Energy Strategy Reviews 24 (2019) 166–177

Contents lists available at ScienceDirect

Energy Strategy Reviews

journal homepage: www.elsevier.com/locate/esr

Review

Current and future prospects of small hydro power in Pakistan: A survey

Waqar Uddin[a,*], Ayesha[b], Kamran Zeb[a,e], Aun Haider[b], Bilal Khan[c], Saif ul Islam[a], M. Ishfaq[a], Imran Khan[a], M. Adil[d], Hee Je Kim[a]

[a] School of Electrical Engineering, Pusan National University Busan, South Korea
[b] Department of Electrical Engineering, University of Management & Technology Lahore, Sialkot Campus, Pakistan
[c] Department of Electrical Engineering, COMSATS University Abbottabad Campus, Pakistan
[d] Department of Electrical Engineering, Air University Islamabad, Pakistan
[e] School of Electrical Engineering and Computer Science, National University of Science and Technology Islamabad, Pakistan

ABSTRACT

Currently, the electrical energy crisis is an important issue in Pakistan. Due to the shortage of electrical power, inhabitants of the country are facing 10–12 h of blackouts in urban areas and 14–20 h in rural areas daily. The current demand for electrical power is 15,000 MW, which is expected to increase further to 49,078 MW by 2050. Conventional energy sources are unable to meet this demand. This paper discusses the potential of Small Hydro Power Plants (SHPPs) to partially overcome the shortage of electricity. Overall, 60,000 MW of hydroelectric resources have been identified in Pakistan. whereas, approximately 11% of the identified resources are operational, producing 7228 MW of electric power. The energy crisis can be easily overcome by installing SHPPs. The use of SHPPs has been estimated to save 120 million tons of coal or 83.3 billion liters of oil in a year. Thus, these plants are environmentally friendly and make a low contribution to global warming. Worldwide, SHPPs provide employment to 0.2 million people. Pakistan Council of Renewable Energy Technology (PCRET) and Sarhad Rural Support Program (SRSP) has installed 1100 SHPPs, with a total capacity of 42.507 MW, which fulfills the electrical energy demand of approximately 0.7 million people in Pakistan.

1. Introduction

Energy is an important factor in the economic growth and development of a country. Currently, many challenges in the development of the energy sector in Pakistan remain to be addressed. In 2006, 57.9 million Tons of Oil Equivalent (TOEs) energy were required in Pakistan. The energy demand is growing at a rate of 11–13% every year. With this growth rate, this energy requirement will reach 179 million TOEs in 2020.

Due to the gap between the supply and demand of electrical power, Pakistan is daily facing 10–12 h of blackouts in urban areas and 14–20 h in rural areas. In 2012, the difference between demand and generation was 8500 MW [1]. Approximately 0.7–0.8 million consumers are connected to a national grid that almost takes 1000 MW energy from the system. There is 7.8% growth rate in electricity demand. This will increase the shortfall to 10,844 MW in 2020 [2]. The exports of Pakistan are severely affected due to under production in industries because of this shortfall in electricity generation [3]. This shortfall is currently fulfilled by the import of crude oil. It currently costs 1.4 billion US dollars, which is much higher than that in 1996 (0.53 billion US dollars). Pakistan spends approximately 20% of its foreign exchange reserves on the import of oil [4] and almost 14.5 billion US dollars for other conventional energy resources, which is 40% of the total imports of the country [5].

The energy demand in Pakistan is expected to be three times higher by 2050. According to the International Energy Agency (IEA), the electrical energy demand of Pakistan will increase to 49,078 MW in 2050 [6], i.e. around three-fold increase. Comparatively, the energy demand is growing faster than energy production [7,8]. Currently, conventional energy resources are mostly used to meet the demand of electrical power in Pakistan, as shown in Fig. 1. The major portion of electric power is availed from conventional energy resources. However, to address the increased demand of electricity, most countries including Pakistan needs to renewable energy sources.

Owing to the geographical location, Pakistan has abundance of renewable energy resources, such as Small Hydro, Wind, Biogas, Biodiesel, Geothermal, and Solar power. To mitigate the energy crisis, the exploration of new renewable energy resources is essential [9]. A shortfall of conventional energy resources is an indication of the increased dependency on renewable resources to revive the economic growth of Pakistan [5]. Throughout the world, among all the available renewable energy resources, small and large hydroelectric power plants provide 16% of electric power [10–12].

