A Review of the Impact of Non-Powered Dams in KSA and as Assessment of their Potential for Hydroelectric Power Generation

Abstract

This study aimed to evaluate the associated impacts of exited non-powered dams in the KSA and potential to retrofit them for hydropower production. The KSA has 559 dams and they vary in capacity and geological location. Furthermore, the benefits from these dams are very limited, and they are wholly non-powered. The King Fahad Dam, which is the largest dam in the country, has a water capacity of 325 MCM, whereas the Hali dam has a capacity of 253 MCM.

Technical feasibility was carried out, and it was found that the Jizan dam has potential for hydropower types in the KSA. This is because of the high frequency of water irrigation flows throughout the year. It has the potential to install a small run-of-river along with float solar phototactic energy, with a total energy production of ROR 159.720 MWh. Furthermore, FPV has been estimated to save 70% of the water evaporation from the reservoir. Hence, the construction of FPV along ROR could introduce a significant benefit as well as mitigate some of the major problems that KSA is currently facing including water security if this project is assumed to be proposed in whole major dams.

Keywords: Hydropower, KSA, Dam, Energy

1.0 Introduction

Global energy consumption is expected to further increase in terms of food, water, and energy supply. The International Energy Agency has predicted that the total demand is expected to grow at an average annual rate of 0.7% by 2030, which is almost half pace of growth observed in the previous ten years and demand is expected to rise until 2050 (IEA, 2023). This increase is due to the rapid growth of the human population and economic development. In addition, politics, conflicts, and climate change are all factors that have forced most countries to look for more sustainable energy resources as well as to work toward net zero carbon goals. Different countries have already established long-term investments in renewable energy (e.g., solar power, wind turbine, hydropower, and geothermal).

Moreover, the hydropower's capacity rose 70% globally over the previous years and currently provides over 15% of the world's electricity (IEA, 2021; IHA, 2023). Some countries have viewed dams as an effective way to meet water and energy demands. For instance, hydropower accounts for 41.7 % of the EU's renewable electricity generation while in China, hydropower accounts for more than 15 % of total power generation in (Huđek et al., 2020; Fan et al., 2020). The dams are frequently used for several primary purposes (e.g., electricity production, flood control, and irrigation). However, dams can have such impacts on water quality, fish, fragmentation of habitats, flow regime, and thermal characteristics of the river as well as displacement of people. Indeed, any dam, whether hydroelectric or not, blocks watercourses and obstructs the movement of certain species such as fish swimming upstream, especially migratory species like salmon and eels. On the other hand, the water blocked by the dam can be used for the generation of renewable energy. This would help to decarbonise fossil fuels including coal, crude oil, and natural gas which are the primary contributor to the rise in greenhouse gas concentration in the atmosphere. In addition, the Middle East's oil countries producer countries shall benefit from those abundant energy resources since they have already established goals toward decarbonisation and net-zero carbon emission. For instance, KSA started its 2030 vision in 2015 and the country has taken a big step toward clean energy, it has released different projects, and those are now under construction which include 16 GW of solar photovoltaic, concentring solar power 25 GW, wind 9 GW, 4 GW by waste to energy and geothermal (Albarbar et al., 2019).

KSA is characterised by an abundance of energy sources. Despite the lack of regularly flowing rivers, Saudi Arabia is one the richest countries, with hundreds of dams containing billions of cubic meters of water as shown in Figure 1. According to the Saudi Ministry of Environment Water & Agriculture, which is responsible for those dams, 559 dams have been built across that country and most of them are found in the south of the Kingdom (MEWA, 2021). In terms of their purposes, some of them are for the recharge of subsurface water in the dam area to supply water to wells in the dam's catchment area. It is also used to safeguard cities and communities from the threats of torrents and floods as well as supplying the stored water for agriculture as needed. Despite this, there is not a single dam in the kingdom that is used for power generation.

Figure 1: Shows the Major two dams in Kingdom of the Saudi Arabia.

So, the aim of this paper is to investigate the impact of the existing water dams and the potential to retrofit them for hydropower production. Therefore, it will mainly (1) evaluate the potential of the existing major dams in Saudi Arabia, (2) investigate the impact of impounded rivers, and finally (3) conduct a feasibility assessment if it is sustainable to retrofit HEP to existing dams.

2.0 Number and Capacity of Dams in the Kingdom of Saudi Arabia

According to the Ministry of Environment, Water, and Agriculture (MEWA, 2021), the kingdom has completed 559 dams in 2019. Those include103 in Riyadh, 57 in Makkah, 41 in Medina, 48 in Al Baha, 13 in Jazan, 27 in Najran, and 171 in Abha while the rest of the dams are located in the North region such as in Tabuk and Hail cities.

Figure 2: Shows the names and locations of major 12 dams in KSA.

There are major dams that are located in different regions of the country. So, as shown in figure 2, these reservoirs have been highlighted in where they are located. These including King Fahad dam which is the largest dam that has been built in KSA while the second-largest dam is Hali which is in Hali Valley in the Makkah region.

Table 1: Shows a summary of major dams of their function and capacity (Chowdhury et al, 2015; MEWA, 2021).

Name	Region	Nearest city	Dam height (m)	Purpose	Capacity (million m^3)	Average water storage (million m^3)
King Fahad	Asir	Bishah	103	Flood Control/ Ground water recharge	325	158
Hali	Makkah	Makkah	87	Flood control	253	117
Rabigh	Makkah		184.5		220	44
Wadi Abha	Asir	Abha	33	Flood Control/ Water supply	213	1.2
Baysh	Jizan	Jazan	74	Flood control	193.64	113
Wadi Murwani	Makkah	Jeddah	61.0	Flood control	183.6	4.43
Najran Valley	Najran	Najran	73	Flood control	86	18.2
Qanuna	Makkah	Makkah	70	Flood control	79.2	39
Jazan Wadi	Jizan	Jazan	35	Flood control/ Irrigation	54.20	34.25
Tharad	Al Baha	Al Baha	25	Flood control/ Water supply	14.14	5.44
Al Hariq	Al Riyadh	Al Riyadh	6.0	Flood control/ Ground water recharge	0.5	0.36
Sadus	Al Riyadh	Al Riyadh	7.0	Flood control/ Ground water recharge	0.4	0.23

It is difficult to classify the purpose of the whole dams in KSA. This is due to the lack of the study on subject as well as accessibility to the related data. However, from the literature and the studies, the primary purpose of most dams is to capture surface water resulting from flash floods as well as to enhance groundwater storage as shown in table 1. For instance, the largest dam in the country, which is King Fahad Dam, was built in 1997 for agriculture management, flood protection, feeding water-bearing sedimentary layers, compensating for groundwater extraction from the region’s groundwater reservoirs, and feeding the water treatment plant (Alquraish et al., 2021). On the other hand, the second largest dam after King Fahad, is the Hali Dam and its primary function is flood control, agricultural municipal water supply, and groundwater recharge.

