



International Journal of Environment and Climate Change

Volume 14, Issue 7, Page 845-867, 2024; Article no.IJECC.119889
ISSN: 2581-8627

(Past name: *British Journal of Environment & Climate Change*, Past ISSN: 2231-4784)

A Review of the Impact of Impounded Rivers in KSA and as an Assessment of their Potential for Hydroelectric Power Generation

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

Article Information

DOI: <https://doi.org/10.9734/ijecc/2024/v14i74324>

Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://www.sdiarticle5.com/review-history/119889>

Review Article

Received: 18/05/2024

Accepted: 22/07/2024

Published: 27/07/2024

ABSTRACT

As an alternative to fossil fuels-based power generation, hydropower offers cheap operating and maintenance costs, a clean, and sustainable domestic energy source. Currently, hydro resources account for about more than 15% of the global electricity, with renewables accounting for 70% of the total. While 150 countries produce hydropower, the kingdom of Saudi Arabia (KSA) has around 559 dams that could have the capacity for hydropower energy production. KSA can meet its internal demand, produce an excess for export, and create jobs for its people by utilising its renewable resource. Therefore, this paper reviews KSA's current dams and assesses their environmental and socioeconomic impacts and then, it is conducted out technical feasibility study if is sustainable to retrofit Hydroelectric Power (HEP) to existing dams.

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Cite as: Nashrey, Ahmed Al. 2024. "A Review of the Impact of Impounded Rivers in KSA and As an Assessment of Their Potential for Hydroelectric Power Generation". *International Journal of Environment and Climate Change* 14 (7):845-67. <https://doi.org/10.9734/ijecc/2024/v14i74324>.

Keywords: Hydropower; KSA; dam; energy.

ABBREVIATIONS

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

1. 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 [1]. 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 [2,3].

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 [4,5]. 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, concentrating solar power 25 GW, wind 9 GW, 4 GW by waste to energy and geothermal [6].

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 Fig. 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 [7]. 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.



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

Aim: The aim of this study is to evaluate and address the impact of impounded rivers in KSA through sustainable development of hydropower energy.

Objectives:

1. Investigate the impact of impounded rivers
2. Conduct a literature review for the sustainability development of hydropower as renewable energy through a case study example
3. Identify the major dams in Saudi Arabia and conduct a feasibility assessment if it is sustainable to retrofit Hydroelectric Power (HEP) to existing dams.

2. 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.

2.1 Environmental Impact

2.1.1 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 [8]. 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 [9]. 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.

2.1.2 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 [10]. 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 [11,12]. 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% [13]. 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 1 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 [14].

Table 1 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 [20]. 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.

2.1.3 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 [21,22]. For instance, Sanmenxia Dam, on China's Yellow River's middle reaches, is famous for its severe sedimentation difficulties [23]. In the Yellow River Basin, the heavily loaded sediments have wreaked havoc on social and economic life (YRB) [24]. 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 [24]. 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 [25].

2.1.4 Greenhouse Gases (GHG)

According to the most current estimate, global gross reservoir GHG emissions were 0.8 Pg CO₂ eq/yr, with a range of 0.5 Pg CO₂ eq/yr to 1.2 Pg CO₂eq/yr [26]. 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 [27]. After the impoundment, CO₂ is created by the decomposition of these organic materials under aerobic or anaerobic conditions [28]. So, the greenhouses gases can be released into the atmosphere from the reservoir in various ways.

Table 1. Shows different types of some fishes that has been disappeared after the dam construction in different country in the world

Location	Name	Ref
China	<i>Paddlefish</i>	[14,15]
France	<i>Atlantic Salmon</i>	[16]
USA	<i>Ptychocheilus lucius,</i> <i>Punctatus, and Notropis</i>	[27,18]
Central Europe	<i>Barbus spp., Esox Lucius, and</i> <i>Perca fluviatilis</i>	[18]
India	<i>Hilsa ilisha, Puntius dubius</i>	[18,19]
Australia	<i>Plectroplites ambiguus,</i> <i>Tandanus tandanus</i>	[18]

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 [27].

Moreover, carbon dioxide emission from downstream rivers generated 1.63 to 32 percent of total carbon dioxide emission from reservoirs, according to [28,29,30,27]. So, it has been found that CO₂ 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 CO₂ emissions [28,29] while CO₂ emissions from the Uatumã River, which flows downstream of the Balbina Dam in Brazil, account for 1.63 to 7% of total CO₂ emissions from the Balbina hydropower system [28,30]. Furthermore, downstream rivers were responsible for 23%, and 9-33% of total CH₄ emissions across the Balbina, and Petit Saut reservoir's surfaces respectively [28]. However, in the Sinnamary River, CH₄ concentrations were 80 to 200 times higher downstream of the dam than upstream of the reservoir, according to Petit Saut [28]. Hence, the

disparity in CH₄ 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 [27].

2.1.5 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 [31]. So, the flows managed by upstream dams affect downstream habits through a process called hydropeaking and thermopeaking [32]. 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 [32]. Furthermore, the temperature of the water released from the upstream dam is likely to differ from the temperature of the water going downstream [32]. 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 [32].

