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Development of hydropower in Afghanistan for clean and sustainable energy:
The Baghdara hydropower project

Naqibullah Ghubar[1], and Habiburahman Shirani[2]
[1]*Ministry of Energy and Water, Kabul, Afghanistan*
[2]*Department of Electrical and Electronics Engineering, Faculty of Engineering, Kabul University, Kabul, Afghanistan*

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ABSTRACT

There are promising opportunities to produce clean and sustainable energy from micro, mini, small and large hydropower plants in Afghanistan. The Government of Afghanistan has planned to build several hydropower plants. One of them is Baghdara Dam Hydro-Power project in Kapisa province and is expected to produce 210 MW. In the feasibility study, two dam axis configurations were considered, one creating a small reservoir, the other creating a large reservoir. However, a recommendation comparing advantages and disadvantages was not addressed. In this paper, we compare possible Baghdara Dam axis locations and recommend one for future construction that produces optimal electric power, especially during the winter season, and provides clean potable water to New Kabul City. We have determined that dam location A (with a small reservoir) would need a long tunnel to the power station, which requires advanced technology and accurate geological surveying that is not available in Afghanistan. Axis D (with a large reservoir) will recharge downstream hydropower plants such as Kapar (120 MW), Naghlo (100 MW), Sarobi-1 (22 MW), Sarobi-2 (180 MW), and Daronta (12 MW). The large reservoir will also stop sediment ponding at the Naghlo hydropower reservoir. This case study shares an in-depth technical and practical lessons-learned with researchers, students, and practitioners.

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1. Introduction

Afghanistan has significant sustainable renewable energy resources with high generation potential. These resources are distributed throughout the country, in contrast to its conventional energy resources, which are concentrated in specific locations. Afghanistan can produce around 318 GW of electricity utilizing available renewable energy sources through a diverse renewable energy portfolio representing Hydro (23,000 MW), Wind (67,000 MW), Solar (222,000 MW), Geothermal (3,000 – 3,500 MW), and Biomass (4000 MW) [1]. Table 1 lists the available renewable potential in Afghanistan. So far, only a few of the planned hydroelectric power projects have been realized. Rapid deployment of renewable energy projects should bring significant socio-economic benefit, employment opportunities, access to energy, energy security, overall growth, and support for international climate change mitigation. The national renewable energy market is expected to grow in the coming decades. The Ministry of Energy and Water (MEW) has developed Afghanistan Renewable Energy Policy, which promotes renewable energy projects to grow the renewable energy sector, particularly in PPP (Public Private Partnership) mode [1].

Sustainable energy is essential to economic and social development of Afghanistan. Compared to other renewable resources, hydropower has a large contribution in the world's power generation [2] and is the main source of power in 55 countries. For several countries, hydropower is the only domestic energy resource available [3].

In this case study, we considered the Baghdara Hydropower Project in Afghanistan, a planned generator with a reservoir that can produce optimal clean

Corresponding author: N Ghubar
Email: eng.naqib@gmail.com

energy. A feasibility study by Fichtner Compay proposed two axes for the dam: axis A with a smaller reservoir and long rocky tunnel, and axis D with a large reservoir and short length tunnel [4]. However, the study did not provide an analysis of each option's strengths and weaknesses. This study analysis determined that the dam axis D was easier to implement and could generate more energy compared to dam axis A.

The paper first considers the importance of hydropower, then states the problem. We looked at various solutions and evaluated its potential impacts on society and the environment.

Table 1: Potential of Afghanistan's renewable energy resources [1].