Small hydro is an alternative source of electrical energy to overcome energy shortages. Many countries around the world have a large potential of small hydro. In China, 19,000 MW of electricity is generated

* Corresponding author.
E-mail address: waqudn@pusan.ac.kr (W. Uddin).

https://doi.org/10.1016/j.esr.2019.03.002
Received 25 September 2018; Received in revised form 25 February 2019; Accepted 6 March 2019
Available online 15 March 2019

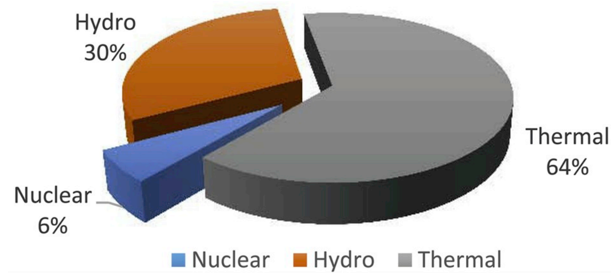

Fig. 1. Shares of conventional energy sources for electric power generation in Pakistan [5].

from 43,000 SHPPs [13]. Similarly, the geographic location and water resources of Pakistan allow the production of 60,000 MW electric power [14]. Of the large available potential, only 7172 MW is generated from hydropower in 2016–17. Fig. 2 presents the hydro power resources in Pakistan.

The Pakistan Council of Renewable Energy Technologies (PCRET), Sarhad Rural Support Program (SRSP) Alternative Energy Development Board (AEDB), Pakistan Council for Appropriate Technologies (PCAT), Pakhtunkhwa Energy Development Organization (PEDO), and Pakistan Renewable Energy Society (PRES) works for the research and development of small hydro plants in Pakistan. The further exploration of renewable energy resources will easily overcome the shortfalls of electricity demand and provide employment. Therefore, Pakistan should allocate more funds and establish a research and development department to extract power from renewable energy resources efficiently. In this regard, this paper focuses mainly on the following aspects of SHPP:

1. Details of the potential of hydroelectric power in Pakistan;
2. Use of SHPP as an alternative energy solution to overcome the energy crisis in Pakistan;
3. Important components used in the construction and operation of SHPP;
4. Impact of small hydro on the environment and local communities in term of job creation, economic benefits and availability of electricity; and
5. Barriers in the construction of SHPP as well as their current and future prospects.

Table 1 Compares the various surveys of SHPP in terms covered topics and respective region.

The remainder of this paper is organized as follows. In Section 2, the overall generation from different sources in Pakistan is discussed. Section 3 reviews SHPPs, whereas Section 4 discusses in detail the different components used in small hydro systems. Section 5 discusses the current and future prospects of small hydro systems in Pakistan. An economical comparison of different renewable energy resources is carried out in Section 6. Section 7 details the different barriers in the promotion and installation of SHPPs. The impact of SHPP on environments is discussed in Section 8. A case study of a small hydro plant is presented in Section 9. Finally, the conclusions are given in Section 10.

2. Electrical power generation in Pakistan

Pakistan has abundance of natural resources. The southeastern and southwestern regions of Pakistan have large reserves of gas, oil, and coal [30]; the northern mountainous areas of Pakistan have an abundance of water resources, i.e. Glaciers. These glaciers melt to form large networks of stream and rivers [31]. In addition, Pakistan is fortunate to have a wind speed of 13.8–16.5 miles per hour [32] while solar energy intensity in the sunbelt of Pakistan is approximately 1,800–2,200 kWh per square meter per day [33]. Currently in Pakistan, the installed capacity of hydro, thermal, coal, nuclear, biomass, solar PV, natural gas, and wind power plant is 26,898 MW. In addition to these operational plants, some power plants are under construction and others are being proposed. The under construction and proposed plants are either new plants or an extension of old plants. Table 2 lists the capacity of installed plants, under construction, and proposed plants.

Apart from these plants, Pakistan has taken the initiative to install a 16,170 MW capacity electric power plant with the cooperation of China under the China-Pakistan Economic Corridor (CPEC) project [35]. Many of these projects will complete around 2020/2021. Table 3 lists the current energy projects.

