Chapter 6

Hydropower Technology: Potential, Challenges, and the Future

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A. Overview of Hydropower Technology in Indonesia

As the COVID-19 pandemic started to become endemic, Indonesia's economy has been bouncing back and steadily growing. Indonesia is one of the 20 countries with the largest economy—and is projected to be the fourth-largest by 2050 (Hawksworth et al., 2017). Along with economic growth, economic expansion is inevitable. And economic development needs to be supported by a robust energy infrastructure that will provide 24/7 energy for Indonesia. The electricity demand is increasing for household use, but only for manufacturing and industrial applications. On the other hand, Indonesia is facing a climate change problem. As one of the most polluting countries in

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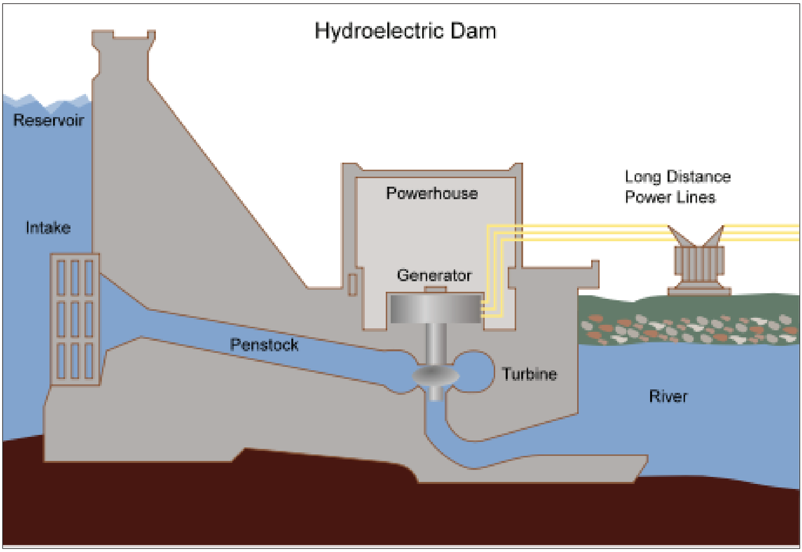
the world, pressure is mounting for Indonesia to reduce—or even eliminate—its dependence on fossil fuel energy (Ritchie, 2019). As of 2021, Indonesia is still relying heavily on fossil fuel energy. A report by National Energy Council shows that more than 60% of Indonesia's electricity generation comes from fossil fuel energy (National Energy Council of Indonesia, 2020). This motivates the Government to introduce new policies to tackle the increasing demand for energy and electricity and the increasing threat of climate. This includes the introduction of Indonesia's national energy plant (Rencana Umum Energi Nasional-RUEN) by the Ministry of Energy and Mineral Resources (Kementerian Energi dan Sumber Daya Mineral-ESDM) and multiple ordinances of National Electricity Supply Business Plan (Rencana Usaha Penyediaan Tenaga Listrik-RUPTL) by the State Electricity Company (Perusahaan Listrik Negara-PLTN) (Peraturan Presiden Nomor 22 Tahun 2017 Tentang Rencana Umum Energi Nasional, 2017; PT Perusahaan Listrik Negara, 2021). In RUEN, it is stated that Indonesia's target 23% of its energy mix comes from renewable energy by 2025 and 31% by 2050. These targets are backed up by Indonesia's Nationally Determined Commitment (NDC) in COP26 (Humas ESDM, 2021).

These commitments and targets boosted Indonesia's expansion to renewable energy technologies, including hydropower technologies. Hydropower energy means converting the energy of moving water into electricity. This includes both large-scale and small-scale hydropower. In 2020, BP Statistical Review reported that hydropower energy contributes around 7% of all energy mix in Indonesia, constituting almost 20,000 GWh of total electricity production in 2020 (B.P. Statistical Review, 2020). Hydropower energy production has been Indonesia's most significant contributor of renewable energy. The electricity generated from hydropower constitutes more than 50% of the total renewable energy produced in Indonesia. However, this technology is very far from reaching its highest potential. With the geography of Indonesia, hydropower should have been one of the highest electricity sources. On the other hand, every development always comes with a cost. In this case, the ecological price is one of the highest costs that should be paid to develop a reliable hydropower energy infrastructure.