Type of Energy	Potential	Work Done
Solar	222,000 MW* 300 days of sunlight Average solar insolation of 6.5 kWh/m2/day	Stand alone: Many systems deployed. Mini-grid: Pilot mini-grids (up to 1MW) deployed. Grid Tied: Draft grid-tie (Kabul Area) pre-feasibility report. Roof-top grid tentative project with capacity of 0.5 to 3 kW generation license. Under construction: Ghor Solar project 5.5 MW and Daikundi solar project 5 MW.
MHP	23,000 MW* hydro potential (including large dams) 600 MW mini and micro potential	Pilot projects (including pay- for- power mini-grids) Prefeasibility studies 125 MHP sites survey Factsheets
Wind	67,000 MW* 36,000 km^2 windy land 5 MW per km^2	16 nos. wind monitoring towers 1-year wind data 100 and 30 kW pilot project Generation license
Biomass	4000 MW* 91 MW MSW 3090 MW agriculture waste 840 MW animal waste	300 Biogas plants survey factsheets W2E business plan Wastewater treatment
Geo-Thermal	Three big possible regions 70 spots 4-100 MW	Two studies Business proposal

2. Hydropower in the world and Afghanistan

Energy is one of the most important commodities for meeting physical needs and for enabling economic development in modern society. According to International Energy Agency (IEA) report (2018) [5], global electricity generation comes from:

- Coal (38.4%)
- Natural gas (23.2%)
- Hydro (16.3%)
- Nuclear fission (10.4%)
- Oil (3.7%)
- Non-hydro renewables (8%)

The fossil fuel energy sources such as coal, natural gas, and oil are not sustainable and contribute to emission of greenhouse gases that affect climate change. Renewable sources such as hydro are clean and help achieve critical targets for sustainability and efficiency by improving the use of energy resources, reducing costs, cleaning the environment, securing energy delivery, and encouraging innovative designs and analysis [6].

Because they require a large workforce, hydro projects can create long-term employment opportunities and other social benefits. Improved roads and infrastructure associated with these projects can help local residents sell crops to customers at markets, transport children to school or university, and access health care and other social services. Hydro-power also improves flood water control and water quality for irrigation, domestic, and industrial use to stimulate the agricultural sector, slow the transformation of forested areas into farmland and leave wildlife habitat intact [2,6]. Reservoirs created by the hydro system can support fisheries, farms, and ranches in the reservoir drawdown area, which in some cases can more than compensate for financial losses that occur with dam construction [7]. Historically, hydropower was the main source of electricity for Afghanistan. Jabel Saraj, the first hydropower plant and operational since 1922, had 3 turbines, each with a capacity of 500 kW. Its power increased by 44 kV and served Kabul. At that time, three micro hydropower plants with a capacity of 20 kW, 60 kW, and 20 kW were installed in Paghman district of Kabul, Jalalabad of Nangarhar province and in Kandahar province, respectively. While these projects were small, they attracted considerable interest from the government and the energy industry. In 1935, the government of Afghanistan developed a strategic plan and a regulatory framework for investment in hydropower. As a result, the following power plants, shown in Table 2 were constructed [8]:

Table 2: Co-investment hydropower plants list.

No.	Name of power plant	Type	Location	Installed Capacity in (kW)	Year Constructed
1	Baba Wali	Hydro	Kandahar	330	1935
2	Chalwarcha	Hydro	Herat	80	1936
3	Chak Wardak	Hydro	Wardak	3360	1941
4	Pulkhomry	Hydro	Baghlan	4800	1941

The power plants listed in Table 2 were all joint projects. The government invested 51% and private sector 49%. In late 1939, the government of Afghanistan nationalized the energy grid, which resulted in the construction and implementation of major hydropower plants seen in Table 3.

Table 3: Afghanistan existing hydro power plants [9].

Name	River	Capacity after rehabilitation [MW]	Date of commissioning/rehabilitation	Annual energy [GWh]	Estimated costs [$m]
Naghlu	Kabul	100	1967 / mid 2013	413	90
Sarobi	Kabul	22	1957 / completed	188	25
Mahipar	Kabul	66	1967 / completed	152	80
Darunta	Kabul	11.5	1964 / 2012	85	14
Assassab.	Kunar	0.7	1983 / *	4	1.2
Charikar	Ghorband	2.4	1973 / *	14	3.6
Jabul Ser.	Salang	2.5	1920 / *	14	3.6
Ghorband	Ghorband	0.3	1975 / *	2	0.6
Kajaki (I & III)	Helmand	33	1975 / completed	272	40
Grishk	Helmand	2.4	1957 / *	14	3.6
Pul-i-Chomri	Pulikhumri	3x1.37=4.12	1950 / 2013-2015	24	6
Pul-i-Chomri II	Pulikhumri	3x2.93=8.79	1962 / 2013-2015	49	13

