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Historical development and heritage significance of hydropower plants in Taiwan

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Abstract

In 2025, Taiwan marks 120 years since the advent of hydropower and the lighting of the first bulb powered by hydroelectricity. Drawing on 15 years of on-site surveillance and mapping, this study provides a comprehensive account of the historical progress, industrial heritage significance, and socioeconomic impact of hydropower plants in Taiwan from the early 20th century to the present, making it the first comprehensive study of hydropower on the island. The high mountainous landscape, dense river networks with high heads and steep valleys, and abundant annual rainfall have made Taiwan an ideal location for hydropower generation, which has become essential to the island's shift toward rapid industrialization and the overall development of its energy infrastructure. This study traces the evolution of Taiwan's hydropower and describes the introduction of critical hydraulic cascades alongside design and construction innovations, difficulties, and operational achievements. By investigating national and local libraries and archival repositories, conducting technical analysis, on-site surveillance, excavation, three-dimensional reconstructions, and policy reviews, the study documents the transition from Japanese Imperial era (1868–1947) infrastructure to modern energy strategies, emphasizing how historical hydropower plants have shaped Taiwan's energy landscape. The conclusion highlights the importance of conserving these engineering legacies while learning from their mistakes and adapting them for sustainable energy futures in the face of changing environmental and technological contexts.

Keywords: Energy; Hydropower; Industrial heritage; Japanese Imperial period; Taiwan; Water

1. Introduction

1.1. Background and motivation

Hydro capacity accounted for 15.4% of total power plant installations globally in 2023, with a total recorded hydro capacity of 1407 GW. It is expected that these facts will contribute to the installed capacity reaching 1562 GW by the end of 2030. Of the total global hydro capacity, 0.33% is in Taiwan (Power Technology, 2024). Hydropower has long been a cornerstone of Taiwan's energy infrastructure, playing a crucial role in the island's modernization and industrial expansion. With its steep topography, where mountains cover 70% of the land with an average height of approximately 1150 m, dense river networks combining 151 major and minor rivers with a total length of 3717 km (Worlddata.info, 2025), and annual average precipitation 2502 mm recorded by the Water Resource Agency (WRA), Ministry of Economic Affairs of Taiwan (MOEA) (WRA & MOEA, 2025), Taiwan possesses natural conditions uniquely suited for hydroelectric development.

Taiwan is a small island nation with a population of around 23.4 million (as of May 2025) and a 99% energy import dependency; therefore, each domestic energy source is extremely valuable. Hydropower was the first commercially available source of electricity in Taiwan, and the hydropower sector led the island's energy generation until 1967, when the rising development exponentially increased consumption, forcing the expansion of more powerful, fossil fuel-dependent systems. However, over the past few decades, a new trend in renewable resources has emerged, and hydropower plants have become an interesting subject once again.

Taiwan has significant hydropower potential, but it is currently only utilizing a small fraction of its capacity despite a 120-year history of hydropower development (Tkáč, 2016; Tkáč *et al*., 2014). In Taiwan, hydropower accounts for 7% of the island's overall installed capacity and 1% of total energy generation (as of 2023), with a projected rise to 4% by 2035. On the contrary, the large hydropower capacity increased from 2010 to 2023 at a compound annual growth rate of 0.43%, with expectations of flat growth (Power Technology, 2023), as the Taiwan Power Company (TPC) plans only a few large-scale projects with an installed capacity above 20 MW (MOEA, 2024). On the contrary, the current backbone of Taiwanese hydropower development is a recent surge in the construction of small hydropower plants (SHPPs), primarily by the private sector, water resource agencies, and agricultural cooperatives managing irrigation canals (Martinelli, 2020; Wu *et al*., 2023).

1.2. Research objectives

Due to the course of historical events, historical records on Taiwanese hydropower plants are scattered, incomplete, or lost. This fact makes the formation of complex databases tedious and time-consuming; however, forming such databases is important for the future technological direction of the hydropower sector, as it reflects on the unfortunate mistakes made in the past. These mistakes are specific to the island's volatile climate and weather, thus vital for incorporation into any newly developed project. Since 2020, Taiwan has experienced a rapid surge in the development of SHPPs, particularly in the private sector. Therefore, ensuring the high quality and durability of designs, as well as understanding the past, is crucial, as these newly built SHPPs form the entire hydraulic and independent energy grid infrastructure, with an estimated feasible potential surpassing 2.6 GW (Energy Taiwan, 2022).

The 15 years of research underwent several stages, starting as a PhD side project and data collection platform for further studies and ultimately culminating in the establishment of the privately owned Slovak-Taiwan Hydropower Research Laboratory, which is currently keeping the first complex database of all Taiwanese hydropower plants starting from historical, planned, up to currently operational cases of all scales stretching from pico systems (installed capacity <5kW) up to the largest pumped SHPPs.

Therefore, concerning the historical hydropower sites, the research objectives culminated from data collection and evaluation to direct site surveillance and excavation. In general, there are five pillars:

(i) To explore the complex origins and gradual advancement trajectory of hydropower infrastructure in Taiwan, starting from its inception during the Japanese rule and its subsequent growth through the post-war periods to modern energy policies.
(ii) To assess engineering achievements, contributions to industrialization, and impacts on local identity and communities, consider the three-fold value-encompassing aspects of Taiwanese culture, economy, and technology alongside the hydropower plants.
(iii) To document the key historical hydropower systems, including their design features, construction challenges, and operational milestones, using methodologies such as archival research, technical analysis, on-site documentation, and three-dimensional (3D) reconstructions.
(iv) To assess the legacy, preservation status, and adaptive reuse efforts of historical hydropower plants (HHPs), it is essential to emphasize the current policies and practices that integrate these heritage sites into sustainable and modern energy frameworks.
(v) To contribute to the discourse on industrial heritage and sustainable energy transitions, offering insights from Taiwan's hydropower experience that may inform broader regional and global approaches to managing historical energy infrastructure.

1.3. Scope and methodology

1.3.1. Scope

This study examines the historical evolution, technological significance, and socioeconomic role of hydropower plants in Taiwan. The study focuses on hydropower plants and hydraulic cascades (in terms of hydroelectric cascade or hydropower cascade as a series of hydropower plants built along the same river or watercourse, arranged in sequence) constructed during the Japanese Imperial Period (1868–1947), their post-war adaptations under the nationalist government, and their ongoing influence on Taiwan's energy infrastructure to the present day. The article is a direct result of 15 years of on-site research, comprising all known and surveyed historical sites, including projects that the Japanese never realized. The article is also the first complex mapping of the Taiwanese historical hydropower cases. These further analyzed cases represent precedent studies of industrial heritage, technological transfer, and regional development across all four hydropower regions, namely:

The northern area covers Taipei, New Taipei, Keelung, Taoyuan, Hsinchu, and Yilan County. It is the area with the island's first hydropower plants.

The middle area covers Miaoli, Taichung, Changhua, Yunlin, and Nantou. It is also the largest hydropower area, boasting the highest concentration of hydropower plants and the highest untapped potential of irrigation canals.

The eastern area covers Hualien and Taitung counties. Due to its geographic orientation and geomorphology, it is the most challenging area, characterized by frequent and severe earthquakes, landslides, and typhoons. On the other hand, it is an area with steep, V-shaped valleys, ideal for impulse turbines.

The southern area covers Chiayi, Tainan, Kaohsiung, and Pingtung County. It is an area with poor climate conditions; therefore, it has the lowest number of hydropower plants across all periods. However, due to the accessibility and connection to the long-distance high-voltage grid, it is an area with a relatively high development potential for decentralized sources.

1.3.2. Methodology

The research employs a multidisciplinary historical and technical approach, combining archival investigation, field surveys, site mapping, and excavation-based reconstruction. The methodology includes:

(i) Archival research

Primary historical records—including blueprints, construction reports, engineering correspondences, and governmental energy policy documents—were gathered from national archives in Taiwan and Japan. Japanese colonial engineering documents and wartime hydro-infrastructure strategies received particular attention.

(ii) Site visits and surveys

Conduction of on-site inspections at all known hydropower facilities, ranging from well-known sites to those requiring physical excavation. These visits involved comprehensive technical documentation of architectural and civil engineering features, as well as remaining mechanical installations and environmental integration, utilizing photography, drone imaging, and global positioning system mapping.

(iii) Excavations and industrial archeology

Selected defunct or partially decommissioned sites were studied using archeological field methods to uncover buried structures, machinery foundations, and transmission lines. This approach helped reconstruct construction phases and assess material resilience over time.

(iv) Technical documentation review

Review of the engineering specifications, structural diagrams, and hydrological data to understand the evolution of hydropower plant design, performance metrics, and adaptation to Taiwan's geophysical constraints. Performing a comparative analysis with contemporary hydropower systems to identify design legacies.

(v) Digital reconstructions and modeling

Based on archival sources and field data, generate 3D models of key facilities to visualize their original configurations and subsequent modifications. These reconstructions help illustrate historical function and provide tools for heritage interpretation.