Hydropower has many potential uses for power generation and sustaining crops through irrigation. The hydro dams can also be used for water supply, flood control, and navigation improvement. A typical cross-section of a conventional hydro dam can be seen in Figure 6.1. It contributes to tackling climate change as a renewable energy source by generating low-carbon, reliable energy. In the long term, it can produce electricity at a low cost and adjust electricity demand from the consumer. This chapter explores Indonesia's hydropower potential and what can be done to achieve the goal. Also, this chapter explains the challenges that make hydropower energy is not reaching its highest potential. This chapter ends with two types of technology currently emerging and should be expanded on a larger scale in Indonesia.



Source: Tennessee Valley Authority (2000)

Figure 6.1 Cross-Section of a Conventional Hydroelectric Dam

B. The Current Status of Hydropower in Indonesia

The hydropower resources are primarily abundant in Indonesia and are blessed by divine nature. Indonesia has more than 800 rivers that can be a potential source of hydropower. It is estimated that Indonesia has the potential for 75 GW of electricity from more than 800 rivers (Hasan et al., 2012). These resources make Indonesia the fourth most significant potential for hydropower. However, because of the high capital necessary, only around 34 GW of electricity can be exploited from all the hydropower potential. Hydropower requires massive and complex infrastructures to extract the power from moving water into energy. These massive infrastructures are for the dams' design, construction, and operation. On the other, potential issues may also come up due to social, political, and environmental issues.

Although there is no international consensus on the definition of the scales of a hydropower plant, some suggest that a hydropower plant that produces more than 10 MW of electricity is considered a large-scale hydropower plant. Plants that generate power between 2.5 MW to 10 MW are considered small-scale hydropower plants. Below that range, the mini-hydropower plant produces below 2 MW, micro-hydropower makes below 500 kW, and the pico-hydropower plant has electricity below 10 kW (Erinofiardi et al., 2017).

With all these potentials, Indonesia has built hydropower infrastructures across the country. PT PLN has listed some of the large-scale hydropower stations in some provinces in Indonesia in Table 6.1.

Table 6.1 Some Operational Large-Scale Hydropower Stations in Indonesia

Hydropower Station	Province	Installed Unit (MW)	Installed Capacity (MW)
Cirata	West Java	8 × 126	1008
Saguling	West Java	4 × 175	700
Sulewana-Poso III	Central Sulawesi	5 × 80	400
Tangga	North Sumatra	4 × 79.25	317
Sigura-gura	North Sumatra	4 × 71.50	286

Hydropower Station	Province	Installed Unit (MW)	Installed Capacity (MW)
Sutami/Brantas	East Java	12 × 35 × 3	281
Musi	Bengkulu	3 × 70	210
Sulewana-Poso II	Central Sulawesi	3 × 65	195
Mrica	Central Java	3 × 61.5	184.5
Asahan I	North Sumatra	2 × 90	180
Singkarak	West Sumatra	4 × 43.75	175
Jatiluhur	West Java	7 × 25	175
Larona	South Sulawesi	3 × 55	165
Sulewana-Poso I	Central Sulawesi	4 × 40	160
Karebbe	South Sulawesi	2 × 70	140
Balambano	South Sulawesi	2 × 65	130
Bakaru	South Sulawesi	2 × 63	126
Koto Panjang	Riau	3 × 38	114
Karangkates	East Java	3 × 35	105

Source: PT Perusahaan Listrik Negara (2021)

The Government of Indonesia has planned to increase the cumulative capacity of large-scale hydropower plants in some Indonesia regions. Specifically, the plan includes an additional 20 MW in the east region of Indonesia, 21 MW in the Java-Bali connection, 11 MW in Sumatra, and 18 MW in the eastern part of Indonesia (Erinofiardi et al., 2017).

