# Ex-Post Analysis of the Tianhuangping Pumped Hydro Storage Project

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# ABSTRACT

The Tianhuangping pumped hydro storage plant is one of the largest globally and has been operational for over 20 years. It is in the East China region, supplying electricity to Shanghai, Zhejiang, Jiangsu, and Anhui. This paper is an ex-post benefit-cost analysis of the Tianhuangping pumped hydro storage project. It estimates the project's net cash flows. It uses it to evaluate the financial impact of the project from the owner's perspective. The analysis projected that the project yielded $34 million in NPV terms to the project owners.

From an economic perspective, the Tianhuangping pumped hydro storage was combined with a coal plant with a capacity sufficient to provide the energy required to pump water into the upper reservoir of the Tianhuangping plant during the off-peak demand period. This pumped storage and coal plant integrated system was compared with HFO and natural gas turbines to estimate the most cost-effective option of providing peak demand power. With the social carbon cost considered, the Tianhuangping pumped hydro storage and coal integrated system was the most cost-effective option. It was estimated to provide peak energy at $0.15/kWh instead of the natural gas-fired turbines and HFO-fired turbines estimated to provide peak energy at $0.16/kWh and $0.17/kWh, respectively.

**Keywords**: financial analysis, cost-effectiveness, pumped hydro storage

ÖZ

Tianhuangping pompalı hidro depolama tesisi, dünyanın en büyüklerinden biridir ve 20 yılı aşkın süredir faaliyet göstermektedir. Doğu Çin bölgesinde, Şangay, Zhejiang, Jiangsu ve Anhui'ye elektrik sağlıyor. Bu makale, Tianhuangping pompalı hidro depolama projesinin sonradan fayda-maliyet analizidir. Projenin net nakit akışlarını tahmin eder. Sahibinin bakış açısından projenin finansal etkisini değerlendirmek için kullanır. Analiz, projenin proje sahiplerine NPV cinsinden 34 milyon dolar kazandırdığını öngörüyordu.

Ekonomik açıdan, Tianhuangping pompalı hidro depolama, yoğun olmayan talep döneminde Tianhuangping tesisinin üst rezervuarına su pompalamak için gereken enerjiyi sağlamak için yeterli kapasiteye sahip bir kömür santrali ile birleştirildi. Bu pompalı depolama ve kömür santrali entegre sistemi, en yüksek talep gücü sağlamanın en uygun maliyetli seçeneğini tahmin etmek için HFO ve doğal gaz türbinleri ile karşılaştırıldı. Sosyal karbon maliyeti dikkate alındığında, Tianhuangping pompalı hidro depolama ve entegre kömür sistemi en uygun maliyetli seçenekti. En yüksek enerjiyi sırasıyla 0,16 $ / kWh ve 0,17 $ / kWh olarak tahmin edilen doğal gazla çalışan türbinler ve HFO ateşlemeli türbinler yerine 0,15 $ / kWh olarak sağlayacağı tahmin ediliyordu.

**Anahtar Kelimeler:** finansal analiz, maliyet etkinliği, pompalı hidro depolama

# DEDICATION

To my wife and family

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Foremost, I would like to express my sincere gratitude to Prof. Dr. Glenn P. Jenkins. Throughout this thesis, he provided me with continuous guidance, resources, and advice. He showed me how to apply classroom-taught economic theory in real-life analysis. His enthusiasm, tenacity, and applied approach inspire and encourage me as a student.

I am also indebted to Dr. Pejman Bahramian for his mentorship as I ventured into this analysis. Taking on a thesis can be a daunting task, especially for the first time. His systematic disintegration of the topic into less daunting parts showed me the ropes. I am very appreciative of his guidance.

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# Chapter 1

# INTRODUCTION

Electrical Energy Storage Systems help to convert electricity to any form that it can store and reconvert back to electricity when needed. They are commonly used to supply peak power (Guédez, Spelling, Laumert, & Fransson, 2014) (Hadjipaschalis, Poullikkas, & Efthimiou, 2009). They also act as backup power in an energy system where the base generation is unavailable (Li, et al., 2018). They incorporate intermittent sources feasible, making them more incorporated into electrical grids as more and more renewable energy generation sources are being sought out (Carbajales-Dale, Barnhart, & Benson, 2014) (Suberu, Mustafa, & Bashir, 2014). Moreover, they help to stabilize the electricity load on the grid (Masaud, Lee, & Sen, 2010). Various technologies can be used for the energy storage system, and there has been numerous literature comparing these various systems for various scenarios (Hadjipaschalis, Poullikkas, & Efthimiou, 2009) (Akinyele & Rayudu, 2014) (Díaz-González, Sumper, Gomis-Bellmunt, & Villafáfila-Robles, 2012) (Connolly, 2009) (Alamri & Alamri, 2009) (Ma, Yang, & Lu, 2014). While there have been numerous relative advantages revealed between these systems, pumped hydro storage is the system that has the largest capacity (Rehman, Al-Hadhrami, & Alam, 2015).

A pumped hydro storage system uses excess energy to pump water from a reservoir at a lower altitude into a high altitude reservoir and releases it back into the lower reservoir through a turbine to produce energy when needed. Despite being a net consumer of electricity as machines cannot have an efficiency of 100%, the pumped storage ability to consume energy at points where the marginal cost of generation is low and provide during peak periods is what makes it economically viable.

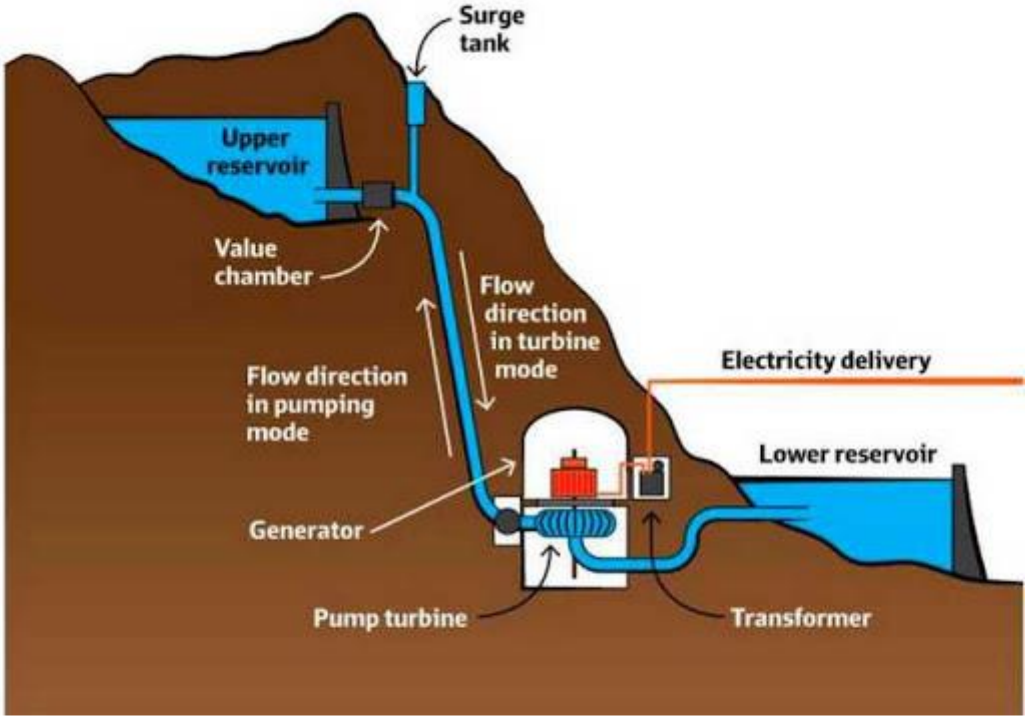



Figure 1. Mechanism of the pumped hydro storage system (Climate Change Balmain-Rozelle)

Over the past half-century, many countries' interest in pumped hydro storage has been steadily increasing as the intermittent renewable energy generation systems become more common (Deane, Gallachoir, & McKeogh, 2010). Being the best form of large scale energy storage, historically, pumped hydroelectricity storage accounts for 95% of the capacity of all stored operational forms of electricity worldwide (United States Department of Energy - Office of Electricity, Sandra National Labs, 2020) and 99% of all bulk electricity storage worldwide (Drax Group, 2017).

## 1.1 Advantages

An advantage of pumped hydro storage over some other electrical storage systems is that it is highly renewable; that is, pumped hydro storage plants usually have a lifespan above 35 years while an alternative like the lead-acid battery has a lifespan of 5 years (POWERTHRU). Using water, gravity, and turbines, the pumped storage plant in itself generates no carbon emission, although the power source being used to pump might be a coal plant – as it is in this particular case of the Tianhuangping pumped storage. Many pumped hydro storage plants have generated power in a minute or less when activated from the switchyard (Naish, McCubbin, Edberg, & Harfoot, 2008) and have low operational and maintenance costs. A pumped hydro storage plant does not need much natural water for its operation, reducing its resource-specific requirements and making it feasible where conventional run-of-the-stream hydro plants would not be possible. Many plants are also used for alternative uses in addition to their primary purpose of electrical energy storage. Some plants serve as tourist attractions - promoting energy tourism in the region and generating external demand for the nearby region, some are used to improve the irrigation system of the nearby farmlands, and some are used for recreation in cases where the velocity of the water is not too high, and so on.

## 1.2 Disadvantages

Its opponents have pointed out some detractions of the pumped hydro storage system. Owing to the scale of pumped hydro storage projects, they have a high capital expenditure requirement; thus, they can have significant implications on the balance of payments of the implementing country (Trisko, Gilead, Johnson, & Sasaki, 1975). Scudder (2012) pointed out that corruption problems have also been observed in many projects, but that occurs with many large capital projects. There already exist some concerns about the construction of large dams; as pumped hydro storage projects invoke the construction of even more dams, the concerns with large dam construction directly translate into this electrical storage system as well. Large dams have been known to have adverse effects on the surrounding ecosystem. It leads to temperature change in the water and alters the expected timing of the run of the stream and its natural distribution, which has direct impacts - geophysical and chemically (World Commission on Dams, 2000). This will cause the water quality to change and affect the primary ecosystem, e.g., planktons, which depend on the natural characteristics of the environment for survival. Without the continual survival of the primary ecosystem, other organisms ahead in the food chain will be severely hampered. The land requirement of large dams and pumped storage projects can negatively affect the inhabiting forest and terrestrial animals (Berhkamp, McCartney, Dugan, McNeely, & Acreman, 2000). Some hydroelectric reservoir dams are also known to emit carbon at low levels, although this is highly site-specific (Rosa & dos Santos, 2000). The project's long duration makes it difficult to appraise properly as many dams usually pass through several changes in political regimes and are subject to force majeure events. There is usually a lack of political will to follow the state of the art procedures; this is especially true for social and environmental matters (Scudder, 2012).