(vi) Policy and socioeconomic analysis

Analysis of the governmental policies on energy and land use to contextualize the role of hydropower in Taiwan's economic development, rural electrification, and post-war industrial policy. To assess the societal impact, where available, incorporate the oral histories based on residents and former energy sector employees, as well as local community narratives. Furthermore, cross-referencing the gathered data with the modern era hydropower plant already mentioned by the International Energy Agency (IEA, 2025), or updating the International Renewable Energy Agency's Global Atlas for Renewable Energy (IRENA, 2025), and International Hydropower Association (IHA, 2022a; IHA, 2022b), where, due to the political nature, Taiwanese cases are merged with those of the Mainland Chinese, making it challenging to separate and to keep a track of. In addition, such a comprehensive study can, in fact, establish a clear hierarchy of the historical development of the Taiwanese hydropower sector and provide a tangible basis for benchmarking, which could be further applied in international research.

In general, this research aims to illuminate Taiwan's hydropower legacy by combining historical records with on-site technical and spatial analysis. It examines not only the engineering achievements but also the cultural and environmental impacts of hydropower on the island's modernization and sustainability planning, as some of the cases directly affect the island's efforts to modernize.

To create a hierarchy and mark specific periods related to political and economic changes, this research employed a further historical division for future studies:

- Japanese Imperial period (1868–1947) (the Colonial era, 1895–1945)
- Post-Japanese Imperial period and American aid (1947–1960)
- Individual development by cutting the energy costs, along with TPC expansion (60s–1st half of 90s)
- Energy market liberalization with Independent Power Producers (IPPs) 1/1995 (2nd half of the 90s) (Industrial Technology Research Institute, 2009)
- SHPPs development boomed in 2020, supported by the Taiwan Small Hydropower Green Energy Industry Alliance (2000s) (TSHPIA, 2023)

2. Historical context

The year 2025 marks a 120-year history of hydropower development in Taiwan. Twenty-three years after Edison's Vulcan Street Plant, Taiwan built its first commercial hydropower plant (1903–1905), depicted in Figure 1, marking the first commercial use of electric power on the island, as it lit the first light bulb in Taipei City. As shown in Table 1, the development of the Taiwanese hydropower sector began in the early stages of electrification in Southeast Asia and the Asia-Pacific region.

With the completion of the Guishan hydropower plant in Wulai in July 1905 (1 month after the Korean Unsan Hydroelectric Power Plant), it ranked among countries such as Japan, Korea, India, Myanmar, New Zealand, and Australia. Although the Guishan power plant was operational with only two units (the third unit arrived in 1907), its initial installed capacity of 600 kW (later increased to 750 kW) was among the highest in Asia. Regarding the installed technology, the twin runners, single-discharge Francis turbine (generally known in the hydropower community as "Francis Camelback") was considered modern and relatively new to the region at that time. Moreover, the "Camelback" turbine technology has recently garnered global attention once again through revival projects led by Voith (2025) and Norcan (2025).

The development of hydropower plants in Far and Southeast Asia began at the turn of the 19th and 20th centuries, primarily in connection with the colonial period (1895–1945) and as a result of the industrial revolution, which led to the electrification of each nation. Japan, India, Myanmar, and Australia were among the first countries to utilize hydropower plants. Hydropower plants were also closely linked to the development of hydraulic structures and waterworks. For example, despite the demolition and subsequent rebuilding of the first Japanese Kaege power station, the sophisticated hydropower cascade of Lake Biwa continues to serve the Shiga prefecture as the largest freshwater lake in Japan, supplying the Kansai region, along with the major cities of Kyoto and Osaka. The rest of Asia, including Taiwan (under Japanese rule from 1895 to 1945), developed hydropower technology at the dawn of the 20th century. The last countries adopting

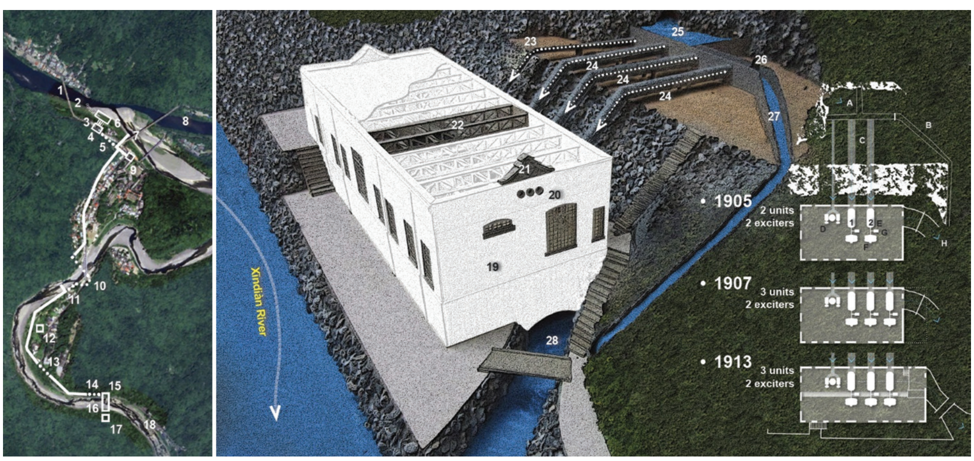

Figure 1. Taiwan's first commercial hydropower plant. Left: The original hydraulic structures along the Xindian River. Right: The reconstruction of Taiwan's first hydropower plant, the Guishan hydropower plant, built in 1905. Following the machinery expansion in 1907 and the powerhouse extension in 1913
Notes: [1]Xindian river, [2]Tailrace, [3]Penstock, [4]Forebay tank, [5]Tunnel No. 4, [6]Guishan Powerhouse, [7]Spillway, [8]Beishi River, [9]Regulating pool, [10]Tunnel No. 3 crossing the Nanshi river via suction bend (Inverted siphon), [11]Watergate, [12]Guardroom, [13]Tunnel No. 2, [14]Tunnel No. 1, [15]Intake, [16]Guishan dam, [17]Boundary monument, [18]Nanshi river, [19]The powerhouse, [20]Openings for the electrical cables output, [21]Roof gable with the original TPC logo, [22]Girders holding the roof, [23]Penstock supplies a pair of exciters, [24]Penstocks supplying turbine units 1–3, [25]Forebay tank, [26]Regulating gates, [27]Overflow spillway 28 Tailrace.
Source: Drawing by the authors.

Table 1. A list of selected cases of the first hydropower plants across Southeast Asia and the Asia Pacific

Region, country, and year of establishment	Name or place of the power plant	Installed capacity
Asia-Pacific		
Japan 1891	Keage Power Station	295 kW (IEEE, 2025a)
Australia 1898	Thargomindah, Queensland-Artesian Hydropower	15 kW (Hydro Power Plant, 2025)
New Zealand 1901	Ōkere Falls Power Station	100 kW (Engineering, 2025)
Korea 1905/6	Unsan Hydroelectric Power Plant	500 kW (KEPCO, 2025)
Taiwan 1905/7	Guinshan hydropower planta	600 kW (B. Lin, 2007)
Hawaii 1906	Wainiha hydropower plant/island of Kaua'i	4,000 kW (Harriman, 2023)
China 1912	Shilongba Hydropower Station, Yunnan Province	240 kW (Ghosh, 2022)
The Philippines 1913	Camp John Hay Hydroelectric Power Plant in Baguio City	560 kW (Salvador & Manalo, 2017)
Southeast Asia		
India 1897	Sidrapong, Darjeeling, West Bengal	130 kW (IEEE, 2025b)
Myanmar 1898	Mogoke – Yeni River	460 kW (Aye, 2017)
Indonesia 1908	Rasak Bungo Hydroelectric Power Plant	700 kW (Newsflare, 2023)
Malaysia 1900	Sempam Hydroelectric Power Station in Raub (Hussein & Raman, 2010)	220 kW (Lee, 2019)
Nepal 1911	Chandra Jyoti Electric Power Station	500 kW (Ramesh, 2021)
Vietnam 1946	Ankroet	600 kW (Huu, 2015)
Bangladesh 1962	Kaptai Hydroelectric Power Station	230,000 kW (Salehin, 2024)
Thailand 1964	Bhumibol Dam	429,000 kW (IEA, 2006)
Kingdom of Cambodia 1968	Kirirom I	10,000 kW (Kirirom 1 Hydropower Dam, 2024)

Note: aTaiwan's first commercial hydropower plant.

hydropower technology were Bangladesh, Thailand, and the Kingdom of Cambodia. These power plants were indeed pioneering technologies and industrial architectures that were challenged by the local climate, weather, maintenance requirements, and the supply of mechanical equipment. However, they paved the way for the electrification of each nation, and in some cases, they were a long-time leading source of electric power.

The unique topography and complex geopolitical history have shaped the evolution of the Taiwanese hydropower sector, which inevitably played a vital role during the overall economic transition from an agricultural to a rapidly industrializing national economy. Within this trajectory, hydropower played a foundational role from its introduction in the early 19^{th} century to 1967/68, when the thermal power plants surpassed the TPC's 721 MW (45.7%) share of renewable energy sources (RES) (TPC, 2025a). In 1967, the RES in Taiwan consisted exclusively of hydropower. This shift displaced hydropower from its position as the primary energy source, relegating it to RES, and later, by 1985 and 1995, further to pumped storage energy solutions, represented by PSHPP Daguan No. 2 (1000 MW) and Mingtan (1602 MW), both using reversible Francis turbine technology.