Besides the large-scale hydropower potential, Indonesia also has some potential to build smaller-scale hydropower by utilizing medium-sized rivers around the country. The utilization of small-scale hydropower has been done since 2005. At that time, 0.45 MW of electricity was generated by small-scale hydropower. Since then, the development is not significant in the coming years. From 2006 to 2010, the electricity generated could only be increased to 0.69 MW (Erinofiardi et al., 2017).

Another example is to utilize micro-scale hydropower. It is estimated that the potential of micro-hydropower is about 459.91 MW. From that number, 20.85 MW of it has been developed by PLN to provide electricity for rural areas (Hasan et al., 2012). Small- and micro-scale hydropower plants might be an excellent option to expand the utilization of hydropower plants, considering Indonesia's distribution of electricity in the islands and the safety of fish and other biotas in the water.

C. Challenges Facing Hydropower

All types of development must come with some risks and costs. Even though in the previous section it is said that Indonesia has about 75 GW of electricity potential from hydropower, it is undoubtedly hard to exploit all those potentials considering the landscape of Indonesia. Any development would indeed have some impact on the surrounding areas. These challenges include the engineering and socio-economic impact of the projects.

1. Geographical Challenges

Although some experts approximated that the hydropower potential in Indonesia is relatively more enormous than in some countries. Undeniably, Indonesia's geography can create challenges that need to be solved or worked around. Indonesia indeed has many rivers that flow across the country. However, the rivers are relatively short. This geographical issue will create problems when a large-scale hydropower plant is constructed. The construction of a large-scale hydropower plant is done by blocking the passage of water to build a dam where the water flow will be directed to the turbines to produce electricity. Creating this dam will also generate a lot of impact on the plant site. In a short river, the construction of large-scale hydropower will be limited to the site constraint (Erinofiardi et al., 2017). It will need an extensive engineering workaround to be able to make the large-scale hydropower dams.

Another problem is related to electricity transmission. As an archipelagic country, Indonesia has more than 17,000 islands. Although some portions of those islands are not inhabited, the inhabited islands need constant electricity transmission to create better-living conditions. Electricity transmission has always been a problem for Indonesia to achieve 100% electrification and balance energy resources. It is well known that as electricity is transmitted among islands, there will be some losses. The losses make the consideration of investing in electricity transmission becomes harder. It also creates gaps in electricity resources in some regions of the country. Right now, most of the manufacturers are on the island of Java. This situation is due to the excessive energy resources accumulated in Java. These gaps will create inequality in the quality of life of the people in the region.

2. Ecological Challenges

Around the world, large-scale hydropower plants have affected fishing activities and fishery production. These effects include direct and indirect impacts of the large-scale hydropower project. The immediate result is that the fish are killed, injured, or physically blocked from their migration. This consequence is likely to happen, especially in large-scale hydropower construction, where dams are the way to generate electricity. Fish can get drawn into the turbines and can injure the fish. Hydropower plants can also alter the habitat upstream and downstream of the river. First, the existence of upstream and downstream will create a barrier effect to the living organisms in the stream. This separation will affect the population of fish and other living organisms. These challenges can be avoided by implementing mitigation measures to the dams. However, it will increase the cost of hydropower plants cost. Upstream, if the condition is not well-maintained, the reservoir can cultivate excess algae and weeds, crowding what has been a challenging environment for the living species in the reservoirs. While downstream, hydropower dams can affect the downstream flow regimes through hydropeaking. Hydropeaking can also alter the upstream habitat as the regime changes from fast-flowing lotic habitat to a slow-flowing lentic habitat (Baumgartner & Wibowo, 2018). Therefore, fish and other living organisms face two types of problems, the existence of dams and turbines create a physical barrier to migration, and the dams alter the flow regimes and habitat availability. Both issues can be mitigated. However, it will increase the cost of building large-scale hydropower plants and make more complicated investments.

For the fish migration problem, some research suggests that the construction of fish passages can be considered to solve the problem. However, some global evidence suggests that the fish passage may cause more harm than good in some instances. Therefore, many considerations need to be taken before constructing a fish passage. If the construction of the fish passage is justified, it will be an excellent way to maintain the river's habitat and maximize the hydropower plants' value.