3. Proposed solution mechanism

Currently, the world energy market has depended almost entirely on nonrenewable, but low cost, fossil fuels. Hydroelectric projects throughout the world provide approximately one-fifth of the world's total electrical energy [2]. With an estimated 75% growth rate in global population likely in the coming decades, especially in urban areas, the need for sustainable energy solutions utilizing compact, interconnected power plants will be more important [5]. However, energy access is not evenly distributed by season or geographical region. Some parts of the world are prone to drought, making water a scarce and precious commodity. In other parts of the world, floods that cause loss of life and property are major problems.

Both water management and renewable energy production uniquely contribute to sustainable development [10]. Approximately 1.6 billion people have no access to electricity and about 1.1 billion are without an adequate water supply even though resources for hydropower development are widely available globally [11]. Afghanistan has a large supply of renewable energy from hydropower, wind, solar, and geothermal, but war and instability prevents renewable energy development as energy demand grows. More energy is imported from other nations, increasing from a 34% share in 2006 to about 73% in 2011

(2250 GWh), The imports originate from these Power Purchase Agreements [9]:

– Iran (22%) under 1 contract.

– Tajikistan (4%) under 2 contracts.

– Turkmenistan (16%) under 2 contracts.

– Uzbekistan (57%) under 1 contract.

Domestic and imported energy supplied for Afghanistan is summarized in Table 4.

Table 4: Historical development of power production and imports in Afghanistan [9].

Year	2006	2007	2008	2009	2010	2011
Hydro [GWh]	644	755	617	835	910	801
Thermal GWh]	213	211	197	93	101	39
Import [GWh]	432	609	752	1,155	1,572	2,246
Total [GWh]	1,289	1,575	1,566	2,083	2,583	3,086

Recently, the government of Afghanistan approved policies to manage the water resource and improve energy supply, creating several policy frameworks to cope with the fast-growing population and the demand for energy [1]. Revenues generated through exported electricity sales can finance other infrastructure systems essential for human welfare, including drinking water supply, irrigation schemes for food production, transportation, recreational facilities, and ecotourism.

Compared to other large-scale energy options, hydropower emits very few greenhouse gases associated with climate change uncertainties in precipitation frequency and intensity. Hydropower projects also do not contribute to the problems of acid rain or atmospheric pollution. Consequently, hydropower can mitigate the widespread human impacts of climate change [6]. However, policies favoring renewable energy and water for sustainable development are driven not only by the potential of supplying energy needs but also by a commitment to implement necessary changes. China, for example, has moved 300 million citizens from poverty since 1990 through increased access to energy [10].

Hydropower is restricted to sites with available water and appropriate geomorphology. As a mountainous country, Afghanistan is well-positioned to develop hydropower projects. Based on Afghanistan energy master plan, the MEW has placed the Baghdara Dam (Kapisa province) as a top priority [9].

In the Power Sector Master Plan 2013 developed by the Asia Development Bank, Table 5 lists the most worthwhile hydropower projects with the earliest possible commissioning dates [9].

Table 5: List of Afghanistan hydropower plant potential options.