3. Development of early hydropower plants

3.1. Japanese imperial period projects

As in most of the world, the early development of the Taiwanese hydropower sector started with a water wheel. In Taiwan, the horizontal-axis water wheels were and are still used to pump water into irrigation canals.

Various records presented in Tables 2 and 3 show that timber, paper, hemp, tapioca, sugar, and ice factories, but mainly rice mills, were initially equipped with horizontal or vertical water wheels to transfer mechanical energy across Taiwan. These small businesses later connected their hydraulic machinery to generators. As technology advanced, most of them replaced water wheels with more efficient turbines, typically an open flume type suitable for low heads and deep, narrow shafts left by the obsolete water wheel technology. Multiple examples of open-flume vertical-axis Francis turbines like those depicted in Figure 2 are still fully functional in Taitung County (Ruiyuan rice mill) (Wang, 2010) and Hsinchu County (Donghai rice mill) (Figure 2) (IEA, 2009) or in the decommissioned case in Pingtung County (Tonglingbu rice mill) (Z. Cai, 2023). Based on the design featuring open-flume turbines, hydropower plants were subsequently established

Table 2. A list of all 62 historical cases successfully identified from the Japanese imperial period (1868–1947)

No.	Year of commissioning and decommissioning	Type and no. of turbines*	Installed capacity* (MW)	Name of the powerplant in Hanyu Pinyin and transcript in Mandarin (alternative names)
1.	1905–1943	2×FH	0.5	Guishan (龟山发电所)[a**]
2.	1906–19XX	1×PH	0.047	Gengziliao (焿子寮发电所)[d]
3.	1906–19XX	X	X	Wudankeng (武丹坑发电所)[d]
4.	1907–1961	X	X	Jiaxian sugar factory (甲仙糖厂)[b]
5.	1908–1926	1×UH	X	Fanshekeng (蕃社坑发电所)[d]
6.	1908–1924	X	0.005	Danan'ao (大南澳发电所)[d]
7.	1909–XXXX	3×FH	2.4	Xiaocukeng (小粗坑发电所)[d]
8.	1910–1913	1×UH	-	Neiwan (内湾发电所)[d]
9.	1908–2008	4×FH	1.6	Zhuzimen (竹仔门发电所)[d]
10.	1911–XXXX	2×FH	0.94	Houli (后里发电所)[d]
11.	1912–1983	1×FV	0.012	Taiwan[d]anan hemp factory (台湾制麻大湳发电所)[b]
12.	1915–19XX	1×FV	X	Tonglingbu rice mill (统领埔碾米厂)[b]
13.	1916–1920	1×FV	0.056	Dongbu (东埔发电所)[d]
14.	1918–1992	4×FH	2.88	Tulongwan (土垄湾发电所)[d]
15.	1919–1988	2×FV	0.2	Ruanqiao (软桥发电所)[d]
16.	1920–1945	1×FH	0.2	Hualian port (1) (Shapodang 1) 花莲港（第一）（砂婆砀第一发电所）[b]
17.	1920–1926	X	X	Chishang tapioca factory (池上树薯工场)[b]
18.	1921–1989	2×FH	1.8	Beishankeng (北山坑发电所)[d]
19.	1922–1941	1×FX	0.025	Fenglin (凤林发电所)[d]
20.	1922–1993	2×FH	0.9	Sheliaojiao (社寮角发电所)[d]
21.	1923–2005	3×FH	1.5	Zhuoshui (浊水发电所)[d]
22.	1924–1963	1×FH	0.06	Baxianshan (八仙山发电所)[d]
23.	1924–1961	1×WH	0.0075	Nanzhuang (南庄发电所)[d]
24.	1925–1973	1×FH	0.2	Taibaliujiu (Taiping) 太巴六九发电所（太平发电厂）[d]
25.	1926–1933	1×FH	0.012	Quanhua temple (劝化堂发电所)[b]
26.	1927–1951	1×PH	1.4	Hualian port (2) (Shāpodang 2) 花莲港（第二）（砂婆砀第二发电所）[b]
27.	1927–1933	1×FV	0.003	Xiaojilong (小基隆发电所)[d]
28.	1928–2001	1×W (later FV)	<0.005	Donghai rice mill (东海碾米厂)[b] (Liao, 2021)
29.	1928–1932	1×FV	0.0015	Guanziling (关子岭发电所)[d]
30.	1928–1937	1×W	0.0015	Kebao'an ice factory (柯保安制冰工场)[b]
31.	1928–1961	1×FV	0.05	Lilong (Guān shān) 里垄发电所（关山发电厂）[d]
32.	1929–1956	1×FH	0.112	Alishan (阿里山发电所)[d]
33.	1929–19XX	1×PH	0.0035	Qurukou (Nanxi) 取入口发电所（楠西发电所）[d]
34.	1930–1958	X	X	Nan'ao sugar factory (南澳糖厂)[b]
35.	1930–1932	1×FV	0.001	Hengliuxi (横流溪发电所)[d]
36.	1930–19XX	1×X	X	Shuanglong village (双龙村发电所)[d]

(Cont'd)

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Table 2. *(Continued)*

No.	Year of commissioning and decommissioning	Type and no. of turbines*	Installed capacity* (MW)	Name of the powerplant in Hanyu Pinyin and transcript in Mandarin (alternative names)
37.	1931–19XX	1×FV	0.05	Wushantou (乌山头发电所)[d]
38.	1931–1970	1×PH	0.5	Sanjiaobu (三角埔发电所)[d] [Figure 4]
39.	1932–19XX	1×FV	0.004	Chendequan rice mill (陈德全精米工场)[b]
40.	1933–19XX	1×FV	0.005	Fengyuan 1 paper factory (丰原制纸株式会社第一工场)[b]
41.	1933–1963	1×PH	1.1	Wangxiangshan 1 (望乡山第一发电所)[d]
42.	1934–XXXX	3×FH	6.375	Tiansongpi (天送埤发电所)[d]
43.	1934–XXXX	5×PH	110	Menpaitan (Sun Moon lake 1) 门牌潭发电所 (日月潭第一发电所)[d]
44.	1934–1941	1×PH	0.175	Wangxiangshan 2 (望乡山第二发电所)[d]
45.	1935–1936	1×W	0.00025	Cunliansheng rice mill (村连盛精米工场)[b]
46.	1935–19XX	1×W	X	Dadong coal mine SHPP system (大东煤矿小水力发电系统)[b]
47.	1935–19XX	1×W	0.005	Fengyuan 2 paper factory (丰原制纸株式会社第二工场)[b]
48.	1936–1963	1×PH	1.15	Wangxiangshan 3 (望乡山第三发电所)[d]
49.	1937–XXXX	2×FV	43.6	Shuilikeng (Sun Moon Lake 2)[d] 水里坑发电所 (日月潭第二发电所)[d]
50.	1938–19XX	FX	0.11	Jiuzhize (鸠之泽发电所)[d]
51.	1939–XXXX	3×PH	2	Qingshui 1 (清水第一发电所)[d]
52.	1941– unfinished	1×FV	0.2	Guinabuke (规那佈刻发电所)[c]
53.	1941–XXXX	2×FV	13	Guishan (新龟山发电所)[d]
54.	1941–XXXX	2×FV	18	Yuanshan (圆山发电所)[d]
55.	1941–1943	2×FV	5	Qingshui 2 (清水第二发电所)[d] [Figure 5]
56.	1941–XXXX	1×KV	2	Muguaxi No. 1 (Chuyin) 木瓜溪第一发电所 (初音发电所)[d]
57.	1941–1955	1×FH	1.8	Xikou (溪口发电所)[d]
58.	1944–XXXX	2×FV	16	Liwu (立雾发电所)[d]
59.	1945–1962	1×FH	0.25	Danan (Dongxing) 大南发电所 (东兴发电厂)[d]
60.	1943–1944	3×FV	24	Tongmen (铜门发电所)[d] [Figure 4]
61.	1943–XXXX	1×PH	15.3	Wanda (万大发电厂)[d]
62.	19XX–19XX	X	X	Lanngdun tribe police station (人伦部落驻在所发电厂)[d]

Notes: [a]Taiwan's first commercial hydropower plant;[b]Hydropower plants related to individual private electric generation businesses (usually mills or factories); [c]Unfinished hydropower plant;[d]Hydropower plants related to the national sector or large electric generation businesses; *The initially installed number and capacity vary in some cases as powerhouses were later updated, and capacity expanded; **Guishan (龟山发电所): initially 0.5 MW in 1905 with two gen-sets; expanded to 0.75 MW in 1913 following the addition of another unit and powerhouse enlargement. X: Refers to the unconfirmed data; XX: Refers to the unknown full year; XXXX: Refers to the unknown year at all.
Abbreviations: F: All types of Francis turbines; H: Horizontal axis arrangement; K: All types of Kaplan turbines; P: All types of Pelton turbines; U: Unknown type of turbine; V: Vertical axis arrangement; W: All types of Water wheels.

in Guanshan, as shown in Figure 3, followed by Zhiben, and finally in Shanping, as represented by Figure 2. The Shanping case utilized the water shafts to mitigate the seasonal flow volatility of the Shanping Creek.