As many countries move to reduce carbon footprint, pumped hydro storage systems have been successfully integrated into their electricity grid. However, a pumped hydro storage project is highly complicated in design, with massive capital cost and a long operational period, it is particularly prone to a considerable level of discrepancy between the planned project and the actual occurrence; in terms of overruns – cost and time, project design, financing, and societal impacts (Awojobi & Jenkins, 2015). The building boom of pumped hydro storage plants has generated an unresolved debate in the energy policy discipline. The construction of large dams, which often require relocation of the local inhabitants, has been detrimental to river basins and impoverish the locals living below the dams since the natural flood pattern is usually crucial for the way they live.

# Chapter 2

# CHINA

## 2.1 Background

The energy production in China was mainly from coal (Wang & Chen, 2010). In 1991, it derived 74% of its total energy production from coal, with oil making up 19%, hydroelectric power making up 4.6%, natural gas with 2%, and the rest from other sources. China has the 4th largest coal reserves globally, which make up 13% of the world total (Mining Technology, 2020). In 2018, it accounted for 46.7% of the world's total coal production while simultaneously becoming the most significant coal importer. The large consuming centers of coal are East China and Central China, while the regions with the best quality coal are Shanxi and Inner Mongolia. The Southwest region accounts for 70% of China's hydroelectric potential, and other energy resources apart from coal, oil, and hydropower were only used in remote regions. China has been steadily increasing its hydroelectric power since the early 1900s. 1900-1949 was characterized by dam development for water conservancy, 1950-1978 was characterized by dam development for irrigation and flood control. With its adoption of the open-door policy, 1978 to 2000 was characterized by the construction of huge dams for hydropower development which saw China leap from a late arrival to the industry to an internationally leading country in various aspects (Jia, 2016). Post-2000, China has continued its international dominance with projects like the South-to-North Water Diversion and the Three Gorges Dam. This saw China lead the world in hydropower generation by a substantial margin, generating 1,232.9 TWh in 2018 compared to a distant second, Brazil, which generated 417.91 TWh in the same year (Statista, 2019). Many hydropower projects, especially early on, were run-of-the-stream projects that did not help with peaking power. While the first pumped hydro storage plant, the Hebei Gangnan Mixed Pumped Storage Station with a capacity of 11 MW, was commissioned in 1968, there was no pumped storage development till the 1990s, except for Miyun Pumped Storage Station with a capacity of 22MW. The arrival of the 1990s saw China invest in pure pumped hydro-storage projects that did not require any natural water, and they invested in large capacity projects that continued into the 21st century. China is not just looking to increase its overall pumped hydro-storage capacity; it has been improving the technology in various ways; for example, adjustable speed units are being employed in the Fengning pumped-storage hydroelectric project (GE Power, 2018).

## 2.2 Energy Sector & Reforms Over the Years

The federal agency for energy purposes in China at the time of the project was the Ministry of Energy. It was created in 1988 to control the use of energy resources and control energy policies. Also established in the same year was the China Energy Investment Corporation (CEIC) and entrusted with managing project financing in the electricity sector. The State Planning Commission (SPC) is the ultimate authority for project approval and funding arrangements.

## 2.3 Implementing Agency

The implementing agency in charge of this project is the East China Electric Power Group Corporation (ECEPGC). As at the time of appraisal, it was known as the East China Electric Power United Corporation (ECEPUC); and before 1989, it was known as the East China Administrative Authority (ECEPA), which was under the supervision of the Department of Defence, and was authorized to oversee government offices in Shanghai, Jiangsu, Zhejiang, and Anhui. After provincial utilities were created in each latter-mentioned region as part of the effort to isolate private and state electricity companies, ECEPGC served as an amalgamation of the local utilities in these regions.

# Chapter 3

# THE PROJECT

The Tianhuangping hydro project is in Anji County, Zhejiang Province. A Special Purpose Vehicle (SPV) was created to manage the project so that all the funding can be pooled together from the various parties. The project was operated by a Limited Liability Company (LLC) known as East China Tianhuangping Pumped Storage Company, Ltd. The lower reservoir is at Daxi Creek by the Xitiao River; the upper reservoir is at an artificial basin in the mountains.

Figure 2. The upper reservoir of the Tianhuangping pumped hydro storage (Wikipedia, 2009)

## 3.1 Objectives & Outcome

The Tianhuangping pumped hydroelectric project was made to accomplish a variety of objectives. Key objectives include:

1) Reduce peak power shortage: The transition from central planning to a market-based economy in the 1980s was characterized by a rapid increase in electricity demand, causing the power generation to be eclipsed by its demand (Zhao, 2001-20). This led to electricity shortages during peak periods up to 20% of demand, which hampered the industrial sector. Electricity shortages have been analyzed to negatively impact productivity (Ozturk, Aslan, & Kalyoncu, 2010), and China was no exception (Yuan, Kang, Zhao, & Hu, 2008). The pumped hydro storage will use the surplus energy available during off-peak periods to pump water from the lower reservoir into the upper reservoir. Releasing this water from the upper reservoir back into the lower reservoir during the peak demand period through a turbine will generate electricity for public consumption. This objective was attained as the project was able to add 1829 MW of peak capacity.
2) Grid balancing, load leveling, and frequency modulation: Disparity between electricity fed into a grid and the electricity consumption from that grid leads to an electricity black-out. The proportion of electricity consumption by consumers is shown below.

Table 1. The proportion of electricity consumption by sector

| **Sector** | | **The proportion of electricity consumption** |
|---|---|---|
| **Industrial sector** | | 62% |

| | | |
|---|---|---|
| **Households** | | 24% |
| **Services** | | 9% |
| **Agriculture** | | 5% |

Apart from the shortage of peak electricity facing the region, there is a large disparity between the capacity needed to satisfy peak electricity demand and the off-peak demand (night) with the large proportion of total electricity consumption. The Tianhuangping hydroelectric project was able to add to the peak electricity generation and increase the off-peak demand for electricity with which water was pumped from the lower reservoir into the upper reservoir. In 2000, it was able to reduce the peak- off-peak capacity load difference by 3400 MW which was 32.44% of the peak- off-peak load difference of the East China grid, and in 2001, it was used about a dozen times to correct abrupt grid frequency by causing it to drop from an abrupt 0.49 Hz to normal 0.14 Hz (Barry Trembath, 2002). The impact of the project was only partially successful in accomplishing this goal. This is because the prevailing market price of electricity does not convey the marginal cost of electricity to the consumers, severely hampering electricity load management. While trying to encourage foreign private investment for an increase in electricity generation, China was committed to energy price reform. The focus was on liberating the on-grid electricity tariffs, especially for renewable energy sources, which allowed electricity-generating projects to recover their costs and generate enough profits (Wee & Wee, 2003). While the electricity generation market was opened for liberalized and experienced increased competition, the transmission and distribution market is a monopoly dominated by the State Grid Corporation of China (SGCC) (Ming, Kun, & Daoxin, 2013).

3) Emergency operation: In addition to peak shaving, off-peak filling, grid balancing, frequency modulation, and load leveling, the Tianhuangping pumped-hydro storage was also called upon to serve as a backup for occasions when an emergency need for electricity generation arise. It was successfully called upon as backup for emergencies ten times in 2001 (Barry Trembath, 2002). With the pumped hydro storage technology's ability to liquidate stored water into electricity in a matter of minutes, they frequently serve as backup during the outage of central generating plants, ensuring grid safety and minimizing risk.

## 3.2 Project Design and Components

### 3.2.1 Original Components

The project was designed by the East China Investigation and Design Institute (ECIDI) in 1990 (ECIDI, n.d.). The location chosen was geographically favorable due to ease of accessibility and the varying degrees of altitude, albeit there was a drawback to the location, which was the soil's weathering, but this was not without a solution.


Figure 3. Tianhuangping pumped hydro storage reservoir (Zhejiang, China, 2016)

The original components of the projects include:

1. Construction of upper and lower reservoirs, water conveyance systems, underground power plants, and hydroelectric power plants.
2. Supply and installations of six single-phase 300 MW turbine power stations.
3. Laying 500 kV transmission lines for 250 km to strengthen existing transmission lines.
4. Environmental management plan.
5. Construction management and engineering services.
6. A study of the optimum operating and production costs of the plant.
7. Staff training

The feasibility study, which was also developed by the East China Investigation and Design Institute (ECIDI) in 1990, was submitted to the World Bank Institute per standard project financing practices. With the large scale of the project, a group of consultants comprising foreign and local experts was formed to review the proposed designs and advise on engineering procedures, construction issues, and dam safety systems (The World Bank, 1993). The East China Investigation and Design Institute (ECIDI) agreed with the East China Power United Corporation (ECEPUC) to further assist during project implementation.

The preparatory works began in June 1992 as planned and started with the access road construction, which totaled 21.4 km lengthwise. An access tunnel of about 1 km was constructed along with two pump stations with a water supply totaling 988 $m^3$ hourly. The power supply was integrated with a with substations – 110 kV/35 kV substation of 12.6 million volt-amperes (MVA) and 35 kV/10 kV substation, and power distribution lines totaling 69 km at various levels of voltage. Also, part of the preparatory works was a diversion tunnel with dimensions 445 m by 5 m by 5.6 m (length by breadth by height) and a communication system. The construction system consists of an optical table of 18 km, a communication cable of 47 km, and a program-controlled exchanger of 250 ports.

Both reservoirs are regulated daily. The upper reservoir is elevation 905.2 meters above average pool level with an adequate capacity of 881.23 cubic meters ($m^3$), and the lower reservoir is at elevation 344.5 meters above average pool level with an adequate capacity of 802.08 cubic meters ($m^3$). The average water conduit length is 1428 meters with a head of 570 meters, making the length to head ratio one of the smallest in the world (Wang & Liu, 2005). There are two headrace tunnels (inclined shafts), lined with concrete, with a length of 882.2 meters and a diameter of 7 meters. There are six penstocks with lengths varying from 229.9 meters to 314.7 meters and diameter ranging from 2 meters to 3.2 meters feeding into the six pumps/turbines. Equally, six tail-water tunnels were constructed for the tail-water system, lined with both steel and concrete, with a diameter of 4.4 meters and lengths varying from 229.3 meters to 246.6 meters. A 500 kilovolt (kV) dry-cable gas-insulated-switchgear was also installed to protect and de-energize electrical devices. An underground powerhouse was also constructed with 198.7 meters by 21 meters by 47.73 meters (length by breadth by height).