However, the water resources of Pakistan are not utilized fully for the generation of electric power. The Water And Power Development Authority (WAPDA) has identified numerous sites for hydropower stations that can produce 60,000 MW of electric power. Until now, the total electrical power produced from hydro resources has been 7228 MW, which is only 11% of the overall potential of hydropower sources identified in Pakistan [14]. Despite this underutilization of resources, the contribution of hydropower is 30% of the total generated electric power [5].

These identified hydropower resources can be constructed on different rivers of Pakistan. The major portion of power from these identified resources can be achieved from the Indus River, which is 66% of all resources identified, as shown in Fig. 3.

These hydropower resources identified are in Punjab, Khyber Pakhtunkhwa (KPK), Sindh, Baluchistan, and Gilgit-Baltistan & Azad

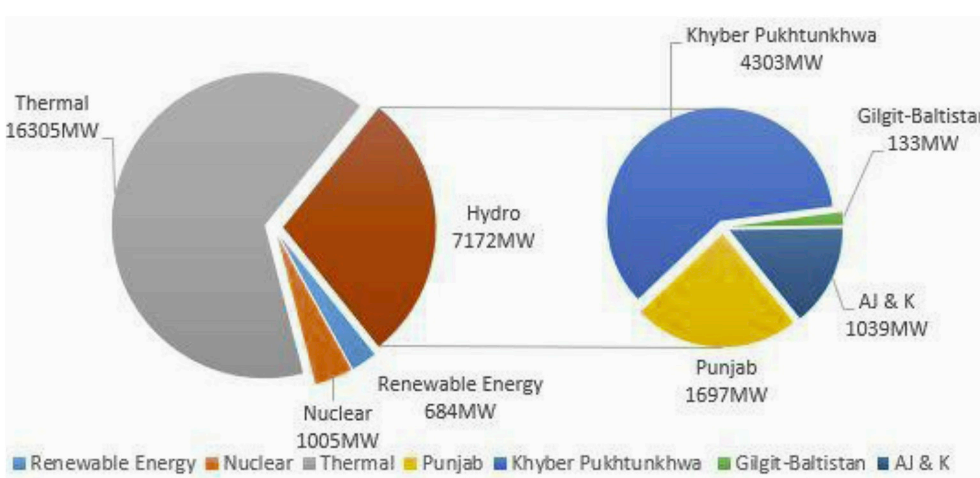

Fig. 2. Hydroelectric Generation in different region of Pakistan [9].

Table 1
Comparison of various surveys of Small Hydro.

Ref No#	Current Status of SHPP	Components used in SHPP	Installed plants	Economic Comparison	Barriers	Environmental Impact	Case Study	Country
[15]	✓	✗	✗	✗	✗	✓	✓	India
[16]	✓	✗	✓	✗	✓	✓	✗	Turkey
[17]	✓	✓	✗	✗	✗	✓	✓	General
[18]	✓	✗	✗	✓	✗	✓	✗	Pakistan
[19]	✓	✗	✓	✗	✗	✗	✗	Pakistan
[20]	✗	✓	✗	✓	✗	✓	✗	Uganda
[21]	✓	✓	✗	✓	✗	✗	✗	South Africa
[22]	✗	✓	✗	✓	✓	✗	✗	Malaysia
[23]	✓	✗	✓	✗	✗	✓	✗	India
[24]	✓	✗	✗	✓	✗	✓	✗	General
[25]	✗	✗	✓	✓	✗	✗	✗	Nigeria
[26]	✓	✓	✗	✓	✗	✗	✗	General
[27]	✓	✓	✓	✗	✓	✗	✗	India
[28]	✓	✗	✗	✓	✗	✓	✓	Thailand
[29]	✓	✓	✗	✓	✗	✓	✗	Malawi
[This Paper]	✓	✓	✓	✓	✓	✓	✓	Pakistan

Table 2
Current scenario & future prospect of electric power generation [34].

Source	Installed Capacity (MW)	Under Construction (MW)	Proposed Plant (MW)
Hydro	7455	6566	44,855
Fossil Fuel	17,038	12,736	10,544
Nuclear	1065	2540	3200
Wind	695	2715	–
Solar PV	81	450	2046
Bagasse	564	481	–
Biomass	0.1	20	–
Total	**26,898**	**25,508**	**60,645**

Table 3
Electric power generation under the CPEC project [35].