Table 3. A list of all 51 historical cases successfully identified from the post-war period

No.	Year of commissioning and decommissioning	Type and no. of turbines*	Installed capacity* (MW)	Name of the powerplant in Hanyu Pinyin and transcript in Mandarin (alternative names)
Post-war/post-Japanese Imperial Period (1868–1947)				
1.	1946/48–1961	1×W	0.010	Shitoushan (狮头山发电所)[c]
2.	1942/45–1949	2×FV	1.5	Wulai (乌来发电所)[c]
3.	1951–1954	X	X	Sanwan (三湾乡简易发电厂)[c]
4.	1951–1962	1×FH	0.033	Zhiben Electric co. (知本电业社)[b]
5.	1952–1960	1×W	0.02	Chishang Electric co. (池上电业社)[b]
6.	1952–1972	1×W	X	Mingfeng rice mill (明丰碾米厂)[a]
7.	1953–1963	2×W	0.0625	Yuguang Electric co. (裕光电业社)[b]
8.	1953–1968	2×W	0.040	Siji (四季发电厂)[c]
9.	1954–1959	1×W	0.05	Guoxingxiang Electric[c]o. (国姓乡电业厂)[b]
10.	1954–1959	X	X	Jiangshang Timber Co. (江上木材行)[a]
11.	1954–1957	X	X	Renhe (人和发电厂)[c]
12.	1955–XXXX	3×FH	21	Tongmen (铜门发电所)[c]
13.	1956–1961	X	X	Nianfeng (年丰发电厂)[c]
14.	1956/57–1965/66	X	X	Ruihe (瑞和发电所)[c]
15.	1956/57–1965/66	X	X	Jiana (加拿村发电厂)[c]
16.	1956–1958	1×W	0.033	Dabu (大埔乡发电所)[c]
17.	1956–19XX	X	0.003	Dili (地利村发电所)[c]
18.	1956–1972	1×FV	0.005	Shanping (扇平水力发电室)[c]
19.	1956–19XX	1×W	0.0075	Luona (罗娜发电厂)[c]
20.	1956–19XX	X	0.0223	Xinyi (信义乡发电厂)[c]
21.	1959–1971	1×W	0.005	Ruifeng rice mill (瑞丰碾米厂)[a]
22.	1957–1960	1×W	0.025	Ruizhuli (瑞竹里发电厂)[c]
23.	1958–19XX	X	0.4	Hongda Industrial Co. (弘大兴业)[a]
24.	1959–1961	1×W	0.01	Fengrong Electric Co. (峯荣电气工厂)[b]
60s–1st half of 90s: individual development and TPC expansion				
25.	19XX–1962	1×W	0.007	Degao Electric Co. (德高电业社)[b]
26.	19XX–1964	1×W	0.185	Dingpingli (顶坪里发电所)[c]
27.	19XX–1961	1×W	0.185	Jinxin Electric Co. (金兴电机厂)[b]
28.	19XX–1949	1×W	0.03	Shangping (上坪发电厂)[c]
29.	19XX–1959	1×X	0.06	Songpu rice mill (松浦碾米厂)[a]
30.	19XX–1962	1×W	0.0075	Xiexing Electric Co. (协兴电业社)[b]
31.	19XX–1968	1×W	0.002	Xinfu rice mill (新福碾米厂)[a]
32.	19XX–1981	X	X	Guanshan Ice Factory (关山制冰厂)[a]
33.	19XX–1981	X	X	Guanshan timber factory (关山制材所)[a]
34.	19XX –1981	1×W	X	Lilongyong rice mill (里垄湧水圳碾米厂)[a]
35.	19XX–1960	X	X	Beiwan (北湾圳发电所)[c]
36.	19XX–1960	X	X	Liaojiashuilong power plant (廖家水泷发电所)[b]

(Cont'd)

Table 3. *(Continued)*

No.	Year of commissioning and decommissioning	Type and no. of turbines*	Installed capacity* (MW)	Name of the powerplant in Hanyu Pinyin and transcript in Mandarin (alternative names)
37.	19XX–1960	X	X	Fucan (福灿发电厂)[c]
38.	19XX–1962	1×W	0.007	Degao Electric Co. (德高电业社)[b]
39.	1960s	1×P	X	Yizekeng (益则坑自用微水力发电系统)[c]
40.	1961–1965	1×W	0.0075	Heming Electric Co. (合明电业社)[b]
41.	1961–1966	1×W	X	Yongrong rice mill (永荣精米所)[a]
42.	1961–2001	2×FV	90	Guguan (关谷发电厂)[c]
43.	1962–1965	1×W	0.024	Shengguang Electric Co. (胜光电业社)[b]
44.	1962–1979	1×W	0.01	Yunfeng Electric Co. (源丰电业社)[b]
45.	1964–1968	1×W	0.015	Nan'ao (南澳乡发电厂)[c]
46.	1970–2004	2×FV	180	Qingshan (青山发电厂)[c]
47.	1973–1982	X	X	Yongfengyu Paper Factory (永丰余纸厂关山厂)[a]
48.	1979–2001	1×FH	3	Dongjin (东锦发电厂)[c]
49.	1990–XXXX	2×FH	2	Peinanshangzhen (卑南上圳小型发电厂)[b]
50.	1991–2001	1×FH	5	Fufeng (富丰发电厂)[c]
2nd half of the 90s: energy market liberalization (e.g., Independent power producers in January 1995)				
2000s: SHPP development boom (e.g., Taiwan Small Hydropower Green Energy Industries Alliance in 2021)				
51.	2009–2019	1×FV	0.98	Xingfu concrete factory (幸福水泥和仁小型水力发电厂)[a]

Notes:[a]Hydropower plants related to private businesses (usually mills or factories);[b]Hydropower plants related to individual private electric generation businesses (Private energy companies);[c]Hydropower plants related to the national sector or large electric generation businesses; *The initially installed number and capacity vary in some cases as powerhouses were later updated, and capacity expanded. X: Refers to the unconfirmed data; XX: Refers to the unknown full year; XXXX: Refers to the unknown year at all.
Abbreviations: F: All types of Francis turbines; H: Horizontal axis arrangement; K: All types of Kaplan turbines; P: All types of Pelton turbines; SHPP: Small hydropower plant; TPC: Taiwan Power Company; U: Unknown type of turbine; V: Vertical axis arrangement; W: All types of Water wheels.

Figure 2. Examples of the open-flume horizontal and vertical-axis Francis turbines. Left: The excavated open-flume horizontal-axis Francis turbine from the water shaft of the Shanping hydropower plant (Deng, 2021). Right: The open-flume vertical-axis Francis turbine in the old *Donghai Rice Mill* (Wang, 2010).
Source: Photos by the authors (left: 2019; right: 2024).

Taiwan's first commercially operated hydropower plants were typically dispersed. They were standalone projects belonging to local energy companies, supporting the local business grid or towns rather than a complex nationwide network. This fact applies even to the very first Taiwanese commercial hydropower plant, Guishan, developed as a mutual investment by a group of Japanese industrialists living in Taipei through the Taipei Electric Light Company (Taipei Electric Co., Ltd.) (B. Lin, 2007). Following the completion of the Guishan power plant on the Xindian River in northern Taiwan, power stations, such as Xiaocukeng, Houli, and Zhuzimen, began operating in the north, central, and southern regions. During this period, the Taiwan governor's office led the development of power plants across the island.

3.1.1. The establishment of TPC (1911)

In 1911, the Taiwan governor's office opened up the private power industry. Between 1910 and 1919, many private power companies established their businesses in various parts of Taiwan. However, the power supply model at that time was still mainly based on the towns around the power stations. In addition, the demand for electricity applications

Figure 3. Pictures from the excavation process. Left: Remaining hydraulic structures of the turbine pit and generator platform of the Guanshan hydropower plant. Middle: The open-flume vertical-axis Francis turbine installed in the powerhouse. Right: Only the tailrace draft tube at the bottom of the turbine pit remains visible.
Source: Photos by the authors (left: 2024; center & right: 2019).

from various locations continued to increase. In April 1919, the Taiwan governor's office promulgated the first TPC order, formally establishing the TPC, a combination of privately owned and state-owned enterprises (Cheng, 2024; Misato, 2015).

3.1.2. Unification of the power industry

Between 1919 and 1940, TPC acquired private electric companies in the western region. In the eastern region, the still private Eastern Electric Company successively acquired local electric companies in Hualien and Taitung. In 1943, the Eastern Taiwan Electric Power Industry Company acquired the Eastern Electric Company to establish Eastern Taiwan Electric Company, officially completing the unification of power across the eastern region. Since then, the eastern and western parts of Taiwan have been operated by the TPC and the Eastern Taiwan Electric Company, respectively (Cheng, 2024). Before the end of World War II (1939–1945) in 1944, TPC completed the acquisition of Eastern Taiwan Electric Company and established the Eastern Branch of TPC, completing the unification of the power industry in Taiwan.

As shown in Table 2, in contrast to the post-war period, the overall energy market during the Japanese Imperial period (1868–1947) was relatively liberal. Multiple energy companies owned hydropower plants and supplied the local grid, while private enterprises utilized these plants to reduce their energy costs. The multiple cases of timber, paper, hemp, tapioca, sugar, and ice factories, as well as mills for grinding crops and rice, support this fact.