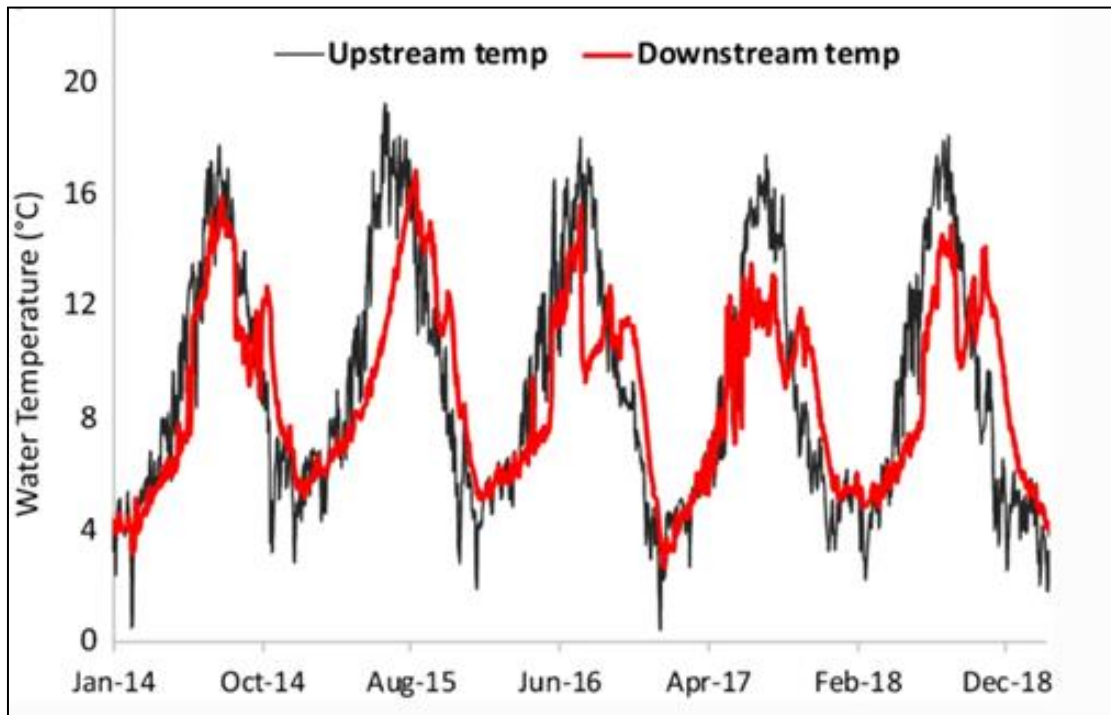


Fig. 2. Shows the temperature variation of downstream and upstream through the year of Detroit dam in the USA [33]

Moreover, Fig. 2 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 [34]. 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 [35]. 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 [36]. The winter temperatures in the river immediately below the dam were substantially higher, with 1.5 °C above the dam at Butterhaugh compared to 4.5 °C immediately below the dam at Yarrow [36]. 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 [36]. 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 [36]. 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 [36]. Therefore, the lag of temperature could only affect the water quality but also threaten the life cycle of fish species.

2.1.6 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 [18]. 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 [37]. 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 contributor 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 [38,18]. 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 impinging. 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. 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.

2.2 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.

2.2.1 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 [39]. 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 [10]. 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 km² at level 182 above sea level, the evaporation loss from the reservoir ranges from 12 × 10⁹ to 16 × 10⁹ m³/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 [41]. 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 [42]. Additionally, the availability of irrigation water through this dam-canal network has aided in enhanced groundwater recharge [43]. 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 [44]. 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 [44]. 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 [42]. Thus, the region has more than achieved the necessary hydrothermal mix of 40:60 [44].

2.2.2 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. 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 m³ of water a day to Bisha city while the Hali dam supplies around 40 m³ 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 [44]. 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.

2.2.3 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 [45]. 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 [46]. 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 [46]. In addition, Dazu Rock Carvings, Three

Gorges, Badong Shenlong Stream are among the 177 A-class scenic locations, with 13 5A Scenic spots [47]. 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 [47].

2.2.4 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 [48,49]. 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 [48]. 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 [48,50]. 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 [50]. 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 [50]. 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 [50].

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.

2.2.5 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 [51]. 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 [52,53]. 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 [54]. Therefore, it appears necessary to devise methods or programs for resettlers to successfully build a life following their migration.

3. SUSTAINABLE DEVELOPMENT OF HYDROPOWER

Almost every new project has made sustainability a top priority in the world. A lot of studies purpose slightly different definitions of sustainability and sustainable development. In essence, sustainability means that what are doing is not at the expense of the future generation [55]. Sustainability is widely acknowledged to be a multifaceted notion. As a result, the triple bottom line concept has become popular, emphasizing the importance of development that is not only economically, but also socially and environmentally sustainable. Hydropower is a versatile technology since it may provide both economic and social benefits [56]. A hydropower project can be built to meet a variety of goals, including energy generation, irrigation, flood control, and tourism. Therefore, the growth of a region or nation in terms of social, economic, and environmental dimensions

is a critical component in the development of hydropower projects [56].

As shown in Table 2, sustainability is more emphasizing in the environmental, social, and economic in assessing hydropower projects for the long term. The three gorges project has been used in this case as it has used the triple bottom line for evaluating the impact of TG. However, this does not mean TGP is a sustainable project, but it can be essential to look at their criteria and evaluate how might sustainable development of HEP are conducted out.

3.1 Three Gorges

3.1.1 Background

The TGP is one of the world's largest hydroelectric complex projects which builds in purpose for flood control, power generation as well as enhancing the navigation and supplying water [59]. The dam is in the Xillingxia Gorge, which has a drainage area of 1 million Km² and a 451 billion m³ annual flow [60]. The TGP crest height is 185 meters, and the dam's maximum height is 181 meters. With a typical storage level of 175 meters, the reservoir's overall capacity is 39.3 billion m³, with a flood control capacity of 22.15 billion m³ [60]. the TGP's generating units generated a total of 98.1 TWh of power which accounting for 14% of China's hydro generation [61]. However, the construction of the project has taken 17 years to be completed when it was begun in 1993. So, the project has been run on schedule through the Three Gorges project

Corporation's (CTGPC) effective organization and coordination, as well as the support of all levels of government and the people of China.

3.1.2 Sustainable development practice

The associated impact of the project has been taken from the early stage of the project. As shown in Table 3, Sustainability challenges are addressed from a triple bottom line viewpoint (environmental, social, and economic). In addition, a life cycle perspective (conception, design, construction, and operation), and system perspective (reservoir, dam, power plant, transmission, the location of the project, and surrounding areas) has been also included in the TGP [62]. The environmental impact evaluation is carried out in accordance with the law of the people's Republic of China on Environmental Effects Evaluation and Regulation on the Administration of Construction Project Environmental Protection. So, all relevant stakeholders were brought together by the State Council to guarantee that several plans were developed to meet these sustainability goals [59]. These plans comprise the TGP's basic design (environmental protection section), the TGP's environmental protection implementation plan on building sites, the TGP's ecological and environmental protection plan for resettlement regions, the TGP's resettlement sites' ecological and environmental protection plan, the TGP's ecological and environmental monitoring plan, and the TGP's cultural relic conservation plan for submerged areas and resettlement areas [59].