3. NIMBY-ism (Not In My Backyard Syndrome)

As mentioned in previous sections, the construction of large-scale hydropower plants could dramatically alter the livelihood of all types of organisms, including humans. Some villages might need to be emptied and sunk to construct a dam. This decision will create socio-economic problems for the local villagers occupying the villages from far before the construction. It can make Not In My Backyard (NIMBY) syndrome. NIMBY often refers to intense, frequently emotional, and usually organized opposition to siting proposals that local community residents believe will result in adverse impacts. In this case, if the approach to the local community is not well-communicated, NIMBY is inevitable. NIMBY is a common phenomenon that can be seen in many countries. Furthermore, it does not limit to large-scale power generation projects. NIMBY can also happen for other projects, such as constructing Las Vegas-like Casino construction in Canada or constructing twenty-four homeless shelters in New York City (Wexler, 1996). As a result, it will significantly impact the construction of hydropower plants. It is challenging for the vendor who builds the hydropower plants and the regulators.

D. Current and Emerging Hydropower Technologies

With all the potentials and challenges explained in previous sections, hydropower plants will still considerably affect the landscape of renewable energy in Indonesia. Technologies have been developed in hydropower construction to minimize the ecological effects of hydropower plant construction.

1. Micro-hydropower Plants

As mentioned in previous sections, the geographical landscape is not always suitable for large-scale hydropower plants. Although large-scale hydropower plant is essential to provide baseload from renewable energy, micro-hydropower plants can also be considered to expand to provide reliable electricity for residential purposes. Micro-hydropower plants can also be a decent option for delivering electricity and farming irrigation. Some locations of micro-hydropower plants are shown in Table 6.2.

Table 6.2 Some Locations of Installed Micro-Hydropower Plants

No	Province	Number of Location	Potential Capacity (MW)
1	South Sumatra	1	9.9
2	West Nusa Tenggara	4	2.02
3	East Nusa Tenggara	8	5.8
4	North Sumatra	1	7.5
5	West Sumatra	3	20.5
Total			45.72

Source: PT Perusahaan Listrik Negara (2021)

Of all these potentials, some of them have been built from 2011 to 2014. The micro-hydro power plants that have been constructed are listed in Table 6.3. Some other plants are also built out of data provided in Table 6.3. Some of them are the Van Der Wick irrigation channel in Yogyakarta (11 kW capacity), Rimba Lestari in West Bandung (18 kW capacity), Mendolo hamlet in Pekalongan (22 kW capacity), Pancuang Taba, West Sumatra (40 kW capacity), Muaro Air, Jambi (30 kW capacity), and Koto Ranah, West Sumatra (30 kW capacity). The last three micro-hydropower plants are in Pesisir Selatan, West Sumatra (Erinofiardi et al., 2017).

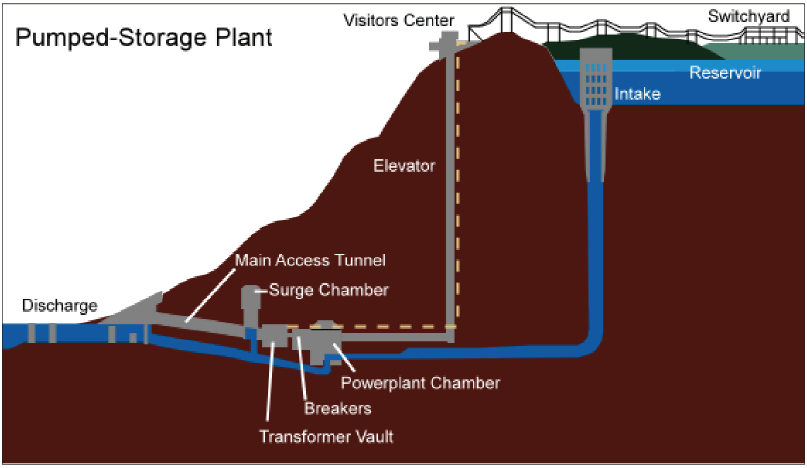
Table 6.3 Installed Micro-Hydropower Plants in 2011–2014

