plant	Hemsil III Power Station
Name of river	Hemsil River
Type of power plant	Dam and waterway type
Year of commission	2019
Maximum output (MW)	83
Maximum discharge (m3/s)	25
Effective head (m)	370
Annual power production (GWh)	91
Overview of the project	Hemsil II Power Station was constructed 55 to 60 years ago, but the power station's maximum discharge and equipment were small against the river inflow. An expansion of Hemsil II (named Hemsil III) has therefore been assessed with the different solutions during the last decades. After planning and later realization of the Norwegian-Swedish Electricity Certificate Market, it was more likely that an expansion plan could be profitable. E-CO Energi, therefore, started an intensive planning in 2011. This ended with the construction of a new waterway and power station system that was close to and parallel with the existing scheme. Maximum output increased from 98MW to 181MW, and annual power production from 537GWh to 628GWh.
Improvement of performance	
Increase in output	Maximum output was increased from 98MW to 181MW.

Increase in power production	Annual power production was increased by 91GWh due to the increase in output.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	N/A
Cost	At the planning stage, the project was assessed as not profitable. This was resolved by the introduction of the Norwegian-Swedish Electricity Certificate Market, which was launched in 2012.
Environmental conservation	The ecological flows were set to 200 l/s in summer and 50 l/s in winter, which correspond to the EIA conclusion.
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	Effective utilization of unused water resources by the expansion of existing power station. The increase in maximum discharge and maximum output made it possible to raise the capacity factor of the power station.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History Nw.03_Hemsil #3 https://www.ieahydro.org/media/5fb06b0d/ Vol2_Case_History_English(207-408).pdf

Project code	**NW04**
Name of the project	Renewal of Hol I Power Station
Location/country of the project	Buskerud County, Norway
Implementing body of the project	E-CO Energi AS
Implementing period	2009 – 2012
Type of the project	Renewal/upgrading
Specifications (before the project)	
Name of power plant	Hol 1 Power Station
Name of river	Votna River, Urunda River
Type of power plant	Dam and waterway type
Year of commission	Unit 2: 1949, Unit 4: 1956
Maximum output (MW)	186MW (Unit 1 & 2: 44MW/unit, Unit 3 & 4: 49MW/unit)
Maximum discharge (m3/s)	N/A
Effective head (m)	Unit 1 & 2: 385m, Unit 3 & 4: 350m
Annual power production (GWh)	754
Specifications (after the project)	
Name of power plant	Hol 1 Power Station
Name of river	Votna River, Urunda River
Type of power plant	Dam and waterway type
Year of commission	Unit 1: 2009, Unit 2: 2011, Unit3: 2012, Unit4: 2010
Maximum output (MW)	220MW (Unit 1 & 2: 57MW/unit, Unit 3 & 4: 53MW/unit)
Maximum discharge (m3/s)	N/A
Effective head (m)	Unit 1 & 2: 395m, Unit 3 & 4: 355m
Annual power production (GWh)	774
Overview of the project	Hol I Power Station utilizes the head from Varaldsetvatn waterfall for units 1 and 2 in Votna River and the head from Strandavatn waterfall for units 3 and 4 in Urunda River. The first two units were commissioned in 1949, and units 3 and 4 in 1955 and 1956 respectively. Due to the aging and deterioration of electrical equipment, E-CO Energi decided to implement a comprehensive renewal. Renewal works were aimed to increase annual power production with increased maximum discharge and improved efficiency for new turbine runners.
Improvement of performance	
Increase in output	Maximum output was increased from 186MW to 220MW by the increase in maximum discharge and improvement of efficiency.
Increase in power production	Annual power production was increased by 20GWh due to the increase in output.
Reliability/flexibility	N/A

Others	N/A
Challenges in the project	
Technology	After the upgrade of generators No.1 and No.2, an unexpected noise occurred and spread in the penstock due to the resonance. Several countermeasures were carried out including cutting the runner blade and isolating the penstock to reduce the noise level.
Cost	The Norwegian government prioritized the target of the increase of renewable power production through the refurbishment of existing power stations. It was an incentive for the renewal.
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	I-2 Renewal of electro-mechanical equipment changing intake discharge/hydraulic head
Requirement A: Effective use of water resources	Utilization of unused potential by increasing maximum discharge and improved turbine efficiency.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History Nw.04_Hol 1 https://www.ieahydro.org/media/5fb06b0d/ Vol2_Case_History_English(409-598).pdf

Project code	NW05
Name of the project	Redevelopment of Hunsfos East Power Station
Location/country of the project	Vest-Agder County, Norway
Implementing body of the project	Agder Energi Hydro Production
Implementing period	2005 - 2008
Type of the project	Redevelopment
Specifications (before the project)	
Name of power plant	Hunsfos West Power Station
Name of river	Otra River
Type of power plant	Waterway type
Year of commission	Unit 1: 1926, Unit 2: 1964
Maximum output (MW)	15.5MW (Unit 1: 3 MW, Unit 2: 12.5 MW)
Maximum discharge (m3/s)	130
Effective head (m)	N/A
Annual power production (GWh)	80
Specifications (after the project)	
Name of power plant	Hunsfos West Power Station
Name of river	Otra River
Type of power plant	Waterway type
Year of commission	Unit 2: 1964 (Unit 1 was abolished in 2008.)
Maximum output (MW)	12.5MW
Maximum discharge (m3/s)	110
Effective head (m)	N/A
Annual power production (GWh)	N/A
Name of power plant	Hunsfos East Power Station
Name of river	Otra River
Type of power plant	Waterway type
Year of commission	2008
Maximum output (MW)	15
Maximum discharge (m3/s)	120
Effective head (m)	14
Annual power production (GWh)	145 (total of Hunsfos West and Hunsfos East)
Overview of the project	Hunsfos West Power Station, a 15.5 MW run-of-river type, had been in operation since 1926 in the western stream of the small island at Hunsfos in the Otra River in southern Norway. In 2008, the old small 3MW unit at the Hunsfos West Power Station was removed due to poor performance, and a new Hunsfos East Power Station with an output of 15MW was

	constructed in the eastern stream of the island. The two plants share a small pond for water intake. The redevelopment has resulted in the effective use of river water for power generation.
Improvement of performance	
Increase in output	The total maximum output was increased from 15.5MW to 27.5MW through the redevelopment.
Increase in power production	Total annual power production was increased by 65GWh due to the increase in output.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	The main challenge during construction was the control of river flow. During construction, the total river flow in the Otra River had to be diverted to the western stream of the river.
Cost	The Norwegian government prioritized the target of the increase of renewable power production through the refurbishment of existing power stations. It was an incentive for the redevelopment.
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	A new power station was constructed to effectively use the unused potential in the river. The increase of power discharge increased maximum output and annual power production.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History Nw.05_Hunsfos East https://www.ieahydro.org/media/5fb06b0d/Vol2_Case_History_English(409-598).pdf

Project code	**NW06**
Name of the project	New construction of Iveland II Power Station
Location/country of the project	Aust-Agder County, Norway
Implementing body of the project	Agder Energi Hydro Production
Implementing period	2013 – 2016
Type of the project	New construction
Specifications (before the project)	
Name of power plant	Iveland I Power Station
Name of river	Otra River
Type of power plant	Dam and waterway type
Year of commission	1945
Maximum output (MW)	45
Maximum discharge (m3/s)	116
Effective head (m)	50
Annual power production (GWh)	350
Specifications (after the project)	Note: Specifications of the existing Iveland I Power Station are the same as those before the project.
Name of power plant	Iveland II Power Station
Name of river	Otra River
Type of power plant	Dam and waterway type
Year of commission	2016
Maximum output (MW)	45
Maximum discharge (m3/s)	100
Effective head (m)	50
Annual power production (GWh)	150
Overview of the project	Iveland I Power Station on the Otra River in southern Norway, with an output of 45MW, has been in operation since 1945. Still, the amount of water used for power generation was low compared to the river flow, so a new Iveland II Power Station with an output of 45MW was built in 2016. The two power stations share an intake dam. Construction of the new power station doubled peak supply capacity and increased total annual generation by 45%.
Improvement of performance	
Increase in output	Maximum output was increased from 45 MW to 90 MW by the construction of a new power station.
Increase in power production	Annual power production was increased by 150 GWh due to the increase in output.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	

Technology	N/A
Cost	The introduction of the Norwegian-Swedish Electricity Certificate Market in 2012 was an investment incentive for the project.
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	A new power station was constructed to effectively use the unused potential in the river. The increase of power discharge increased maximum output and annual power production.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History Nw.06_Iveland II https://www.ieahydro.org/media/5fb06b0d/ Vol2_Case_History_English(409-598).pdf

Project code	**NW07**
Name of the project	Redevelopment of Rånåsfoss III Power Station
Location/country of the project	Akershus County, Norway
Implementing body of the project	Akershus Energi AS
Implementing period	2010 – 2016
Type of the project	Redevelopment
Specifications (before the project)	
Name of power plant	Rånåsfoss I Power Station
Name of river	Glomma River
Type of power plant	Dam type
Year of commission	1922
Maximum output (MW)	54
Maximum discharge (m3/s)	540
Effective head (m)	12.5
Annual power production (GWh)	220
Specifications (after the project)	Note: The existing Rånåsfoss I Power Station was redeveloped as the new Rånåsfoss III Power Station.
Name of power plant	Rånåsfoss III Power Station
Name of river	Glomma River
Type of power plant	Dam type
Year of commission	2016
Maximum output (MW)	81
Maximum discharge (m3/s)	N/A
Effective head (m)	N/A
Annual power production (GWh)	280
Overview of the project	At Rånåsfoss Falls on the Glomma River system in Norway, the Rånåsfoss I Power Station with an output of 54MW had been in operation since 1922 and the Rånåsfoss II Power Station with an output of 45MW since 1983. After about 90 years of operation, the Rånåsfoss I has noticeably deteriorated in performance due to aging. In addition, the intake dam was overflowing for 2-3 months per year. Therefore, a complete renewal of the Rånåsfoss I was planned and the power station was redeveloped in 2016 as the new Rånåsfoss III Power Station with an output of 81MW.
Improvement of performance	
Increase in output	Maximum output was increased from 54 MW to 81 MW by the increased maximum discharge using the unused overflow at the intake dam.
Increase in power production	Annual power production was increased by 60 GWh due to the increase in output.
Reliability/flexibility	N/A

Others	N/A
Challenges in the project	
Technology	N/A
Cost	The introduction of the Norwegian-Swedish Electricity Certificate Market in 2012 was an investment incentive for the project.
Environmental conservation	N/A
Legal restriction	N/A
Others	The existing buildings have a high cultural value, and their preservation was a challenge.
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	Effective utilization of unused potential at the intake dam by increasing maximum discharge in the redevelopment.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History Nw.07_Rånåsfoss #3 https://www.ieahydro.org/media/5fb06b0d/Vol2_Case_History_English(409-598).pdf