No.	Project	River	Province	Capacity [MW]	Comm. date	Annual Energy [GWh]	Est. cost [$m]
1	Baghdara	Panshir	Kapisa/Parvan	210	2021	968	600
2	Surobi 2	Kabul	Lagman	180	2021	891	700
3	Kunar A (Shal)	Kunar	Kunar	789	2022	4772	2000
4	Kajaki Addition	Helmand	Helmand	100	2021	493	300
5	Kukcha	Kukcha	Badakhshan	445	2022	2238	1400
6	Gulbahar	Panshir	Panshir/Baghlan	120	2021	594	500
7	Capar	Panshir	Panshir	116	2021	574	450
8	Kama	Kunar	Nangarhar	45	2021	223	180
9	Kunar B (Sagai)	Kunar	Kunar	300	2021	1485	600
10	Kajaki Extension	Helmand	Helmand	18.5	2015	91	90
11	Olambagh	Helmand	Uruzgan	90	2021	444	400
12	Kilagai		Baghlan	60	2021	297	250
13	Salma	Hari Rud	Herat	40	2020	197	200
14	Upper Amu	Amu Daria		1000	2023	4955	2500
15	Dashtijum	Pyanj		4000	2023	19819	8000

4. Methodology

Baghdara Dam is located north of Kabul. A road through Bagram that crosses the Panjshir River on a bridge known as Fishermen's Bridge defines the upper boundary. Topographic maps show the river elevation at Fishermen's Bridge is 1460 meters above sea level. At this level, many acres of arable land would be lost, and many villages would be flooded. At 25 km downstream of Fishermen’s Bridge, the Pajshir enters a narrow gorge, which extends uninterrupted to the Naghlu reservoir [12].

Between Fishermen's Bridge and the entrance to the gorge, the Panjshir flows through numerous channels meandering across a broad, fertile flood plain. While upstream access to the potential reservoir area is easy, access to the river from the gorge is extremely difficult due to the steep sides of the gorge and its remote location from roads. Traversing either bank at the river level is difficult due to intermittent ridges descending steeply into the river on both sides. The project's main structures would be located in the gorge, potentially backing the Panjshir River up to the fertile flood plain [12].

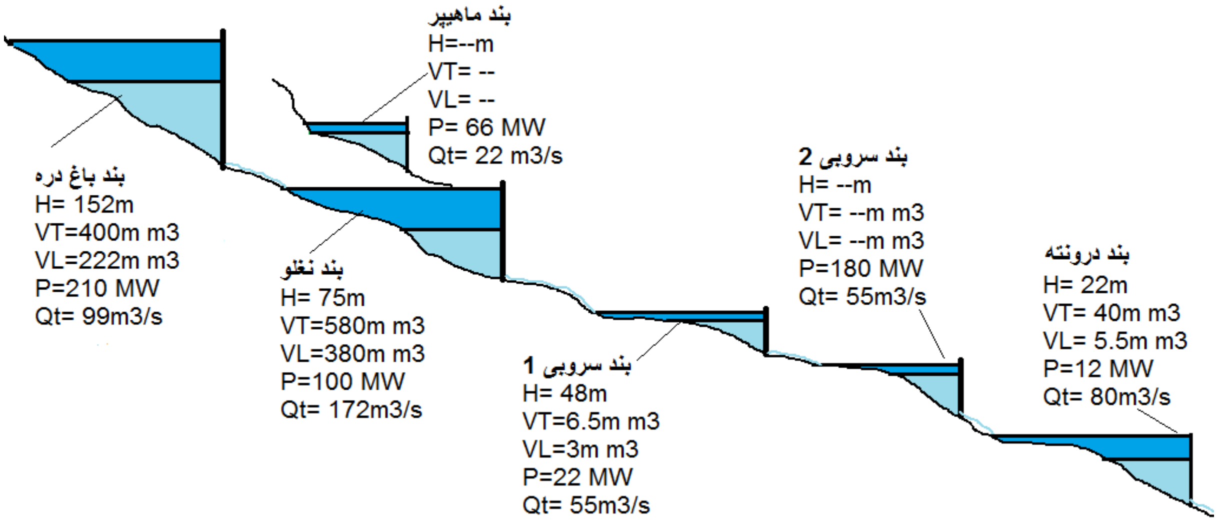

Figure 1. Effect of upstream Baghdara dam on downstream cascade dams.

Each dam structure affects energy generation, river flow, and sediment collection in downstream cascade dams. Properly locating the storage and cascade dams along the river should be holistically evaluated [13] to assess the combined effect on the Panjshir River, fishing and the environment before construction begins since changes are hard to implement once ground is broken. Information from topographic surveys and maps informed this evaluation of potential locations for dams and generators. Two options were chosen for this assessment [12].