Two hundred ninety-eight staff members of the implementing corporation, ECEPUC, from various departments across the organization were sent abroad in 39 groups for further technical training. This was done to strengthen the organization's ability to handle such large projects by transferring financial systems from similar French and British companies like Electricité de France (EDF) and increasing technical abilities in mechanical, electrical, and mechatronic engineering.

## 3.3 Environment Management Plan

The environment management plan aimed to understand the potential negative impacts of constructing the Tianhuangping pumped-hydro storage plant and create and carry out a plan to reduce the identified impacts to an acceptable level. ECIDI started the analysis of potential impacts in 1986. The THPCC spearheaded the environmental management plan in conjunction with ECIDI. The multi-organization team also employed the services of supervision engineers and contractors. In the implementation, precautions were taken against reducing water quality, downstream effects, landslide, seismic activity, and rural displacement.

## 3.4 Contract Procurement

The procurement of contracts was done following the procurement guidelines of the World Bank in 1993. Pump/turbine units, control system, substation equipment, construction equipment, and bituminous concrete lining were procured via International Competitive Bidding (ICB), with a margin of preference of 7.5% provided for domestic contractors for the procurement of civil works and the lower of import duty of goods and 15% of its CIF price advantage given to locally manufactured goods. The local components of the project were procured via Local Competitive Bidding (LCB). Foreign firms were allowed to participate in the local biddings, but the local components' prevailing domestic prices were below world prices. Limited International Bidding was used for procuring contracts of lower cost, i.e., cost below $200,000 per contract, and they tally up to $2 million.

A consortium led by Kvænar won the contract of $160 million to supply powerhouse equipment, with partners such as Elin Energiversorgung (VA Technologie) and GE Hydro. Elsag Bailey and Elin Energiversorgung were contracted to supply the control system to the East China Power Dispatch Centre (ESPDC) (Power Technology).

## 3.5 Design Changes

The switchyard, which was planned to be constructed west of the upper reservoir, was alternatively constructed closer to the control center and outgoing high-voltage lines exiting the main transformers, which was 500 meters lower than the planned location. Although this relocation came with higher construction cost for the component in question, the choice was made due to ease of operation and cheaper equipment cost as it reduced the investment needed to purchase equipment to connect the high voltage part of the main transformers to the 500 kilovolt (kV) gas-insulated-switchgear located in the switchyard.

A new component added to the project was constructing two new 500 kV substations named the Hangdong and Sijing substations. The Sijing substation was constructed in Songjiang county, Sijing town, Shanghai, while the Hangdong substation was constructed at Qiaosi town, near Hangzhou, Zhejiang Province. This component is discussed in 3.7 alt.

## 3.6 Implementation Delays

Time overruns are quite common in large-scale projects, and this case was not an exception. The beginning of the bituminous concrete lining of the upper reservoir was delayed by heavy rainfall in 1995 and led to a delay in consequent operations ending in a 4-month delay in reservoir impoundment. In 1996, a landslide occurred due to torrential rainfall, which filled the river bed where the lower reservoir was supposed to be constructed with 200,000 cubic meters ($m^3$) of weathered volcanic rock mass; the volume of dirt into the river bed was about two-thirds of the total landslide. The Tianjian Corporation extracted the rock mass filling by the landslide unstable slopes were consolidated to prevent any similar event in the future (Chen, Zhang, Ho, Wu, & Li, 2008). This caused an additional 8-months delay in construction and was estimated to have caused a direct cost increase of ¥258.37 million but has worked out well as there has been no account of landslide since then.

There was a breakdown of winding insulation in 3 of the main transformers. The cause of these breakdowns was pinned to the cooling systems supplied by a subcontractor. 2

of the units were rejected and ordered from a local supplier while the other one was repaired. This led to delays ranging from 2-14 months in the commissioning of these units.

## 3.7 Hangdong & Sijing Substations

The construction of these 500 kilovolts substations is a new component of the project that was not included in the initial appraisal. The Sijing substation was constructed in the plains of the Yangtze River delta in the suburban of Shanghai beside the small Sijingtang River, 13 km away from the city's urban regions. The Hangdong substation was constructed at the north bank of Qiantangjang River, west of Hangzhou bay, 22.5 km away from Hangzhou urban. Hangzhou is the capital of Zhejiang Province. The location chosen for constructing these substations was away from schools, hospitals, cultural relics, factories, and highly populated regions.

### 3.7.1 Rationale Behind the Construction of the Substations

Electricity consumption in the Shanghai region was growing at a faster pace than the national average. For example, from 1991 to 1995, electricity consumption grew at 10.87% annually in the Shanghai region. This was 9.99% higher than the national average. As more and more power generation sources were being developed to reach the growing demand, power networks' construction was usually lagging. This caused frequent overloading of the existing power networks led to unsafe operations. Without the construction of the added transmission capacity by the Sijing 500 kilovolts substation, the prior power system will not have the capacity to balance power demand and output. The prevailing power network in the region was 220 kilovolts. The construction of the 500-kilovolt substations also helped link the existing 220 kilovolts regional power systems to the 550-kilovolt central system while alleviating power shortage problems in the places north the Huangpujiang River.

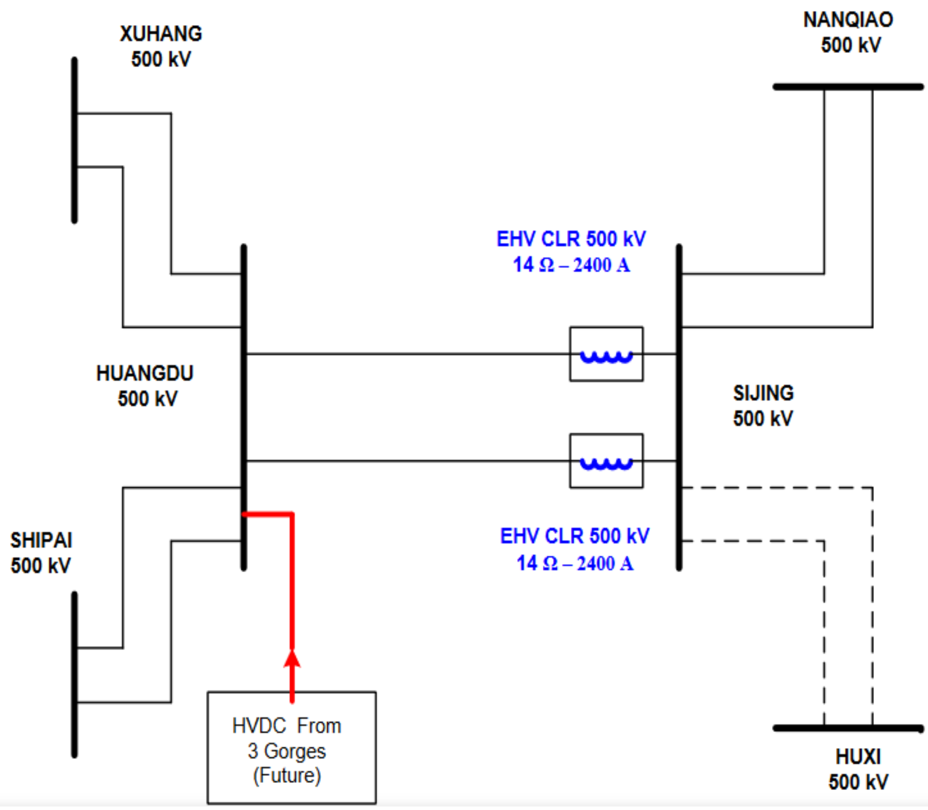



Figure 4. How the Sijing substation fits into the Shanghai 500 kV system (Cigre Comite Chileno)

The Hangdong substation is part of the Government's plan to construct grids to take large currents and quickly transfer electric power from the north to the south and from the east to the west.

The Sijing substation is located close to the loading central, making the transfer of power from the system to the 220-kilovolt power grid an easy feat, increasing the south power grid's overall reliability. It will meet the power demand of the south power grid of Shanghai while also meeting the Shanghai Power Grid's step-down capacity.

### 3.7.2 Components of the Substation

The components of the substation subproject include:

1. Environmental Impact Assessment (EIA).
2. Resettlement Action Plan (RAP).

3. Preparatory works.
4. Construction of civil works.
5. Erection and testing of substation equipment.


Figure 5. The Sijing 500 kV substation (Cigre Comite Chileno)

### 3.7.3 Environmental Impact Assessment for the Substations

The impact of the added substation components was evaluated by the Nanjing Environmental Protection Research Agency (NAPRI) in 1998.

#### 3.7.3.1 Treatment of Water

##### 3.7.3.1.1 During Construction Period

Due to the nature of the site chosen for these substations' construction, they were not close to any essential assets that needed relocation. The rivers located close to the substations are less than 80 meters in depth, so there was no requirement to build the tows in the water for output transmission lines, reducing the water bodies' impact. The main effect on the surrounding water bodies occurred during the construction period when some 15 $m^3$ was consumed daily to construct each of the substations. This water consumption was mainly used for mixing concrete. The impact of the water consumption on the rivers was negligible. A precipitate tank was used to treat the living water consumed by construction persons and was only discharged after the region's standard discharge requirement was reached.

#### 3.7.3.1.2 During Operational Period

During the operational period, the staff and workers in each substation consume about 15 $m^3$ of water daily. Also, wastewater sewage of approximately 12.5 $m^3$ is generated daily with $BOD_5$ (5-day biochemical oxygen demand) concentration between 160 – 280 milligrams per liter and suspended solids ranging from 280 – 400 milligrams per liter. This is then treated before being discharged for irrigation purposes.

Oil leaks were rarely seen. The oil leaks came mostly during maintenance and were minimal. According to regional rules, the oil wastewater is discharged after being treated until the oil concentration is below 10 milligrams per liter.

#### 3.7.3.2 Treatment of Dust

The transportation of soil sediment during the construction phase led to the creation of rising dust. The impact of this will not be on a large scale and will be short-lived as it disappeared post-completion. Nevertheless, measures were taken to reduce the rising dust effect, following the construction management guidelines of both the World Bank and the regional authorities. These measures included spraying transported sediment with water, covering soil surfaces with fabric, and installing construction dust screens around the construction site. No dust or atmospheric pollution is generated during the operational phase of the substations.