Project code	NW08
Name of the project	Expansion of Kongsvinger Power Station
Location/country of the project	Hedmark County, Norway
Implementing body of the project	Eidsiva Vannkraft
Implementing period	2008 – 2011
Type of the project	Expansion
Specifications (before the project)	
Name of power plant	Kongsvinger Hydropower Plant
Name of river	Glomma River
Type of power plant	Dam type
Year of commission	1975
Maximum output (MW)	21
Maximum discharge (m3/s)	250
Effective head (m)	10.25 (gross head)
Annual power production (GWh)	130
Specifications (after the project)	
Name of power plant	Kongsvinger Hydropower Plant
Name of river	Glomma River
Type of power plant	Dam type
Year of commission	2011
Maximum output (MW)	43
Maximum discharge (m3/s)	500
Effective head (m)	10.25 (gross head)
Annual power production (GWh)	200
Overview of the project	Kongsvinger Power Station with an output of 21MW on the Glomma River system in Norway has been in operation since 1975. After more than 30 years of operation, the efficiency of the water turbine had declined due to aging, and a complete rehabilitation was needed. However, because of the significant loss of power generation due to the long-term suspension of power generation for the rehabilitation of the existing unit, a new 22MW Unit 2 was installed in 2011, and comprehensive maintenance of Unit 1 was carried out later without any loss of power. The power generation rate of river water has been greatly improved by the addition of Unit 2.
Improvement of performance	
Increase in output	Maximum output was increased by the expansion of generating unit.
Increase in power production	Annual power production was increased by 70 GWh due to the increase in output.
Reliability/flexibility	N/A

Others	N/A
Challenges in the project	
Technology	River flow control during construction
Cost	N/A
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	A new unit was installed to effectively use the unused potential in the river.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History Nw.08_Kongsvinger https://www.ieahydro.org/media/5fb06b0d/Vol2_Case_History_English(409-598).pdf

Project code	**NZ101**
Name of the project	Renewal of Whakamaru Power Station
Location/country of the project	Whakamaru, New Zealand
Implementing body of the project	Mighty River Power Ltd.
Implementing period	2013 – 2017
Type of the project	Renewal/upgrading
Specifications (before the project)	
Name of power plant	Whakamaru Power Station
Name of river	Waikato River
Type of power plant	Dam type
Year of commission	1956
Maximum output (MW)	104.4
Maximum discharge (m3/s)	344
Effective head (m)	N/A
Annual power production (GWh)	N/A
Specifications (after the project)	
Name of power plant	Whakamaru Power Station
Name of river	Waikato River
Type of power plant	Dam type
Year of commission	2017
Maximum output (MW)	124.4
Maximum discharge (m3/s)	376
Effective head (m)	N/A
Annual power production (GWh)	+28 (additional)
Overview of the project	Whakamaru Power Station, located on the Waikato River in the North Island of New Zealand, has been operating since 1956 with a total output of 104.4MW from four units. The Unit 1 water turbine was refurbished in 2010, and the other generating facilities were completely renewed and upgraded in 2017 due to aging and declining performance after over 60 years of operation. The maximum output increased to 124.4MW due to the increase of maximum water discharge.
Improvement of performance	
Increase in output	Maximum output was increased by increasing maximum discharge in the renewal.
Increase in power production	Annual power production was increased due to the increase in output.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	

Technology	An axial air supply system to the runner was installed to stabilize the partial load operation due to the increase of maximum discharge.
Cost	N/A
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	I-2 Renewal of electro-mechanical equipment changing intake discharge
Requirement A: Effective use of water resources	Existing units were renewed and upgraded to effectively use the unused potential in the river by increasing maximum discharge.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] WHAKAMARU POWER STATION REHABILITATION PROJECT https://www.andritz.com/resource/blob/264346/1870d2627fca1f311055c30720f5e0de/twining-whakamaru-rehabilitation-data.pdf

Project code	**PT101**
Name of the project	Redevelopment of Socorridos Power Station
Location/country of the project	Autonomous Region of Madeira, Portugal
Implementing body of the project	Madeira's Public Electricity Company
Implementing period	2004 – 2007
Type of the project	Redevelopment
Specifications (before the project)	
Name of power plant	Socorridos Power Station
Name of river	N/A
Type of power plant	Dam and waterway type
Year of commission	1995
Maximum output (MW)	24
Maximum discharge (m3/s)	6
Effective head (m)	450/433
Annual power production (GWh)	N/A
Specifications (after the project)	Note: Specifications of the existing Socorridos Power Station are the same as those before the project. A new pumping station and a new storage reservoir/tunnel were constructed at the existing power station.
Name of power plant	Socorridos Power Station
Name of river	N/A
Type of power plant	Dam and waterway type
Year of commission	2007
Maximum output (MW)	24
Maximum discharge (m3/s)	6
Effective head (m)	450/433
Annual power production (GWh)	N/A
Overview of the project	Socorridos Power Station was commissioned in 1995, as the largest and most important multi-purpose hydraulic system for the production of water for public supply, irrigation and hydro energy in Madeira. The system includes a 15.5km long succession of underground tunnels and open canals as well as a hydropower station with a capacity of 24MW. However, the capacity of the power station's loading chamber (head tank) was not enough for a stable power supply all year round. Therefore, a project was implemented in 2004-2007 to transform the Socorridos Power Station into a reversible system with a new storage reservoir/tunnel and a new pumping station. This system made it possible to pump up water from a new reservoir to a new tunnel at night when water supply and electricity demand are low to secure the amount of water for stable power generation, water supply, and irrigation.

Improvement of performance	
Increase in output	No
Increase in power production	N/A
Reliability/flexibility	The new reversible water use system has contributed to stable power generation all year round and increased the reliability of power generation.
Others	N/A
Challenges in the project	
Technology	N/A
Cost	The project was funded by the European Regional Development Fund (ERDF).
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-2 Development without using unused potential
Requirement A: Effective use of water resources	The project has made the best and most efficient use of water resources for the supply, irrigation, and production of electricity by introducing a pumped storage power generation system.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	The new reversible water use system has contributed to stable power generation all year round and increased the reliability of power generation.
Others	N/A
References	[1] Optimizing the Multiple Purpose Function of the Socorridos Hydro Power Station for Use All Year Round to Produce Water for Public Supply, Irrigation and Electricity https://ec.europa.eu/regional_policy/en/projects/best-practices/portugal/1444/download

Project code	**PT102**
Name of the project	New construction of Salamonde II Pumped Storage Power Station
Location/country of the project	Viseu District, Portugal
Implementing body of the project	Energias de Portugal (EDP)
Implementing period	2015
Type of the project	New construction
Specifications (before the project)	
Name of power plant	Salamonde I Power Station
Name of river	Cávado River
Type of power plant	Dam & waterway
Year of commission	1953
Maximum output (MW)	42
Maximum discharge (m3/s)	44
Effective head (m)	N/A
Annual power production (GWh)	244
Specifications (after the project)	Note: Specifications of the existing Salamonde I Power Station are the same as those before the project.
Name of power plant	Salamonde II Pumped Storage Power Station
Name of river	Cávado River
Type of power plant	Pumped Storage
Year of commission	2015
Maximum output (MW)	224
Maximum discharge (m3/s)	200
Effective head (m)	118
Annual power production (GWh)	386
Overview of the project	Salamonde I Power Station in North Portugal was commissioned in 1953 with a capacity of 42MW. In 2015, a new pumped storage power station with a capacity of 224MW, Salamonde II, was constructed using the existing intake reservoir for the Salamonde I Power Station.
Improvement of performance	
Increase in output	Maximum output was increased by the construction of a new pumped storage power station.
Increase in power production	Annual power production was increased due to the increase in output.
Reliability/flexibility	The reliability and flexibility of power plant operation was improved by the new pumped storage power station.
Others	N/A
Challenges in the project	

Technology	Construction work of tunnel and underground power station adjacent to the existing underground facilities had to be carried out safely and with minimal effects on the operation of the existing power station.
Cost	N/A
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-2 Development without using unused potential
Requirement A: Effective use of water resources	N/A
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	The reliability and flexibility were improved by the increase of peak supply capacity due to the newly constructed pumped storage power station.
Others	N/A
References	[1] Salamonde II underground hydroelectric complex in the North of Portugal. Design and construction https://www.researchgate.net/publication/332500115_Salamonde_II_undergound_hydroelectric_complex_in_the_North_of_Portugal_Design_and_construction

Project code	**PT103**
Name of the project	New construction of Frades II Pumped Storage Power Station
Location/country of the project	Viseu District, Portugal
Implementing body of the project	Energias de Portugal (EDP)
Implementing period	2017
Type of the project	New construction
Specifications (before the project)	
Name of power plant	Frades I Pumped Storage Power Station
Name of river	Cávado River
Type of power plant	Pumped storage type
Year of commission	2005
Maximum output (MW)	194
Maximum discharge (m3/s)	N/A
Effective head (m)	N/A
Annual power production (GWh)	N/A
Specifications (after the project)	Note: Specifications of the existing Frades I Pumped Storage Power Station are the same as those before the project.
Name of power plant	Frades II Pumped Storage Power Station
Name of river	Cávado River
Type of power plant	Pumped storage type
Year of commission	2017
Maximum output (MW)	766
Maximum discharge (m3/s)	200
Effective head (m)	414
Annual power production (GWh)	N/A
Overview of the project	The Venda Nova and Salamonde dams were built in the 1950s and 1960s in the Cávado River in northwestern Portugal. Frades I Pumped Storage Power Station using the existing two reservoirs was commissioned in 2005 with a capacity of 194MW. In addition, the Frades II Pumped Storage Power Station was newly constructed in 2017 using the existing two reservoirs for Frades I with two units of 378MW variable speed pump-turbine.
Improvement of performance	
Increase in output	Maximum output was increased by the construction of a new pumped storage power station.
Increase in power production	N/A
Reliability/flexibility	The reliability and flexibility of power plant operation were improved by the new variable speed pumped storage power station.
Others	N/A

Challenges in the project	
Technology	Construction work of underground structures adjacent to the existing underground facilities had to be carried out safely and with minimal effects on the operation of the existing power station.
Cost	N/A
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-2 Development without using unused potential
Requirement A: Effective use of water resources	N/A
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	The reliability and flexibility were improved by the increase of peak supply capacity and variable speed pump-turbines due to the newly constructed pumped storage power station.
Others	N/A
References	[1] Tunneling project of the year https://awards.ita-aites.org/images/Proceedings/2016/20-VENDA-NOVA-III-REPOWERING-PROJECT.pdf [2] Award-Winning Pumped-Storage Hydro Facility a Modern Marvel https://www.powermag.com/award-winning-pumped-storage-hydro-facility-a-modern-marvel/ [3] VOITH Project Report Frades II http://voith.com/ca-fr/2012-10-12_Project_Report_Frades_II.pdf

Project code	**PT104**
Name of the project	Operation change of Valeira Power Station
Location/country of the project	Viseu District, Portugal
Implementing body of the project	Energias de Portugal (EDP)
Implementing period	2019
Type of the project	Change of power plant operation
Specifications (before the project)	
Name of power plant	Valeira Power Station
Name of river	Douro River
Type of power plant	Dam type
Year of commission	1976
Maximum output (MW)	246
Maximum discharge (m3/s)	360
Effective head (m)	28.5
Annual power production (GWh)	610
Specifications (after the project)	Note: Specifications of the existing Valeira Power Station are the same as those before the project.
Name of power plant	-
Name of river	-
Type of power plant	-
Year of commission	2019
Maximum output (MW)	-
Maximum discharge (m3/s)	-
Effective head (m)	-
Annual power production (GWh)	-
Overview of the project	Energias de Portugal (EDP) and GE have been collaborating to develop methodologies to extend the operating range of hydro turbines using digital technology. A three-phase methodology was developed based on the historical operation data, field tests using sensors and a remote monitoring system for machine risk management. This approach was successfully applied to the Kaplan turbines at the Valeira Power Station on the Douro River in 2019, showing good perspectives for the other power stations on the river.
Improvement of performance	
Increase in output	No
Increase in power production	Annual power production is expected to increase by reducing the lower threshold and improving the efficiency of turbine operation.
Reliability/flexibility	Reducing the lower limit of power plant operation improves flexibility in the power supply to the Iberian Electricity Market.
Others	N/A

Challenges in the project	
Technology	It was required to install the appropriate sensors and to collect data.
Cost	N/A
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	III-1 Optimized operation of electro-mechanical equipment
Requirement A: Effective use of water resources	Effective utilization of unused potential in the river by extension of the operating range of hydro turbine.
B: Improved and/or advanced methodologies	A new methodology was developed to extend the operating range of hydro turbine using digital technology.
C: Improvement of reliability/flexibility corresponding to market needs	Range extension of power plant operation improves flexibility in the power supply to the Iberian Electricity Market.
Others	N/A
References	[1] F. André, et al.: Range extension: Methodologies to increase operational flexibility of hydropower plants through digital technology, Hydro2019, Porto, Portugal.