Table 2. Criteria for assessing the long-term viability of hydropower projects [57,58]

Environmental	Social	Economical
Air and water quality	Equitable distribution of the benefits of the project	Saving on GHG emission and improved air quality
Activities on the terrestrial and aquatic environmental	Reduce poverty and enhance the quality of life	Capita cost and recurrent cost
Equitable distribution of the benefits of the project	Effectiveness and ongoing compensatory and benefits	Payback period
Rare endangered species	The impact of displacement on individuals and communities	
Passage of fish species	Public health	
Pest species within the reservoir (flora & fauna)	Communities' acceptance	
Downstream hydrology and environmental flows	Protection of cultural heritage	
Adoption of independently audited environmental management systems		



Fig. 3. Shows the Three Gorges Dam [59]

Table 3. Show the criteria used for evaluation of the Three Gorges dam’s impact [62,48]

	Category	Indictors
Environmental	Water quality	Biochemical oxygen demand (BOD), diffusivity, land submergence and, nutrients, water quality underneath of the dam
	Local climate	Wind, fog, temperature, humidity, precipitation
	Water temperature	The temperature in upstream and downstream of the dam
	Sedimentation	Reservoir, downstream river channel
	Environment geology	Induced earthquake, stability of reservoir banks, reservoir leakage
	Terrestrial plants and vegetation	Species and exotic species, forest and vegetation, resource plants, and economic forest
	Aquatic organisms	Fingerling variation, spawning ground, rare aquatic animal, fish resources
	Estuary environment	Salinity intrusion, runoff variation, soil salinization, sediment accumulation and erosion accumulation, estuary, and offshore fishery
	Reservoir inundation and migration	Land submergence, resettlement plan, the environmental capacity of migration
	Construction	Water quality, atmosphere, noise, landscape conservancy
Socioeconomic	Flooding control	Submergence of cultivated land, guarantee for production and daily living, infectious disease, life, and property loss
	Power production	Air pollution, solid waste, thermal pollution
	Navigation	Maritime risk, land transport pressure
	Natural landscape	Natural landscape
	Historic landmarks and sites	Heritage buildings, ancient cultural sites
	Power generation	Affordable and cheap power
		Efficiency
	Dam construction	Job creation employment, tourism, irrigation and water supply, drought, and flood protection.
	Cultural relics and landscape	Traditional building, cultural relics, nature landscape
	Public health	Hygiene, sanitary and health care system, infectious diseases
Flood control	Farmland impounded, life security, loss of life and property	

Furthermore, the Chinese government has also taken more mitigation to reduce the potential impact of the project. According to the water pollution treatment planning at the Three Gorges Reservoir and its upstream, the government invested RMB 39.2 billion in water pollution prevention and control in the Three Gorges Reservoir and its upstream from 2002 to 2010 while around RMB 1.2 billion in soil erosion prevention and protection activities [62]. To appropriately treat solid waste and wastewater, various sewage water treatment plants were developed [48]. Meanwhile, in order to protect the reservoir area's ecological environment, 1959 enterprises located in submerged areas were closed owing to a variety of concerns including major pollution, out-of-date technology, and high energy intensity (1012 slated to be closed). In addition, the government has spent more than RMB 45.58 billion for people displacement and resettlement [48]. So, this accounts for about 40% of the total investment of the project.

Furthermore, the project's environmental concerns have been investigated, and certain significant environmentally friendly technologies have been explored and applied. The following are the primary significant technologies that are being researched and implemented; (1) variability of ecological environment, land use, and ecological restoration in the TGP reservoir's water level change region; (2) eutrophication in the branches and reservoir bays: trend, impact mechanism, forecast technology, and control technology; (3) pollution features and control

technology of non-point sources, sewage from small towns, and solid wastes; (4) reservoir environmental capacity for aquatic breeding, breeding modes, and pollution control technology and (5) study on the impact mechanisms on biological species caused by hydrological change; (6) reservoir key technology for water quality early warning, water quality assurance, and water environment management. Although the government has implemented some control and measures to mitigate and prevent associated issues of the project, there are still some other ecology issues such as fish mitigation [62]. Furthermore, an annual report on environmental protection is published each year to highlight accomplishments in environmental sustainability management. TGP publishes an annual report on water and soil conservation in the building regions, as well as an annual report on ecological and environmental issues in the construction areas, monthly [62].

4. RESULTS AND DISCUSSION

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

According to the Ministry of Environment, Water, and Agriculture [63], the kingdom has completed 559 dams in 2019. Those include 103 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.



Fig. 4. Shows the names and locations of major 12 dams in KSA

Table 4. Shows a summary of major dams of their function and capacity [63]

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

There are major dams that are located in different regions of the country. So, as shown in Fig. 4, 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.

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 4. 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 [64]. 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.

4.2 Climate Data of the Region

When selecting a site for hydropower generation, there are various factors should be taken into account at the early stage of the selection. These include the rainfall data, the available water head, and water storage.

The Kingdom of Saudi Arabia is categorised as having an arid climate, meaning that it lacks permanent rivers or lakes, experiences little to no precipitation in most places, and experiences high temperatures most months of the year. However, the southern regions where Jizan, Baysh, and King Fahad dams are located, experienced more rainfall than other parts of the country. Rainfall can occasionally occur as intense storms with high rates of precipitation over brief periods of time, resulting in abrupt flash floods that seriously can damage property and human life.