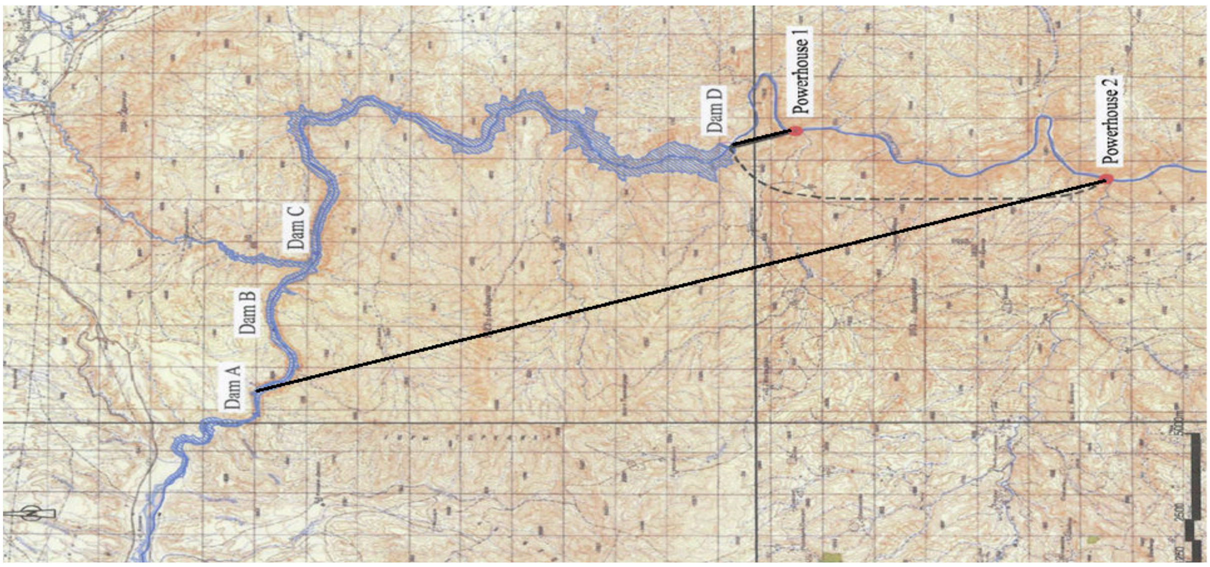

Figure 2. Baghdara Dam potential dam and powerhouse sites.

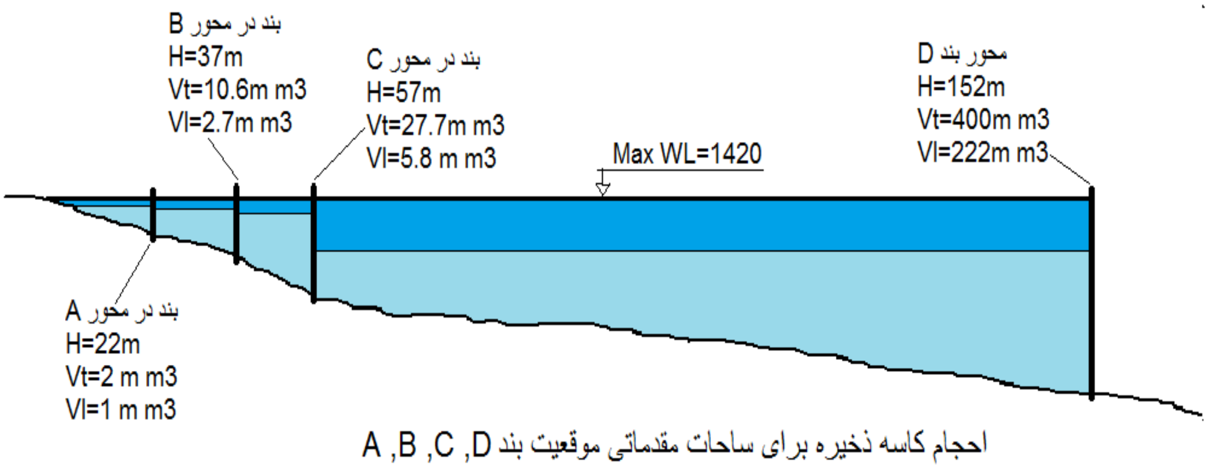

Figure 3. Evaluation of dam axis location (A, B, C and D).