Project code	**SW01**
Name of the project	New construction of Veytaux II Pumped Storage Power Station
Location/country of the project	Canton de Vaud, Switzerland
Implementing body of the project	Alpiq Suisse SA
Implementing period	2012 – 2016
Type of the project	New construction
Specifications (before the project)	
Name of power plant	Veytaux I Pumped Storage Power Station
Name of river	N/A
Type of power plant	Pumped storage type
Year of commission	1971
Maximum output (MW)	240 (60MW x 4units)
Maximum discharge (m3/s)	Turbine: 32, Pump: 24
Effective head (m)	878
Annual power production (GWh)	N/A
Specifications (after the project)	Note: Specifications of the existing Veytaux I Power Station are the same as those before the project.
Name of power plant	Veytaux II Pumped Storage Power Station
Name of river	N/A
Type of power plant	Pumped storage type
Year of commission	2016
Maximum output (MW)	240 (120MW x 2units)
Maximum discharge (m3/s)	Turbine: 25, Pump: 19
Effective head (m)	878
Annual power production (GWh)	N/A
Overview of the project	Veytaux I Power Station was commissioned in 1971 as a pumped storage power plant with an output of 240MW. It is located in western Switzerland and utilizes the upper Hongrin reservoir and lower Lake Geneva. In order to respond to the increasing demand for peak power and balancing energy, a new Veytaux II Pumped Storage Power Station with an output of 240MW was built adjacent to the existing Veytaux I and started operation in 2017. The Veytaux II Power Station utilizes the existing waterways of penstock and tailrace for Veytaux I.
Improvement of performance	
Increase in output	Maximum output was increased by the construction of a new pumped storage power station.
Increase in power production	No

Reliability/flexibility	The reliability and flexibility of power plant operation were improved by the new pumped storage power station.
Others	N/A
Challenges in the project	
Technology	Precautions and countermeasures were taken to ensure the safety of excavation work near the existing power station in operation.
Cost	N/A
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-2 Development without using unused potential
Requirement A: Effective use of water resources	N/A
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	The reliability and flexibility of power plant operation were improved by increasing maximum output and regulating power by the new pumped storage power station.
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History Sw.01_Veytaux https://www.ieahydro.org/media/5fb06b0d/Vol2_Case_History_English(409-598).pdf

Project code	**SW101**
Name of the project	Renewal of Profray Power Station
Location/country of the project	Le Châble, Val de Bagnes, Canton of Valais, Switzerland
Implementing body of the project	Altis Power Company
Implementing period	2006 – 2007
Type of the project	Renewal
Specifications (before the project)	
Name of power plant	Profray Power Staion
Name of river	-
Type of power plant	Waste water turbining before treatment
Year of commission	1993
Maximum output (MW)	0.67
Maximum discharge (m3/s)	0.24
Effective head (m)	323
Annual power production (GWh)	0.585
Specifications (after the project)	
Name of power plant	Profray Power Staion
Name of river	-
Type of power plant	Waste water turbining before treatment
Year of commission	2007
Maximum output (MW)	0.38
Maximum discharge (m3/s)	0.1
Effective head (m)	430
Annual power production (GWh)	0.85
Overview of the project	The wastewater from the Verbier ski resort is collected in a storage basin of 400m3, equipped with a 6 mm trash rack to remove floating material. This basin is also used as a forebay for a hydro scheme where the power house is located 2.3km away from the treatment plant. After passing through the hydro turbine, the wastewater discharges into the treatment plant inlet before finally being released to the nearby river. A bypass is incorporated to guarantee the wastewater treatment operation, whether or not the hydro plant is operational, and for times when the operational discharge needs to be greater than the turbine maximum discharge. The power plant which was originally commissioned in 1993 was refurbished and improved in 2007. After 14 years in service, the control panel was out of date and in need of upgrading. The generator bearings needed to be replaced, and sand in the turbined water resulted in significant abrasion to the runner and nozzles (and consequent decrease in efficiency). In addition to this maintenance work, the first turbine was somewhat

	oversized as it was designed for the wastewater treatment plant maximal discharge of 240 l/s. This anticipated the peak of the tourist season, which, in fact, only reached a few days per year and, therefore, was not optimal regarding the annual energy generation. The first turbine had been in service for 14 years, with limited maintenance (about 40 hours per year).
Improvement of performance	
Increase in output	As the original equipment was oversized, the refurbishment led to a lower maximum output and a lower design flow.
Increase in power production	Annual power production has been increased from 585MWh to 850MWh (+45%) by a better efficiency due to an appropriate choice of the design flow.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	Reduction of the design flow leading to a reduction of the turbine dimensions when using raw wastewater. Specific design for easy maintenance and clogging risk reduction.
Cost	N/A
Environmental conservation	N/A
Legal restriction	N/A
Others	High reliability as installed in a multipurpose industrial environment.
Characteristics regarded as "Hidden Hydro"	
Classification of development type	I-2 Renewal of electro-mechanical equipment changing intake discharge
Requirement A: Effective use of water resources	N/A
B: Improved and/or advanced methodologies	Optimal use of the available water by an appropriate choice of the design flow. Use of wastewater.
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] EU funded project SHAPES, Energy recovery in existing infrastructures with small hydropower plants - Multipurpose schemes, Overview and examples, case study No 11, p.36, ESHA and Mhylab.

Project code	SW102
Name of the project	Redevelopment of Schils Power Station
Location/country of the project	Flums, Canton of St. Gallen, Switzerland
Implementing body of the project	St. Gallisch-Appenzellische Kraftwerke AG (SAK)
Implementing period	2017 – 2021
Type of the project	Redevelopment
Specifications (before the project)	
Name of power plant	Originally 5 power stations (Altes / Neues Sägengüetli, Pravizin 1+2, Felsen)
Name of river	Schils River
Type of power plant	Waterway
Year of commission	1866 – 1943
Maximum output (MW)	about 8.1
Maximum discharge (m3/s)	0.4 - 2.5
Effective head (m)	480m for the first adduction, 368m for the second one. Each divided in two stages.
Annual power production (GWh)	0.585
Specifications (after the project)	Note: The old 5 power stations were replaced by a new power station with two penstocks and two units.
Name of power plant	Schils Power Station
Name of river	Schils River
Type of power plant	Waterway
Year of commission	2021
Maximum output (MW)	13.5 (11.5 + 2.0)
Maximum discharge (m3/s)	3.3 (2.6 + 0.7)
Effective head (m)	490, 368
Annual power production (GWh)	48
Overview of the project	Five hydropower stations with a total output of approximately 8.1MW built since 1866 on the Schils River in the canton of St. Gallen, Switzerland, were owned by SAK in 2014 and redeveloped in 2017-2021. The intake structures and penstocks were renewed, and the five generating units were removed to form a new Schils Power Station consisting of two new generating units with a total output of 13.5 MW, which was commissioned in 2021.
Improvement of performance	
Increase in output	Total output was increased from 8.1 to 13.5MW by the redevelopment.
Increase in power production	Annual power production was increased due to the increase in output.
Reliability/flexibility	N/A
Others	N/A

Challenges in the project	
Technology	N/A
Cost	N/A
Environmental conservation	A fishway was installed at the intake facility to allow fish to migrate between the upstream and downstream reaches of the river.
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	Existing power stations were redeveloped to effectively use the unused potential in the river by increasing maximum discharge.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] Wasserkraftwerk schils https://www.sak.ch/ueber-sak/standorte/wasserkraftwerke/kw-schils

Project code	**SW103**
Name of the project	Renewal of Milan Power Station
Location/country of the project	Bex, Canton of Vaud, Switzerland
Implementing body of the project	Salines Suisses SA
Implementing period	2020 – 2023
Type of the project	Expansion
Specifications (before the project)	
Name of power plant	Bévieux Power Station
Name of river	Avançon River
Type of power plant	waterway type
Year of commission	1943
Maximum output (MW)	2
Maximum discharge (m3/s)	4.1
Effective head (m)	75.8
Annual power production (GWh)	10.5
Specifications (after the project)	Note: The Bévieux Power Station was expanded as the Milan Power Station.
Name of power plant	Milan Power Station
Name of river	Avançon River
Type of power plant	waterway type
Year of commission	2023
Maximum output (MW)	4.2
Maximum discharge (m3/s)	7
Effective head (m)	76.6
Annual power production (GWh)	15.7
Overview of the project	Salines Suisses SA, on its industrial site in Bex, built the first run-of-river Bévieux Power Station in 1943 to continue its industrial activities when facing the shortage of coal and wood in Europe. In 2029, the existing water right validity will be over and Salines Suisses SA had to renew it to continue the power plant operation. Between 2005 and 2010, the Swiss Confederation set up a financial aid system that allowed operators wishing to upgrade or refurbish their installations, to receive a subsidy on each kWh produced. Due to the age of the installations, the need to renew the water right in the near future, and in view of the subsidy available, it was decided to refurbish and upgrade the hydroelectric installation. The aim of the project was to optimize the maximum flow of water that could be taken from the river (while respecting the laws regarding the environmental flows) and to limit as much as possible the head losses and the unavailability of turbines. From this came the choice to add a third unit, allowing the turbining of the smallest low water flow.

Improvement of performance	
Increase in output	Increase from 2.0 to 4.2 MW by expansion
Increase in power production	Increase from 10.5 GWh to 15.7 GWh due to the increase of design flow, the decrease of head losses (penstock of 1600 mm diameter instead of 1100 mm) and the addition of a small unit for the lowest available flows (at least 35 days per year).
Reliability/flexibility	The previous power station had two units with a flow repartition of 1/3-2/3. The new one has 3 units with a flow repartition 1/5-2/5-2/5. It will allow better flexibility and the turbining of flows between 0.4m3/s and 7m3/s.
Others	The installation of 3 units instead of 2 will optimize the production and maintenance periods.
Challenges in the project	
Technology	N/A
Cost	Respect for the budget is a real challenge, considering the amount of special works due to the increase of the penstock diameter.
Environmental conservation	The discussions with the NGO and Authorities regarding the mitigation measures were long and difficult. The decided mitigation measures were finally unfeasible and new ones had been discussed.
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	The Swiss federal and local laws require that the water resources be used to the fullest extent possible. A renewal of the water right with the same design flow was not allowed.
B: Improved and/or advanced methodologies	Optimization of the whole power scheme.
C: Improvement of reliability/flexibility corresponding to market needs	The flexibility of the power plant is a priority. It is achieved by the use of three units.
Others	N/A
References	N/A