The development of hydropower plants in Taiwan evolved from the colonial-era (1895–1945) support for technology to a driving force behind trade and industrialization. During the Japanese Imperial Period (1868–1947), particularly the second half, the electrification of water mills and their later retrofitting with modern turbines led to a significant decentralization of power generation in the private market. Hydropower plants secure faster, cheaper, and safer production of mechanical as well as agricultural products. The national sector was somewhat scattered and ununified, with the yet-to-be-completed island-wide power grid. However, it represented the large-scale hydropower development supplying the major cities and public facilities. Since the start of the Pacific War (1941–1945), numerous projects were either put on hold or never completed due to the technology's continued dependence on imports from Japan or other sources, and various powerhouses never received their turbine technology because the Allied forces sank the supply ships. The large-scale hydropower plants, such as the Sun Moon Lake hydropower cascade, were targets of Allied air raids (TaiwanAirBlog, 2012). As a result, the Japanese military forces painted most hydropower plants with camouflage and guarded them with bunkers (Figures 4 and 6).

3.2. Japanese Imperial period (1868–1947) grid development

3.2.1. The prototype of Taiwan's power grid

In 1905, the Guishan power station in Xindian, New Taipei, was completed, and the electricity was transmitted to the Gutingzhuang substation using an 11 kV transmission line (Huang, 2014). Furthermore, the Keelung substation in Taipei City formed Taiwan's

Figure 4. Elements of the Sanjiaopu hydropower plant, built at the bottom of the Caoshan waterway. Sanjiaopu is the only hydropower plant in Taiwan that utilizes tap water from Artesian wells, and it is also the only power plant designed after the water treatment process, demonstrating the cleanliness of hydropower technology.
Source: Photos by the authors (2022).

Figure 5. Once a pinnacle of the Japanese Hydropower Industry, the remains of the old Tóngmén powerhouse. Left: The tall generator hall in the foreground of the powerhouse. Right: The remaining ruins of the second Qingshui powerhouse background structure, built initially behind the powerhouse turbine and generator hall, still stand along the Mugua River. Both power plants faced the same fate: being entirely flooded, silted up, and subjected to severe landslides.
Source: Photos by the authors (2025).

first power grid system. Later, the Houli and Zhuzimen power stations, established by the central and southern governors' office, switched to 33 kV transmission lines as their primary power supply. According to the Taiwan Governor-General's Office Civil Engineering Bureau, the power grid in 1911 consisted of 11 and 33 kV lines. It mainly supplied small areas in cities around the power stations, namely Taipei, Keelung, and Jinguashi to the north, Taichung and Changhua in the middle, as well as Tainan and Kaohsiung to the south (Figure 7) (Cheng, 2024). Other private electric companies established in 1911 primarily supplied electricity to city centers, resulting in power plants' urban locations and the direct transmission of electricity from these plants to users without the need for substations.

3.2.2. East-west power grid after completion of the Sun Moon Lake Hydropower Project

In 1919, the Taiwan Electric Power Company was established and began preparing for the Sun Moon Lake Hydropower Project. The expectation was that the transmission line would extend from the power plant to the north and south at 154 kV (Figure 7), with the southernmost reaching Kaohsiung and the northernmost reaching Badu, Keelung. The transmission line project was completed ahead of schedule, whereas the power station project finished on schedule. The temporary wooden pole lines from Fengyuan to Taipei were completed in 1929. In 1931, the temporary wooden pole lines from Menpaitan–Taiping–Fengyuan, Jiji–Zhushan, and Zhushan–Zhuoshui were also completed (Cheng, 2022). The Zhuoshui power station was acquired from the Chia-Nan Canal Water Conservancy Association at the time, and its Zhuoshui–Wushantou 33 kV transmission line was utilized as the main trunk to the south, completing the 33 kV north–

Figure 6. Air raids and defense bunkers. Left: Zhuzimen hydropower plant, the one-man bunker against the Allied air raids and potential defense. Middle: The roadside concrete bunker guarding the access road to Xiaocukeng hydropower plant. Right: The concrete bunker guarding the entrance to the Chuying hydropower plant and the overall access to the Mugua river cascade.
Source: Photos by the authors (left: 2015; middle & right: 2024).

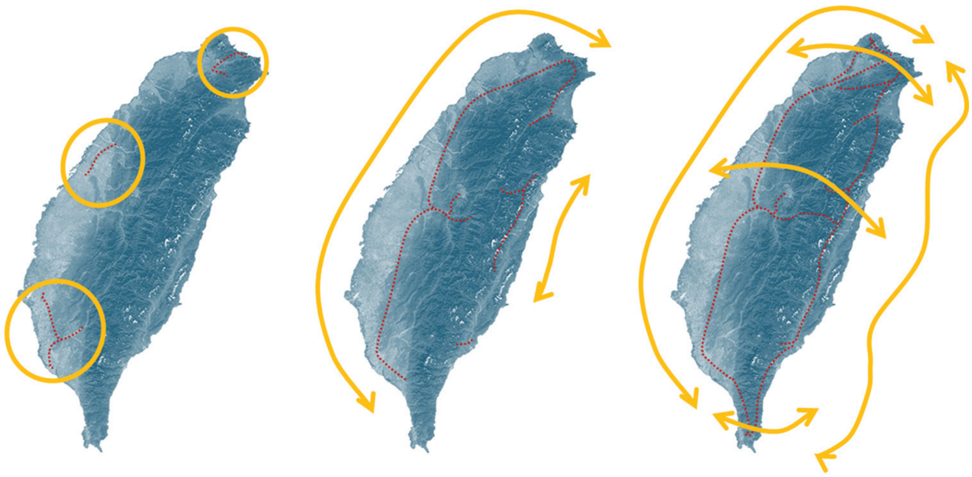

Figure 7. Simplified development of the Taiwanese grid system from the local supply. Left: The Japanese Imperial Period (1868–1947). Middle: Expansion and unification. Right: The modern smart grid system (Cheng, 2022).
Source: Drawing by the authors.

south parallel power grid system. At the same time, the Tiansongpi power station in Yilan was connected to the 11 kV transmission line of the Keelung substation, thereby including Yilan in the western power grid.

In 1934, the Sun Moon Lake Hydropower Project was entirely completed, and the north–south transmission line system in western Taiwan was officially upgraded to 154 kV. The transmission line from the Tiansongpi power station to the Keelung substation was upgraded to 66 kV, setting the standard for the 154 kV primary transmission line and 66, 33, and 11 kV secondary transmission lines in Taiwan during the Japanese colonial period (1895–1945) (Cheng, 2022).

During the Japanese Imperial Period (1868–1947), the eastern part of Taiwan was connected to the Huagang secondary substation in Hualien city in 1940, following the completion of the Tongmen power station on the Mugua river and the Qingshui power station (in the past known as the Qingshui second power station) (Figures 5 and 7). The 66 kV transmission line was connected to the Huagang secondary substation in Hualien City, and the southernmost point was Yuli, forming a local power grid system in the east. In Taitung, the 33 kV parallel Da Nan power station, Taiba Liujiu power station, and Taitung thermal power station were used to supply the city (Deng, 2018).

4. Post-war periods

4.1. Early post-war period (1945–1970)

4.1.1. United States' aid and reconstruction work

In 1945, following the end of World War II, the nationalist government arrived in Taiwan to assume control and establish the Taiwan Electricity Regulatory Commission, which was tasked with surveying various power facilities that had been operated during the Japanese Imperial Period (1868–1947). In response to the demand for electricity during the post-war period, the nationalist government actively undertook the repair of various facilities destroyed by the war and assumed control of unfinished power construction projects from the Japanese Imperial Period (1868–1947). The TPC was officially established on May 1, 1946. The most significant project at that time was the restoration of Sun Moon Lake No. 1 and No. 2 power plants, which had been severely damaged during the Allied air raids (TaiwanAirBlog, 2012).

In 1951, the United States began providing Taiwan with economic assistance in response to the Mutual Security Act, commonly known as US aid. Until 1965, the Nationalist government utilized US aid funds to accelerate the repair and takeover of numerous large-scale hydropower projects, including the Wulai power plant, Deji reservoir and Deji power plant, Tianlun power plant, Wushe reservoir and Wanda power plant, Liwu power plant, among others.

4.1.2. Small-scale private power companies with franchises before rural electrification

From the 1950s to the 1980s, TPC and the Electric Power Company, which had been established during the Japanese colonial period (1895–1945), were unable to meet the rising electricity demand. Consequently, they were permitted to issue business licenses to small-scale private power companies. During this period, numerous private power companies were established in rural areas across the east and west of Taiwan. Most of them were using diesel generators, thermal power plants, or water wheel-powered generators attached to saw and rice mills. Among them, the number of private power companies in the eastern region was the largest. Since 1954, Sun Yun-Xuan (1913–2006), the chief engineer of TPC at the time, has led the promotion of Taiwan's rural electrification project. The power grid of TPC in the western region has expanded to rural areas. Compared to private power companies, TPC's more stable and lower electricity prices have led to the decline and eventual disappearance of private power companies one after another. Most private power companies in the eastern region did not cease operations until the completion of the rural electrification project in the 1980s.