3.0 Impact of Impounded Rivers

Dams can aid human socioeconomic development by providing water for drinking, irrigation, and energy as well as other benefits such as jobs, and providing electricity. However, the large dam can cause a slew of issues, including sedimentation in reservoirs, erosion in downstream reaches, and disruption to stream and terrestrial ecology. Furthermore, impounded rivers alter flow conditions and, as a result, water flow conditions and downstream reaches, which has an impact on wildlife in the reservoir and downstream reaches.

3.1 Environmental Impact

3.1.1 Wildlife

Riparian corridors are shown to be important for birds and terrestrial animals, reservoirs have both beneficial and detrimental effects on aquatic and terrestrial animals (Domínguez-López et al., 2014). However, there is no existing information on the types of waterfowl and animals that live on KSA dams, but the most popular wildlife is Sand Gazelle, Leopard, Fox, Camel, Caracal, Wolves, and Ovis. In addition, most of these animals are found on the sarawat chain mountains. Most reservoirs are surrounded by these chain mountains and reservoirs provide a stable water source that may benefit a variety of these species. Hence, these dams could have a significant impact on the distribution and abundance of birds and wild animals in the region.

Furthermore, the disruption of the seasonal flood regime along the river is the main severe downstream consequence of the river management on mammals and birds (Figarski et al., 2015). So, the reduction in flooding has the potential to modify vegetation communities that are vital to a variety of animal and bird species in the long run. Thus, many animals could have developed behavioural patterns to coincide with seasonal flooding in an arid region, where riparian vegetation may be the only substantial vegetation. Therefore, changes in vegetation may put the birds and animals at risk that rely on it in jeopardy if the flooding regimes are altered.

3.1.2 Fishes

Dam construction can have a greater impact on riverine fish than any other human activity. The conversion of naturally lotic surroundings to lentic habitats is one of the immediate consequences of river impoundment (Turgeon et al., 2019). In addition, impoundment of reasonably fast-moving dams and impounded rivers could eliminate riverine fish, which rely on flowing water for all of their ecological needs (Neves et al., 1990; Penczak et al., 2000). For instance, following the impoundment of the TGR, YEMCs in China, fry resources dropped by more than 90%, while adult resources dropped by more than 50% (Yi et al., 2010). Furthermore, many significant commercial fish travel from the river system to the sea, either to produce or to feed. Reservoirs will flood huge spawning sites, and great dams will block upstream and downstream migrations. As a result of river impoundment, fish species may become extinct. Hence, table 2 lists some of the native species that have become extinct from dammed rivers. For instance, the Gezhouba dam in China, which blocks the Chinese paddlefish's migration route and prevents mature fish from traveling to the higher sections of the river to reproduce, may be to blame for the species' extinction (Zhuang et al., 2016).

Table 2: Shows different types of some fishes that has been disappeared after the dam construction in different country in the world.

Location	**Name**	**Ref**
China	*Paddlefish*	(Zhuang et al., 2016; Zhang et al., 2020)
France	*Atlantic Salmon*	(Vandeputte et al., 2021)
USA	*Ptychocheilus lucius,* *Punctatus, and Notropis*	(Dymond et al., 2021; Wang et al., 2014)
Central Europe	*Barbus spp., Esox Lucius, and Perca fluviatilis*	(Wang et al., 2014)
India	*Hilsa ilisha, Puntius dubius*	(Renjithkumar et al., 2016; Wang et al., 2014)
Australia	*Plectroplites ambiguus, Tandanus tandanus*	(Wang et al., 2014)

Table 2 shows some of the fishes such as Atlantic Salmon have vanished after the Dordogne River dammed in France. However, this does not mean water dams harm all fish species. For instance, lentic fish have been replaced with lotic species in the reservoir fish ecosystems of Xingajiang and Danjiangkou and have dominated the fish community (Zhong et al., 1996). Larger reservoirs may support the growth of certain species such as in Jisheries reservoir in China where following the dam building, a narrow river section is replaced by a significantly larger reservoir. Therefore, it has been found that fish life has been positively changed after the reservoir scale changed.

3.1.3 Sedimentation

Sedimentation deposition can be found anywhere in a water system. As a stream enters a reservoir, it slows down, and the majority of suspended particles will eventually settle to the reservoir’s bottom. In addition, many elements influence sedimentation, including the speed and amount of water created by the incoming stream, as well as the size and weight of sediment particles. However, sedimentation deposition is a type of environmental pollution that could result in harmful consequences (Chamoun et al., 2016; Baoligao et al., 2016). For instance, Sanmenxia Dam, on China’s Yellow River’s middle reaches, is famous for its severe sedimentation difficulties (Wang et al., 2005). In the Yellow River Basin, the heavily loaded sediments have wreaked havoc on social and economic life (YRB) (Ran et al., 2020). As a result, the loss of storage can be caused by sedimentation, as well as the reservoir’s flood control, power generation, and water supply function can be reduced (Wang et al., 2005). So, sediment can clog intakes and dramatically increase the abrasion of hydraulic machinery, lowering efficiency and raising maintenance costs. However, the implementing sediment traps method could lower suspended solids concentrations downstream. This method is a manmade ‘basin’ or depression on the river where sediment settles out and accumulates, allowing it to be readily removed.

3.1.4 Greenhouse Gases (GHG)

According to the most current estimate, global gross reservoir GHG emissions were 0.8 Pg CO_2 eq/yr, with a range of 0.5 Pg CO_2 eq/yr to 1.2 Pg CO_2eq/yr (Li et al., 2020). So, the flooded organic matter in the original woods, soils, and vegetations, allochthonous input from terrestrial ecosystems or neighbouring upstream rivers, and photosynthetic fixation by phytoplankton were all carbon sources in the reservoirs (Yang et al., 2014). After the impoundment, CO_2 is created by the decomposition of these organic materials under aerobic or anaerobic conditions (Guérin et al., 2008). So, the greenhouses gases can be released into the atmosphere from the reservoir in various ways. These including diffusive flux at the reservoir surface, gas bubble flux in the shallow zones of a reservoir, water degassing flux at the powerhouse outlet downstream of turbines and spillways, and flux across the air-water interface in rivers downstream of dams (Yang et al., 2014).