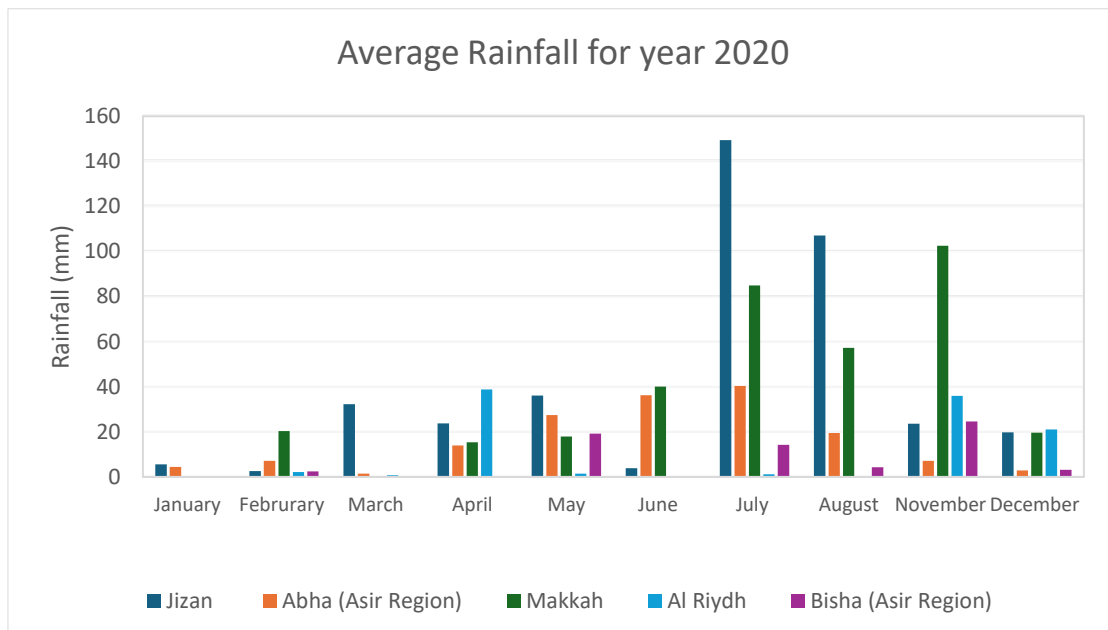


Fig. 5. Shows the average rainfall where most dams are located with respect to each month for the year 2020

As shown, from the graph, it is clear that Jizan city is recording the highest rainfall over the year compared to other parts of the country. This is obviously due to the topographically driven convective rain of the city region. The region has a long and high chain of mountain, and a large amount of water falls through these mountains during the rainy seasons. The runoff water which varies from 2 to 2.4 billion cubic meters each year, is mainly found in the southeast and along the coast where rainfall is plentiful and consistent.

However, average rain of other cities such as Riyadh, it crossed high rain during winter seasons but not like other cities such as Abha, and Makkah region. This is also back to convective rain of the region.

Furthermore, there is no reordered rainfall in KSA between the September and October according to MEW and no clear reasons stated the reasons behind this. However, probably due to the low precipitation during these seasons.

4.3 Site Selection

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 million cubic meters (MCM) of water.

4.3.1 Water head and storage

Table 5 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 normal water storage in a range between 29 and 38 million cubic meters.

Table 5. Shows the average water head in m and the water storage in the dam in million m3 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 5 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 5, 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 m³ 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.

4.3.2 Water discharge

The discharge is the amount of water released from the dam and the values have been represented as m³/day.

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 Fig. 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 m³ 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 m³/s. Moreover, when compared to June, no discharge has been recorded which can be due to the little precipitation that can form.

4.3.3 Jizan Dam

This dam is in the Jizan province of the southwest of Saudi Arabia that located in the port of the Red Sea a. Furthermore, the Jizan is one of the Kingdom's most fertile agricultural regions, with a wide range of high-quality and diverse agricultural products [65]. 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 area is approximately 2,852,279.83 m² based on current water capacity and 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 Fig. 7.

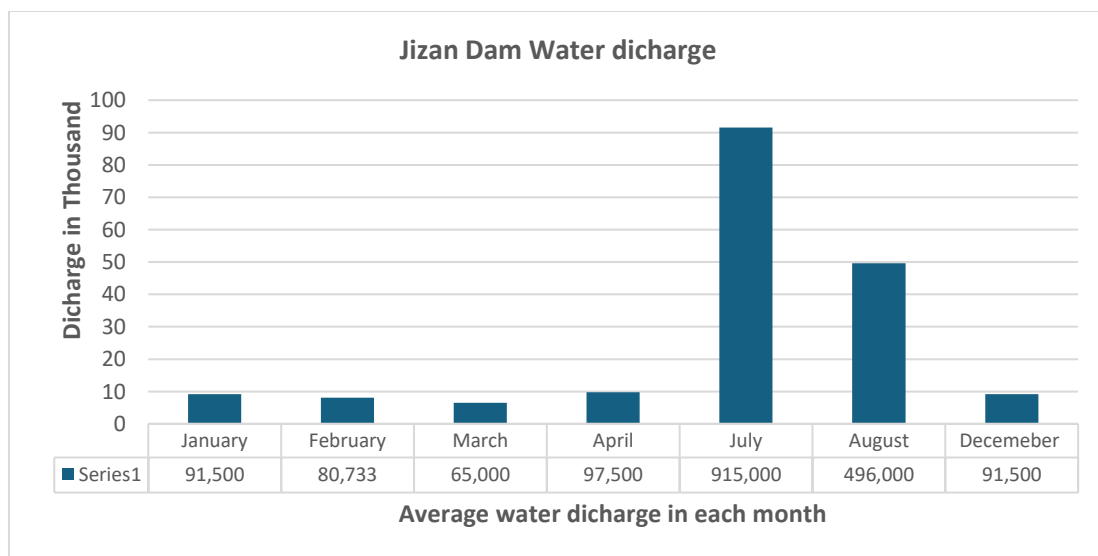


Fig. 6. Shows the average water discharge from the dam in 10 thousand with respect to each month for the year 2020