4.2. Post-war grid development

4.2.1. The restoration project of the east-west power grid in the early post-war period

In 1945, World War II (1939–1945) ended. Due to the bombing of the first and second power stations in Sun Moon Lake during the war, the 154 kV transmission system in the north and south was broken, and each formed an independent power grid. Following emergency repairs by TPC, the North of Sun Moon Lake was powered by 140 kV, the South of Sun Moon Lake by 110 kV, and other areas and the eastern region by 33 kV. In October 1946, following emergency repairs by TPC, the 140 kV power supply emergency repair project was completed in the south of Sun Moon Lake.

In November 1951, TPC emphasized that the eastern region had sufficient power generation to support the western region. With the help of the US, the east-west interconnection transmission line, which was planned but not built during the Japanese colonial period (1895–1945), was completed. Starting from the Wanda power plant in Nantou county, it crossed the Nenggao crossing road in the central mountain range to reach the Tongmen power plant in Hualien county. In September 1953, the first line transmission operation was completed, marking the completion of the integration and connection of Taiwan's east-west power grid (Figures 7 and 8). Following this, the 66 kV Hualien County Yuli secondary substation and the Taitung secondary substation were completed in 1965. The Huadong transmission line was completed, and the power grid system of the entire island of Taiwan was connected in parallel (Cheng, 2022; Deng, 2018).

4.2.2. Western 345 kV ultra-high voltage (UHV) power grid and eastern 161 kV primary power grid

In 1966, due to the imbalance between the north and south of Taiwan's power grid system, the existing 154 kV

Figure 8. The electrification monument and Chiayi substation. Left: The "Light by Eight Columns" Monument, completed in 1953, commemorates the completion of the east-west transmission line. Right: Chiayi primary substation control room built in 1934 as a substation for Sun Moon Lake's 154 kV powerline.
Source: Photos by the authors (left: 2023; right: 2017).

transmission system was unable to bear the load, and it was challenging to find a suitable site for a new power plant in the north. TPC began constructing a 345 kV UHV transmission system. It was not until 1976 that the first 345 kV UHV transmission line was completed, starting from Banqiao in the north, passing through Taichung Tianlun, and reaching Kaohsiung Gaogang, which was commonly known as "ultra-high voltage line 1." At the same time, in 1970, TPC upgraded the 154 kV transmission system to the 161 kV transmission system, and the 66 kV to the 69 kV transmission system, thereby completing the classification of Taiwan's UHV, primary, and secondary transmission systems (Cheng, 2022).

In 1979, in response to the completion of large power plants, such as the second nuclear power plant in the north and the Xiehe power plant, the northern region completed the UHV transmission loop system. In 1985, in response to the completion of large power plants, such as the third nuclear power plant in the south and the Xingda power plant, the second north-south UHV transmission line was built from Longtan in the north through Zhongliao in Nantou to Longqi in Tainan, commonly known as the "ultra-second line."

In 1980, the 161 kV primary transmission line from Fenggang, Fangshan township, Pingtung County, to the Taitung primary substation in Beinan township, via Dawu township, Taitung County, was completed (Deng, 2018). In 1987, the 161 kV primary transmission line from Taitung to Hualien was completed.

The second section of the eastern region of Taiwan was connected in parallel with the entire island's power grid. The section no longer relies solely on the 66 kV Wanda-Tongmen A and B lines for power supply.

5. Modern era (1990–2000)

5.1. Energy market liberalization

5.1.1. Opening up to the Independent Power Producers

After the 1990s, due to the difficulty in developing large-scale power generation projects in Taiwan, power generation and consumption gradually became unbalanced, resulting in a power supply reserve capacity rate of only about 5% during the summer, when power consumption typically peaks. In 1991 alone, there were 14 nationwide power outages, and 16 occurred in 1994.

The Ministry of Economic Affairs officially opened the IPP business in 1995, and large private thermal power plants, such as Haihu, Xintao, Xingneng, Xingyuan, Jiahui, and Fengde, appeared one after another. However, in response to the provisions of the Electricity Industry Act, the power transmission and distribution industry was still a franchised industry of TPC at that time. Therefore, only the power generation part would be announced by the Ministry of Economic Affairs, based on the assessment of power demand, to open the installation capacity that IPPs can apply for, allowing private power generation companies to invest and construct.

5.1.2. Energy transformation and amendments to the Electricity Industry Act

Since 2016, in response to the change of political parties in the central government, the new ruling party has comprehensively promoted energy transformation policies after taking office, gradually decommissioning nuclear power generation after the expiration of the operating license, reducing coal-fired thermal power generation, increasing natural gas thermal power generation, and vigorously promoting renewable energy, such as wind power generation and solar photovoltaics. During this period, Taiwan's electricity industry underwent a policy of liberalization. The 2017 amendment to the Electricity Industry Act is expected to split TPC into three major subsidiaries: power generation, transmission, and distribution by the end of 2025. TPC will transform into a holding company, which means that Taiwan will transition from its previous open IPP model to a fully liberalized electricity market. However, this policy promotion was hindered by several factors, including changes in the international situation, increased energy costs, and substantial investment in power construction. Until the separation deadline of TPC in 2025, the Electricity Industry Act was amended again to revert to TPC's decision to maintain the current business model without splitting.

Hydropower was not a key development project in Taiwan's energy transformation until 2017, when TPC began to cooperate with the Water Resources Agency (WRA) of the Ministry of Economic Affairs to take stock of dams and weirs under the jurisdiction of the WRA in various parts of Taiwan and promote small hydropower projects with an installed capacity of less than 20 MW, including the Taoyuan Shizhen Liantong pipeline, Miaoli Jingshan, Jiji Nan'an, and Yunlin Hushan. In March 2021, the Taiwan Small Hydropower Green Energy Industry Alliance was established, and private operators began to actively invest in small hydropower generation. This trend has continued to this day.

5.2. Modern grid development

5.2.1. Rising energy demand

Since 1994, the power demand in the northern region has continued to increase. However, the construction of power plants has been unable to keep up with the demand, resulting in the two existing UHV transmission lines being overloaded as they send electricity from the south to the north. Therefore, the government launched the third north-south UHV transmission line project. However, due to the public's growing environmental awareness and the challenges of acquiring land, the third UHV transmission system project progressed at a slow pace. It was not until the 1999 blackout and the 921 earthquake that the public became aware of the fragility of the power grid system, prompting the government to accelerate the construction of the third UHV transmission system by emergency order. In 2002, the third north-south UHV transmission line, which starts from Shenkeng Shenmei in the north, passes through Zhongliao in Nantou, and arrives at the Chiayi Chiamin UHV substation, was completed. It is commonly known as the "Ultra-Three Lines."

After World War II (1939–1945), the development of the private hydropower sector continued at two levels. The newly formed national TPC utilized the post-war US aid program to assess, rebuild, and largely continue with the originally Japanese development plans. Meanwhile, the private sector retrofitted its turbines into more modern and robust systems to support factories and agriculture. Until the 1970s, Taiwan's private energy sector developed multiple hydropower projects, which were later overshadowed by large-scale investments from TPC. Following the finalization of the nationwide grid, the electrification of rural areas, and the availability of cheaper energy from fossil fuels, the installed capacity of the hydropower sector increased in the late 1960s. The private hydropower energy market was suppressed by the TPC's cheap and stable electricity supply until its liberalization and the recent surge in small hydropower development, primarily driven by the water structures owned by the WRA, such as irrigation canals or water treatment plants.

In 1998, given the poor reliability of the eastern power grid in Taiwan, which only relied on the two 161 kV and 69 kV lines for mutual support, TPC launched the planning of the new east-west transmission line, planning to connect one line from the Daguan power plant and Mingtan power plant in Sun Moon Lake, Nantou County, through the Danda forest road in the central mountain range, across the Qicai lake, and connect to the Wanrong forest road to Fenglin town, Hualien County, and set up the Fenglin UHV substation, which became the first UHV substation in the eastern region. With the completion of the new east-west transmission line, the reliability of the eastern power grid has increased. The original 69 kV Wanda-Tongmen line, which no longer transmits power, is only pressurized and retained for backup until it was decided to be abolished and abandoned after 2016 due to maintenance difficulties (Deng, 2018).

5.2.2. The rise of renewable energy and the strengthening of the power grid after the 2000s

Following the 2000s, the backbone of Taiwan's power grid was essentially completed. TPC shifted its focus to expanding existing substations and building new transmission lines, gradually reducing the construction of 69 kV secondary transmission lines. Instead, it concentrated on limiting the voltage of 161 kV primary transmission lines to distribution lines. The plans promoted during this period included the sixth and seventh transmission, along with the transformation plans and others (TPC, 2008; Zhu, 2016).

In the 2010s, in response to the rise of science parks and renewable energy wind power generation in various parts of Taiwan, TPC changed to promote regional power grid reinforcement plans, including the first phase of the north district, the first phase of the central district, and the first phase of the south district. The plan is to directly supply power between power plants and science parks to reduce the risk of power outages caused by routes passing through multiple substations. In response to the wind power grid connection, multiple booster stations were added in the western coastal areas, and the transmission capacity of the existing power grid was expanded. In addition, a 161 kV submarine cable was constructed in 2011 to connect the Sihu substation in Yunlin County to the primary substation in Penghu, allowing Penghu island and Taiwan to be connected in parallel and form a power grid by 2021. This move is also in response to the Penghu Low Carbon Island Plan, which is expected to install offshore wind power stations near Penghu and transmit excess electricity back to Taiwan (TPC, 2025b).