Moreover, carbon dioxide emission from downstream rivers generated 1.63 to 32 percent of total carbon dioxide emission from reservoirs, according to (Guérin et al., 2006; Abril et al., 2005; Kemenes et al., 2011; Yang et al., 2014). So, it has been found that CO_2 emission from the Sinnamary River in France, which flows downstream of the Petit Saut Dam, account for 22 to 31 percent of the Petit hydroelectric system’s total CO_2 emissions (Guérin et al., 2006; Abril et al., 2005) while CO_2 emissions from the Uatumã River, which flows downstream of the Balbina Dam in Brazil, account for 1.63 to 7% of total CO_2 emissions from the Balbina hydropower system (Guérin et al., 2006; Kemenes et al., 2011). Furthermore, downstream rivers were responsible for 23%, and 9-33% of total CH_4 emissions across the Balbina, and Petit Saut reservoir's surfaces respectively (Guérin et al., 2006). However, in the Sinnamary River, CH_4 concentrations were 80 to 200 times higher downstream of the dam than upstream of the reservoir, according to Petit Saut (Guérin et al., 2006). Hence, the disparity in CH_4 emissions upstream and downstream is most likely due to the strong disturbance caused by water moving through turbines and spillways, as well as the quicker water velocity in downstream rivers (Yang et al., 2014).

3.1.5 Thermal Regime

Variable inflows and outflows in reservoirs generate water level fluctuations, resulting in a complicated mixing of dynamic and dynamic flow patterns that regulate reservoir temperature regimes (Xie et al., 2017). So, the flows managed by upstream dams affect downstream habits through a process called hydropeaking and thermopeaking (Choi et al., 2018). The upstream dams only release water during the hydropower-producing period which makes short-term oscillations in water discharge in the downstream reach, and this is known as hydropeaking (Choi et al., 2018). Furthermore, the temperature of the water released from the upstream dam is likely to differ from the temperature of the water going downstream (Choi et al., 2018). The water discharged from the dam in the winter and summer is often warmer and cooler than the water flowing in the winter and summer, respectively (Choi et al., 2018).

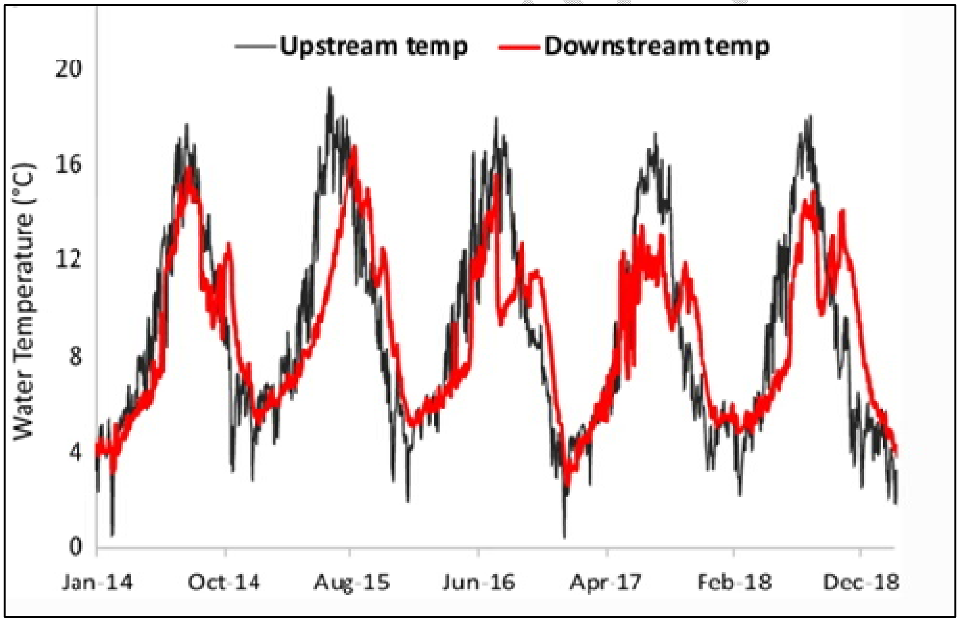

Figure 3: Shows the temperature variation of downstream and upstream through the year of Detroit dam in the USA (Ahmad et al., 2020)

Moreover, figure 3 shows the fluctuation of temperature from downstream and upstream. So, it can be noticed that the downstream temperature is higher during some days in the winter season while in summer is cold. However, this case can vary from location to location as well as it can depend on wind velocity which can have also an impact on the mixing rate, resulting in the variation of temperature.

However, for instance, the water temperature upstream was higher than that of the downstream during the heating phase after the TGP was installed, but lower during the cooling period (Long et al., 2016). In addition, in all four seasons, changes in air-water temperature interaction after the TGR's construction had a cooling effect ranging from 0.26 Celsius to 0.94 Celsius. The most significant drop (2.1 °C) occurs in August when the river should be relatively warm (Tao et al., 2020). On the other hand, the Kielder reservoir that is located in Northumberland in Newcastle upon Tyne in the UK has shown a significantly large lag of downstream temperature. So, it has been found that there was a considerable lag delay for temperature in reaching 7 and 11 °C during the winter and summer respectively (Haile, 1989). The winter temperatures in the river immediately below the dam were substantially higher, with 1.5 °C above the dam at Butteryhaigh compared to 4.5 °C immediately below the dam at Yarrow (Haile, 1989). So, due to reservoir stratification, the cooler discharge was followed in early summer, resulting in a significant time lag before the required water temperature of 7 Celsius was reached (Haile, 1989). Additionally, during June when the temperature is 7 Celsius, young salmon begin to feed, and this time lag can cause the newly emerged fry to starve (Haile, 1989). When the baby fish develop more slowly in the cooler temperatures in summer, they would reach the smelting stage later in the year, as smoltification requires a water temperature of 11 Celsius (Haile, 1989). Therefore, the lag of temperature could only affect the water quality but also threaten the life cycle of fish species.

3.1.6 Water Quality

The river water is influenced by a variety of ways including sedimentation as well as a thermal regime which can be considered to have an impact on water quality. So, for instance, sedimentation transport can contain other materials such as phosphate and nitrate (Wang et al., 2014). These two components can come from different sources including domestic sewage, industrial wastewater, livestock and poultry breeding excrement, aquaculture effluent, groundwater, surface runoff, and atmospheric inputs are all major sources of nutrients in rivers (Hu et al., 2012). Although these materials are needed for the aquatic environment, the excessive amount of the nutrient materials can cause considerable effects. For instance, phosphorus and nitrogen is a major contributors to excessive algae development and poor water quality although potassium, magnesium, trace elements (iron, manganese, and copper), and organic molecules all play a role in this formation (Hilton et al., 2006; Wang et al., 2014). In addition, the dissolved oxygen in the reservoir can be reduced, probably due to the decomposition of a series of algal blooms and the deep, low-oxygen water periodically im-pinging (Xin et al., 2020). As a result, the reduction of DO may result in death for species in the reservoir. Furthermore, algal blooms can also interfere with recreational activities such as fishing, swimming, boating, and tourism (Tekile et al., 2015). However, it has been suggested that in order to avoid the algal bloom growth, each reservoir should have the capability to maintain acceptable water quality under a particular nutrient load. Therefore, this could need a big effort to develop a system for estimating necessary nutrient loadings in order to prevent algal growth.