Run-of river option A2:

Option A2 was selected as the best of the run-of-river options. Being located near the head of the gorge, dam site A is significantly more accessible.

Table 6: Key parameters of option A2 [12].

	Option A2
Max. height of dam (m)	22
Reservoir water level m asl	1420
Reservoir area 106 m2	0.5
Reservoir volume 106 m3	1.9
Storage capacity 106 m3	0.9
Length of head race tunnel km	17.7
Gross head m	255

Option Dl with a storage reservoir:

With the maximum reservoir operating level confined to 1420 meters above sea level, dam site D is the best option, The Reservoir Operation and Generation Report suggested constructing a cascade of two hydropower stations in the gorge capture the energy.

Table 7: Key parameters of option D1 [12].

	Option Dl
Max. height of dam (m)	152
Reservoir water level m asl	1420
Max. reservoir area 106 m 2	7.4
Reservoir volume 106 m3	400.0
Storage capacity 106 m3	220.7
Length of head race tunnel km	1.2
Gross head m	190

The topography of dam site D is well-suited for a concrete arch dam instead of a rock-fill dam design. Although rockfill is available in the immediate vicinity of dam site D, construction of a spillway and other relevant structures is seriously impeded by the lack of space. There was no evidence that clay is available in the project area to construct an impermeable core [12].

Annual electricity generation of options A2 and Dl (GWh) [12].

	Assumed Installed Capacity [MW]					
Project Option	90	120	150	180	210	240*)
A2	636.4	765.1	860.4	948.2	1036.1	-
Dl	647.1	743.5	831.3	901.2	967.4	1018.8

Table 9 provides a Preference Matrix for ranking and comparing Options A2 and Dl.

Table 8: Comparison of factors for the preference matrix [12].

Parameter	Option A2	Option D1
Environmental	No major adverse impacts; mitigation measures can be implemented	No major adverse impacts; mitigation measures can be implemented
Social	Negligible adverse impacts with max. reservoir operating level < 1420 m; numerous positive impacts	Negligible adverse impacts with max. reservoir operating level < 1420 m ; enhanced positive impacts with larger installed capacity than AI and ability to serve peak demand
Technical	Larger construction risks than 02 (due to long tunnel and longer	Peaking operation and higher

	duration of construction)	available capacity in winter are significant technical advantages
Economic	0.061 US$/kWh cost of energy	0.057 US$/kWh cost of energy

5. Environmental and social impact

Previous studies on Baghdara Dam project suggested that a maximum reservoir operating level of up to 1460 meters above sea level (m asl) would back up the Panjshir River to Fishermen's Bridge; at this level, some 20,000 people would have to be resettled (Map 2). If the maximum reservoir operating level were reduced to 1,440 m asl, fewer than 10,000 people might be displaced (Map 3). Project options that limit the maximum operation water level to 1420 m as1 essentially mitigate the need for resettlement and would not impact on irrigated area (Map 4) [12]. No forest areas are affected by the project, and according to present knowledge, there is no adverse impact upon areas of ecological value in the potential reservoir area, in the gorge of the Panjshir River, and in the potential resettlement areas. With the exception of graveyards located along the Panjshir River valley, protected areas that include historical or cultural sites are not affected by setting the reservoir water level maximum to 1420 m as l [12].

Figure 4. Maximum reservoir operating level up to 1460m as1.

Figure 5. Maximum reservoir operating level up to 1440m as1.

Figure 6. Maximum reservoir operating level up to 1420m as1.