5.2.3. Current operation structure of the Taiwan power grid

Currently, the Taiwan power grid is operated by the TPC as a franchised sole operator, with transmission systems at 345 kV, 161 kV, and 69 kV, distribution systems at 22.8 kV and 11.4 kV, and the central dispatch control center serving as the dispatching backbone. The Taipei Central Dispatching Center, located in the Taipei TPC General Administration Office, and the Kaohsiung Central Dispatching Center, situated in the Kaohsiung–Pingtian Power Supply District Operation Office, are responsible for the 345 kV UHV transmission and transformation system, as well as power plants. There are six area dispatch control centers in Keelung, Taipei, Hsinchu, Taichung, Xinying, and Kaohsiung. The Hualien–Fenglin UHV substation oversees dispatching operations in the Hualien–Taitung region and is responsible for the 161 kV primary transmission and transformation system, as well as the

69 kV transmission lines. The TPC regional business offices throughout Taiwan have distribution dispatch control centers and feeder dispatch control centers, which are responsible for the 69 kV secondary substation and the 22.8 kV/11.4 kV distribution systems, among other responsibilities (Figure 7) (F. Lin, 2019).

6. Technical and architectural aspects

6.1. Architecture and design

The early hydropower plants in Taiwan were constructed during the Japanese Imperial Period (1895–1945), when the colonial style, initially based on traditional Western forms, was slowly shifting toward a more modern approach. The architecture, construction, and façade appearance of the first Taiwanese hydropower plants were heavily influenced by the initial Japanese colonial esthetics, with forms reflecting traditional Japanese woodcraft and timber architecture. This style was later combined with Baroque and Neoclassical elements, as well as early modernist industrial design principles.

Powerhouses and auxiliary buildings were constructed with an emphasis on functionality. However, they also reflected stylistic influences from the Meiji, Taisho, and early Showa periods, blending imperial Japanese formalism with emergent global trends in industrial architecture. Generally, the hydropower architectural styles in Taiwan could be roughly divided into 4 periods.

(i) First half of the Japanese Imperial Period (1868–1919) (Xiaocukeng [1909], Zhuzimen [1908]).
(ii) Second half of the Japanese Imperial Period (1920–1947) (Sanjiaobu [1931] [Figure 4], Yuanshan [1941]).
(iii) Post-war period Japanese revival and functionalism (Tongmen [1955], Shimen [1964]).
(iv) Current sustainability trends (Lijia [2023], Hushan [2025]).

The first half of the Japanese Imperial Period (1868–1919) was an era of significant Japanese architecture, an icon of colonialism, exemplified by the work of Uheiji Nagano. Despite being built as functional structures, the hydropower buildings were characterized by a dominant blend of Baroque and Neoclassical elements, which were influenced by Western styles introduced from Japan. The era is characterized by symmetrical façades, hipped or gabled roofs with specific monitor tops, oculi, and bottom ventilation slots, as well as decorative elements, such as tilework and wooden eaves, particularly in publicly exposed facilities (Figure 9). These western-influenced proportions, with subtle Japanese ornamentation and a sense of precision and detailing, create a hybrid style unique to colonial Taiwan. From a material point of view, the commercial hydropower houses based in the vicinity of cities of this era, despite being pioneering engineering structures, continue to face mostly natural challenges. They could be considered mastered technology in comparison to remote hydropower houses, which were much more exposed and built with less durable materials, mostly found on-site. For example, Fanshekeng had a wooden headrace canal, whereas the Neiwan headrace structures, as aqueducts, were built from bamboo-reinforced concrete, a precursor to reinforced concrete (RC), due to the lack of steel (Tkáč, 2019). In general, the remote powerhouses used local/aboriginal stone masonry (flat stone technique) (Chen, 2006), or they were built mainly from wood and straw.

The second half of the Japanese Imperial Period (1920–1947) marks the rise of modernist trends in the 1930s and

Figure 9. The typical Oculus window of publicly exposed facilities. Left: Homage to the legacy at the façade of the new Zhuoshui unit. Middle: Part of the Zhuoshui hydropower plant's main façades. Right: Part of the significantly symmetrical Zhuzimen hydropower plant's main façades.
Source: Photos by the authors (left & right: 2015; middle: 2019).

1940s, as hydropower plant façades began to resemble American Art Deco and the German Bauhaus movement, shifting the entire style toward linear, stripped-down functionalism (Figure 4). RC and steel-frame construction became the standard, allowing for broader spans and more efficient internal layouts, often with multiple floors to accommodate modern vertical technology. This technology typically consisted of a turbine hall at the bottom and a tall generator hall on top (Figure 5). However, there were still cases that faced engineering challenges, such as the early penstock of the Sanjiaopu powerhouse, which was initially made of ceramic. However, according to a report by the University of Science and Technology of China (CUTe, 2008), the material was later changed to welded mild steel due to the lack of stainless steel, the significant water pressure, and concerns about the quality of drinking water from artesian wells.

The post-war period focused on finishing, rebuilding, and later expanding the projects left by the Japanese. Hence, most of the hydropower plants were finished or newly built, reflecting elements of both previous Japanese eras. However, the rise of floor plants and the need to accommodate new, advancing technologies pushed ornaments aside, giving way to a focus on utilitarianism and functionality. However, the latest powerhouses are the Wanda unit No. 3 or Wanda-Songlin unit, despite both being utilitarian structures, their façades begin to show attempts to reflect cultural identity through the use of colors and a revival of Aboriginal patterns, much like the very first remote hydropower houses built at the very beginning of the Japanese Imperial Period (1868–1947).

The modern era, marked by the liberalization of the energy market in 1994, allows for more freedom in choosing styles and technologies. However, this time, it reflects the beauty of mechanical parts in environmentally friendly enclosures, incorporating light and recyclable materials, along with the revival of wooden frames, marking a reconnection with the Japanese Architectural studios once again. Another factor is the ability of the powerhouse to be educational; hence, modern SHPPs are adopting an open-technology design approach whenever possible. For example, Lijia and Hushan SHPPs (TSHPIA, 2024; TSHPIA, 2025).

The first Taiwanese hydropower plants were remarkable engineering marvels that leveraged the island's steep topography and abundant hydrological resources. However, these cases were also engineering pioneers struggling with the challenges of the island's volatile weather, changing hydraulic conditions, landslides, earthquakes, and, relatively often, landslides. All the adjustments and alterations in the successive projects were lessons learned from sometimes disastrous experiences, proving how important it is to design hydropower plants in coherence with the surrounding conditions. For example, the oldest Guishan hydropower plant (1905) used to have a marking of the flood level on the wall, which later led to the redesigning and fortification of the entire powerhouse. These modifications could be later seen in other projects, especially in the second half of the Japanese Imperial Period (1920–1945), as various forms of floodwalls, levees, or raised constructions eventually led to adopting the vertical axis technology submerged in the underground substructure in the projects designed between 1930 and 1945, and even after the Nationalist government took over. The flooding problems finally gave way to underground cavern types in 1955, which, after the unfortunate and ironic complete flooding of the cases of Qingshan (the last projects with the US aid program) and Guguan caverns in 2004 and 2002, became equipped with a specific blast door capable of withstanding pressure from potential flooding.

6.2. Engineering features

The hydraulic works layouts of hydropower plants often followed a linear plan along the riverbed, allowing gravity to do much of the work. Broadly, these structures were divided into the headrace, powerhouse, and tailrace sections. Specifically, the key hydraulic works included a sophisticated combination of hydraulic retention structures (e.g., Guishan hydropower plant's diversion dam, the first RC structure in Taiwan [Xia *et al.*, 2005]), water conveyance systems such as culverts, hydraulic tunnels, aqueducts, siphons, and imported state-of-the-art turbine technologies (e.g., Guishan [1905] and Zhuzimen [1908] hydropower plants, notable dual Francis Camelback turbines with horizontal and vertical inflow, respectively). Often, the most exposed structures were those of the hydraulic works around the intake and powerhouse; thus, in most historical and excavated cases, the remaining structures are those carrying water from the intake to the powerhouse (Taibaliujiu [Taiping, 1925], Hualien port I [Shapodang I, 1920], Hualien port II [Shapodang II, 1927]) (Figure 10).

As presented in Tables 2 and 3, the majority of early hydropower plants in Taiwan utilized reaction turbines due to the ability to retrofit the existing mills. The Japanese developers generally preferred low heads and large flow volumes facilitated by abundant rainfall and relatively complex yet cost-efficient penstock technology. The preference for lowland locations also avoided potential insurgencies and attacks by the indigenous people living in the high mountain areas, protecting their territories. This was a particularly exposed problem at the very beginning of the hydropower industry, where, in fact, many Japanese

Figure 10. Remains of the forebay tanks of the two power plants responsible for supplying the Hualien Port. Left: Shapodang II. Right: Shapodang I.
Source: Photos by the authors (2024).

Figure 11. Daguan I, a powerhouse. Left: The penstock. Right: Turbine hall.
Source: Photos by the authors (2016).

died during clashes with the indigenous population. Hence, in the spirit of mutual respect and to prevent loss of life, each time a powerhouse was planned, rigorous negotiations were led with the tribal leaders, essentially asking for permission to use the tribal land.