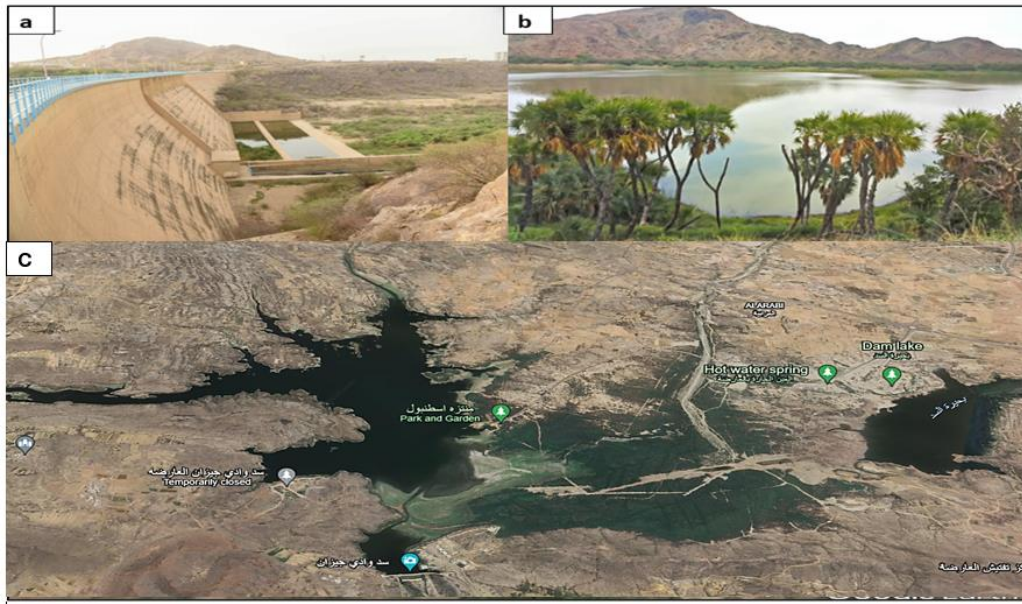


Fig. 7. Shows the Jizan dam and reservoir

Table 6. 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

4.3.4 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/m³), g is the gravity (m/s²), and H is the water head (m).

Table 6 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 m³ while in Mar was opened for two days with a low amount of water.

5. POTENTIAL OF INTEGRATING ROR WITH OTHER RENEWABLE ENERGY

According to [66,67], small Run-of-River ROR can be installed for water height between 5 and 15 meters. So, since the water head is varying from 10 to 13 meters while the power output is varying 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 7, 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 [68]. 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 [68].

Table 7. Shows different types of renewable energy in term of cost per kWh [68]

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 7, 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/m²/d) as well as the velocity of the wind (m/s) in the site using RETScreen as shown in Table 8.

Table 8. Illustrates the average solar radiation (kWh/m²/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 [69]. 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 8. On the other hand, it has been found the average daily solar radiation is competitive which is 6.24 kWh/m²/d as shown in Table 8 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. HYBRID ROR AND FPV

Fig. 8 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 [70]. 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 boosting economic development in the region in terms of job creation and tourism.

Table 9. Illustrates the solar energy production in Mega Watt for each month in the year

Month	kWh/m ² /d	MWh
January	5.02	443,871.79
February	5.52	440,848.37
March	6.40	565,892.32
April	7.14	610,958.34
May	7.26	641,934.10
June	6.91	591,277.61
July	6.52	576,502.80
August	6.51	575,618.59
September	6.57	562,184.35
October	6.32	558,818.66
November	5.56	475,760.27
December	5.12	452,713.85

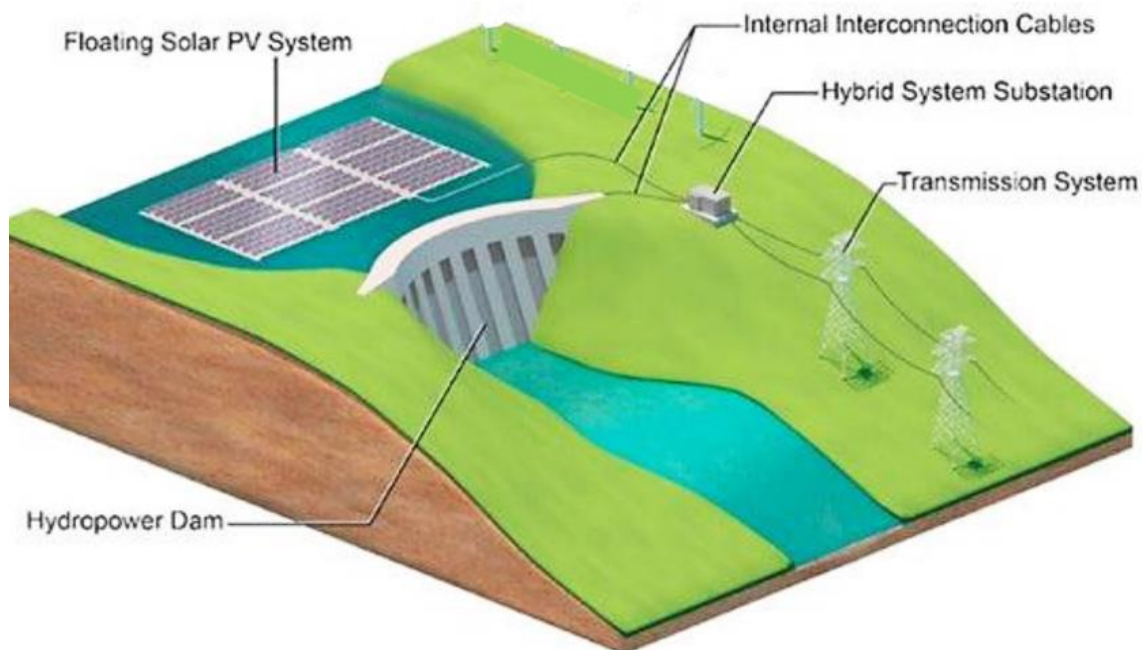


Fig. 8. Schematic diagram of Float solar PV with hydropower [71]

The idea of FPV can support the country's water and energy security. This can be through coverage of water basins of the dam to reduce water evaporation. It is very desirable since the country's condition is considered to be arid. The total production from PV only is 6,496,381 MWh based on current reservoir area whereas from ROR is 159,720 MWh. The Jizan region electricity demand was 6,363,299.96 MWh for 2022 according to the DataSaudi and the value of PV can overestimate electricity demand in Jizan. Thus, this can replace the source of electricity generation from fossil fuels to renewable energy and power the whole city on reliable and clean energy source with cheap value.

In addition, 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 [72]. Furthermore, electricity produced through the water cycle and sun is more affordable than fossil fuels (e.g., coal and gas). For instance, 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 [73]. This partial anticorrelation reduces the yearly swings in electric energy generation significantly. 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.