Energy Sources	Priority Projects Capacity (MW)	Actively promoted Projects Capacity (MW)
Fossil Fuel	7560	4620
Hydro	1590	1100
Wind	200	100
Solar PV	1000	–

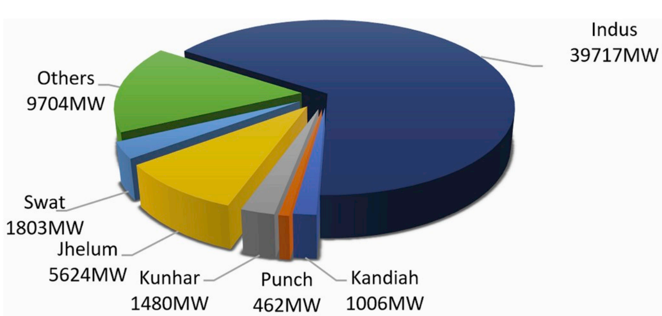

Fig. 3. Identified resources of hydel power [14].

Jammu & Kashmir (AJ& K). KPK can produce 40% of power from hydro resources, whereas the resources identified in Gilgit-Baltistan have the largest share of 36%. Fig. 4 shows the amount of electric power produced from the hydro sources in the various regions of the country.

3. An overview of SHPP

Based on the power generation capacity, SHPPs can be categorized to Small hydro, Mini, Micro, and Pico [36,37]. The definition of small hydro varies from the country to country. Usually, the upper limit for SHPP varies from 10 to 30 MW, whereas the upper limit for micro hydro is $<$ 100 kW [38]. Table 4 lists the classifications of hydro plants according to their capacity in different countries.

3.1. The working principle of small hydropower

A hydropower system uses running water to produce mechanical energy. This energy is later converted to electrical energy using generators. SHPP generally does not require poundage or reservoirs. The plant is established on run-of-the-river. Water is diverted from the mainstream to create a head that is then passed through a pipe (penstock) with high energy. The pressurized water in the penstock rotates the turbine that spins the shaft coupled to the generator [40–42]. Fig. 5 presents the entire process of water flow and the turbine. The intake from the stream, canal, forebay, penstock and power house can be clearly visualized in Fig. 5.

The mathematical expression for the generation of electrical power in SHPP is given as follows: [44–46].

$$P = \rho g H Q \times \eta \quad watts \tag{1}$$

where P represents the electrical power produced; ρ is the density of water (Normaly $997 Kg/m^3$); g is gravity ; H is the net available head (m); Q is the water flow rate (m^3/s); and η is the efficiency of the system. The efficiency of the SHPP is in the range of 60–80% [47].

4. Major components of SHPP

SHPP employs different components to convert mechanical energy to electrical energy. Each component is designed specifically to maximize the extraction of energy from running water. Water flowing in the river contains both potential energy and kinetic energy. In small hydropower plants, the potential energy of water is used to produce electricity. The following are the important components of a typical SHPP.

4.1. Water reservoir

The reservoir of water is the place where the water is stored and produces a head for the conversion of mechanical to electrical energy [48]. The altitude of water in the reservoir determines how much potential energy the water possesses [49]. Apart from having high potential energy, a high site of the reservoir allows the smooth flow of water downward. The natural height of water flowing in a river is less than the height of water in the reservoir. This improves the overall potential energy of the water, which helps produce more electricity in the power generation unit [46].

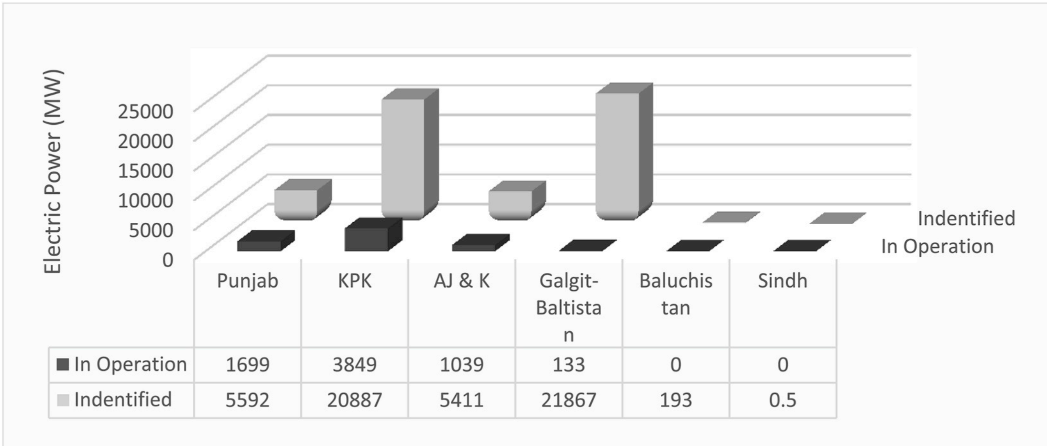

Fig. 4. Area-wise operational & identified hydel power resources [14,36].