**3.7.3.3 Treatment of Noise**

**3.7.3.3.1 During Construction**

Some of the machines employed for construction had high noise levels. The highest of which came from excavators, which had noise ranging from 95 to 110 decibels. Other construction machines had noise levels ranging from 85 to 100 decibels. The prevailing regulation regarding noise level in the regions is shown in the table below.

Table 2. Legal noise limits in the PRC as at implementation

| **Standard name & class** | **Regulated decibels** | |
|---|---|---|
| | **Daytime** | **Night-time** |
| **Urban environment noise standard (National Standard of the People's Republic of China, 1993)** | 55 | 45 |
| **Boundary noise standard for industrial enterprises (Environmental Quality Standard for noise, 1990)** | 55 | 45 |
| **The boundary noise limit for construction site (Environment Quality Standard for Noise, 1990)** | 65-85 | 55 |

The noise impact from the construction boundary range from 57 to 82 decibels at a meter from the construction site. Due to the regulations, machines that made a high amount of noise were only used during the day.

**3.7.3.3.2 During Operation**

The predicted noise levels before execution are detailed in the table below.

Table 3. Appraised noise levels of the substations

| | Noise level at 1m outside the fence (decibels) | | | | |
|---|---|---|---|---|---|
| | **East** | **South** | **West** | **North** | **Centre** |
| **Sijing substation** | 44 | 46 | 45 | 47 | 57 |
| **Hangdong substation** | 45 | 46 | 45 | 46 | 56 |

During operation, the noise level was similar to the Doushan 500 kilovolt substation and the Jiangdu 500 kilovolt substation. Being located in rural areas, the acoustic environment was suitable, and the noise levels met the requirements according to the prevailing regulations. This was per the planned scenario.

**3.7.3.4 Resettlement Action Plan**

The Resettlement Action Plan (RAP) was entrusted by East China Electric Power Group Corporation to be prepared by East China Investigation and Design Institute (ECIDI) in September 1998 per the legal regulations of the country, region, and World Bank standard guidelines to detail measures that would be taken for the resettlement and/or rehabilitation of people affected by the project or Project Affected Persons (PAPs).

**3.7.3.4.1 Land Acquisition and Project Affected Persons**

The implementation of the Sijing substation planned to acquire 140 mu (~9.3 ha) of land. The acquired land was a paddy field that was owned by an agricultural collective. One hundred eight mu (~7.2 ha) of the acquired land was from the Zhaojia group, while the remaining 32 mu (~2.1) was from the Xiaochang group. The Hangdong substation implementation was similarly planned to use 146.1 mu (~9.74 ha) of land, which was also farmland from the Xinye group and Hexing Group in Hongqi Village. With the optimization of the chosen sites, there were no residents at either site to be resettled, hence reducing the cost that might have been needed for the resettlement of project-affected persons.

Although there was no need to replace houses or resettling people since no one lived on the acquired farmlands, the farmland represented people's livelihood, and as such, there was a need for economic compensation. The actual occurrence of events required a slightly less amount of land than the planned scenario; hence, fewer people were affected economically. The comparison between the planned scenario and actual occurrence is shown in the table below.

Table 4. Planned vs. actual occurrences of the RAP

| | Land requisition (mu) | | Farmers affected (people) | | Rural labor affected (people) | |
|---|---|---|---|---|---|---|
| | Planned | Actual | Planned | Actual | Planned | Actual |
| **Sijing** | **140** | **122** | **134** | **118** | **87** | **78** |
| **Hangdong** | **146** | **147** | **9** | **9** | **6** | **6** |
| Total | 286 | 269 | 143 | 127 | 93 | 84 |

As shown by the table above, the reduction in the acquired land from the appraised 286 mu to the actual 269 mu caused the number of farmers affected by the paddy farm acquisition to drop from 143 farmers to 127 farmers and the number of rural people whose source of livelihood were impacted to drop from 93 people to 84 people.

#### 3.7.3.4.1.1 Compensation

The compensation paid for the acquired land from the villages essentially went according to the planned scenario. The main difference occurred in the green crop compensation rates. This is because the green crop compensation rate is calculated based on the seasonal outputs and the actual compensation occurred in a different season than the appraised season. The comparison between the planned compensation and the actual occurrence of events is shown in the table below.

Table 5. Planned vs. actual compensation for PAPs of Hangdong & Sijing substations

| | **Land compensation (¥/mu)** | | **Labour compensation (¥/person)** | | **Crops compensation (¥/mu)** | | **Total compensation (¥/mu)** | |
|---|---|---|---|---|---|---|---|---|
| | **Appraised** | **Actual** | **Appraised** | **Actual** | **Appraised** | **Actual** | **Appraised** | **Actual** |
| **Sijing** | 8,800 | 8,800 | 40,000 | 40,000 | 1,600 | 2,000 | 127,929 | 140,000 |
| **Hangdong (Village)** | 7,200 | 7,200 | 9,600 | 9,600 | 600 | 500 | 79,056 | 75,000 |
| **Hangdong (ZXADC)** | | | | | | | 10,200 | 51,700 |

The appraised and actual compensation rates were fixed at ¥40,000 per labor for Sijing but ¥9,600 per mu for Hangdong. In addition to the compensation for land, labor, and crops to Xiaochang village for the Sijing substation, as shown above, a pension fund worth ¥6.9 million was set up for the elderly occupants of the village, and an equal amount of farmland which was nationally reserved was allocated to the village's project affected persons in compensation of the lost land.

For the Hangdong substation, only 5.1 mu of the 146.5 mu acquired was from Hongqi Village, with the remaining 141.4 mu acquired from the Zhejiang Xinghai Agricultural Development Company (ZXADC), which is a state farm. Hongqi Village was compensated ¥7,200 per mu for the acquired land. ¥30,000 was used to improve the village's infrastructural facilities, and ¥55,680 was shared among village group members. Land, which is the same as that acquired from the village, was also allocated to the farmers affected by the land acquisition.

Compensation for land acquisition from the Zhejiang Xinghai Agricultural Development Company (ZXADC) went differently from those of the Xiaochang and Hongqi Villages. A single compensation was paid to the corporation, which amounted to ¥7.3 million, vastly different from the planned ¥1.44 million. An amount of ¥1.58 million was also disbursed to the state farm corporation for infrastructural and irrigational improvements.

Following the land acquisition, the Xiaochang Village had a per capita income increase annually by 12.3% for the two years (1999 - 2000). The per capita income of the Hongqi Village increased by 6% annually during the same timeframe.

## 3.8 The Loan

The project, which was developed domestically, was submitted to the World Bank for the PRC's financial assistance after domestic approvals. The agreed loan of US$ 300 million was negotiated with the country for 20 years, with a 5-year grace period. The disbursement follows a Bank standard of 9 years, and the interest rate charged was the World Bank's standard variable interest rate. An assurance was agreed with the Government to on-lend the loan's disbursements to ECEPUC for a maximum loan duration of 20 years, with the same interest rate and similar grace period; although ECEPUC bore the commission charges and foreign exchange risk. ECEPGC was able to complete the loan repayment in 15 years.

## 3.9 Mechanical Completion

Mechanical completion of any project refers to the completion stage to sustain production at a specified capacity for a certain period. The Tianhuangping pumped hydro storage project was mechanically completed in 2001, albeit electricity generation began in 1998. The target overall conversion efficiency rate at appraisal at completion was 74%; this was increased as the actual plant operated at an overall conversion efficiency of 80.12%, 81.60%, 80.63%, and 79% from 1999 till 2002. The indicators of the status of its mechanical completion are shown in the table below.

Table 6. Mechanical completion of the Tianhuangping pumped hydro storage plant

| **Indicator** | **Target at completion** | **1999** | **2000** | **2001** | **2002** |
|---|---|---|---|---|---|
| **Unit availability** | 88% | 81.97% | 54.90% | 86.30% | 93.22% |
| **Plant service power rate** | N/A | 0.29% | 0.23% | 0.26% | 0.20% |
| **Overall conversion efficiency** | 74% | 80.12% | 81.60% | 80.63% | 79.00% |
| **Successful generator start-up** | 99% | 94.46% | 97.00% | 98.99% | 99.31% |
| **Successful pump-turbine start-up** | 97% | 86.09% | 86.14% | 94.36% | 97.72% |
| **Successful shut-down** | 99.5% | 97.01% | 98.98% | 99.43% | 99.78% |
| **Successful mode change** | N/A | 98.91% | 98.81% | 99.79% | 99.69% |

The average overall conversion efficiency at completion was better than the targeted 74% and reaching 80% till 2002. It describes the ratio of electricity the pumped hydro storage plant will generate from the power required to pump the water into the upper reservoir. The plant service power rate is the proportion of generated electricity used by the same plant. It is the difference between the gross electricity generation and the electricity generation that is available for sale. Low unit availability in 2000 was caused by a powerhouse flooding which incapacitated it. Anti-flooding measures were taken against. Unit availability was significantly lower than targeted for the initial two years of operation but closed the gap in 2001 and eclipsed the target from 2002. This was the same case for the rate of successful start-ups of the available pump-turbine units, which was over 10% below target for the first two years before closing the gap by mechanical completion and eclipsing its target by 2002. The success rate in shutting down the latter was slightly below target in the first year of operation but was a target range from there on out.

Each pump/turbine unit has a maximum capacity of 306 MW; hence the total capacity of the six pumps/turbine units of the Tianhuangping is 1,836 MW. The total peak hour in the region is 1,404 hours per annum, and it is during this period that plant will be in operation. At peak capacity, the plant will be able to generate gross energy of 2,578 GWh. A fixed plant power rate of 0.4% was assumed. This assumed rate was conservative but appropriate as it will balance out as the plant wears out.

Consequently, the net capacity of the Tianhuangping plant is 1,829 MW, and the net energy produced by the plant and available for sale is 2,567 GWh at the 1,404 hours of utilization. As time goes on, it is typical for the plant's wear and tears to cause a reduction in overall efficiency. The proportion of annual reduction in overall conversion efficiency was taken as 2.62%.

# Chapter 4

# METHODOLOGY & DATA

The data used for the analysis was mainly obtained from project documents made publicly available by the World Bank. The project analysis carried out employs the cost-benefit approach. This appraisal employs data and information based on actual project completion data. The data projected in the analysis began in 2003, with all figures of the 11 years before that period being the actual figures reported by THPCC and the World Bank.