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 [74]. 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 [74]. In addition, 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 occur in the year.

However, FPV might introduce some impacts on the thermal regime such as preventing sunlight penetration as well as it might reduce the wind

mixing with water surface temperature. So, since the stratification increases as the temperature increases, the stratification will be reduced on the reservoirs as well as the temperature [75,76]. However, the temperature reduction due to the FPV coverage can be dependent on the size of the float solar photovoltaic install coverage. It has been found that temperature changes were minimal for limited FPV coverages whereas large FPV resulted in significant drops. Furthermore, no study has yet investigated the changes of float solar photovoltaic on fishes' habits. Most FPV plants were installed after 2014 [77] and the first FPV plants built in the world were constructed at Aichi Prefecture Japan in 2017 [78]. Therefore, this earlier time of FPV emerging may have led to a little investigation on the environmental impact although economic or socioeconomic benefits have been widely found.

Nonetheless, coupling FPV with ROR can introduce significant environmental and socioeconomic impacts on the local region. These include cheap power supply, reduced land usage, and supported water saving. In addition, Jobs such as suppliers, financier, project design/permitting, and other indirect jobs such as restaurants and retail, are induced because of direct and indirect employment creation [79-81].

7. CONCLUSION

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. It has been identified from the literature as well as from the results, that KSA has a significant problem in water security. On the other hand, the major reason for the building dam was only to flood control. However, damming rivers can produce considerable effects especially, on fish such as in France where some dams have caused some native species to be extinct. In addition, creation of the dam can cause lag in a temperature such as in Kielder which has a considerable a lag delay for the temperature downstream reaching 7 and 11 Celsius in summer and winter.

Nonetheless, sustainable development of HEP can introduce a significant impact on the ecosystem, and 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 over the long previous years.

Therefore, this article has also evaluated and found the potential of implementing a small run-of-river hydropower type with float solar Power at Jizan dam. In addition, FPV reduces evaporation and enhances power generation. 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.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. International Energy Agency. World energy outlook 2023: Overview and key findings. Available:<https://www.iea.org/reports/world-energy-outlook-2023/overview-and-key-findings> [Accessed 12th January 2024].
2. International Energy Agency. Hydropower special market report: Executive summary. Available:<https://www.iea.org/reports/hydropower-special-market-report/executive-summary> [Accessed 12th January 2024].
3. International Hydropower Association. 2023 world hydropower outlook. Available:<https://www.hydropower.org/publications/2023-world-hydropower-outlook> [Accessed 12th January 2024].
4. Hušek H, Žganec K, Pusch MT. A review of hydropower dams in Southeast Europe—distribution, trends and availability of monitoring data using the example of a multinational Danube catchment subarea. *Renewable and Sustainable Energy Reviews*. 2020;117:109434.
5. Fan JL, Hu JW, Zhang X, Kong LS, Li F, Mi Z. Impacts of climate change on hydropower generation in China. *Mathematics and Computers in Simulation*. 2020;167:4-18.
6. Albarbar A, Arar A. Performance assessment and improvement of central receivers used for solar thermal plants. *Energies*. 2019;12(16):3079.
7. Ministry of Environment, Water, and Agriculture. Distribution of the number of dams and their capacity up to 2019. Available:<https://www.mewa.gov.sa/ar/InformationCenter/OpenData/GeographicData/Pages/default.aspx> [Accessed 13th January 2024].
8. Domínguez-López ME, Ortega-Álvarez R. The importance of riparian habitats for avian communities in a highly human-modified Neotropical landscape. *Revista mexicana de biodiversidad*. 2014;85(4): 1217-27.
9. Figarski T, Kajtoch Ł. Alterations of riverine ecosystems adversely affect bird assemblages. *Hydrobiologia*. 2015;744: 287-96.
10. Turgeon K, Turpin C, Gregory-Eaves I. Dams have varying impacts on fish communities across latitudes: a quantitative synthesis. *Ecology Letters*. 2019;22(9):1501-16.
11. Neves RJ, Angermeier PL. Habitat alteration and its effects on native fishes in the upper Tennessee River system, east-central USA. *Journal of Fish Biology*. 1990;37:45-52.
12. Penczak T, Kruk A. Threatened obligatory riverine fishes in human-modified Polish rivers. *Ecology of Freshwater fish*. 2000;9(1-2):109-17.
13. Yi Y, Yang Z, Zhang S. Ecological influence of dam construction and river-lake connectivity on migration fish habitat in the Yangtze River basin, China. *Procedia Environmental Sciences*. 2010;2:1942-54.
14. Zhuang P, Zhao F, Zhang T, Chen Y, Liu J, Zhang L, Kynard B. New evidence may