3.2 Socio-Economic Impact

Dam projects can have a wide range of economic consequences, both in the location where they are built and in the surrounding area. The dam's main outputs can include such as enhancing water availability for agriculture and water supply for communities surrounding the dam, industry, and hydropower generation, and flood control.

3.2.1 Water and Energy Security

Temperature changes, rainfall patterns, droughts, and floods, are all major indications of climate change that have significant impacts on river systems which will consequently affect hydropower dam production (Hasan et al., 2018). However, the temperatures in the Middle East are expected to rise by up to 4.5 Celsius, which, combined with a projected 25% decrease in average annual precipitation and changing precipitation patterns, could pose serious challenges to water resource management (Jamali et al., 2013). The evaporation losses are often substantial in arid countries such as Saudi Arabia as well as other middle east countries. For instance, Egypt's Nasser reservoir has an average water surface area of 6500 km^2 at level 182 above sea level, the evaporation loss from the reservoir ranges from 12×10^9 to 16×10^9 m^3/year. Although no information has been revealed on the water loss from KSA dams, only one article has stated that the water loss from Wadi Murwani dam that located in Makkah province, the calculated evaporation loss is 4.7 to 6 m/year (Lopez et al., 2014). In addition, the water loss can be significant with a large reservoir as it would be larger. Therefore, the largest dams such as Hali, and king Fahad can have a significant water loss throughout the year.

Although most KSA dams have been built to mitigate and solve the water security, it is still and expected the KSA will be suffering from the low water availability. However, when compare dams in KSA with a country such as India that has high resources of water and annual precipitation, dams have shown great influence on food and water security. For instance, the Bhakra dam that is located on the Sutlej River in India irrigates 10 million acres of land (Pal et al., 2013). Additionally, the availability of irrigation water through this dam-canal network has aided in enhanced groundwater recharge (Bhatia et al., 2008). So, surface return flow or groundwater recharge can replenish the water lost through seepage in the canal irrigation system. Furthermore, the availability of large surpluses of foodgrain from the region has greatly reduced the country's reliance on food grain imports to meet the population's foodgrain needs (Bhatia et al., 2007). It has also helped to shield the country from droughts to a significant extent, making Indian agriculture more sustainable, contributed to the country's food security, and helped to reduce the wide variation of food prices in the market (Bhatia et al., 2007). On another hand, the Bhakra system's hydropower plants providing approximately 1325 million watts of energy per year for surrounding states Ragasthan, Punjab, and Haryana as well as the national capital region of Delhi (Pal et al., 2013). Thus, the region has more than achieved the necessary hydrothermal mix of 40:60 (Bhatia et al., 2007).

3.2.2 Water Supply for Household and Industry

It has been estimated that a total of 25 dams store 303.5 million cubic meters of water for drinking purposes each year in KSA (Shakhawat et al., 2015). So, the most benefit of water is the nearby community around the dam and even urban community through water desalination companies. For instance, the King Fahad dam can supply around 40,000 m^3 of water a day to Bisha city while the Hali dam supplies around 40 m^3 millions of waters in a year to the surrounding areas. However, most reservoir locations are far from urban areas and most of them are placed in the mountainous environment. Thus, this may have made it difficult for other industries or manufacturing to benefit from those reservoirs. However, these benefits from existed dams can be limited for the household but in a country with high water resources, the case is not the same. For instance, in India, The Bhakra system canals, and groundwater recharge have had a considerable impact on the availability of drinking water in Punjab and Haryana's rural and urban areas. In addition, the system has delivered water to industries, small businesses, and household enterprises in the two states. The Bhakra dam system provides a significant amount of drinking water to Delhi, producing around 900 million litres per day, or 40% of Delhi's total surface water supplies (Bhatia et al., 2007). Therefore, it can be concluded that the scale, purpose, and climate of the reservoir could have a considerable impact on surrounding and even far areas.

3.2.3 Tourism

When a dam becomes a major tourist destination, businesses, hotels, and restaurants spring up around it. So, whether for hydroelectric power generation or agricultural irrigation, irrevocably modifies the terrain and generates a new feature that permits the fulfilment of the project (Dias-Sardinha et al., 2015). However, with aid from pictures and previous visits to some dams in KSA, it can be found that area is relatively poor in terms of economic development and other activity. This can be due to three reasons; (1) their locations are far from the urban areas; (2) the poor transportation infrastructure serving to the site of the reservoirs; (3) low level of socio-economic developments in the area.

However, the dam can enhance the number of tourists in the place and even the surrounding areas of the project such as in Three Gorges. The dam's construction has immediately provided new and major potential areas for tourism growth. The TG is well known for its stunning scenery and diverse cultural offerings (Xu et al., 2018). So, natural features such as mountains, water, gorges, woods, and springs, as well as cultural traditional dwellings, festivals, ethnic costumes, and music, are abundant in locations (Xu et al., 2018). In addition, Dazu Rock Carvings, Three Gorges, Badong Shenlong Stream are among the 177 A-class scenic locations, with 13 5A Scenic spots (Tu et al., 2021). Furthermore, the project of TG is the largest one in the world and the region are rich with other tourism activity before the dam was constructed. Thus, this has also been well economically developed and enhanced tourism in the region. In 2018, The TG region welcomed about 564 million travellers, accounting for 21% of all tourists in China, and earned USD 39.58 billion in tourism revenue, accounting for 21% of overall tourism revenue (Tu et al., 2021).

3.2.4 People Displacement

It is estimated that 40-80 million people were displaced and resettled because of dam construction in the world between 1950 and 200 (Huang et al., 2018; Rousseau et al., 2021). Dam-induced displacement and resettlement that has a negative influence on local socio-economic conditions. Furthermore, it has been indicated that resettlement can cause disruption by impoverishment host communities, disrupting social fabric, and destroying economic assets (Huang et al., 2018). For instance, the resettlement of Three Gorges has been projected to be over 1.3 million people which has caused their social networks to become disjointed and potentially resulting in disputes with the new host community (Huang et al., 2018; Wilmsen, 2016). Moreover, a study has been carried out on 521 households within five years of displacements and has shown the earnings usually dropped, livelihoods were demolished, and permanent employment was replaced by more transient jobs, although infrastructure and housing were developed (Wilmsen, 2016). However, 8 years on, the study has shown significant change within the same groups. So, the economic inequality has decreased, food security has increased, and overall welfare has improved (Wilmsen, 2016). This appeared to be due to the Chinese government's determination to simulate the regional economy and increase corporate investment has paid off in this region of the project (Wilmsen, 2016).