## 4.1 Financial Analysis

For the financial analysis, one is only considering the pumped hydro storage investment as a standalone project. It buys off-peak energy for pumping and sells energy during peak demand periods. The financial impact of the project was analysed for 37 years (1992 till 2028) since the operation began. To mitigate the risk of price fluctuations for energy purchased, a power purchase price for pumping was agreed upon. This power purchase price was only allowed to fluctuate based on the inflation seen in the sector; that is, the producer price index reported in the electricity sector was used as the escalation factor of the cost of power purchase. Also, a two-part tariff was agreed. The two-part tariff system, as the name suggests, consists of 2 prices merged to form the plant's compensation for energy sale. It consists of an energy price and a capacity price. The capacity price represents the fixed cost of the plant, while the energy price compensates for the variable costs of the pumped hydro storage plant. This was to make sure that the cost of the electricity produced by the plant was fully compensated and the private investors were able to get decent returns for their investment. The 2-part tariff policy was implemented during an era where the Government had a priority to increase private and foreign investments in the power sector. Hence, while many electricity projects approved post-1990 had some sort of marginal cost pricing, there are many plants in the grid with highly inefficient pricing patterns. Although the energy output of the Tianhuangping plant to the grid was priced efficiently during peak hours, this was not the case for many other plants in the grid. The prevailing market price of electricity does not reflect the marginal cost of production due to cross-subsidization and other artificial-based pricing mechanisms used by the Government (Wang, Zhou, & Yang, 2017).

The lack of efficient peak pricing of all energy generation sales to the grid severely limits load management and energy conservation by consumers. This is because allowing marginal cost pricing to consumers makes people will cause people to adjust their energy consumption habits, shifting energy consumption during peak periods to off-peak periods wherever possible. This will cause the load duration of the grid to change and will reduce electricity costs across the grid. Abhyankar et al., (Abhyankar, Lin, Liu, & Sifuentes, 2020) analysed the southern China grid and estimated that market-based operation, which will lead to efficient pricing, will reduce electricity cost by up to 35% relative to the 2016 baseline.

Since the pumped hydro storage is a net consumer of electricity, marginal cost pricing is imperative to its financial lucrativeness. If the price of energy during off-peak periods is similar with the price in peak periods, then the pumped hydro storage project will be financially unattractive. The financial net present value (FNPV) is the criterion used to evaluate the financial feasibility of the project. The |FNPV can be expressed as in equation 1 below.

$$FNPV_{t=0} = \sum_{t=0}^{k} \frac{Inf_t - Out_t}{\prod_t (1+r_t)} \qquad (1)$$

Where $Inf_t$ denotes the financial inflows both from operation and the residual value of the assets in year *t*, $Outf$ denotes the outflows accumulated in producing the energy available for sale, *k* denotes the total number of years that the analysis was carried out for, *t* refers each year, and *r* denotes the discount rate. Financial inflows to the project are denoted as in equation 2.

$$Inf = \big(Capt \times Cap \times (1 - PSR)\big) + (Ent \times Cap \times hrs \times (1 - PSR)) + RV \qquad (2)$$

Where $Capt$ represents the capacity tariff per MW of net capacity non-inclusive of tax, $Cap$ refers to the gross capacity of the plant in MW, $PSR$ refers to the plant service power rate, $Ent$ refers to the energy tariff excluding tax per MWh at which peak time electricity is sold. The number of hours that the plant will be operated per annum is denoted as *hrs*, and $RV$ represents the residual value of assets during the final year of analysis after the effect of depreciation has been subtracted. The plant service rate describes the proportion of energy generated that is used by the plant itself. It represents the difference between the gross energy generated and the energy that is available for sale. The financial outflows from the project are given by equation 3 below.

$$Outf = Capex + Enp + (Ovh \times Cap) + O\&M + Tax \qquad (3)$$

Where $Capex$ refers to the annual capital expenditure spent during each year of the construction period, $Enp$ refers to the cost of energy purchased for pumping, $Ovh$ refers to the overhead cost per MW, and $O\&M$ refers to the operation and maintenance. The cost of energy purchased to pump the water is given by equation 4 below.

$$Enp = \frac{Cap \times hrs}{Eff} \times Cpp \tag{4}$$

Where $Eff$ refers to the proportion overall energy conversion efficiency of the plant, and $Cpp$ represents the pre-agreed price of power purchased/kWh to pump the water for storage. The O&M cost consists of the maintenance cost, material cost per MW of installed capacity, and labour cost for workers inclusive of added benefits of pension, welfare, and housing benefits. Mathematically, the operation and maintenance cost for any given year *t* is derived as equation 5.

$$O\&M_t = \left(W^{no.} \times S^{avg.} \times (1 + pens + welf + hous)\right) + \left(Main_{2001} \times (1 + 0.74\%)^{(t-2001)}\right) + (Matr \times Cap) \tag{5}$$

Where $W^{no.}$ denotes the number of workers employed at the plant and $S^{avg.}$ denotes the average salary of plant workers. The proportion of employer's contribution to workers' pension, welfare, and housing are denoted by $pens$, $welf$, and $hous$ respectively. The maintenance cost was indexed to the maintenance cost expended in 2001 and escalated by 0.74% annually to compensate for additional wear and tear with time. Also, $Matr$ denotes the material cost per kW of installed capacity.

## 4.2 Economic Analysis

This section analyses the Tianhuangping pumped hydro storage from the perspective of the society. In measuring the benefit of electricity projects, the 'least alternative cost' principle is employed. (Jenkins et al., 2019) declares that "this principle states that one should not attribute to a project a value of benefits that is greater than the least alternative cost one would have to incur by providing an equivalent benefit stream in a different way". In employing the  least cost principle, the alternative cost that would have been incurred instead of the appraised project represents the benefit of the appraised project since that would be the amount spent if the appraised project is not undertaken. There are 2 common ways in which this is done for electricity projects. One method is to analyse all viable options to compare all levelized costs, and the other is to establish a standard alternative that can serve as a benchmark for comparison purposes. For this economic analysis, the Tianhuangping pumped hydro storage plant was compared with a standard gas-fired turbine alternative. The standard alternative is a gas turbine operating to supply peak power for 1404 hours per annum, giving it a load factor of 16%, which is the same as the Tianhuangping pumped hydro storage plant runs for.

While the gas turbine generates its own electricity, the pumped hydro storage plant has to rely on excess energy from the coal plant in the off-peak period to generate the energy which it stores in the form of water to convert back into electrical energy during peak period. Hence, for this analysis it is important to consider the source of electrical energy used to power the pump for filling the pumped hydro storage plant. The energy used by the Tianhuangping pumped hydro storage was bought from coal plants, at a subsidized price/MWh. Seeing as it is essential to incorporate the coal plant with the pumped hydro storage unit, the economic analysis was set up to also compare the levelized costs of a pumped hydro storage and coal integrated unit versus gas-fired turbine units. The nature of the economic analysis is further explained in 5.3 below.

Mathematically, the levelized cost of a plant *i* is given by equation 6 below.

$$LC_i = \frac{\sum_{t=0}^{k} \frac{C_{it}}{\prod_t (1+EOCK_t)}}{\sum_{t=0}^{k} \frac{Cap_{it} \times hrs_{it} \times (1-PSR_{it})}{\prod_t (1+EOCK_t)}} \qquad (6)$$

Where $EOCK_t$ represents the economic discount rate in the year *t* which was taken to be 12%, $C_{it}$ represents the economic value of capital costs and variable costs of plant *i* in year *t*, $Cap_{it}$ refers to the capacity of plant *i* provided to the grid in year *t*, $hrs_{it}$ refers to the amount of hours per annum that plant *i* was utilized for in the year *t*, and $PSR_{it}$ refers to the plant service power rate, which describes the proportion of the gross energy produced by the plant which it uses for itself instead of passing it on to the grid. The numerator of equation 6 above represents the cost valuation in present value terms, while the denominator represents the valuation of the energy generated to the grid. The economic valuation of the cost of a plant *i* is composed of 2 parts as shown by equation 7 below.

$$C_{it} = Capex_{it}^{e} + Opex_{t}^{e} \tag{7}$$

Where $Capex_{it}^{e}$ represents the economic valuation of the capital cost for plant *i* and $Opex_{it}^{e}$ refers to the operating costs for plant *i*. The latter is described, mathematically, by equation 8 below.

$$Opex_{it}^{e} = O\&M_{it}^{f} \times Cap_{it} \times hrs_{it} + O\&M_{it}^{v} \times Cap_{it} \times hrs_{it} + CE \times C0_{2i} \times Cap_{it} \times hrs_{it} + FR_{i} \times FP_{it} \times hrs_{it} \times Cap_{it} \tag{8}$$

Where $O\&M_{it}^{f}$ refers to the unit energy cost of the fixed part of the operation and maintenance costs for plant *i*, $O\&M_{it}^{v}$ refers to the unit variable part of the operation and maintenance cost for plant *i*, $CE$ refers to the monetary valuation of carbon cost to the environment, $C0_{2it}$ refers to the carbon factor of the fuel used in powering plant *i*, $FR_{it}$ refers to the fuel requirement of the fuel used for plant *i*, and $FP_{it}$ refers to the price of fuel used for plant *i* in year *t*. The capacity for the coal plant is described mathematically by equation 9 below.

$$Cap_{c} = \max_{t=0\to k} \frac{Cap_{p} \times hrs_{pt}}{\left(\frac{eff_{pt} \times \left((Capf_{c} \times 8760) - hrs_{pt}\right)}{1+PSP_{C}}\right)} \tag{9}$$

Where $k$ denotes the total number of years that the analysis was carried out for, $Cap_p$ denotes the gross capacity of the pumped hydro storage plant, $hrs_{pt}$ denotes the amount of hours that the pumped hydro storage plant was used for the year $t$, $PSP_c$ denotes the plant service power rate of the coal plant which is the ratio of gross energy generation that the coal plant uses for itself, $eff_{pt}$ refers to the efficiency of the pumped hydro storage plant for the year $t$ expressed in percentage, and $Capf_c$ denotes the capacity factor of the coal plant.

# Chapter 5

# RESULTS

This section discusses the outcome of the ex-post analysis of the Tianhuangping pumped hydro storage project. Firstly, the sources and uses of funds both ex-ante and ex-poste are presented. Then the financial feasibility of the project is evaluated. The next step in the analysis is to determine the economic feasibility of the pumped hydro storage as opposed to the standard gas turbine is measured in the form of cost savings to the east China grid.

## 5.1 Sources and Uses of Funds

Here, the sources of financing that made up the capital cost is evaluated. The allocation of pooled equity is described. A loan worth $300 million was agreed between the World Bank and the People's Republic of China. The table compares the planned sources and uses of funds statements made at appraisal with the actual occurrences during the implementation of the project.