Table 4
Different definition used for small hydro plant [25,39].

Country	Micro-hydel (KW)	Mini-hydro (KW)	Small-Hydro (MW)	Large Hydro (MW)
China	–	500	0.5–25	> 25
Canada	–	–	1–25	> 30
USA	< 100	100–1000	1–30	> 30
Russia	100	–	–	–
France	5–5000	–	–	–
UK	100	101–1000	1–15	> 15
India	–	–	5	> 5
Brazil	100	101–1000	1–30	> 30
Turkey	1–100	101–1000	1–10	> 10
Various	100	1000	10	> 10

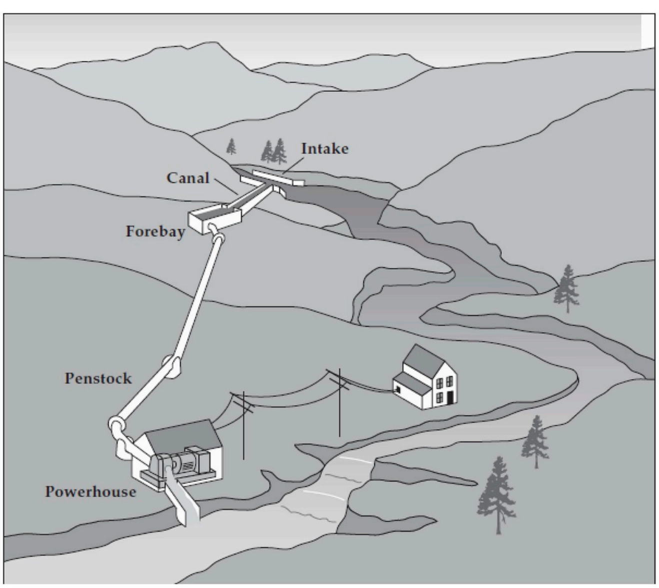

Fig. 5. Layout of a small hydro plant [43].

4.2. Intake or control gates

Control or inlet gates are constructed inside the reservoir or dam. These gates control the flow of water from the reservoir to SHPP. The water flows toward the turbine through the penstock due to the height produced by the reservoirs. The water flowing across the gates retains kinetic and potential energy in an SHPP [50].

4.3. Penstock

The penstock is a long pipe that brings water flowing from the reservoir to the power generation unit, which contains the generator and turbines. The water in the penstock possesses potential energy because of its height and kinetic energy due to its motion [51].

The total amount of power generated by a small hydropower plant depends on the amount of water flowing through the penstock and the height of the water reservoir [44]. The water through the penstock is controlled by control gates. The penstock is usually made of steel, wood staves, high-density polyethylene, concrete, concrete with a steel lining, open channel, rock tunnel, or glass fiber [48].

4.4. Turbine used in hydro power plants

The turbine rotates a shaft, which is often used to drive an electrical generator in an SHPP. As the flowing water drops on the turbine blades, potential and kinetic energy are transformed into the rotational motion of the blades. The rotation of the blade rotates the shaft, which in turn, rotates the rotor of an electric generator. The selection of turbine used in small hydro plants is important for harnessing the maximum amount of energy and dependent on the flow rate of water and the available head. The two available choices of turbines are Impulse Turbine and Reaction Turbine [52], which are divided further into the types given in Fig. 6.

Table 5 lists these turbines and their approximated head. For a low and medium head, the reaction turbine is a suitable choice while Pelton turbines are used for a medium and high head.

On the other hand, the selection of the turbine is also dependent on the flow of water. For a small water flow & higher head (> 50 m), a Pelton or Turgo turbine is the best choice, whereas a propeller or Kaplan turbine is a suitable choice for large water flow and low heat (< 10 m). Fig. 7 summarizes the application of these turbines related to the head and power generated.