No.	Province	Location	Capacity (kW)
1	North Sumatra	Samosir, South Tapanuli	56.2
2	West Sumatra	West Pasaman, Mentawai, Solok	54
3	Riau	Kampar	8
4	Jambi	Sarolangun	18
5	South Sumatra	South Ogan Komering Ulu, Muara Enim	43
6	Lampung	West Lampung	80
7	West Java	Ciamis	24.4
8	East Java	Situbondo	15
9	West Nusa Tenggara	Lombok, East Lombok, Sumbawa	350
10	East Nusa Tenggara	Ngada, East Manggarai, Central Rote, Central Sumba, South Central Timor	273
11	West Kalimantan	Kapuas Hulu, Landak	450
12	Central Kalimantan	Gunung Mas, Lamandau	48.3
13	North Sulawesi	Sangihe	14.1
14	Gorontalo	Gorontalo, North Gorontalo, Bone Bolango	145.2
15	Central Sulawesi	Lamatoli Morowali	20.6
16	West Sulawesi	Mamasa	120
17	South Sulawesi	North Luwu	40
18	Southeast Sulawesi	North Konawe, North Buton	28
19	Maluku	West Seram	30
20	West Papua	South Sorong, Maybrat, Manokwari	596
21	Papua	Bintang Mountains, Bintuni Bay, Yalimo, Jayapura	186.36
	Total		2,600.75

Source: Kementerian ESDM (2016)

2. Pumped Storage Hydroelectricity Plants

Pumped Storage Hydroelectricity (PHS) Plants use two water reservoirs at two different elevations, as seen in Figure 6.2. PHS offers the flexibility of electricity production based on the electricity demand. When there is low electricity demand or abundant electricity generation from other sources, the plant's power is used to pump up the water from the lower elevation reservoir to the higher elevation reservoir. On the other hand, when the electricity demand is at its peak, the power will be generated through water flows from higher elevations to lower elevations using a turbine. This generated power is then transmitted to satisfy the demand. The loop continues depending on the electricity demand. By this configuration, PHS can balance the demand and supply of electricity and improve the reliability of electricity services in an environmentally sustainable way (Stocks et al., 2019).



Source: Tennessee Valley Authority (2012)

Figure 6.2 Racoon Mountain Pumped-Storage Plant

The concept of PHS is relatively new in Indonesia. As of September 2021, the World Bank has approved a loan to create Indonesia's first pumped-storage hydropower plant. This move aligns with the Government's pledge toward climate change and energy transition. At the same time, the financing will be used to construct Upper Cisokan PHS between Jakarta and Bandung. The expected capacity for this facility is 1040 MW (World Bank, 2022).

PSH offers a unique opportunity to move beyond the first project, especially in Indonesia. PSH can be used to store other renewable energy such as solar PV and wind. PSH is a mature technology that is cheaper than many alternatives for energy storage. Some PSH can be put in remote areas far from rivers and residential areas (off-river). It is possible as PSH can be a closed-loop system and located away from rivers and residential areas. As long as two reservoirs have two different elevations (100–1200 m altitude difference), it is possible to create PSH. The round-trip efficiency is typically about 80%, which is relatively good compared to other renewable energy sources. With Indonesia's topography, PSH can be a good opportunity for reliable electricity storage at a relatively low cost (Stocks et al., 2019).

E. Conclusion

Indonesia has great potential in hydropower. However, those potentials are limited to Indonesia's geography and socio-economic issues. Indonesia's rivers are typically not ideal for constructing a large-scale hydropower plant. Also, the ecological problems due to the possible destruction of the river ecosystem and NIMBY syndrome can affect large-scale hydropower plant projects. Although hydropower plants are necessary to be the renewable energy baseload, the use of hydropower can be expanded in different ways. One way is to reduce the capacity of the hydropower plant and create micro-hydropower plants. Micro-hydropower plants will be an essential addition to residential and farming areas. The other way is to use pumped-storage hydroelectric plants. PSH offers flexibility and reliability to fulfill the supply and demand of electricity that can also be built far from rivers and residential areas. In these ways, hydropower can be a renewable energy backbone for Indonesia.

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