Project code	**SW104**
Name of the project	Renewal of Glarey Power Station
Location/country of the project	Bex, Canton of Vaud, Switzerland
Implementing body of the project	Energie renouvelable de l'Avancon SA
Implementing period	2020 – 2023
Type of the project	Expansion
Specifications (before the project)	
Name of power plant	Glarey
Name of river	Avançon
Type of power plant	Waterway type
Year of commission	N/A
Maximum output (MW)	N/A
Maximum discharge (m3/s)	N/A
Effective head (m)	16.3
Annual power production (GWh)	N/A
Specifications (after the project)	
Name of power plant	Glarey
Name of river	Avançon
Type of power plant	Waterway type
Year of commission	2023
Maximum output (MW)	2.2
Maximum discharge (m3/s)	7
Effective head (m)	38.7
Annual power production (GWh)	7.3
Overview of the project	An about 80-year-old hydropower station on the Avancon River in the canton of Vaud, Switzerland, has been upgraded. The existing intake and penstocks were removed, and a new intake and penstocks were installed to connect directly to the upstream power station. Two generating units were installed to increase output and improve the efficiency of power plant operation. The environmental flows in the river were increased to comply with new regulations.
Improvement of performance	
Increase in output	Total output was increased by increasing intake discharge and hydraulic head by the renewal.
Increase in power production	Annual power production was increased due to the increase in output.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	

Technology	Specific foundations for the power station were needed.
Cost	No intake in the river was possible due to high costs, so the water was taken directly from the upstream power station.
Environmental conservation	No intake in the river was possible due to environmental effects, so the water was taken directly from the upstream power station.
Legal restriction	Legal regulation for the natural environment requires increased environmental flows.
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	The existing power station was renewed and upgraded to effectively use the unused water discharge and hydraulic head at the intake from the upstream power station.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	N/A

Project code	SW105
Name of the project	Renewal of Farettes Power Station
Location/country of the project	Aigle & Ormonts Valley, Canton of Vaud, Switzerland
Implementing body of the project	Romande Energie SA
Implementing period	2012 – 2016
Type of the project	Expansion
Specifications (before the project)	
Name of power plant	Farettes Power Station
Name of river	Grande Eau River
Type of power plant	Waterway type
Year of commission	1967
Maximum output (MW)	6.7
Maximum discharge (m3/s)	2.5
Effective head (m)	N/A
Annual power production (GWh)	54.7
Specifications (after the project)	
Name of power plant	Farettes Power Station
Name of river	Grande Eau River
Type of power plant	Waterway type
Year of commission	2016
Maximum output (MW)	22.5
Maximum discharge (m3/s)	6.5
Effective head (m)	353
Annual power production (GWh)	80.2
Overview of the project	The Farettes Power Station commissioned in 1967 on the Grande Eau River in the canton of Vaud, Switzerland, was originally designed for a flow that reached around 150days per year. A possible extension of the design flow was studied in the modernization of the power station and finally a design flow of 6.5m3/s (reached around 80days per year) instead of 2.5m3/s was chosen. The hydraulic head was also increased thanks to the use of a pressurized headrace tunnel. The water coming from the outlet of the Pont-de-la-Tine Power Station flows through a 5km, 3m diameter tunnel before reaching the surge tank from which an 800m, 1.4m diameter penstock leads to the powerhouse, feeding two 5-nozzle Pelton units.
Improvement of performance	
Increase in output	Total output was increased by increasing intake discharge and hydraulic head by the renewal.
Increase in power production	Annual power production was increased due to the increase in output.

Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	Installation of vertical Pelton Turbine instead of horizontal ones in the existing powerhouse.
Cost	N/A
Environmental conservation	Conservation of the natural environment and landscape was needed.
Legal restriction	Water permit modification due to the increase of design flow, and construction permit approvals.
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	The existing unit was renewed and upgraded to effectively use the unused water discharge and hydraulic head in the river.
B: Improved and/or advanced methodologies	The existing headrace tunnel for free-surface flow was replaced by a new pressurized tunnel to increase hydraulic head.
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] https://issuu.com/hydro-exploitation/docs/hydroscope_no_26_juin_2016 [2] https://www.romande-energie.ch/conditions-internet/23-grd/romande-energie/154-portes-ouvertes-du-chantier-des-farettes [3] https://www.romande-energie.ch/entreprises/25-communique-de-presse/364-130821-communique-fr

Project code	**US01**
Name of the project	Expansion of Abiquiu Hydropower Station
Location/country of the project	New Mexico City, USA
Implementing body of the project	County of Los Alamos
Implementing period	2009 – 2012
Type of the project	Expansion
Specifications (before the project)	
Name of power plant	Abiquiu Power Staion
Name of river	Rio Chama River
Type of power plant	N/A
Year of commission	1990
Maximum output (MW)	13.8
Maximum discharge (m3/s)	36.8
Effective head (m)	N/A
Annual power production (GWh)	N/A 0.355 during the low flow period of November through February
Specifications (after the project)	
Name of power plant	Abiquiu Power Staion
Name of river	Rio Chama River
Type of power plant	N/A
Year of commission	2012
Maximum output (MW)	16.9 (13.8 + 3.1)
Maximum discharge (m3/s)	43.9 (36.8 + 7.1)
Effective head (m)	N/A
Annual power production (GWh)	19.79 (additional) 6.27 during low flow period of November through February
Overview of the project	The 13.8 MW Abiquiu Power Station, which was commissioned in 1990 on the Rio Chama River in New Mexico, USA, could not operate reliably and efficiently during the low flow winter months due to operational limitations of the minimum water use (about 7m3/s). For this reason, a new 3.1MW low-flow turbine (horizontal Francis, operating range 2-7m3/s) was installed in 2012. This expansion significantly improved the efficiency of power generation through winter, with power generation from November to February increasing by 1700% over the pre-project period.
Improvement of performance	
Increase in output	Total output was increased by adding a low-flow turbine.
Increase in power production	Annual power production was increased due to the increase in output.

Reliability/flexibility	Installation of a new low flow turbine allowed the plant to significantly increase its generation through winter and provide additional flexibility year-round.
Others	N/A
Challenges in the project	
Technology	The installation of a new low-flow turbine required the construction of a new powerhouse and cofferdam. In order to complete the in-river work during winter, the permanent cofferdam was designed to be incorporated into the powerhouse structure, thereby allowing for a single year low flow installation period and reducing environmental impacts.
Cost	This project was funded in part by the Recovery Act through the Department of Energy’s Wind and Water Power Program.
Environmental conservation	The river was temporarily dewatered, so fish capture/release was necessary.
Legal restriction	Permitting requirements posed a challenge because designs had to be finalized in time to allow the permitting approval process before the low-flow period when construction was scheduled to take place.
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	Effective utilization of unused potential in the river during winter by installing a low-flow turbine.
B: Improved and/or advanced methodologies	The operation of power station was optimized by installing a low-flow turbine.
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History US.01_Abiquiu https://www.ieahydro.org/media/5fb06b0d/ Vol2_Case_History_English(409-598).pdf [2] https://www.osti.gov/servlets/purl/1044399

Project code	**US02**
Name of the project	Renewal of Boulder Canyon Power Station
Location/country of the project	Colorado, USA
Implementing body of the project	City of Boulder, Colorado
Implementing period	2010 – 2012
Type of the project	Renewal
Specifications (before the project)	
Name of power plant	Boulder Canyon Hydropower Station
Name of river	Middle Boulder Creek
Type of power plant	N/A
Year of commission	1910
Maximum output (MW)	20 (The output was reduced to 10MW due to the failure of one unit since 2000.)
Maximum discharge (m3/s)	N/A
Effective head (m)	N/A
Annual power production (GWh)	8.5
Specifications (after the project)	
Name of power plant	Boulder Canyon Hydropower Station
Name of river	Middle Boulder Creek
Type of power plant	N/A
Year of commission	2012
Maximum output (MW)	5
Maximum discharge (m3/s)	1.05
Effective head (m)	557.8
Annual power production (GWh)	between 11-12
Overview of the project	At the Boulder Canyon Power Station with an output of 20MW, which was commissioned in 1910 on Middle Boulder Creek in Colorado, one of the two aged units had been out of service since 2000 due to failure, and the other was in need of renewal. Due to decreases in river flow available for power generation, the remaining unit was oversized and inefficient. It was replaced with a more efficient 5MW Pelton turbine in 2012. The new unit had a reduced maximum output, but improved efficiency in the use of river water for power generation, resulting in a 37% increase in annual power production.
Improvement of performance	
Increase in output	No
Increase in power production	Annual power production was increased due to the improved efficiency in the use of the reduced river flow for power generation with a new small-scale turbine/generator.

Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	A small-scale turbine/generator was installed and the power generation operation was optimized to match the river flow.
Cost	A small turbine/generator was installed to maximize efficiency and reduce investment costs. On the other hand, the unanticipated replacement and refurbishment of transformer and station equipment resulted in increased costs. This project was funded in part by the Recovery Act through the Department of Energy's Wind and Water Power Program.
Environmental conservation	N/A
Legal restriction	N/A
Others	Special efforts were directed toward documenting the (largely original) interior of the plant and installing new equipment without modifying the plant exterior in order to preserve the historical significance of the facility. In addition, a significant portion of the historical equipment was preserved in place. The hydropower plant is considered eligible for nomination to the National Register of Historic Places due to unique engineering features. Plant modernization had to account for this.
Characteristics regarded as "Hidden Hydro"	
Classification of development type	I-2 Renewal of electro-mechanical equipment changing intake discharge/hydraulic head III-1 Optimized operation of electro-mechanical equipment
Requirement A: Effective use of water resources	N/A
B: Improved and/or advanced methodologies	A small-scale turbine/generator was installed and the power generation operation was optimized to match the river flow.
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History US.02_Boulder Canyon https://www.ieahydro.org/media/5fb06b0d/Vol2_Case_History_English(409-598).pdf [2] https://www.osti.gov/servlets/purl/107202

Project code	**US03**
Name of the project	Renewal of Cheoah Power Station
Location/country of the project	Robbinsville, North Carolina, USA
Implementing body of the project	Alcoa Power Generating, Inc
Implementing period	2010 – 2012
Type of the project	Renewal/upgrading
Specifications (before the project)	
Name of power plant	Cheoah Power Station
Name of river	Little Tennessee and Cheoah Rivers
Type of power plant	Dam type
Year of commission	1919
Maximum output (MW)	88 for units 1-4 (unit 5 was added in 1941 and renewed in 1995)
Maximum discharge (m3/s)	267
Effective head (m)	N/A
Annual power production (GWh)	N/A
Specifications (after the project)	Note: Units 1-4 were upgraded and unit 5 was not included in the renewal project.
Name of power plant	Cheoah Power Station
Name of river	Little Tennessee and Cheoah Rivers
Type of power plant	Dam type
Year of commission	2012 (2 units were operational by 2012, the 2 remaining units were replaced after this period)
Maximum output (MW)	162 (132MW for units 1-4 and 30MW for unit 5)
Maximum discharge (m3/s)	N/A
Effective head (m)	56.4
Annual power production (GWh)	Cheoah Power Station
Overview of the project	The Cheoah Hydropower Station, located on the Little Tennessee and Cheoah Rivers in North Carolina, USA, was commissioned in 1919 with a total output of 88MW from units 1-4, and unit 5 was added in 1949. Units 1-4 were completely renewed between 2010 and 2012 due to aging and increased risk of failure. The renewal improved equipment efficiency and increased output and annual power generation.
Improvement of performance	
Increase in output	Maximum output was increased by the renewal and upgrade of power units.
Increase in power production	Annual power production was increased due to the increase in output.
Reliability/flexibility	Extending the expected life of the plant to 40-50 years as estimated.
Others	N/A

Challenges in the project	
Technology	N/A
Cost	This project was funded in part by the Recovery Act through the Department of Energy's Wind and Water Power Program.
Environmental conservation	N/A
Legal restriction	N/A
Others	The project was delayed due to post-2008 recession.
Characteristics regarded as "Hidden Hydro"	
Classification of development type	I-1 Renewal of electro-mechanical equipment without changing intake discharge/hydraulic head
Requirement A: Effective use of water resources	N/A
B: Improved and/or advanced methodologies	The aged units were replaced with re-designed high-efficiency turbine/generators.
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] IEA Hydro (2016) Annex 11, Case History US.03_Cheoah https://www.ieahydro.org/media/5fb06b0d/Vol2_Case_History_English(409-598).pdf [2] https://www.osti.gov/servlets/purl/1068051