On other hand, it can be proved that KSA existed dams have not caused a major displacement of a large community, and even there is no information has been mentioned resettlement of people due to the impounded rivers in KSA. Furthermore, the capacity of a large dam is relatively small compared to the TG as well as the existed reservoir are mostly relying on waterflood and do have not permanent rivers flows. Additionally, a major reservoir is located far away from the community and constructed in a very less popular region.

3.2.5 Jobs Creation

One of the most visible and immediate effects of a dam project, can be the provision of numerous job possibilities, either directly through the construction and maintenance of the dam or indirectly through the creation of services and infrastructure. Project design/permitting, turbine production, and other direct employment fall under this category. Suppliers, financiers, others establish indirect jobs to help implement projects and support/supply existing direct jobs. Jobs in the service sector, such as restaurants and retail, are induced because of direct and indirect employment creation. For instance, Sinop Dam in Brazil is implemented in the population around 211,260 and the provided direct jobs are around 300 (De Faria et al., 2017). Furthermore, the construction of hydropower dam can provide even more full-time jobs for the community such as in the USA where approximately 30,000 direct full-time equivalents work (FTEs) in the hydropower industry as of 2014 (Keyser et al., 2019; Uría-Martínez et al., 2014). However, the number of permanent formal jobs can be very little after the dam is constructed and resettlers might force to change their jobs into one that is different from their original job (e.g., Farmer, Ranchers, and Fishman). Resettlement with a change of vocation such as from agriculture to other industries is inherently more difficult than relocating as farmers (Nakayama et al., 1999). Therefore, it appears necessary to devise methods or programs for resettlers to successfully build a life following their migration.

4.0 Site Selection for Hydropower Potential

When selecting a site for hydropower generation, there are various factors should be taken into account. These include the geography of the site, climate, the available water head, and water storage as well as the accessibility to the location. Therefore, the Jizan dam has been selected for this study due to some obvious reasons that have been explained later in this article. Jizan dam is the only irrigation that is built in KSA compared to other dams which they mostly for flood control and recharge of the groundwater purposes. Furthermore, after reviewing the water discharge from the King Fahad Dam, which is the largest water storage reservoir in the country, it has been found that no even monthly water discharge, and very rare to find water released in the year from the dam although it contains 158 MCM of water that have the potential for HEP generation.

4.1 Jizan Dam

This dam is in the Jizan province of the southwest of Saudi Arabia that located in the port of the Red Sea as shown in figure 2. Furthermore, the Jizan is one of the Kingdom’s most fertile agricultural regions, with a wide range of high-quality and diverse agricultural products (Nouh, 1983). The dam plays important role in managing the stored water and draining in accordance with agricultural irrigation needs for the development and expansion of the agricultural region. Furthermore, the Jizan reservoir is located about 65 kilometres from Jizan city where most agricultural and mountainous regions are located that caused considerable high water during July and August as shown in figure 4.

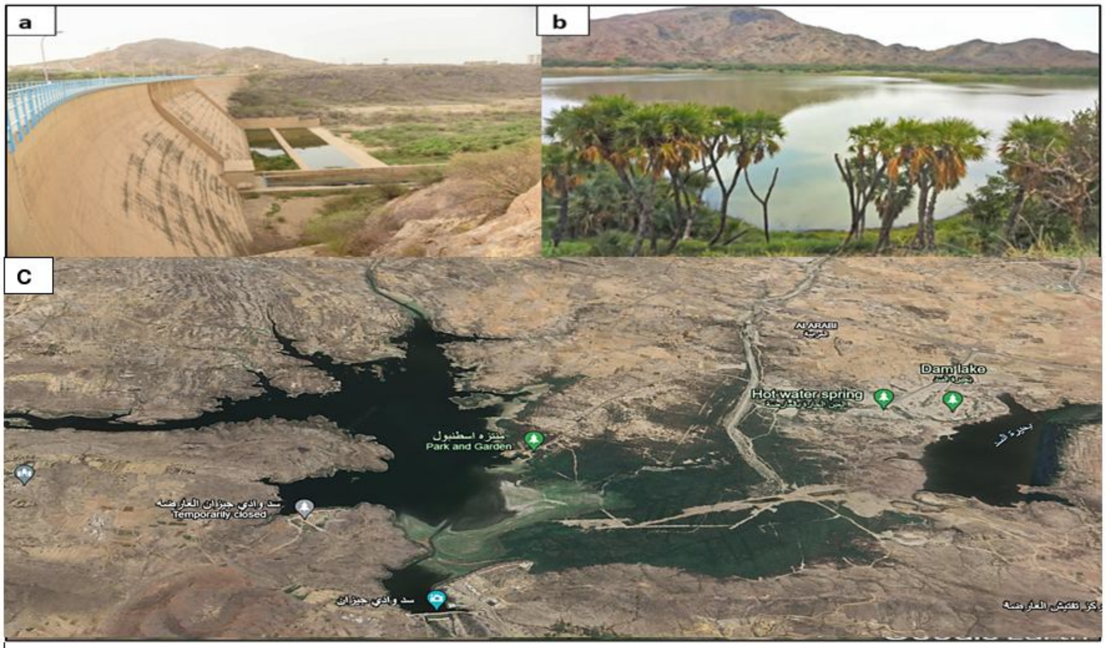

Figure 4: Shows the Jizan dam and reservoir.

4.1.1 Climate Data of the Site

The climate data for the location have been analysed through RETScreen. So, the precipitation and temperatures for the whole year have been illustrated using this software.

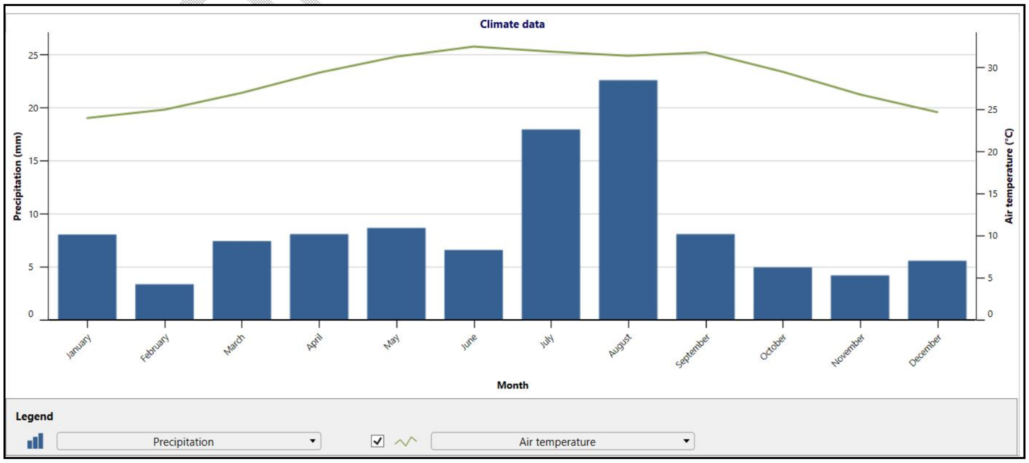

Figure 5: Shows precepation and air temperature average through the year in the Jizan region in 2021.