6. Result and discussion

In this paper, we compared all options with Baghdara Dam axis location and recommended a suitable placement for future construction to maximize electric power generation, especially during winter and provide clean potable water to New Kabul City. Our results suggest that a dam with a small reservoir at location A needs a long tunnel to the generator station, requiring advanced technology (TBM) and accurate geology surveys that are not available in Afghanistan. A dam in location D with a large reservoir will recharge downstream hydropower plants such as Kapar (120 MW), Naghlo (100 MW), Sarobi-1 (22 MW), Sarobi-2 (180 MW) and Daronta (12 MW). The large reservoir will stop sediment ponding at the Naghlo hydropower reservoir [14,15].

- Run of river (A2) will produce less energy because snow-melt will stop during winter.
- Storage (D1) will produce maximum energy during winter months.
- During winter, the storage option produces twice as much energy as the run-of-river option.
- Option A2 requires an 18-km headrace tunnel and TBM, which is not available.
- Options D1 and A2 have same environmental impact at reservoir level 1420m asl.
- Economic benefits: 0.057US$/kWh for option D1 and 0.061US$/kWh for option A2.
- Option A2 requires more spillway capacity than Option D1 to pass PMF.
- Option D1 will reduce sedimentation to Naghlo reservoir.

Hydropower has an extensive list of advantages: efficient power generation, flood protection, flow regulation, irrigation, fossil fuel avoidance, a long depreciation period, revenue by an adequate electricity rate, and low operating–maintenance–replacement costs. In addition, hydropower plants can supply energy to the grid immediately and provide essential back-up power during major electricity outages or disruptions. Other benefits are gained from hydropower:

- Each Dam project affects energy generation, river flow, and sediment pooling at downstream cascade dams. Properly locating the storage and run-of-river dams along the river should be evaluated upstream and downstream.
- Operation of the run-of-river power plants can be coordinated to provide optimal energy generation when needed, especially if there is a reservoir at the head of the cascade. Reservoirs store potential energy for production when the demand is highest.
- When water resources are not available to replenish reservoirs by natural inflow, pumped-storage schemes can be used to assist in the storage of energy from other generation sources.
- Hydropower supports winter peak and daily peak demand.
- Power generation can be adjusted very quickly from zero to maximum and vice versa within a few minutes.
- Hydropower can support hourly variations of load at the dispatch center.
- Response times relying on other sources of energy cannot change as quickly (Figure 7).

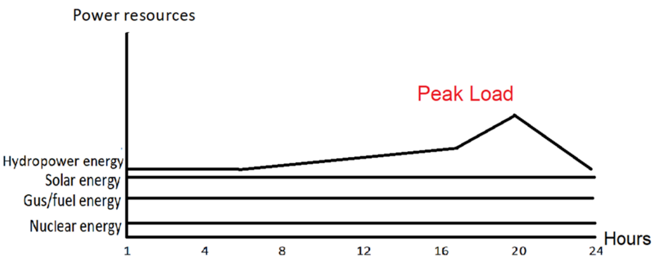

Figure 7. Hydropower support daily peak demand.

7. Conclusion

Hydro plants are superior to other power plants with their beneficial socioe-conomic and environmental impacts [15]. Policies supporting hydro encourage private sector participation, improve energy supply for sustainable socio-economic development, and serve as an additional income source for the government budget. These advantages decrease financial budget deficits, encourage technology transfer, and accelerate economic development of the country once hydraulic energy investments become operation on schedule [11].

Low operational costs of hydropower, minimal environmental impact, and responsive adaptability to demand spikes favor hydro over other alternative energy sources. Hydro plants with large reservoirs have multipurpose benefits and profitability, such as flood protection, recharge of downstream cascade dams, domestic water storage, and expanded access throughout the nation that promote economic development. As a "green energy" source, hydro has minimal impact on the environment as it does not contribute to pollution or CO2 emission [16]. Small/mini-hydro plants can be built where hydrological and topological conditions are more challenging. Renewing and revising domestic renewable energy policies and regulations should also consider the benefits to society.

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