Table 7. Actual vs. planned sources and uses of funds of the Tianhuangping plant (Real 2001 values)

| SOURCES AND USES OF FUNDS AT APPRAISAL | | ACTUAL SOURCES AND USES OF FUNDS | |
|---|---|---|---|
| **Sources of funds** | **Million $** | **Sources of funds** | **Million $** |
| IBRD | | IBRD | |
| Project loan | 300.00 | Loan disbursement | 260.50 |
| TCC | 2.90 | TCC | 2.50 |
| Government Companies | | Government Companies | |
| SEIC | 139.13 | SEIC | |
| ECEPUC | 34.78 | ECEPGC | 219.48 |
| SPDC | 104.35 | SPDC | 131.69 |
| JPIC | 69.57 | JPIC | 87.79 |
| ZPPDC | 46.38 | ZPPDC | 58.53 |
| APPDC | 23.19 | APPDC | 29.26 |
| Total sources of funds | 720.30 | Total sources of funds | 789.75 |
| | | | |
| Uses of proceeds | | Uses of proceeds | |
| Civil works | 164.00 | Civil and preparatory works | 259.00 |
| Pumped hydro goods | 325.90 | Pumped storage goods | 288.45 |
| Services | 54.00 | Services | 59.70 |
| TCC-related financing | 3.50 | TCC-related financing | 2.50 |
| Interest during construction | 172.90 | Interest during construction | 180.10 |
| **Total uses of funds** | **720.30** | **Total uses of funds** | **789.75** |

The loan given to the People's Republic of China by the World Bank was lent on to ECEPGC. It is discussed more in 3.8 üst. The TCC represents the equity received from the federal Government described as technical credit. After the CEIC was restructured, its stake and commitment were taken over by ECEPGC. The power generated from the pumped storage plant was agreed to be shared with each municipality power company per the capital contribution. The reduction in the disbursed loan was because the loan was disbursed against all the foreign costs of civil works, imported equipment, and consulting and training services. Intense competition during the international competitive bidding (ICB) procurement process led to a significant reduction in price than what was initially assumed at appraisal. The real cost overrun for the actual pumped hydro storage plant is 9.6%.

Table 8. Planned vs. actual sources and uses of funds for the Hangdong and Sijing substations (Real 2001 values)

| **SOURCES AND USES AT APPRAISAL**<br>**Sources of funds** | **Million $** | **ACTUAL SOURCES AND USES**<br>**Sources of funds** | **Million $** |
|---|---|---|---|
| IBRD | 25.92 | IBRD | 17.18 |
| Government | 65.22 | Government | 46.86 |
| Total sources of funds | 91.14 | Total sources of funds | 64.04 |
| | | | |
| Uses of funds | | Uses of funds | |
| Civil and preparatory works | 23.84 | Civil and preparatory works | 29.62 |
| Substation goods | 54.74 | Substation goods | 30.09 |
| Services | 3.01 | Services | 0.71 |
| Interest during construction | 9.55 | Interest during construction | 3.62 |
| **Total uses of funds** | **91.14** | **Total uses of funds** | **64.04** |

The real cost underrun for the construction of the Hangdong and Sijing substations was 29.7%. This underrun offset some of the overrun in the construction of the actual pumped storage plant. In total, the entire project had a cost overrun of 5.2% in real. This overrun is impressive when the effect of the landslide is taken into consideration. This contributed to an overrun in domestic costs leading to a general overrun in the project although there was an underrun in the foreign costs.

## 5.2 Financial Impact

This section discusses the project as it impacted the domestic owners who contributed to its capital. It evaluates the return that the project generated to the domestic owners of the project, regarding them not as government agencies, but purely as capital investors.

Figure 6 shows the net cashflow of the project to its owners. The capital investment began in 1992 and construction was concluded in early 2001. Operation, however, began with the commemoration of the first pump turbine unit which was in September 1998. Other units were employed in years following. The total outflow was calculated according to equation 3 above. With the investment cost ending in 2001, the cost post-2001 was the operating cost required to run the plant. The total inflow was calculated as equation 2 above. The commissioning of the first unit in late 1998 accounts for the relatively small inflow in 1998. The operation was analysed for 30 years. This makes 2028 the year where the project closes and remaining assets are sold off. Hence, the inflow shown in 2028 is simply the residual value from the sale of existing asset after economic depreciation loss has been accounted for. The financial net cashflow, which refers to the difference between the total financial inflows and outflows of the project is shown in below, both from the perspective of the project owner as well as the total investment point of view.

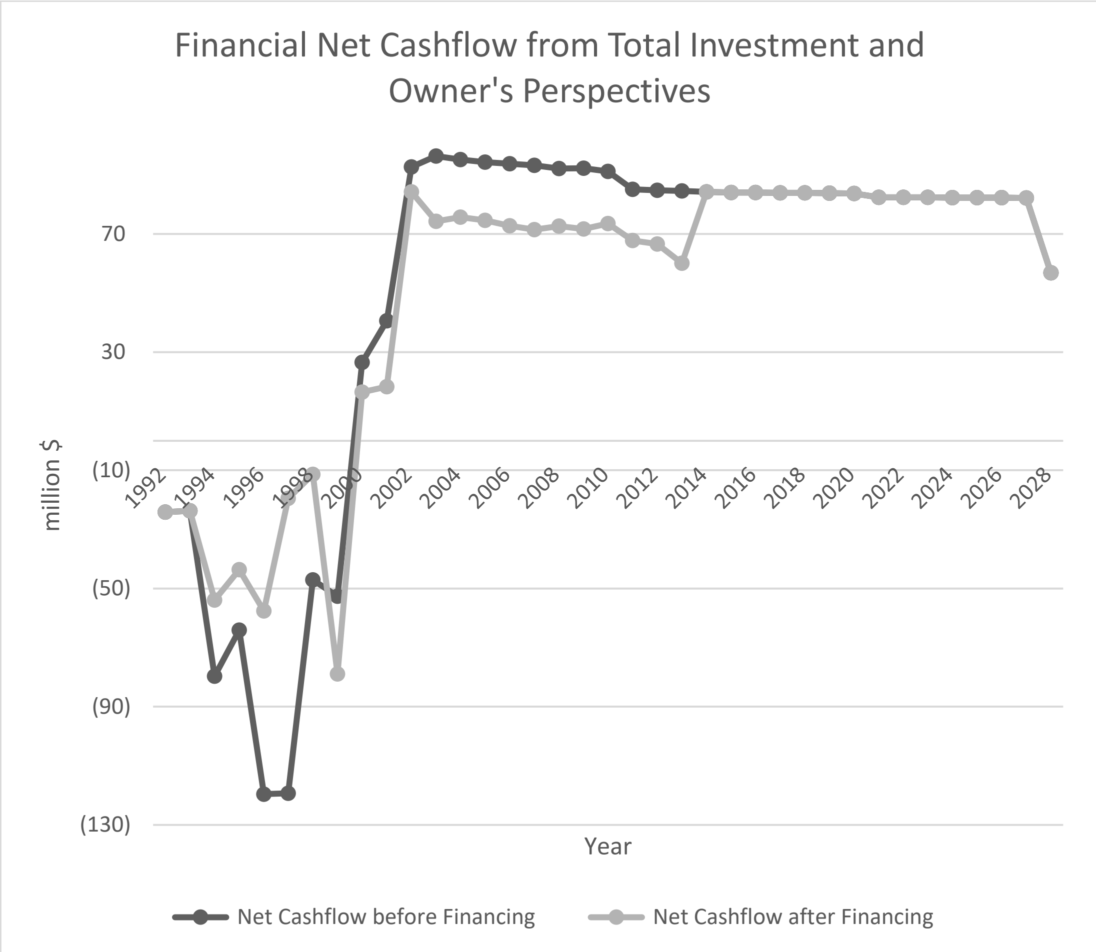



Figure 6. Net Cash flow from the perspective of both the project owner and total investment

From Figure 6, the impact of the world bank loan on the cash flow is shown. The disparity between the net cashflow before financing and the net cash flow after financing shows the combined impacts of loan drawdowns, and interest and principal repayments. The net cashflow before financing represents the perspective of the banker. It is also referred to as the total investment point of view because the banker takes into account all financial benefits and costs of the project in order to determine the financial feasibility of the project, the need for loans, and the likelihood of repayment on loan and interest.

Conversely, the net cashflow after financing represents the project outlays with which the owner examines the project. Unlike the banker, the project owner includes the impact of financing in estimating the project net cashflows.

Table 9. Financial NPV of the Tianhuangping pumped hydro storage plant from the owner's perspective (2020 values)

| **Parameter** | **Value** | **Unit** |
|---|---|---|
| **Discount Rate** | 12.00% | per cent |
| **NPV** | 34 | million USD |
| **IRR** | 12.86% | per cent |

The NPV explains how much return the project will provide for its investors over and above their financial opportunity cost. The financial NPV of the project as shown in Table 9 above is $34 million. This translates that the project owner, which is ECEPGC in this case, will make $34 million in present value terms over the years of appraisal more than if they had invested the capital in an alternative project that would have generated a 12% rate of return over the same period. The IRR is the rate of return if used as the discount rate would make the financial NPV of the project equal to zero. Table 9 above shows that the project will yield a 12.86% rate of return. Since the IRR is higher than the considered financial discount rate, it shows that the project will generate more return than an alternative use of capital which will yield a 12% rate of return over the same period.

## 5.3 Economic Impact

The result of the economic impact describes the least cost method of generating electricity from the perspective of the society as a whole. It provides a comparison between the Tianhuangping pumped hydro storage project and the standard gas turbine alternative as stated in 4.2 above. This analysis evaluates the economic impact of the options from an optimisation perspective where the system planners are designing the expansion of the coal plants and pumped hydro storage capacity to yield a least cost supply. The coal capacity in the off-peak can be used to generate electricity at the at the marginal running cost of the coal plant to be used to pump the water that is stored by the pumped hydro storage facility. Later, the water can be released into the lower reservoir through a turbine to supply electricity during peak demand period.

### 5.3.1 Long Run Analysis: Optimisation of Electricity Grid

This analysis aims to analyse the more cost-effective method of providing the generated peaking power. It is aimed at understanding the optimal method of adding peak energy to the grid between both alternatives. For a long run system planning, it is important to combine the pumped hydro storage with an energy generation source to compare against the use of gas turbine generation alone to meet the demand for electricity during the peak period.