Figure 5 has been also generated through RET screen and it can be clear from the graph that during July and August, high precipitation and the average precipitation during these two months are 21.70 and 26.04 mm respectively. On the other hand, low precipitation is usually recorded during February and November with 2.80 and 4.20 mm. Furthermore, the average low precipitation is due to the country's climate is classed as an arid climate zone that has no permanent rivers and lakes, receives little precipitation and does so infrequently, and has a high temperature for much of the year (Abu-Abdullah et al., 2020). However, the KSA southwestern region where is Jizan located, receives more rainfall than the rest of the country. Rainfall can occur as catastrophic events with high precipitation rates over short periods, resulting in rapid flash floods that would normally collect through dams (Abu-Abdullah et al., 2020).

4.1.2 Water Head and Storage

Table 3 has been generated with the aid of the KSA Ministry of Environment Water and Agriculture daily reports for the whole KSA dams that record the changes in water reservoirs when there is discharge or inflow of water into the dam. So, it has been found that the Jizan reservoir has normall water storage in a range between 29 and 38 million cubic meters.

Table 3: Shows the average water head in m and the water storage in the dam in million m^3 *for various months.*

Month	Head (m)	Water storage (MCM)
January	12.16	35.19
February	11.90	33.44
March	11.66	31.46
April	11.29	29.05
July	12.10	35.10
August	12.09	34.50
November	12.52	38.44
December	12.34	36.81

This table represents the average two variables for 8 months of the year while the rest 4 months (e.g., June, October, May, and September) have not recorded any changes in outflow or inflow. Probably, during these months, the dam is used for other purposes rather than irrigation such as drinking water purposes to the community through the water recycling plant. Furthermore, it can be clear from table 3, there is no big fluctuation in water storage of the dam, and this can be due to the country's policy which wants to save more water and reduce the water consumption of agriculture such as in Nov, the dam received 549,000, 91,500, and 366,000 m^3 in different three days and this amount of water has not been discharged during this month. However, this dam is the only dam used for irrigation and it has been observed that from previous visits, the various agricultural lands are found surrounding the dam downstream such as Sorghum, Barley, Millet, Sesame, Guar as well as other vegetables such as Mango.

4.1.3 Water Discharge

The discharge is the amount of water released from the dam and the values have been represented as m^3/day.

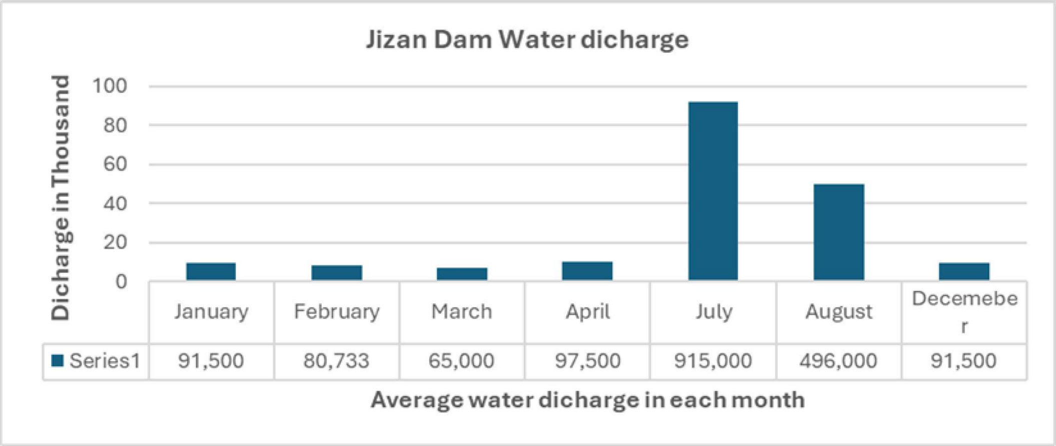

Figure 6: Shows the average water discharge from the dam in 10 thousand with respect to each month for the year 2020.

The average water discharges have been calculated for the year 2020. This is due to the lack of the available data. Nevertheless, it can be noticed from figure 6, the water discharge is high during the July months although, the dam gate was opened only a few times which are 25th, and 26th to discharge 1,006,500, and 1,006,500 cubic meters respectively while on the 27th, 732,000 cubic meters of water. This was due to the heavy rain and the dam received around 12 million of water during the 23rd and 24th. Furthermore, the same was noticed during August but it was around 2,323,500 m^3 has been collected through the Jizan reservoir. For other months, there was quiet discharge from the dam such as during February and January, when gate was opened frequently to discharge water while during Feb, the gate was opened for around 15 days to discharge usually 65 thousand cubic meters per day, with flowrate 0.75 m^3/s. Moreover, when compared to June, no discharge has been recorded which can be due to the little precipitation that can form.

4.1.4 Estimation of Hydropower Potential

The average flowrate and head for each month have been calculated in order to find the energy production in kWh. This has been done using the following equation:

$$P = \eta \rho \, Q g \, H$$

Where P represents the power production (kW), η represents the efficiency, ρ is the density of water (kg/m^3), g is the gravity (m/s^2), and H is the water head (m).

Table 4: Shows the calculated energy production from Jizan dam in kWh through the average year.

Month	**Average flowrate (m^3/s)**	**Average head (m)**	**Estimated Energy Production**	
			kW	kWh
January	1.06	12.16	107.48	23215.66
February	0.93	11.94	92.59	33332.40
March	0.75	11.66	72.92	3500.17
April	1.13	11.31	106.58	5115.29
July	10.59	12.3	1086.15	78202.80
August	5.74	11.98	573.40	13761.57
December	1.06	12.22	108.01	2592.24
Total	21.26	83.57	2147.13	159720.13

Table 4 shows the main findings of 8 months of water discharge from the Jizan dam. The highest share is showing from July with an average of 78202.80 kWh while the lowest share is from December and March with 2592.24 and 3500.17 kWh. This is because, in Dec, the gate was opened for one day in late of the month to discharge 91,000 m^3 while in Mar was opened for two days with a low amount of water.

5.0 Potential of Integrating ROR with Other Renewable Energy

According to (Okot, 2013; Singal et al., 2010), small ROR can be installed for water height between 5 and 15 meters. So, since the water head is varies from 10 to 13 meters while the power output is varies from 72.93 to 1086.15 kW in the site, the type and scale of hydropower that can be potential in this site is the small run-of-river. However, since the ROR is an intermittent energy source, integrated with other renewable energy (e.g., solar power, wind turbine, and or other fossil fuels) can be essential to promote electricity throughout the whole period.