Project code	**US101**
Name of the project	Renewal of Ludington Pumped Storage Power Station
Location/country of the project	Michigan, USA
Implementing body of the project	Consumers Energy, Detroit Edison
Implementing period	2013 - 2021 (estimated)
Type of the project	Renewal/upgrading
Specifications (before the project)	
Name of power plant	Storage Power Station
Name of river	Lawrence River System (Lake Michigan)
Type of power plant	Pumped storage type
Year of commission	1973
Maximum output (MW)	1872
Maximum discharge (m3/s)	1886
Effective head (m)	98
Annual power production (GWh)	N/A
Specifications (after the project)	As of August 2020, five of the six units had been replaced, and the sixth unit was expected to be completed in 2021.
Name of power plant	Ludington Pumped Storage Power Station
Name of river	Lawrence River System (Lake Michigan)
Type of power plant	Pumped storage type
Year of commission	2021 (estimated)
Maximum output (MW)	2160
Maximum discharge (m3/s)	2160
Effective head (m)	98
Annual power production (GWh)	N/A
Overview of the project	At the Ludington Pumped Storage Power Station in Michigan, which was commissioned in 1973 with a maximum output of 1872MW, five of the six pump-turbines and peripheral equipment were renewed and upgraded during 2013-2020. The remaining unit was expected to be upgraded by 2021. The upgrades improved pump-turbine efficiency, output, pumping discharge, and cavitation performance, increasing peak supply capacity.
Improvement of performance	
Increase in output	Maximum output was increased by the increase of maximum discharge and efficiency of turbines.
Increase in power production	N/A
Reliability/flexibility	The reliability and flexibility of power plant operation were improved by increasing peak supply capacity.
Others	N/A

Challenges in the project	
Technology	N/A
Cost	N/A
Environmental conservation	N/A
Legal restriction	In the United States, regulations for inland transportation of power generation equipment varied from state to state, resulting in complicated procedures.
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	I-2 Renewal of electro-mechanical equipment changing intake discharge
Requirement A: Effective use of water resources	N/A
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	The reliability and flexibility of power plant operation were improved by increasing peak supply capacity.
Others	N/A
References	[1] ENVIRONMENTAL ASSESSMENT FOR HYDROPOWER LICENSE https://www.ferc.gov/sites/default/files/2020-06/P-2680-113-EA.pdf [2] hydro review https://www.toshiba.com/taes/cms_files/hydro_review.pdf

Project code	**US102**		
Name of the project	Renewal of Alabama Power Company's Power Stations		
Location/country of the project	Alabama, United States		
Implementing body of the project	Alabama Power Company		
Implementing period	2010 – 2014		
Type of the project	Renewal		
Specifications (before the project)			
Name of power plant	Lay (unit 1 & 4)	Bouldin (unit 2)	Jordan (unit 4)
Name of river	Coosa River	Coosa River	Coosa River
Type of power plant	Dam type	Dam & waterway type	Dam type
Year of commission	1914	1968	1927
Maximum output (MW)	177	225	100
Maximum discharge (m3/s)	N/A	N/A	N/A
Effective head (m)	N/A	N/A	N/A
Annual power production (GWh)	N/A	N/A	N/A
Specifications (after the project)	Note: Specifications of the existing power stations are the same as those before the project except for annual power production.		
Name of power plant	Lay (unit 1 & 4)	Bouldin (unit 2)	Jordan (unit 4)
Name of river	Coosa River	Coosa River	Coosa River
Type of power plant	Dam type	Dam & waterway type	Dam type
Year of commission	2010 – 2014	2010 – 2014	2010 – 2014
Maximum output (MW)	177	225	100
Maximum discharge (m3/s)	N/A	N/A	N/A
Effective head (m)	N/A	N/A	N/A
Annual power production (GWh)	Average 10.9% increase per unit	Average 10.9% increase per unit	Average 10.9% increase per unit
Overview of the project	From 2010 to 2014, Alabama Power Company performed renewal of four units at three of the hydropower developments in east-central Alabama under licenses issued by the Federal Energy Regulatory Commission. The renewal included the replacement of the 1940s to 1960s old-type turbines with state-of-the-art turbines to increase generation capacity and increase individual unit reliability. The refurbishment included gate components, turbine shafts, and generator brake system refurbished or replaced, and new seals installed. Units were re-aligned.		
Improvement of performance			
Increase in output	No		
Increase in power production	Average power increase per unit of 10.9%		

Reliability/flexibility	The four upgraded units should provide more reliable service and reduced maintenance for a significant number of years.
Others	
Challenges in the project	
Technology	N/A
Cost	Unanticipated costs from additional work required.
Environmental conservation	N/A
Legal restriction	N/A
Others	Delays caused by heavy rain events and changes in vendor ownership (contract had to be re-negotiated). Delays were also caused by testing/modeling of performance, which took longer than anticipated.
Characteristics regarded as "Hidden Hydro"	
Classification of development type	I-1 Renewal of electro-mechanical equipment without changing intake discharge/hydraulic head
Requirement A: Effective use of water resources	N/A
B: Improved and/or advanced methodologies	Replaced old turbines with re-designed, high-efficiency turbines. Gate components were refurbished for more effective wicket gate operation.
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] https://www.osti.gov/servlets/purl/1177138

Project code	**VU101**
Name of the project	Expansion of Sarakata River Power Station
Location/country of the project	Santo Island, Vanuatu
Implementing body of the project	Vanuatu Ministry of Lands and Natural Resources
Implementing period	2007 – 2009
Type of the project	Expansion
Specifications (before the project)	
Name of power plant	Sarakata River Power Station
Name of river	Sarakata River
Type of power plant	Waterway type
Year of commission	1995
Maximum output (MW)	0.6
Maximum discharge (m3/s)	2.9
Effective head (m)	27.8
Annual power production (GWh)	N/A
Specifications (after the project)	
Name of power plant	Sarakata River Power Station
Name of river	Sarakata River
Type of power plant	Waterway type
Year of commission	2009
Maximum output (MW)	1.2
Maximum discharge (m3/s)	5.8
Effective head (m)	27.8
Annual power production (GWh)	N/A
Overview of the project	Sarakata River Power Station was built in 1995 on Santo Island, Vanuatu, with an output of 0.6MW and was the main source of power supply to the city of Luganville. However, as electricity demand increased, the plant needed to be expanded, and a new 0.6MW unit was added in 2009.
Improvement of performance	
Increase in output	Maximum output was increased by the expansion of existing power station.
Increase in power production	Annual power production was increased due to the increase in output.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	Landslide protection work on the foundation and slopes around the existing headrace channel

Cost	The project was funded by the Japan International Cooperation Agency and the Government of Vanuatu.
Environmental conservation	N/A
Legal restriction	N/A
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	Effective utilization of unused potential in the river by increasing maximum discharge.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] JICA ODA: The Project for Improvement of Sarakata River Hydroelectric Power Station https://www.jica.go.jp/oda/project/0614000/index.html

Project code	**ZWE101**
Name of the project	Expansion of Kariba South Power Station
Location/country of the project	Mashonaland West Province, Zimbabwe
Implementing body of the project	Zimbabwe Power Company (ZPC)
Implementing period	2015 – 2018
Type of the project	Expansion
Specifications (before the project)	
Name of power plant	Kariba South Power Station
Name of river	Zambezi River
Type of power plant	Dam Type
Year of commission	1959 – 1962
Maximum output (MW)	750 (125 x 6units)
Maximum discharge (m3/s)	N/A
Effective head (m)	86
Annual power production (GWh)	5000
Specifications (after the project)	
Name of power plant	Kariba South Power Station
Name of river	Zambezi River
Type of power plant	Dam Type
Year of commission	2018
Maximum output (MW)	1050 (125 x 6units, 150 x additional 2units)
Maximum discharge (m3/s)	376 (additional 2 units)
Effective head (m)	86 (6units), 89 (additional 2 units)
Annual power production (GWh)	N/A
Overview of the project	Kariba South Power Station was built in 1959 along with the Kariba Dam on the Zambezi River in Zimbabwe, and six units with a total output of 750MW were commissioned between 1959 and 1962. Two new units were added in 2018 to increase peak supply capacity by utilizing the overflow at the dam, making it the largest hydropower plant in the country with a total output of 1050MW.
Improvement of performance	
Increase in output	Maximum output was increased by the expansion of power units.
Increase in power production	Annual power production was increased due to the increase in output.
Reliability/flexibility	N/A
Others	N/A
Challenges in the project	
Technology	N/A

Cost	N/A
Environmental conservation	N/A
Legal restriction	The water intake allocation is managed by the Zambezi River Authority (ZRA), which is formed by the Zimbabwe and Zambia governments.
Others	N/A
Characteristics regarded as "Hidden Hydro"	
Classification of development type	II-1 Development using unused potential
Requirement A: Effective use of water resources	New units were installed to effectively use the unused potential at the existing intake dam. Increase of power discharge increased maximum output and annual power production.
B: Improved and/or advanced methodologies	N/A
C: Improvement of reliability/flexibility corresponding to market needs	N/A
Others	N/A
References	[1] Zimbabwe Power Company (ZPC) http://www.zpc.co.zw/powerstations/2/kariba-south-power-station [2] SYSTEM DEVELOPMENT PLAN Zimbabwe Electricity Transmission & Distribution Company https://rise.esmap.org/data/files/library/zimbabwe/Cross%20Cutting/CC%202.pdf

APPENDIX B

HYDROPOWER GENERATION FROM ENVIRONMENTAL FLOWS: CHARACTERISTICS AND CHALLENGES

Installing a new facility that generates hydroelectric power using environmental flows (e-flows) release at existing power station is one of the ways to improve the performance of existing power station with untapped energy production. Most of hydropower facilities have ensured the release of steady water flows from the intake dam for the purpose of maintaining river environments in a section of reduced water flows below the dam. In recent years, the increased focus on renewable energy development has increased the installations of power generation equipment using e-flows release to increase output and power generation. However, most of the development opportunities have faced civil and electrical challenges, such as economic efficiency, topographical restrictions for the installation of equipment, turbine type selection, and control of water flows for power generation. Here follows a summary of characteristics, challenges and solutions regarding e-flows power generation based on the case history study in the IEA Hydro Task 16 subtask 2. Case history data are summarized in Tables 1 and 2.

B.1 What is E-flows?

In Japan, the e-flows rate is determined considering the protection of plants and animals, fisheries, and attractive scenery, as well as the prevention of river pollution. Regarding the installation of hydropower facilities in Japan in accordance with the River Act, the river administrator permits the use of water with stipulations that prioritize the release of water flows necessary to not interfere with existing water use and to manage downstream river environments. Water is then taken from the remaining flow below the maximum permitted intake. In pumped-storage power stations, the stored water in the lower reservoir is pumped to generate electricity, so the river inflow to the reservoir is not stored but released downstream to preserve river environments.

Cases in other countries demonstrate similarities with situations found in Japan, where regulatory bodies licensing or relicensing of electricity producers require e-flows to protect river environments below dams.

B.2 Results of developing hydropower from e-flows

Tables 1 and 2 summarize case history data regarding e-flows power generation collected in subtask 2, including 31 cases from Japan and 4 cases from other countries.