For the sake of this analysis, since the energy to be converted into hydroelectricity was sourced from coal plants, it was necessary to compare the capital cost and operating cost of the pumped hydro storage and the coal plants plus their operating costs that together meet the peak demand with the capital plus operating costs of gas turbine plants that can perform similar peak energy generation. The operating costs are derived as equation 8 above and are inclusive of fuel, O&M, and social cost of carbon externality. By integrating the coal plant with the pumped hydro storage, the available energy that can be produced by the coal plant during the off-peak period can be stored via the pumped storage to be released at the peak demand period.

The Tianhuangping pumped storage plant has a capacity of 1,836 MW which operates for 1,404 hours per annum as is represented by area A in Figure 7 below. This requires 3,613 GWh of energy during the off-peak period to pump water to the upper reservoir that will be used to generate during peak periods. The coal plant used had a capacity factor of 85%. With 1404 hours of peak time in the east China grid, the coal plant will have 6,042 hours of off-peak time to generate the annual energy required for pumping water for the pumped storage plant. As denoted by Figure 7, this off-peak generation, represented by area C, will be converted to area A by the pumped storage plant. This conversion will not be 100% as some proportion of energy will be lost due to inefficiency in energy conversion. The overall conversion efficiency of the pumped hydro storage averaged 74% over the years of operation but was as high as 81.6% in 2000. Its effectiveness reduces over time as the plant wears and tears. Also, some energy is lost to plant service as the Tianhuangping project itself makes use of 0.4% of its gross energy generation. Equation 9 above was used to estimate the minimum capacity of a coal plant that is required to generate this amount of energy during the off-peak period. The minimum capacity for the coal plant, operating with an 85% load factor, required to generate the required energy output to supply the pumped hydro storage plant during the off-peak period was 598 MW. This also takes into consideration the 4.5% of gross energy generation that the coal plant uses for itself.

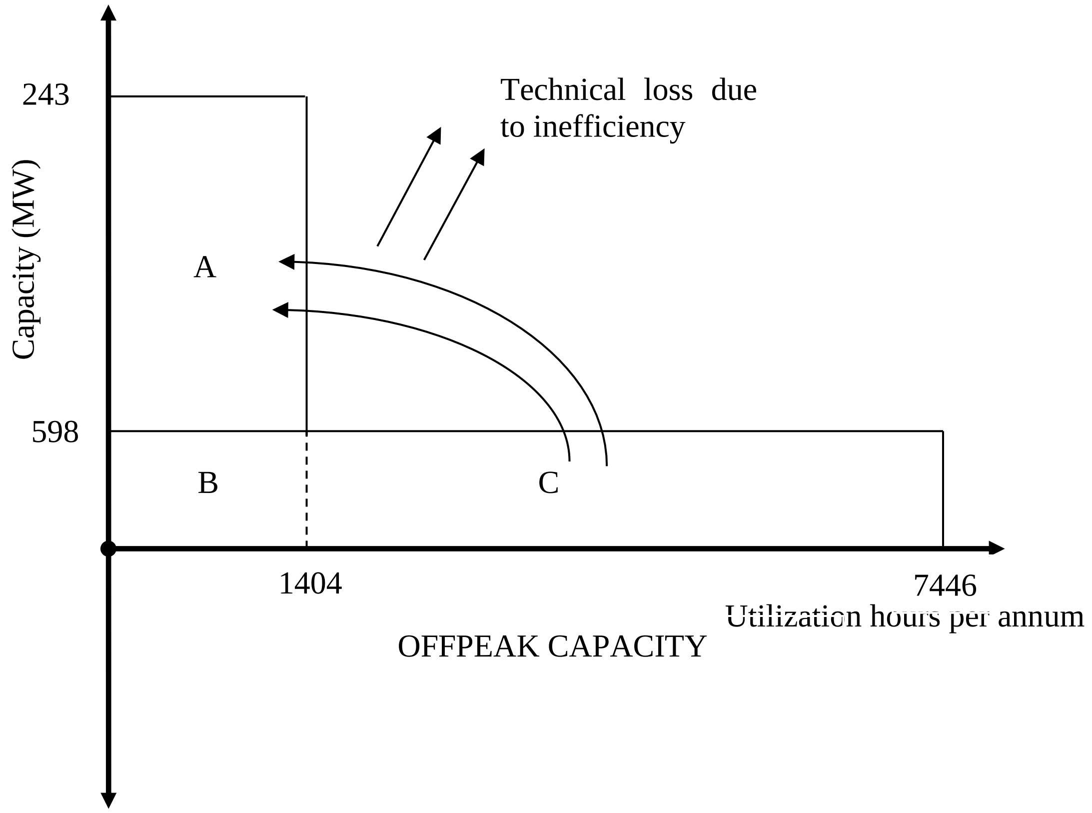



Figure 7. Annual operation schedule of the pumped hydro storage and coal integrated units.

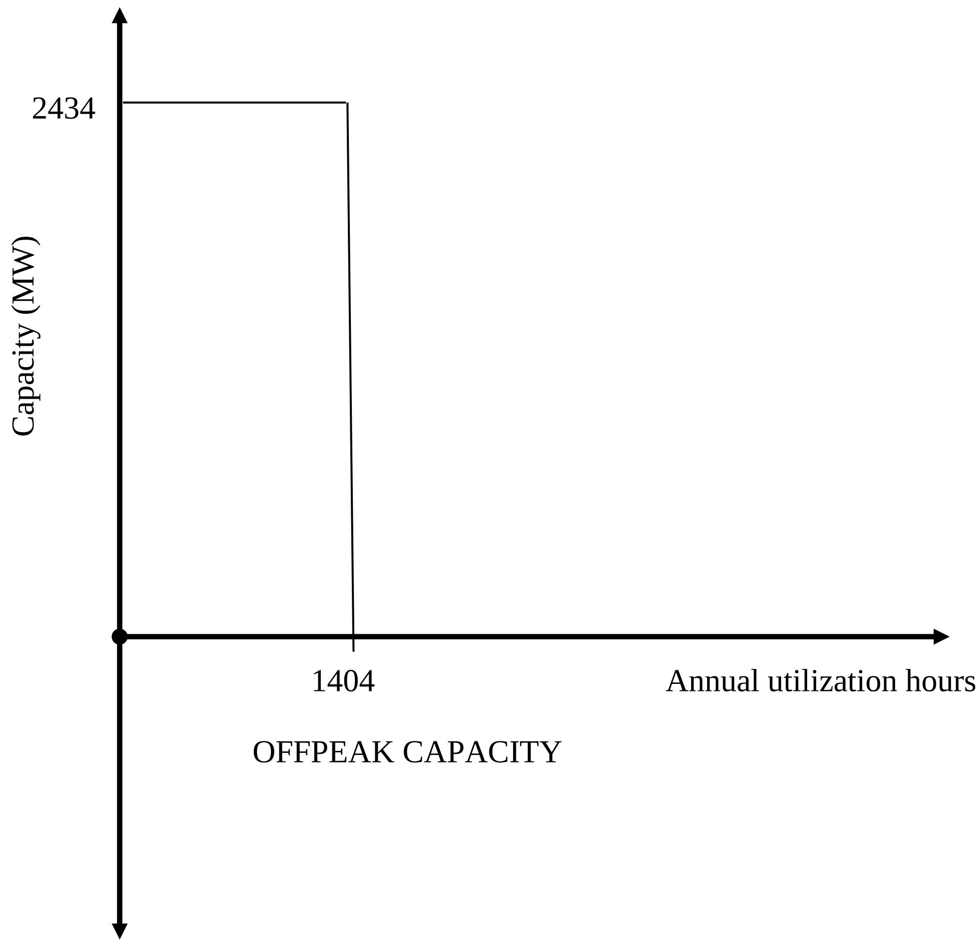



Figure 8. Annual operation schedule of the gas-fired turbine

An important aspect of this is that the coal plant will also add to the peaking capacity in addition to that already provided by the pumped storage plant. Therefore, this coal plant – pumped hydro storage integrated system will add a combined capacity of 2,434 MW to the peak period. Hence, the coal plant will work during the off-peak period to generate energy for pumping, while during the peak period, it will add 840 GWh (an equivalent of the area B in Figure 7 above) of peaking energy annually to the grid. This is in addition to 3,417 GWh of annual peaking power added by the pumped storage plant, so 4,257 GWh of peaking power will be added to the grid by integrating these 2 systems.

Since the gas turbine generates its own energy during the peak period, there will be no need for any integration with another electricity generation source. Although, the gas turbine will have to compensate for the coal and pumped hydro storage plants by matching the capacity added by the integration of both plants. As shown by Figure 8 above, 2,434 MW capacity gas turbines that will operate for 1,404 hours per annum was used for comparison.

#### 5.3.1.1 Levelized Cost of Energy

For the levelized alternative cost of energy, to compare with the pumped storage and coal combination, a gas turbine of 2,434 MW capacity was used as an alternative plant. The analysis of both these coal and gas turbine plants were based on unit costs published by the Energy Information Administration (EIA) (EIA, 2020). This comparative appraisal also considered the environmental externality of all plants by including the valuation of the social cost of $CO_2$ produced by the plants. For the gas turbine plant, the analysis also considered the use of natural gas and HFO. The estimation of the results of the analysis shown in Figure 9 below includes the capital costs, fuel cost, O&M costs, as well as the social cost of carbon as described by equations 6, 7, and 8 above.