Integrating ROR with another cost-effective energy source can be desirable and sustainable to meet the power demand. Therefore, cost estimation per kWh of the main renewable energy sources has been taken into account for integration ROR.

5.1 Cost Estimation per kWh

Although the cost of hydropower can be lower than other RE in terms of $/kWh as shown in table 4, it can be high in terms of installed capacity. The cost of large hydropower is 1050 to 7650 USD/kW in terms of installed capacity while small HEP is in a range between 1300 to 8000 USD/kW with an average of 4650 USD/kW (IRENA, 2012). So, since the calculated high energy from the Jizan dam is 1086.15 kW, it could cost around 5050,597.5 USD. Moreover, installation of small hydropower at a dam that was built for another purpose could cost as little as USD 450 per kW (IRENA, 2012).

Table 5: Shows different types of renewable energy in term of cost per kWh (IRENA, *2020).*

Renewable energy	Cost ($/kWh)
Hydropower	0.047
Concentrating solar power	0.182
Solar photovoltaic	0.068
Offshore wind turbine	0.115
Onshore wind turbine	0.053
Bioenergy	0.066

As shown in table 5, windfarm, and bioenergy can have a cheaper value per kWh. Bioenergy generation provides a variety of solutions for a variety of feedstocks and technology. They can produce extremely competitive, dispatchable electricity when low-cost feedstocks are available, such as by-products from onsite agricultural or forestry processes. However, bioenergy can be extremely difficult in KSA, since the weather condition is arid which means less forest as well as the low agricultural regions that might be found in the country. In addition, this type of energy can be quite difficult even for many countries which may be due to the sustainable agricultural waste supply. However, windfarm and solar photovoltaics can be good options and they have good electricity prices which are 0.053, and 0.068 $/kWh respectively. Furthermore, they are dependent on Earth's natural resources (e.g., sun, and wind) while at the same time, they do not produce waste such as coal and other fossil fuels. Therefore, it could be much more beneficial to integrate one of these with a small ROR.

5.2 The Available Solar and Wind Resources in Jizan

Hybrid projects combining other renewables such as wind or solar power with hydropower facilities have the potential to generate a significant amount of the world's annual electricity. So, this study has only focused on renewable energy integration where other fossil fuels have not been included. Therefore, the study has analysed the daily solar radiation (kWh/m^2/d) as well as the velocity of the wind (m/s) in the site using RETScreen as shown in table 6.

Table 6: Illustrates the average solar radiation (kWh/m^2/d) and the wind velocity in (m/s) for each month in the year.

Month	kWh/m^2/d	m/s
January	5.02	3.10
February	5.52	3.20
March	6.40	3.20
April	7.14	3.20
May	7.26	3.20
June	6.91	3.30
July	6.52	3.80
August	6.51	3.60
September	6.57	3.20
October	6.32	3.00
November	5.56	3.10
December	5.12	3.10
Annual	6.24	3.30

After reviewing some articles to find the standard wind velocity for air for the potential of small wind farm energy, it has been found that the average annual wind speed in the Jizan site is relatively low compared to other constructed offshore around the world. Furthermore, according to Renewable UK criteria, a site with an average mean wind speed of 4 to 5 m/s can be worthwhile for the construction small wind farm (Drew et al., 2013). Hence, it might not be technically feasible to integrate ROR with wind turbines since it has an average annual velocity of 3.3 m/s as shown in table 6. On the other hand, it has been found the average daily solar radiation is competitive which is 6.24 kWh/m^2/d as shown in table 6 and there is less variation of solar throughout the year which can be due to the location of KSA on the sunbelt as well as the frequent solar radiation in the site that can make it viable to construct Solar Photovoltaic.

6.0 Hybrid ROR and FPV

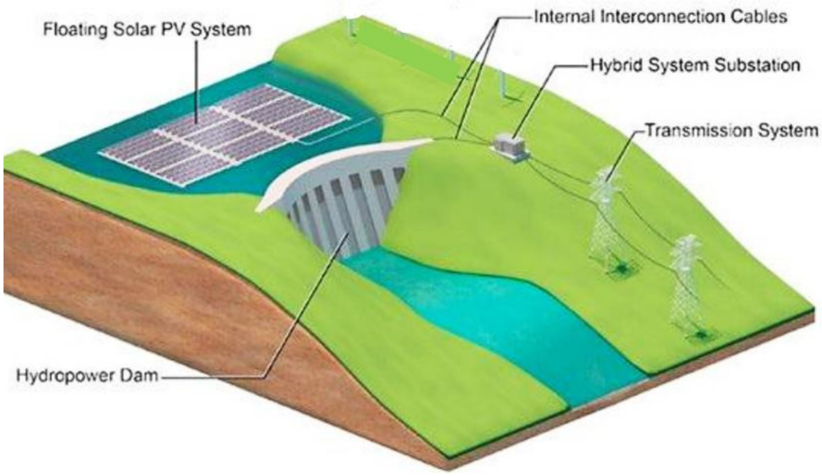

Figure 7: Schematic diagram of Float solar PV with hydropower.

Figure 7 shows the structure of the hybrid system of FPV along with hydropower. So, floating solar panels have been chosen with ROR for the Jizan dam due to the availability of land around the dam as well as the surrounding location mountainous which has made large water streams on land flowing to the dam. Installing solar power around the dam could be highly exposed to flooding water which could destroy solar power infrastructure. Hence, a reservoir place can be a safe location to install PV using a buoyant structure.

It is possible to provide a novel technique that combines floating solar with battery storage and ROR. To fulfil peak demands, the floating solar resource can be combined with a battery energy storage device such as Valve-regulated lead-acid, Lithium-Ion, and Vanadium flow batteries. In addition, in distributed generation systems, storage batteries are critical for power balancing which can compensate for the unpredictability and fluctuation of the integrated system as well as increase supply reliability as the battery's energy is continually changing (Chen et al., 2012). By altering ROR production, a floating solar system near a reservoir's dam compensates for the unstable generation of this system, and a PV system can compensate for the hydro energy shortfall in the medium to long run.

6.1 Benefits of the Hybrid ROR and FPV

The implementation of ROR along with float solar power can introduce such benefits in terms of water saving, renewable and cheap electricity supply, providing water for irrigation as well as it might boost economic development in the region such as tourism. Therefore, job creation might be increased directly and indirectly through the construction of the project.

Jobs creation. Jobs created can be probably introduced in the place during the construction and even after the construction of the project. So, the surrounding community can get more benefits from the area.

Cost-effective. Electricity produces through the water cycle and sun, making it more affordable than fossil fuels (e.g., coal and gas).