In Japan, the time of large-scale hydropower development has come and gone, and small-scale hydropower is being promoted as renewable energy. Hydropower generation from e-flows is one example of this. While dams conventionally discharge e-flows through pipes and valves or flood gates, the number of hydropower facilities adding water turbines and generators for e-flows while updating discharge methods is growing. Most of these were implemented when the water rights of existing hydropower facilities underwent renewal after the year 2000. This period coincides with the enforcement of renewable portfolio standards (RPS) policy–driven support for renewable energy development, including hydropower generated from e-flows (enforced in

2003), and it seems some operators other than electric power companies were given support for their development of e-flows hydropower.

Most of these e-flows projects generate a small amount of hydropower, less than 500 kW, with water use set at a maximum that exceeds the standard values of e-flows (0.1 to 0.3 $m^3/s/100\ km^2$), generally less than 1.0 to 3.0 m^3/s. Because the layout of these hydropower facilities has the water discharging after generating hydropower directly below the dam, the hydraulic head often varies from 10 to 50 m, depending on the dam height. Some hydropower facilities, however, boast a high head of approximately 100 m (the highest being the Okutadami E-flow Power Station, at 130.3 m).

B.3 Characteristics of e-flows hydropower

B.3.1 Hydropower facility layout

B.3.1.1 Water intake and water conveyance equipment

In most layouts, water is taken from the dam by diverting it from the existing hydropower water conveyance equipment and conveying it to the generator directly below the dam. Due to the difference in the type of power generation in existing hydropower facilities, penstock is made to branch from the existing canal (of dam and waterway type) or existing penstock (of dam type) and connect to a powerhouse directly below the dam (Houri No. 2 Power Station and Shin-Tonami Power Station).

When the intake is independent of the existing hydropower facility, the existing e-flows equipment within the dam body may be used, and hydropower equipment like water turbines and generators may be added to the end of the discharge outlet (as in the Dashidaira Power Station). There are some instances where new e-flow equipment has been installed in the dam, where the outlet required drilling into the dam body (as in the Shin-Kushihara Hydropower Station), or a siphon was installed as a simple outlet (Okuwanojiri Power Station).

Because e-flows hydropower facilities are installed directly below dams, and because water intake and conveyance equipment must be installed under the constraints of local topography and existing power station structures, design and construction efforts aimed at layouts enabling greater efficiency and cost savings are much in demand.

B.3.1.2 Hydropower facility

Because existing hydropower facilities obliged to release e-flows often have dams and waterways that create areas with recessed water levels, discharge is made to flow out directly below the dam. Therefore, e-flows hydropower equipment is either installed in new hydropower facilities directly below dams (as in the Houri No. 2 Power Station) or added inside existing powerhouses (as in the facility at Okutadami E-Flows Power Station). These sites, being directly below dams, are geographically narrow and lack access to well-maintained roads, which must be thoroughly considered, as these factors put considerable limitations on the facilities' design and construction.

In some instances (as in the Kawabaru E-flows Power Station), the difficulty of installing hydropower equipment has led to the omission of the powerhouse thanks to the installation of underwater turbines (which perform well submerged). Generators are stopped, and turbine inlet valves are closed when turbine interiors must be inspected. However, because e-flows rates must be maintained, bypass pipes are attached to the ends of the penstock as an alternate outlet.

New North Fork hydropower plant using e-flows (USA) is an example that established an innovative upstream fish passage system installed at the outlet of the power plant for fish protection measures. Water discharge from turbines is routed from the outlet through a screened floor of a concrete fish trap. Fishes are attracted to the trap through a slotted fish entrance, which then lifts the fish to the top of the dam on a tram via a transport hopper. A model test demonstrated that the configuration could achieve the desired flows and resulted in a satisfactory tailrace diffuser strategy.

B.3.2 Water turbine

When selecting water turbines used in generating hydropower from e-flows, stakeholders must consider not only the effective head and volume of water used, but also any fluctuations in flow rate and turbine head due to changes in reservoir water levels. Figure 1 shows turbine models used in each case history listed in Table 1 on the small-scale turbine selection diagram.

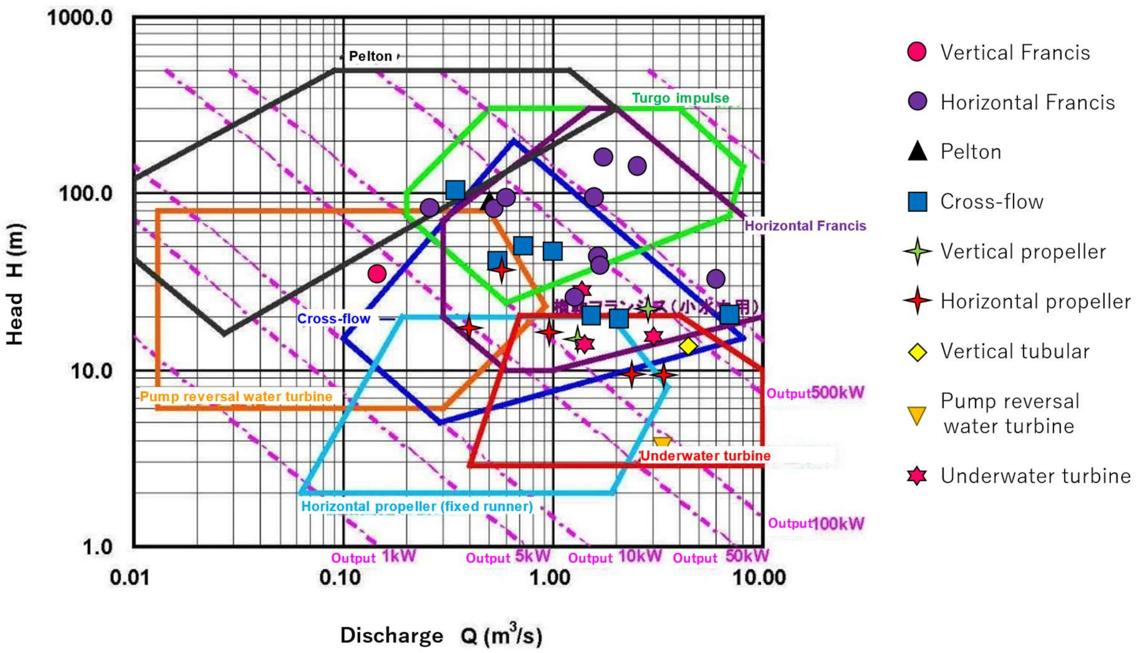


Figure 1. Turbine selection diagram for small-scale hydropower with the case history data
(The plots show data in Table 1 by turbine type)

Cross-flow turbines are prevalent in turbine-type operations, with propeller turbines being common for relatively low flow and Francis turbines for high flow rates. The cross-flow turbine's simple structure is characterized by its ease of use and maintenance, ability to adjust flow rate with its guide vane, wide operation range, and affordability. Because it is a type of impulse turbine, the runner position must be higher than the tail water level, giving the cross-flow turbine the disadvantage of being unable to fully utilize the head. Unlike the cross-flow turbine, the Francis turbine is perpetually filled with water from the runner to the draft tube, meaning the head from the turbine to the tailwater level can be used effectively and the flow rate adjusted. For low head, propeller turbines are suitable, as they are installed where neither the head nor the flow rate fluctuates because its ability to adjust flow rate is removed from the turbine itself to reduce cost. Among propeller turbines, underwater turbines boast few installation restrictions because the turbine and generator are integrated into one unit and installed underwater in the piping, omitting the need for a powerhouse.

Ultimately, turbine selection requires consideration of the characteristics of each unique site (topography around existing dams, reservoir operation, etc.) and comparison of economic, maintenance, flow control, and quality control factors.

B.3.3 Hydropower discharge control

The volume of water used to generate hydropower from e-flows must always exceed the e-flows rate against the dam’s fluctuating water levels. Hydropower generation falls into one of three types of operations: (i) fixed discharge via adjustments to the outlet controls (the e-flows rate is also the maximum volume of water permitted for use, a rate which is maintained regardless of the dam’s water level), (ii) outlet devices have fixed intervals of closure (the e-flows rate is set to the flow rate at the lowest water level, while the maximum discharge is set to the flow rate when the water level is at full capacity), and (iii) outlet devices have fixed intervals of closure and output is fixed (outlet devices are fixed down to normal water level, while the output is fixed above normal water level). The type of operation informs the selection of applicable turbines.

Of these, operations with (ii), fixed outlet devices, do not require flow rate adjustment controls. This holds the advantage, therefore, that a simple turbine with a fixed runner mechanism may be installed, like a propeller turbine. It is necessary to note, however, that because it will use more flow than essential to generate power, the volume of water used in an existing power station will be reduced, resulting in a decrease in total electrical output. Still, compared to the days before e-flows hydropower operation, when spillway gates and dam outlets lacked automated controls, discharge exceeded required flow rates, and existing facilities’ power generation was unavoidably reduced, the use of water resources could be said to have been greatly improved by today’s practices.

At the hydroelectric power plant for the Castelo do Bode (Dam type) in Portugal, primary and secondary (smaller) turbines produce hydropower from discharge, outlet devices were installed directly below the dam to support e-flows, and controls enabling interconnectivity between these devices and a device to connect to the power grid were added. The combined operational pattern enabled by its primary and secondary turbines is optimized for e-flows rates that change month by month.

B.4 Challenges and solutions in developing hydropower from e-flows

B.4.1 Civil engineering challenges

E-flows facilities involve generator equipment being newly installed in existing dams and power stations. The challenge here, however, is the construction of simple facilities to reduce costs as well as utilize existing equipment as much as possible. Existing outlet in the dam is used for e-flows generation facilities by installing generator equipment, but it should be noted that small diameter of pipe will increase head loss. The simple siphon pipe is installed when the water intake is independent of the existing hydropower facility. This can be done without considering the effects on the dam itself, unlike the process of installing new outlet devices that involve drilling into the dam, and there are instances (such as the Aihara Power Station) where turbine inlet valves have been omitted. However, measures must be taken against siphon break caused by siphon water column separation and air entrainment vortex generation at the siphon opening when siphon height is increased at a low reservoir water level.

The powerhouse is built below the dam in a topographically narrow space and requires some ingenuity in design and construction to keep it from becoming submerged during flooding. There are instances where this flooding issue was circumvented and the powerhouse was omitted because underwater turbines have built-in generators (like the Kawabaru E-Flows Power Station), as well as instances where space was lacking below the dam for a powerhouse and generator equipment was instead installed in the shaft of an outlet side wall (as in the Koami Power Station and Akiba No. 3 Power Station). Instances like the following took safety and costs into consideration when conducting in-stream construction directly below the dam: construction of a cofferdam to install a generator facility was restricted to seasons not prone to flooding (Okuwanojiri Power Station), restrictions on dewatering and drilling and blasting required to install generator equipment outside the side wall were avoided by constructing the generator equipment inside the dam's outlet side wall (Koami Power Station), and a horizontal propeller turbine was installed in an existing tunnel originally used to build the dam (Kagehira Power Station).

B.4.2 Electrical challenges

It is required that the maximum discharge of turbines generating hydropower from e-flows always exceeds the necessary e-flows rate and adapt to seasonal changes in flow rates and water levels in the reservoir. Many types of turbines satisfy these requirements, but selection between them must comprehensively take into consideration of equipment cost, maintenance management, and flow rate control.

Because the guide vanes of underwater turbines are fixed (meaning their flow rates cannot be adjusted), it is necessary to match the volume of water used when the dam water level is low to the e-flows rate, and to set the intake flow rate when the dam is at full capacity as the maximum discharge for use. The required e- flows rate may therefore be exceeded by this operation and the total output including that of the existing power station may be reduced, making it necessary to compare maintainability and economic efficiency of electrical options including that of the civil engineering equipment (e.g., powerhouse omissible).