- support the persistence and adaptability of the near-extinct Chinese sturgeon. *Biological Conservation*. 2016;193:66-9.
15. Zhang H, Jarić I, Roberts DL, He Y, Du H, Wu J, Wang C, Wei Q. Extinction of one of the world's largest freshwater fishes: Lessons for conserving the endangered Yangtze fauna. *Science of the Total Environment*. 2020;710:136242.
 16. Vandeputte M, Bestin A, Fauchet L, Allamellou JM, Bosc S, Menchi O, Haffray P. Can we identify wild-born salmon from parentage assignment data? A case study in the Garonne-Dordogne rivers salmon restoration programme in France. *Aquatic Living Resources*. 2021; 34:7.
 17. Dymond JR, MacKay HH, Burrige ME, Holm E, Bird PW. The history of the Atlantic salmon in Lake Ontario. *Aquatic Ecosystem Health & Management*. 2019;22(3):305-15.
 18. Wang ZY, Lee JH, Melching CS. *River dynamics and integrated river management*. Springer Science & Business Media; 2014.
 19. Renjithkumar CR, Roshni K, Kurup BM. Exploited fishery resources of Muvattupuzha River, Kerala, India.
 20. Zhong Y, Power G. Environmental impacts of hydroelectric projects on fish resources in China. *Regulated Rivers: Research & Management*. 1996;12(1):81-98.
 21. Chamoun S, De Cesare G, Schleiss AJ. Managing reservoir sedimentation by venting turbidity currents: A review. *International Journal of Sediment Research*. 2016;31(3):195-204.
 22. Baoligao B, Xu F, Chen X, Wang X, Chen W. Acute impacts of reservoir sediment flushing on fishes in the Yellow River. *Journal of hydro-environment research*. 2016;13:26-35.
 23. Wang G, Wu B, Wang ZY. Sedimentation problems and management strategies of sanmenxia reservoir, yellow river, china. *Water resources research*. 2005;41(9).
 24. Ran Q, Zong X, Ye S, Gao J, Hong Y. Dominant mechanism for annual maximum flood and sediment events generation in the Yellow River basin. *Catena*. 2020; 187:104376.
 25. Wang ZY, Chunhong HU. Strategies for managing reservoir sedimentation. *International Journal of Sediment Research*. 2009;24(4):369-84.
 26. Li Z, Sun Z, Chen Y, Li C, Pan Z, Harby A, Lv P, Chen D, Guo J. The net GHG emissions of the China Three Gorges Reservoir: I. Pre-impoundment GHG inventories and carbon balance. *Journal of cleaner production*. 2020;256:120635.
 27. Yang L, Lu F, Zhou X, Wang X, Duan X, Sun B. Progress in the studies on the greenhouse gas emissions from reservoirs. *Acta Ecologica Sinica*. 2014;34(4):204-12.
 28. Guérin F, Abril G, de Junet A, Bonnet MP. Anaerobic decomposition of tropical soils and plant material: Implication for the CO₂ and CH₄ budget of the Petit Saut Reservoir. *Applied Geochemistry*. 2008; 23(8):2272-83.
 29. Abril G, Guérin F, Richard S, Delmas R, Galy-Lacaux C, Gosse P, Tremblay A, Varfalvy L, Dos Santos MA, Matvienko B. Carbon dioxide and methane emissions and the carbon budget of a 10-year-old tropical reservoir (Petit Saut, French Guiana). *Global biogeochemical cycles*. 2005;19(4).
 30. Kemenes A, Forsberg BR, Melack JM. CO₂ emissions from a tropical hydroelectric reservoir (Balbina, Brazil). *Journal of Geophysical Research: Biogeosciences*. 2011;116(G3).
 31. Xie Q, Liu Z, Fang X, Chen Y, Li C, MacIntyre S. Understanding the temperature variations and thermal structure of a subtropical deep river-run reservoir before and after impoundment. *Water*. 2017;9(8):603.
 32. Choi B, Choi SU. Impacts of hydropeaking and thermopeaking on the downstream habitat in the Dal River, Korea. *Ecological Informatics*. 2018;43:1-1.
 33. Ahmad SK, Hossain F. Realizing ecosystem-safe hydropower from dams. *Renewables: Wind, water, and solar*. 2020;7(1):2.
 34. Long LH, Xu H, Ji DB, Cui YJ, Liu DF, Song LX. Characteristic of the water temperature lag in Three Gorges Reservoir and its effect on the water temperature structure of tributaries. *Environmental Earth Sciences*. 2016;75:1-3.
 35. Tao Y, Wang Y, Rhoads B, Wang D, Ni L, Wu J. Quantifying the impacts of the Three Gorges Reservoir on water temperature in the middle reach of the Yangtze River. *Journal of Hydrology*. 2020;582: 124476.

36. Haile, S.M. Environmental impacts of Kielder Reservoir. Newcastle University; 1989.
37. Hu J, Qiao Y, Zhou L, Li S. Spatiotemporal distributions of nutrients in the downstream from Gezhouba Dam in Yangtze River, China. *Environmental Science and Pollution Research*. 2012;19:2849-59.
38. Hilton J, O'Hare M, Bowes MJ, Jones JI. How green is my river? A new paradigm of eutrophication in rivers. *Science of the Total Environment*. 2006;365(1-3):66-83.
39. Hasan MM, Wyseure G. Impact of climate change on hydropower generation in Rio Jubones Basin, Ecuador. *Water Science and Engineering*. 2018;11(2):157-66.
40. Jamali S, Abrishamchi A, Madani K. Climate change and hydropower planning in the Middle East: implications for Iran's Karkheh hydropower systems. *Journal of Energy Engineering*. 2013;139(3):153-60.
41. Lopez O, Stenchikov G, Missimer TM. Water management during climate change using aquifer storage and recovery of stormwater in a dunefield in western Saudi Arabia. *Environmental Research Letters*. 2014;9(7):075008.
42. Pal I, Lall U, Robertson AW, Cane MA, Bansal R. Diagnostics of Western Himalayan Satluj river flow: warm season (MAM/JJAS) inflow into Bhakra dam in India. *Journal of Hydrology*. 2013;478:132-47.
43. Bhatia R, editor. Indirect economic impacts of dams: Case studies from India, Egypt, and Brazil. Academic Foundation; 2008.
44. Bhatia R, Malik RP, Bhatia M. Direct and indirect economic impacts of the Bhakra multipurpose dam, India. *Irrigation and Drainage: The Journal of the International Commission on Irrigation and Drainage*. 2007;56(2-3):195-206.
45. Dias-Sardinha I, Ross D. Perceived impact of the Alqueva dam on regional tourism development. *Tourism Planning & Development*. 2015;12(3):362-75.
46. Xu G, Chen Y, Xu L. Geography and tourism. *Introduction to Chinese Culture: Cultural History, Arts, Festivals and Rituals*. 2018;43-65.
47. Tu J, Luo S, Yang Y, Qin P, Qi P, Li Q. Spatiotemporal evolution and the influencing factors of tourism-based social-ecological system vulnerability in the Three Gorges Reservoir Area, China. *Sustainability*. 2021;13(7):4008.
48. Huang Y, Lin W, Li S, Ning Y. Social impacts of dam-induced displacement and resettlement: A comparative case study in China. *Sustainability*. 2018;10(11):4018.
49. Habich-Sobiegalla S, Plümmer F. *The Political Economy of Hydropower in Southwest China and Beyond*. London: Palgrave Macmillan; 2021.
50. Wilmsen B. After the deluge: A longitudinal study of resettlement at the Three Gorges Dam, China. *World Development*. 2016; 84:41-54.
51. De Faria FA, Davis A, Severnini E, Jaramillo P. The local socio-economic impacts of large hydropower plant development in a developing country. *Energy Economics*. 2017;67:533-44.
52. Keyser DJ, Tegen SI. *Workforce Development for US hydropower: Key trends and findings*. National Renewable Energy Laboratory (NREL), Golden, CO (United States); 2019.
53. Uría-Martínez R, O'Connor PW, Johnson MM. *Hydropower market report data*. Washington, DC: Wind and Water Power Technologies Office, US Department of Energy. DOE/EE-1195; 2014.
54. Nakayama M, Yoshida T, Gunawan B. Compensation schemes for resettlers in Indonesian dam construction projects: Application of Japanese "Soft Technology" for Asian Countries. *Water international*. 1999;24(4):348-55.
55. Kuhlman T, Farrington J. What is sustainability?. *Sustainability*. 2010; 2(11):3436-48.
56. Nautiyal H, Goel V. Sustainability assessment of hydropower projects. *Journal of Cleaner Production*. 2020;265:121661.
57. International Hydropower Association. *Hydropower Sustainability Assessment Protocol*. Available: <https://www.hydropower.org/assessment-protocol> [Accessed 1st February 2024].
58. International Hydropower Association. *Hydropower Sustainability Guidelines*. Available: <https://www.hydropower.org/publications/hydropower-sustainability-guidelines> [Accessed 1st February 2024].