The initial reaction turbine technology follows global development trends, utilizing open-flume Francis turbines with vertical arrangements in cases of mill retrofitting or dual-action Francis turbines with horizontal arrangements due to maintenance and accessibility considerations. This approach is informed by the fact that the first hydropower plants in Taiwan were built at ground level. Later, impulse turbine technology, specifically the Pelton runner, was also introduced, as it perfectly aligns with the ground-level architecture. Although the first recorded use of the Pelton turbine dates back to 1906 in the Gengziliao powerplant, Pelton turbines were used more broadly in the late 1920s and early 1930s, following the resolution of problems with the indigenous people in 1924–1926, which included the removal of all guard posts and the dismantling of the Aiyong Line (Evanhoe, 2008; Ye, 2019).

The impulse turbines were either single or dual horizontal Pelton turbines with dual nozzles (Taiwan's only vertical shaft Pelton runner was installed in the underground Bihai unit in 2011). Furthermore, Taiwan's largest power plant using Pelton turbines is the former Sun Moon Lake power plant No. 1, as photographed in Figure 11—it was built in 1934 and is now known as Daguan I. At the time of its construction, it was the largest power plant in Asia and the seventh largest in the world. Whether impulse or reaction turbines, the technology was imported primarily from Swiss, German, and Japanese manufacturers, as well as from the USA, reflecting Taiwan's reliance on foreign technology during its early energy development phases. Except for four cases built between the 1980s and early 1990s as a stride for domestically produced technology, namely Liugui, Shuili, Houlizhen, and Longxi power plants, the turbine technology in Taiwan has been predominantly imported to this day.

The half-submerged architecture, featuring turbine technology, was located exclusively in the substructure, with the generator positioned in the superstructure. It emerged alongside the shift from horizontal to vertical technology arrangements and was primarily implemented to address lessons learned from typhoons, floods, and earthquakes. The vertical arrangement became available during World War II (1939–1945), which explains why most power plants from that era were equipped with vertical Francis or Kaplan turbines.

The first underground or so-called cavern-type architecture was implemented only a decade after the end of the Japanese Imperial Period (1868–1947), in 1955, near the Mugua River, adjacent to a Tongmen power plant. The original turbines were extracted through the roof of the entirely silted-up powerhouse and placed into the cavern above and to the right of the original powerhouse. This case also marks the beginning of the retrofitting period during Taiwan's nationwide repair of the power generation facilities left behind by the Japanese. The retrofitting and expansion era was led by the newly formed national TPC established by the Taiwan Provincial Government.

7. Cultural and historical legacy

7.1. Preservation and heritage

To recognize the significance of the island's early industrialization, several sites, including the historic Guishan power plant site, Xiaocukeng, Houli, Zhuoshui, Sanjiaobu (Figure 4), Danan (Dongxing), and the old Zhuzimen power plant, have been designated as cultural heritage monuments by the Ministry of Culture. These powerhouses feature original architecture and fully mechanical components, offering tangible insights into early 20^{th}-century engineering practices and the quality of manufacturing at the time. As the old powerhouses housing century-old machinery were no longer efficient, new powerhouses were built next to them, rather than allowing the transformation of the old powerhouses into industrial history museums or public exhibits. This is the case of the Zhuoshui (P. Cai, 2022) and Zhuzimen (Joci, 2020) old power plants, which now feature visitor centers and interpretive displays curated in collaboration with local historical societies (Figure 9). Another perspective on heritage site studies would be an immeasurable and unique source of information on operation. Based on a comparative study (Figure 12) between HPPs and currently operated HPPs, including those recently developed by the private sector, it is clear that Taiwan is slowly redeveloping the same hydropower corridors that were previously established. Thus, information from historical studies on a particular corridor can only help engineers improve their design by learning from recorded disasters that exposed the limitations of old powerhouses or by selecting the right technology for a specific river profile, which has already proven crucial in several newly built SHPPs.

7.2. Public perception and education

As of 2016, the TPC initiated a series of heritage-engaging exhibitions to raise public awareness of its valuable industrial heritage. Among the first exhibitions were hydropower-related events, such as the 2018 Exhibition of Hydropower Plants and their history, titled "Power Infrastructure as Landscape," which showcased the history, development timeline, and original blueprints of Japanese-era (1868–1947) hydropower plant projects (TPC, 2018). In 2019, the TPC opened an exhibition titled "Just Flow" to celebrate the 100-year history of hydropower. The exhibition showcased artifacts from individual HHPs as part of TPC's cultural heritage (TPC, 2019). Following these two events, TPC established various educational facilities at the individual hydropower plants, including the hydropower units, such as the Tianpi unit in Yilan, the Tongmen unit in Hualien, the Guishan unit in Wulai, and the old Zhuzimen unit in Meinong. However, the complete reimagination or adaptive reuse of these structures has yet to take place, as it is quite challenging to transform these spatially concrete structures into another function that aligns with the still-operational units built alongside. In contrast to cases like the Japanese adaptive reuse of the former Taisho-era (1912–1926) Nizayama hydropower plant (1925) into the Nizayama Forest Art museum (Nizayama, 2025), the Taiwanese cases are still in the rediscovery and conservation phase. Since the technology in the mentioned Taiwanese cases is still fully operational and the powerhouses are connected to their original water sources, following the case of the 1904 Slovak hydropower plant Lubochna (MVE, 2017), they can be turned into fully functional museums with an exposition of the fully mechanical technology.

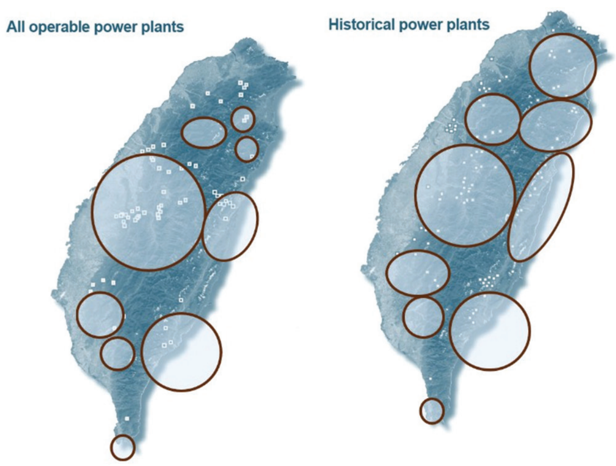

Figure 12. Comparison based on on-site mapping of all the Taiwanese hydropower plants. Left: The 65 recently operating hydropower plants. Right: All 111 historical cases.
Source: Drawing by the authors.

Hydropower plants are also subject to festivals. There are cultural festivals, often held in proximity to historic hydropower plants, for example, an annual waterway festival in Sanjiaobu (Figure 4), where the public can see the artesian wells, the interior of the powerhouse, and many other parts of the famous Caoshan waterway, built as the second stage of the drinking water source for Taipei city. It was the Japanese engineer Sano Tojiro (1869–1929), a student of the famous William Kinnimond Burton (1856–1899), both fathers of the water supply systems in Japan and Taiwan, who designed the entire waterway system.

8. Conclusion

The 120 years of the hydropower sector in Taiwan are closely tied to the first commercial use of electricity, marking a sustainable approach to harnessing the region's abundant natural resources. The study shows the cross-section of the multifaceted legacy of Taiwan's HHPs, tracing their evolution from early 20th-century Japanese colonial infrastructure to critical elements of Taiwan's modern energy system. The research represents the first attempt to present the topic comprehensively in connection with the development of the necessary infrastructure, with the hope of serving as a foundation for a more detailed investigation.

The findings reveal how these hydropower plants not only catalyzed industrialization but also served as platforms for technological innovation and regional development, and even contributed to socioeconomic transformation. The TPC and the Taiwanese government recognize their value as industrial heritage sites, both nationally and regionally, due to their engineering significance and continued operational presence. Historical hydropower infrastructure is essential not only for understanding the technical accomplishments of the past but also for drawing lessons on resilience, sustainability, and adaptive reuse in the recent era, where discussions related to climate uncertainty have become an inevitable part of engineering practice.

Comparative studies using countries where the Taiwanese hydropower technology originates from, e.g., Japan, Germany, Switzerland, or the US, and cross-reference it with similar hydropower developments in countries, such as Japan, Malaysia, Indonesia, Philippines, Korea, and Hawaii, could also shed light on shared challenges and diverse approaches to Pacific Climate and mountainous hydroelectric development. Such investigations will deepen our appreciation of Taiwan's hydropower legacy, connect Asia-Pacific historical hydropower development, and surely help guide sustainable transitions in energy infrastructure worldwide.

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Conflict of interest

The authors declare that they have no competing interests.

Author contributions

Conceptualization: Štefan Tkáč
Formal analysis: Štefan Tkáč
Investigation: All authors
Methodology: Štefan Tkáč
Writing–original draft: Štefan Tkáč
Writing–review & editing: All authors

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data

The data are publicly available via an interactive map on our research lab webpage: https://sites.google.com/view/slovaktaiwanhydropowerresearch/tw-hpp-map?authuser=0. As this represents ongoing research, the online dataset is subject to periodic updates and may change over time.

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