Consider cases illustrating the effective use of general-purpose horizontal propeller turbines, where a single horizontal propeller turbine would have been installed with a higher head than the device was designed for. So, two units were installed in a line, dividing the head practically in half (as in the Kagehira Power Station.)

B.4.3 Challenges in cost reduction

Because the unit price of e-flows hydropower is modest, there is little benefit and significant cost to stakeholders scaling up their operations. Therefore, unless the generated hydropower is used to power the generator facilities themselves or is included in the power generation cost of an existing power station, stakeholders may find the hurdles set quite high for developing it as a new power source. In Japan, those adopting e-flows hydropower would find renewable energy subsidies indispensable. While RPS policies (2003 to 2012) and feed-in tariff (FIT) policies (post-2012) do support small hydropower (including e-flows hydropower) development, such efforts remain as modest as they were before the year 2000.

Fees for electrical work on turbines, generators, and the like account for much of the construction costs of e-flows hydropower. Reducing equipment costs will therefore become pivotal in a plan to improve economic efficiency. Such a plan will require (i) selection of turbines from a standard product lineup, (ii) simplification of specifications that take into consideration the conditions of use and installation and selection of affordable turbines, and (iii) arrangements that include bulk purchases including auxiliary electrical equipment.

Table 1 Case histories of e-flows hydropower station: Specifications

Power Station	Provider	Construction Period	Drainage Area (km²)	Dam Type	Dam Height (m)	E-flows rate (m^3/s)	Specific E-flows rate ($m^3/s/100 km^2$)	P (kW)	Q (m^3/s)	He (m)	E (MWh)	Turbine Type
Houri No. 2	Miyazaki Pref. Enterprise Bureau	2010-12	45.2	CG	60.0	0.14	0.31	35	0.14	34.75	209	Vertical Francis
Tsuchimurokawa	TEPCO	1996-99	13.5	CG	105.2	—	—	350	0.50	89.94	1225	3-Nozzle Horizontal Pelton
Kawabaru E-flows	Kyushu Electric Power Co.	2010-11	359.2	CG	23.6	N/A	—	150	1.40	12.78	1300	Underwater turbine
Kagehira	Shikoku Electric Power Co.	2009-10	270.8	CG	62.5	0.54	0.20	150	0.58	37.24	N/A	Horizontal propeller
Okutadami E-flows	JPOWER	1999-03	595.1	CG	157.0	2.56	0.43	2700	2.56	130.30	N/A	Horizontal Francis
North Fork Skokomish	USA	2009-13	N/A	CA/CG	71.60	2.8~8.5	—	3600	3.40	N/A	22000	Vertical Francis
Dashidaira	KEPCO	2013-14	461.2	CG	76.7	1.68	0.36	520	1.76	37.29	2290	Horizontal Francis
Isawa No. 4	Iwate Prefecture Enterprise Bureau	2011-12	N/A	CG	Approx. 25.0	1.90	—	170	2.28	9.85	1193	Horizontal propeller
Shin-Tonami	Gunma Prefecture Enterprise Bureau	2010-11	635.3	CG	40.0	1.83	0.29	1000	7.00	20.49	4000	Cross-flow
Iino	Tohoku Electric Power Co.	2013-14	2756.0	CG	21.5	3.00	0.11	230	3.20	9.57	1699	Horizontal propeller
Shin-Kushihara	Chubu Electric Power Co.	2014-15	514.2	CG	38.0	1.49	0.29	230	1.56	19.80	1700	Cross-flow
Okuwanojiri	KEPCO	2010-11	1341.8	CG	32.1	2.70	0.20	480	2.82	22.50	3750	Vertical propeller
Kuttari	JPOWER	2013-15	940.0	RF	27.5	4.00	0.43	470	4.40	13.40	N/A	Vertical tubular
Doshi Dam	Kanagawa Pref. Enterprise Bureau	2005-06	112.5	CG	32.8	0.30	0.27	50	0.40	18.50	280	Horizontal propeller
Azuma No. 2	Gunma Prefecture Enterprise Bureau	2004-06	254.0	CG	140.0	0.33	0.13	240	0.33	100.12	1864	Cross-flow
Koami	Tochigi Prefecture Enterprise Bureau	2006-07	606.1	CG	23.5	1.15	0.19	130	1.31	14.00	987	Horizontal propeller
Takato Sakura	Nagano Prefecture Enterprise Bureau	2015-17	377.4	CG	30.9	0.96	0.25	199	1.10	23.00	199	Horizontal Francis
Aihara	Yamaguchi Pref. Enterprise Bureau	2013-14	543.0	CG	7.8	N/A	—	82	3.20	3.87	328	Pump reversal water turbine
Akiba No. 3 (small turbine)	JPOWER	1988-91	4490.0	CG	89.0	6.00	0.13	1700	6.00	32.90	N/A	Horizontal Francis

Managawa Dam	MLIT	-2003	223.7	CA	127.5	0.67	0.30	490	0.67	95.50	2650	Horizontal Francis
Isawa No. 3	Iwate Prefecture Enterprise Bureau	2011-14	185.0	RF	127.0	1.80	0.97	1500	1.80	105.20	11729	Horizontal Francis
Inekoki	TEPCO	1998-99	470.4	CA	60.0	1.34	0.28	510	1.64	41.33	3015	Horizontal Francis
Kazunogawa Microhydropower	Kandenko	-2014	13.5	CG	105.2	0.25	1.85	160	0.25	82.00	735	Horizontal Francis
Akigami	C-Tech	2015-16	83.3	CG	74.0	0.29	0.34	290	0.73	50.33	1330	Cross-flow
Sakore	C-Tech	2017-18	770.0	CG	18.0	2.78	0.36	380	3.03	14.81	2660	Underwater turbine
Ayado	TEPCO	-1998	1696.6	CG	14.5	4.23	0.25	670	11.23	8.06	N/A	Vertical propeller
Hitotsuse E-flows	Kyushu Electric Power Co.	-2013	445.9	CA	130.0	0.90	0.20	330	0.90	50.42	2200	Horizontal Francis
Higashigochi	Chubu Electric Power Co.	-2001	329.2	CG	69.0	0.55	0.17	170	0.55	40.62	N/A	Cross-flow
Shin-Okuizumi	Chubu Electric Power Co.	2017-18	464.60	CG	44.5	N/A	—	320	2.07	19.00	1300	Cross-flow
Kamishiiba E-flows	Kyushu Electric Power Co.	-2013	223.6	CA	110.0	0.52	0.23	330	0.52	81.40	2400	Horizontal Francis
Hegsetdammen kraftverk	Norway	-2015	1527.00	CA	30.0	1.50	0.001	280	1.20	29.40	350	Underwater turbine
Castelo do Bode	Portugal	-2020	3950.00	CA	115	0.64-26.32	0.00016-0.0067	194	3.00	93.70	8321.00	Horizontal Francis
Wonorejo Dam	Indonesia	-2002	N/A	RF	100.0	N/A	—	200	0.95	15.00	N/A	Horizontal propeller
Kyogoku Meisui no Sato	HEPCO	2016	51.3	RF	54.0	3.3	0.06	730	3.3	29	1700	Horizontal propeller
Torao	TEPCO	2011	31.2	CG	120.0	0.35	0.01	270	0.35	101	1600	Horizontal Francis

Table 2 Case histories of e-flows hydropower station: Characteristics

Power Station	E-flows Discharge Method	Characteristics of E-flows Hydropower Generation
Houri No. 2	Hydropower is generated by discharging water directly below the dam from penstock branching from the headrace of the existing Hori Power Station (dam and waterway type).	E-flows from Houri Dam was operated at a higher flow rate than specified via manual adjustments to the gate added to the outlet of pipe to adapt to changes in water levels. Installing e-flows hydropower facilities has enabled automatic adjustment to the required flow rate and therefore increased volume of water used for hydropower generation at the existing Hori Power Station (vertical Francis).
Tsuchimurokawa	E-flows discharges directly below the dam from a selective intake device installed in the existing pumped-storage lower dam, generating hydropower.	The power station's flow rate was made to be adjusted as part of the dam's discharge controls, and the target flow rate was adjusted by combining the controls to open the turbine needle valve and switch nozzles when generating hydropower and controlling the outlet gate when hydropower generation is stopped.
Kawabaru E-flows	Hydropower generates from water discharged directly below the dam from penstock branching from the headrace of the existing Kawabaru Power Station (dam and waterway type).	To improve economic efficiency and maintainability, an underwater turbine-generator was installed, eliminating the need for a powerhouse and therefore simplifying the facility.
Kagehira	Hydropower generates from water discharged directly below the dam from penstock branching from the intake of the existing Kagehira Power Station (dam and waterway type).	By installing two affordable horizontal propeller turbines in a row inside a narrow existing tunnel (used during construction), stakeholders saved space, adapted the facility to the high head, and adjusted the facility for a fixed flow rate in response to fluctuating water levels in the dam. No single turbine would have fulfilled the requirements of the 37.24 m head in the plans. Stakeholders therefore decided the high head would be split between two horizontal propeller turbines installed in a row.
Okutadami E-flows	Hydropower generates from water discharged directly below the dam from penstock branching off from the penstock of the existing Okutadami Power Station (dam and waterway type).	The e-flows hydropower facilities were installed using the e-flows discharge devices installed in the expansion of the Okutadami Power Station. An easily maintained horizontal Francis turbine with a head ratio (Hmax/Hmin) of 2.05 was installed. Stakeholders also planned ahead so when the existing primary No. 1 penstock stopped running e-flows, the alternative No. 4 penstock would be used to run e-flows for discharge.
North Fork Skokomish	Water turbine-generator installed in existing e-flows outlet discharges water directly below the dam.	The new North Fork hydropower facilities (Francis turbines) were installed directly under the Cushman No. 2 dam to use the e-flows discharged through a discharge valve. A fish ladder was also constructed.
Dashidaira	Water turbine-generator installed in existing e-flows outlet discharges water directly below the dam.	Water turbine-generator was installed on the end of Dashidaira Dam's existing e-flows discharge pipe, conveying water to the water turbine-generator. To adapt to seasonal fluctuations in e-flows as well as changing dam operation water levels, stakeholders had a turbine-generator with adjustable speed (horizontal Francis) installed.
Isawa No. 4	Hydropower generates using e-flows discharges water directly below the dam siphoned from the existing Isawa No. 2 Power Station's Wakayanagi intake weir.	Isawa No. 4 Power Station is a small hydropower station using both irrigation water and the e-flows discharged from Isawa No. 2 Power Station's Wakayanagi intake weir (intake device) into the Isawa River. The horizontal propeller turbine can adapt to fluctuations in flow rate and head. One of the site's characteristics is its use of a siphon to take in water without affecting existing facilities, as well as the installation of an alternative discharge pipe so e-flows may continue at the standard flow rate when hydropower discharge is stopped.