59. Suo, L., Niu, X. and Xie, H. The three gorges project in China, in *Comprehensive Renewable Energy*. 2012;179–226.
60. Wu LH, Li M, Guo YY, Yang XL. Influence of three gorges project on water quality of Poyang Lake. *Procedia Environmental Sciences*. 2011;10:1496-501.
61. Cheng D, Shi X, Yu J. The impact of green energy infrastructure on firm productivity: Evidence from the Three Gorges Project in China. *International Review of Economics & Finance*. 2021;71:385-406.
62. Liu J, Zuo J, Sun Z, Zillante G, Chen X. Sustainability in hydropower development—A case study. *Renewable and Sustainable Energy Reviews*. 2013;19:230-7.
63. Ministry of Environment, Water, and Agriculture. Dams daily bulletin. Available:<https://www.mewa.gov.sa/ar/Ministry/Agencies/TheWaterAgency/Topics/Pages/13-11-2018-1.aspx> [Accessed 13th January 2024].
64. Alquraish MM, Abuhasel KA, Alqahtani AS, Khadr M. A comparative analysis of hidden markov model, hybrid support vector machines, and hybrid artificial neural fuzzy inference system in reservoir inflow forecasting (Case study: The king fahd dam, saudi arabia). *Water*. 2021;13(9):1236.
65. Nouh M. An approach for water planning in Jizan in Saudi Arabia. *International journal of modelling and simulation*. 1983;3(2):89-94.
66. Okot DK. Review of small hydropower technology. *Renewable and Sustainable Energy Reviews*. 2013;26:515-20.
67. Singal SK, Saini RP, Raghuvanshi CS. Analysis for cost estimation of low head run-of-river small hydropower schemes. *Energy for sustainable Development*. 2010;14(2):117-26.
68. International Renewable Agency. Renewable energy cost analysis – Hydropower. Available:<https://www.irena.org/publications/2012/Jun/Renewable-Energy-Cost-Analysis---Hydropower> [Accessed 1st February 2024]
69. Drew DR, Barlow JF, Cockerill TT. Estimating the potential yield of small wind turbines in urban areas: A case study for Greater London, UK. *Journal of Wind Engineering and Industrial Aerodynamics*. 2013;115:104-11.
70. Chen L, Liu Y. Scheduling strategy of hybrid wind-photovoltaic-hydro power generation system. In *International Conference on Sustainable Power Generation and Supply (SUPERGEN 2012)* 2012;1-6. IET.
71. Solomin E, Sirotkin E, Cuce E, Selvanathan SP, Kumarasamy S. Hybrid floating solar plant designs: a review. *Energies*. 2021;14(10):2751.
72. Fereshtehpour M, Sabbaghian RJ, Farrokhi A, Jovein EB, Sarindizaj EE. Evaluation of factors governing the use of floating solar system: A study on Iran's important water infrastructures. *Renewable Energy*. 2021;171:1171-87.
73. Cazzaniga R, Rosa-Clot M, Rosa-Clot P, Tina GM. Integration of PV floating with hydroelectric power plants. *Heliyon*. 2019;5(6).
74. Martín-Chivelet N. Photovoltaic potential and land-use estimation methodology. *Energy*. 2016;94:233-42.
75. Capotondi A, Alexander MA, Bond NA, Curchitser EN, Scott JD. Enhanced upper ocean stratification with climate change in the CMIP3 models. *Journal of Geophysical Research: Oceans*. 2012;117(C4).
76. Exley G, Armstrong A, Page T, Jones ID. Floating photovoltaics could mitigate climate change impacts on water body temperature and stratification. *Solar Energy*. 2021;219:24-33.
77. Mittal D, Saxena BK, Rao KV. Floating solar photovoltaic systems: An overview and their feasibility at Kota in Rajasthan. In *2017 international conference on circuit, power and computing technologies (ICCPCT) 2017*;1-7. IEEE.
78. Santos-Borja AC. Dealing with uncertainties: floating solar farm in natural lakes. In *IOP Conference Series: Earth and Environmental Science*. 2021;789(1):012036. IOP Publishing.
79. Abdallah S, Abd Elmohemen M, Hemdan S, Ibrahim K. Land assessment for agricultural use in jizan basin, ksa, after 48 years of jizan dam construction. *Journal of the Indian Society of Remote Sensing*. 2019;47:1895-904.
80. Abu-Abdullah MM, Youssef AM, Maerz NH, Abu-AlFadail E, Al-Harbi HM, Al-Saadi NS. A flood risk management program of

- Wadi Baysh dam on the downstream area: An integration of hydrologic and hydraulic models, Jizan region, KSA. *Sustainability*. 2020;12(3):1069.
81. Solomin E, Sirotkin E, Cuce E, Selvanathan SP, Kumarasamy S. Hybrid floating solar plant designs: A review. *Energies*. 2021;14(10):2751.

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