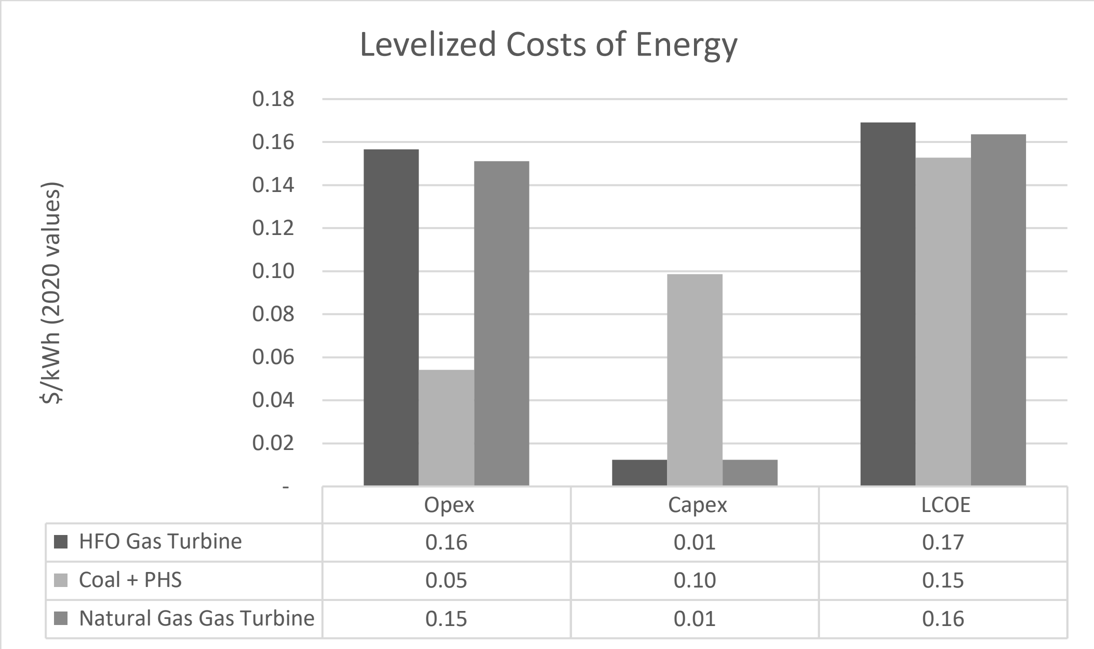
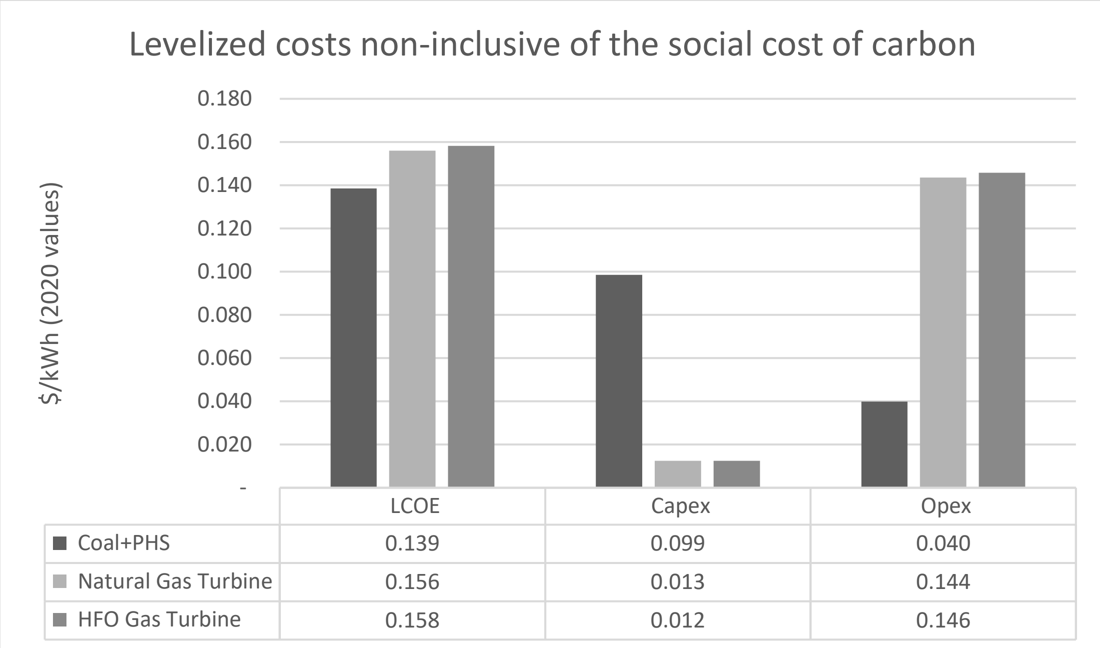


Figure 9. Levelized cost of energy ($/kWh)

The results show the integrated system of coal and pumped hydro storage plants to be more cost-effective than either the HFO-fired gas turbine or the natural gas-fired turbine. The levelized cost estimates include both capital, fuel, and carbon costs. The coal and gas turbine integrated system has a levelized cost $0.15 per kWh while the natural gas-fired turbine cost $0.16 per kWh and the HFO-fired turbine cost $0.17 per kWh. The pumped hydro storage and coal integrated system required a levelized capital cost of $0.10 per kWh. This is ten times what is required to cover the capital cost per kWh by the gas turbine plant. In contrast, the natural gas-fired turbine required three times the operating cost of the coal and pumped storage integrated system. This operating cost, represented by equation 8, is inclusive of O&M costs, fuel cost, and the social cost of $CO_2$. It is sensitive to oil and gas prices because the fuel cost makes up a significant proportion of the operating cost. The HFO-fired turbine has a per kWh operating that is even slightly higher than that of the natural gas-fired turbine at $0.17 per kWh. The burning of coal generates more carbon externality into the atmosphere than either natural gas or HFO. The levelized costs of the plants without including the social cost of carbon is shown in Figure 10 below.




| | LCOE | Capex | Opex |
|---|---|---|---|
| Coal+PHS | 0.139 | 0.099 | 0.040 |
| Natural Gas Turbine | 0.156 | 0.013 | 0.144 |
| HFO Gas Turbine | 0.158 | 0.012 | 0.146 |

Figure 10. Levelized cost non-inclusive of the social cost of carbon ($/kWh)

Figure 10 shows a greater discrepancy between the levelized costs of the coal and pumped hydro storage integrated system than the levelized costs which includes the social cost of capital. If the social cost of carbon is accounted for, the coal and pumped hydro storage plant is $0.011/kWh cheaper than the natural gas turbine, but without including the social cost of carbon, the coal and pumped hydro storage integrated unit becomes $0.017/kWh cheaper than the natural gas turbine. The HFO turbine makes the least cost-effective option in both scenarios.

Furthermore, with the coal and pumped hydro storage combination unit being a high capital – low operating cost project and the alternative being a low capital – high operating cost project, the results of the analyses are highly subjective to the economic discount rate. A lower economic discount rate will improve the benefit of the coal and pumped hydro storage integrated plant. This is because it will not diminish the valuation of the operating cost incurred in each year of operation in NPV terms as much as the higher discount rate.

Table 10. What-if analysis of the prevailing economic discount rate ($/kWh - 2020 values)

| | **Natural Gas Turbine** | | | | **Coal + PHS Integrated System** | | |
|---|---|---|---|---|---|---|---|
| | **LCOE** | **Capex** | **Opex** | | **LCOE** | **Capex** | **Opex** |
| **Base Case** | **0.164** | **0.012** | **0.151** | | **0.153** | **0.099** | **0.054** |
| **12.00%** | 0.164 | 0.012 | 0.151 | | 0.153 | 0.099 | 0.054 |
| **11.00%** | 0.163 | 0.011 | 0.151 | | 0.148 | 0.094 | 0.054 |
| **10.00%** | 0.162 | 0.011 | 0.151 | | 0.143 | 0.089 | 0.054 |
| **9.00%** | 0.160 | 0.010 | 0.151 | | 0.139 | 0.085 | 0.054 |
| **8.00%** | 0.159 | 0.009 | 0.151 | | 0.135 | 0.081 | 0.054 |

The prevailing economic discount rate for these analyses is 12%. From Table 10, it is clear that a lower prevailing economic discount rate will cause the levelized cost of the coal and pumped hydro storage combined unit to reduce faster than the gas turbine. With the prevailing 12% discount rate, the coal and pumped hydro storage integrated unit is $0.011/kWh cheaper than the natural gas-turbine unit. As the discount rate reduces, this difference in the levelized cost increases at a decreasing rate. It shows that if the prevailing economic discount rate is 8%, the coal and pumped hydro storage integrated unit will be $0.024/kWh cheaper than the natural gas-turbine. This is because with a lower opportunity cost of capital, the concentration of capital investment in the investment phase for the coal and pumped hydro storage is less expensive from year to year.

#### 5.3.1.2 Aggregate Cost Savings

Having estimated the levelized cost in the section above, this section aggregates the cost saving components of the pumped hydro storage and coal integrated system.

Table 11. Aggregate cost savings

| **AGGREGATE COST SAVINGS** | **NPV** | **Unit** | ∑ |
|---|---|---|---|
| CAPEX SAVINGS | | | |
| Real Capital Cost for gas turbine | 157.3 | million USD | 1082.2 |
| Capital Cost for Integrated System | 1241.8 | million USD | 5683.7 |
| Capex cost savings | -1044.6 | million USD | -4601.5 |
| | | | |
| OPEX SAVINGS | | | |
| Opex for gas turbine | 1908.5 | million USD | 13929.3 |
| Opex for Integrated System | 683.0 | million USD | 5032.5 |
| Opex savings | 1225.5 | million USD | 8896.8 |
| **Aggregate cost savings** | **180.9** | **million USD** | **4295.3** |

The cost-saving shows the total value that is saved instead of a per-unit basis as explained in 5.3.1.1 above. As explained in the section above, the gas turbine would have a lower investment cost. The gas turbine would have saved $1,045 million in present value terms in capital cost as compared to the pumped storage and coal integrated plant. Considering only the operational cost, the cost savings from the lower operational cost of the pumped storage and coal integrated plants unit as opposed to the gas turbine will result in saving $1,226 million in net present value terms over the 30 operational years of the appraisal. By considering both these results, one can conclude that the construction of the Tianhuangping pumped hydro storage in combination with the coal plant was economically $181 million more beneficial in net present value terms than the alternative of generating electricity to meet the peak demand using gas turbine in present value terms.

# Chapter 6

# SUMMARY

In conclusion, the Tianhuangping pumped hydro storage project was evaluated for both its financial viability to its project owners. It was also evaluated for its economic benefit from a long-run system-planning perspective. For optimisation of electricity grid, with the Tianhuangping pumped hydro storage plant sourcing its energy from coal plants during the off-peak, the economic analysis combined the required coal plant with the Tianhuangping pumped hydro storage to get an accurate economic comparison against natural gas or HFO-fuelled turbines.

Financially, the Tianhuangping project was evaluated to return the owner with $34 million in net present value terms. From the long run systems planning perspective, the implementation of the Tianhuangping pumped hydro storage in combination with the coal plant that was necessary to provide it with the off-peak energy required to pump water into the upper reservoir for storing energy was found to be more cost-effective than either of the gas turbines. This analysis considered the capital cost, fuel cost, O&M cost, and the social cost of carbon for all plants involved. Without the social cost of carbon, the coal and Tianhuangping pumped hydro storage integrated unit was found to be even more competitive than the previous scenario which included the social cost of carbon.

With its high capital intensiveness, large projects like these are often feared. This project has shown that despite the high capital cost that came with the pumped storage plant, it was the better alternative economically while being financially profitable. Moreover, it was also shown that if standard practices of project management are followed, a large project like the pumped hydro storage will neither be environmental disasters nor impoverish the nearby region but lead to an increase in the welfare of the people surrounding it.

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