Shin-Tonami	The intake and headrace of existing Tonami Power Station are shared and water redirected via penstock and discharged downstream of dam.	The power station uses the outflow from Hiraide Dam not used for hydropower generation as well as e-flows to improve the river environment downstream of Hiraide Dam.
Iino	Water flows through the existing Horai Power Station (dam and waterway type) intake and through the new generator facility and outlet, which is connected to the Horai Power Station intake sediment drainage channel and discharges downstream of the dam.	The e-flows hydropower station makes use of e-flows discharged from the intake dam of the existing Horai Power Station. So as not to let values fall below the e-flows rate, stakeholders set the maximum discharge for e-flows hydropower generation after considering its fluctuations (approximately 5% of the flow rate) caused by output fluctuations at the Horai Power Station connected directly to the intake weir. They also installed a simple horizontal propeller turbine-generator to cut costs and shorten the construction period.
Shin-Kushihara	A new intake device flows water from the right bank upstream of the dam, and water is conveyed downstream of the dam via penstock to the generator facility. Previously, e-flows were discharged from the spillway gates.	The e-flows hydropower station (with a cross-flow turbine) makes use of e-flows discharged from the intake dam serving the Yahagi No. 2 Power Station. Factors considered and measures implemented include the narrowness of the construction side, penetration of the existing concrete dam body, and a wire sawing method to cause less vibration for the existing structure. Compared to an e-flows rate of 1.49 m^3/s, the maximum discharge was determined after considering the ±2.5% variance due to dam water level fluctuations, ultimately adding 5% for 1.56 m^3/s. Additionally, Yahagi No. 2 Power Station was able to increase output (approximately 400,000 kWh) thanks to the elimination of approximately 0.2 to 0.3 m^3/s overflow resulting from the use of spillway gate incapable of minor adjustments.
Okuwanojiri	A siphon from a new intake device upstream on the dam's left bank conveys water downstream of the dam via penstock to the generator facility. Previously, e-flows were discharged from the spillway gates.	The site was modified to allow the e-flows rate to be discharged according to the volume used for hydropower generation even when the dam's operational water levels are at their lowest. Because an underwater turbine was used, the powerhouse could be omitted. Out of consideration for safety and the cost of in-stream construction directly below the dam, the construction period for work on the cofferdam was restricted to seasons not prone to flooding.
Kuttari	With the existing e-flows outlet device installed on the dam's left bank, a new water turbine generator was installed in the outlet valve room. After generating hydropower, water discharges directly below the dam.	The e-flows hydropower facilities were installed at Kuttari Dam, which was already serving the existing Kumaushi Power Station. Compared to an e-flows rate of 4.00 m^3/s, the maximum discharge was determined after considering the variance due to dam water level fluctuations and control of the generator, ultimately adding 5% for 4.20 m^3/s, with an upper and lower limit of 4.4 and 4.0, respectively. An S-type tubular turbine was installed for its environmental friendliness (high performance against oil leaks).
Doshi Dam	Water is redirected from the headrace of the existing Doshi No. 1 and No. 2 Power Stations (dam and waterway type) and is discharged directly below the dam to generate hydropower. Previously, pumps rerouted the water for outflow.	The e-flows hydropower facilities (horizontal propeller turbine) were installed below Doshi Dam. Because the dam's water level fluctuates by 5 m, or 25% of the total e-flows head of 20 m, stakeholders installed flow rate controls to ensure stable and sufficient e-flows.
Azuma No. 2	Water flows into penstock branching from penstock of the existing Azuma Power Station (dam type) and discharges directly below the dam to generate hydropower.	The e-flows hydropower facilities (cross-flow turbine) were installed at Kusaki Dam, which was already serving Azuma and Odaira Power Stations. Factors considered and measures implemented include an operational pattern adaptive to power generation where the reservoir water level fluctuates ((1) outlet adjustment controls for fixed flow rate; (2) controls for outlets closing at fixed intervals to secure e-flow rate at lowest water level; and (3) controls for both

		outlets closing at fixed intervals and for fixed output) and installation of fixed flow rate controls by adjusting outlets so the existing power station experienced the lowest degree of power reduction. Out of consideration for the existing Azuma Power Station's power level, the maximum discharge was matched with the e-flows rate.
Koami	Water flows from penstock branching off from the headrace of the existing Kawaji No. 2 Power Station (dam and waterway type) and discharges directly below the dam to generate hydropower.	The e-flows hydropower facilities were installed at Koami Dam, which was already serving Kawaji No. 1 and No. 2 Power Stations. The structure lacks guide vanes, resulting in changed output due to the dam's fluctuating water levels. It is worth pointing out that costs were reduced by, rather than installing a new intake, etc., branching and conveying water from the headrace of another existing power station, and construction limitations were dramatically reduced with the decision to install the generator equipment inside the outlet side wall.
Takato Sakura	A siphon takes in water from the existing Takato Dam and conveys water to the generator facility directly below the dam to be discharged.	The e-flows hydropower facilities (horizontal Francis) were installed to take water from Takato Dam, which was already serving Haruchika Power Station. Effects on the dam body from the use of a siphon was mitigated, and maintenance costs were reduced. Because in general turbines are most efficient at 80 to 90% of the maximum discharge, the maximum discharge was determined to be in the range of discharge equivalent to 1.2 m^3/s (e-flows rate 0.96 m^3/s / 80%), at 1.10 m^3/s.
Aihara	Water flows into a siphon from Aihara Dam (which is a re-regulating reservoir for Shin-Abugawa Dam Power Station) and conveyed to the generator facility directly below the dam.	Power is generated by using the head of Aihara Dam (which is a re-regulating reservoir for Shin-Abugawa Dam Power Station, directly below Abugawa Dam) and some of Aihara Dam's discharge. Construction costs were reduced by using a pump reversal water turbine, which removes the need for flow rate adjustment controls by the generator and which was made possible by the shared use of the existing outlet gate. By installing a siphon, stakeholders were able to reduce civil construction costs relating to water intake facilities and omitted the need for an inlet gate.
Akiba No. 3 (small turbine)	After branching off from Akiba No. 3 Power Station's new penstock, water is conveyed to a small turbine inside the same powerhouse to generate hydropower before being discharged directly below the dam.	A new, third power station that would use dam overflow and a small turbine that would use e-flow was installed. The existing Akiba reservoir was getting much inflow, and the No. 1 and No. 2 power stations were generating power, but a new, third power station was built to use overflow Akiba Dam experienced approximately 100 days a year. Small hydropower facilities were built in the third structure.
Managawa Dam	Water branches off from the e-flows outlet, generates hydropower, and discharges directly below the dam.	Managawa Dam was built with flood controls and unspecified irrigation and electricity generation functionalities. Water hardly flowed for approximately 3 km downstream of the dam, which stakeholders sought to remedy through a water and environmental program, which set e-flows to 0.67 m^3/s. The e-flows were put to use by micro hydropower devices (horizontal Francis) that were installed for dam management.
Isawa No. 3	Water branches off from Isawa No. 1 Power Station's penstock (JPOWER, dam type) and generates hydropower before discharging directly below the dam.	Isawa Dam was built to replace Ishibuchi Dam, and its e-flows came to be used by micro hydropower station (horizontal Francis) installed there. The Isawa No. 1 and No. 3 Power Stations share a powerhouse, penstock, outdoor switchyard, power lines, and the like.

Inekoki	The intake installed in the dam body conveys water to the generator facility directly below the dam before being discharged.	The 510 kW Inekoki Power Station was built to use the e-flows from Inekoki Dam, the intake of which powers Ryushima Power Station.
Kazunogawa Microhydropower	Using the channel redirecting water from the Kazunogawa Dam, e-flows generate hydropower and discharges directly below the dam.	Kazunogawa Microhydropower Station, a run-of-the-river facility, has an effective head of 82 m and an output of 160 kW. It uses the channel redirecting water to Kazunogawa Dam, the lower, second dam for TEPCO's Kazunogawa Pumped Storage Hydropower Station.
Akigami	Water branches from existing e-flows outlet pipe, flowing into the newly installed generator facility before discharging directly below the dam.	Akigami Dam is an intake structure that increases the water storage capacity of Asahi Dam, which serves the operations of the Asahi Power Station. The e-flows from Akigami Dam are used to generate the new Akigami Hydropower Station's rated output of 290 kW.
Sakore	Water flows from the existing intake into a siphon and generator facility in a vertical shaft directly below the dam before discharging.	Higashi-Ueda Dam is an intake structure for Higashi-Ueda Power Station and Chuuro Power Station. Sakore Hydropower Station was built to use the dam's 2.78 m^3/s e-flows to generate its rated output of 380 kW.
Ayado	An existing channel for large woody debris was reconstructed as a headrace, conveying the dam's e-flows for hydropower generation and discharging the flows directly below the dam.	Ayado Dam is an intake structure for Saku Power Station and Chuuro Power Station. Ayado Power Station was built to use the dam's e-flows to generate its rated output of 670 kW.
Hitotsuse E-flows	Water branches off from the channel between the existing Hitotsuse Dam to the Hitotsuse Power Station, generating hydropower as e-flows and discharging directly below the dam.	Hitotsuse E-flows Power Station is a micro hydropower station built to use Hitotsuse Dam's e-flows to generate 330 kW.
Higashigochi	Water branches off from the existing e-flows outlet pipe to the new generator and discharges directly below the dam.	Higashigochi Hydropower Station is a micro hydropower station (cross-flow turbine) built to use the e-flows discharged from Hatanagi No. 2 Dam. The guide vane is automatically controlled to discharge a fixed volume of water regardless of dam water levels. When not generating power, the adjacent outlet valve opens automatically to release e-flows.
Shin-Okuizumi	Water branches off from the existing e-flows outlet pipe to the new generator and discharges directly below the dam.	Shin-Okuizumi Hydropower Station is a micro hydropower station (cross-flow turbine) built to use Okuizumi Dam's e-flows to generate 320 kW.
Kamishiiba E-flows	A generator was installed for Kamishiiba Dam's e-flows. After generating hydropower, the e-flows discharges directly under the dam.	Kamishiiba E-flows Power Station is a micro hydropower station built to use Kamishiiba Dam's e-flows to generate 330 kW.
Hegsetdammen kraftverk	Water runs from the dam to the e-flows pipe, to be conveyed to the water turbine-generator, where it generates hydropower before discharging directly below the dam.	Hegsetfoss Power Plant was built to use the e-flows from Hegsetdammen, the dam holding the Bjørga reservoir. The power plant generates 280 kW, and it was designed to generate hydropower by using an integrated water turbine-generator due to the positioning of an existing outlet pipe.
Castelo do Bode	Water discharges directly below the dam from the primary and secondary turbines of the existing power station (dam) and the newly installed discharge facilities.	Combined operational patterns are optimized to accommodate required e-flows rates (which change monthly), with the installation of outlet works enabling e-flows directly below the dam as well as primary and secondary turbines generating hydropower with discharge from an existing power station (dam type).

Wonorejo Dam	A water turbine-generator was installed in the discharge facilities of Wonorejo Dam. Water discharges directly below the dam.	At the Wonorejo Hydropower Plant, a water turbine-generator was introduced to generate hydropower from the discharge required of the Wonorejo Multipurpose Dam. The hydropower generated is used for dam management. A pressure-reducing valve for adjusting pressure allows the facility to adapt to changes in dam water levels.
Kyogoku Meisui no Sato	Water flowing from the outlet works generates hydropower and flows through the Kyogoku Dam discharge tunnel. A turbine and generator were installed inside the same dam's gate room.	Kyogoku Meisui no Sato Power Station was built to use water discharged from the outlet works of Kyogoku Dam, the lower (second) dam serving Kyogoku Pumped Storage Power Station built by HEPCO. Penstock was installed to branch from the outlet works and take in water flowing at a maximum of 3.3 m^3/s. A total of four horizontal propeller turbines were installed, installed two by two in parallel and succession.
Torao	A power station that generates power via the unused head of the channel redirecting the water from the lower (second) dam serving the pumped-storage hydropower station.	To reduce changes in water quality and impact on the ecosystem downstream of the dam, stakeholders built an intake dam upstream of Ueno Dam (the lower, second dam serving Kannagawa Pumped Storage Power Station) to take in river water, redirect it away from the reservoir, and generate power from the outflow from the channel redirecting water downstream of the dam.