Reduction of power variation. During the hot season, when the energy from the water dam reports a drop in power due to the seasonal water cycle, PV panels produce the highest energy production in a temperate country such as Italy (Cazzaniga et al., 2019). This partial anticorrelation reduces the yearly swings in electric energy generation significantly. (Cazzaniga et al., 2019). Furthermore, a battery storage system might be implemented, with ROR being reduced during the day when the PV plant is operational and increased at night, during cloudy circumstances, or during peak demand periods to guarantee electricity is supplied to match demand.

Reduced land usage. The fundamental benefit of floating or submerged PV plants is that they do not require any land, with the exception of a small area for electric cabinets. Unlike land-based PV plants, floating or submerged PV plants have little influence on the landscape because of the lower surface occupancy (Martín-Chivelet, 2016). Furthermore, Floating PV plants are not only more cost-effective than land-based plants, but they also eliminate the need to compete with agricultural or green zones (Martín-Chivelet, 2016).

Less soiling due to dust. Water bodies could be typically less dusty than other common PV deployment places such as cities and deserts. So, this could be one of the most beneficial in a country such as KSA where dust storms frequently occurr in the year.

Installation and decommissioning. Floating PV facilities are more compact than land-based plants, have a simpler management system, and are easier to build and decommission (Cazzaniga et al., 2019). The main benefit is that there is no fixed structure, and floating system mooring can be installed and removed in a completely reservable manner, unlike land-based plant foundations, which are far more intrusive and permanent (Cazzaniga et al., 2019).

Water-saving and water quality. Additional benefits of partial coverage of water basins include reduced water evaporation. This can be highly desirable in KSA since the country's condition is considered to be arid. So, it has been found that evaporation of water from bodies of water can be reduced by 70% and power gain enhanced by 5.93% due to backwater cooling of PV modules (Mittal et al., 2017). However, this result is dependent on the climate and the percentage of the surface that is covered. A relative benefit is the reduction of the problem of algal bloom, which is agricultural significant in developed countries. The problem of algae blooms can be solved by partially covering the basin and reducing light on biological fouling immediately below the surface.

7.0 Conclusion and Further Discussion

To sum up, this article has evaluated the environmental, economic, and social impact of the impounded rivers as well as the potential of HEP in Saudi Arabia. So, it has been identified from the literature as well as from the results, that KSA has a significant problem in water security. Hence, the major reason for the building dam was mostly to flood control and enhance groundwater supply. In addition, it has also been found that the only dam used for water irrigation is the Jizan dam while another major reservoir such as the largest dam (King Fahad) is mainly used for groundwater recharge.

Moreover, through other studies of hydraulic dams such as Three Gorges, Kielder, Bhakra, and Jizan dams, the associated impact of impounded rivers (e.g., fish mitigation, greenhouse gases, thermal regime, people displacement, energy, and water security) have been evaluated. The damming river can produce considerable effects, especially on fish such as Paddlefish fishes in Gezhouba Dam, which blocks the Chinese paddlefish's migration route and prevents mature fish from traveling to the higher sections of the river to reproduce as well as in other countries such as France, US, Europe, and India where some dams have caused some native species to be extinction. Furthermore, the lag of temperature due to the created dam can have a significant impact on fishes such as Kielder which has a considerable lag delay for the temperature downstream reaching 7 and 11 Celsius in summer and winter. In addition, the reservoir loss capacity due to the sedimentation is another issue that resulted in the coarsening of the bed might become unsuitable for native and invasive species to use as an ecological habitat and a breeding site.

Although dams can introduce a significant impact on the ecosystem, economic benefits such as water supply, tourism, and cheap electricity supply are found. For instance, the Bhakra dam has helped to shield India from droughts to a significant extent, making Indian agriculture more sustainable, contributing to the country's food security, and helping to reduce wide variation in prices. Furthermore, dams create good landscapes and enhance the community as well as the country's tourism economy such as Three Gorges where in 2018, the region welcomed about 564 million travellers, accounting for 21% of all tourists in China, and earned USD 39.58 billion in tourism revenue. However, in KSA, it can be difficult to estimate the benefit of the existing dams since all dams are non-powered and this could be due to the country's reliance on oil as well as the lack of experience in renewable energy. Therefore, this article has also evaluated the potential of hydropower construction using the Jizan dam as a site for the study.

The total energy production from the Jizan dam has been estimated to be 159.72 MWh and the type of hydropower that was identified as suitable for variance in the discharge is a small run-of-river. In addition, since ROR is intermittent energy, the hybrid system is essential to promote electricity generation. So, the float solar power has been selected due to the significant soil erosion caused by water floods during the heavy rain around the dam. Although FPV is a little bit an expensive than windfarm, analysis of wind resources in the site has been lower than preferable or interesting value. Furthermore, when utilized together, the complementary characteristics of FPV and small ROR can help reduce intermittency. Because there is low water discharge of water in the Jizan dam, ROR production would stop. So, the recent advancement in power has allowed FPV and ROR to function in an integrated system with battery or even grid-tied backup electricity. Alternative diesel and fossil fuel generators emit more greenhouse gases than integrating ROR along with FPV. Small run-of-river have very high energy payback ratios, generate minimal pollutants, and have lower environmental externalities than large dams. This hybrid system would improve energy and water security as well as it may reduce environmental consequences such as Algal bloom growth.

Furthermore, FPV reduces evaporation and enhances power generation due to the back cooling by 70% and 5.93% respectively. Hence, the construction of FPV along ROR could introduce a significant benefit as well as mitigate some of the major problems that KSA is currently facing if this project is assumed to be proposed in all major dams. So, this is due to three major reasons; (1) the local authority is struggling with water security nearly in the whole region of the country; (2) it will also help the country meet the net zero carbon goal by 2060 (3) hybrid FPV with ROR will also enhance energy security in the country as well as it may reduce other electricity sources prices. Therefore, future work may include an economic analysis to determine how the Levelized cost of electricity generation between hybrid FPV along ROR compared to the diesel generation in Saudi Arabia.

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Abbreviation

TGP	Three Gorge Project
HEP	Hydroelectric Power
ROR	Run of River hydroelectricity
FPV	Floating photovoltaic system
GHGs	Greenhouse gases
KSA	Saudi Arabia
CSP	Concentrated Solar Power
MEWA	Saudi Ministry of Water and Agricultural
GDP	Gross domestic product
MCM	Million cubic meters
RMB	Chinese Yuan

CO_2 e	Carbon dioxide Equivalent
CO_2	Carbon dioxide
CH_4	Methane
TW	Terawatt
kWh	A kilowatt hour
MW	A megawatt
RE	Renewable energy
GW	Gigawatt
BOD	Biochemical oxygen demand
CGD	Concrete gravity dam
ECRD	Earth rock fill dam
m	meter
m/s	Meter per second
Pg	Picogram
Pg CO_2 e/yr	Carbon dioxide Equivalent per year
USD	United State dollar