4.5. Types of hydraulic turbine

4.5.1. Impulse turbine

Due to its simplicity in design and lower cost, impulse turbines are used frequently in small hydro plants [55]. These are suitable for medium and high heads [50]. Indeed, their effectiveness for a low head has made them an attractive practice in several countries [56]. The impulse turbine moves the runner using the velocity of water. Several types of impulse turbines are used in SHPPs based on their efficiency as shown in Fig. 8.

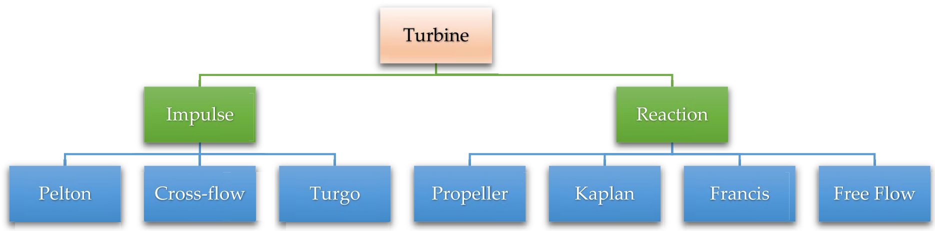

Fig. 6. Types of turbine [53].

Table 5
Turbine Classifications [54].

	Low (< 10) m	Medium (10–50) m	High (> 50) m
Turbine Type	Crossflow Francis Propeller	Crossflow Francis Turgo Multi-jet Pelton	Pelton Turgo Multi-jet Pelton

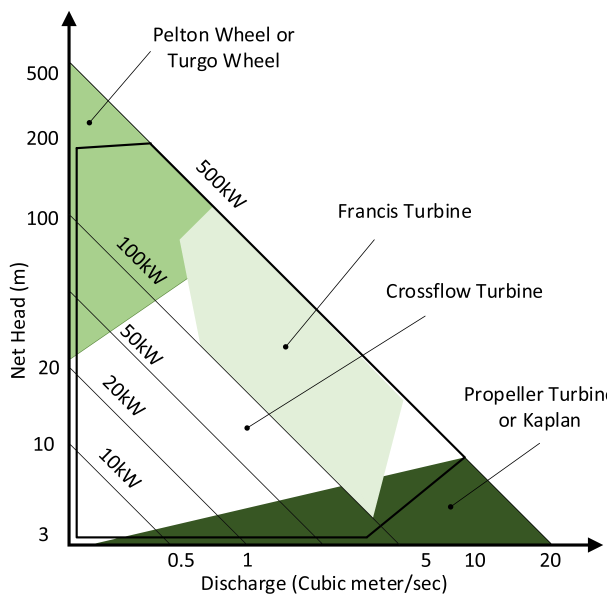

Fig. 7. Turbine relation with Net Head & Discharge [50].

4.5.1.1. Pelton. The free-stream turbine is another name for the Pelton turbine, which is used for a low volume of water and high heads from 100 m to 1000 m [57–60]. The use of a single jet Pelton turbine recently took place in an SHPP plant [59]. The efficiency of the Pelton turbine has a high rate of 70–90% [61].

4.5.1.2. Turgo. In numerous projects, Turgo wheel alters the location of low heads from 3.5 m down to 1 m to improve the turbine performance [62,63]. The modified form of the Pelton turbine is a Turgo turbine model made exclusively by Gilkes in England. The cast wheel runner of this turbine resembles fan blades fastened to external edges. The stream of water is smeared into one side and exits to the other side. The efficiency of the Turgo turbine for SHPP is quite sensitive to jet position and jet inclined angle [62–64]; its efficiency is 67–85% [65].

4.5.1.3. Crossflow. The cross-flow turbine (CFT) has a smaller capacity so it is used in SHPPs for low head and high flow applications [57]. This can be used in both horizontal and vertical configurations. An extended, a rectangular-section nozzle is fixed against curved vanes on a cylindrically shaped runner used in a drum-shaped cross-flow turbine [66]. The turbine looks like the blower of a “squirrel cage” shape and allows the flow of water twice across the blades. The first part is when the water pulls out inside and the other part is from the outside to the inside of the blades. The guide vane of the turbine leads the flow to an inadequate runner portion on the entrance side. The CFT design is suitable for a large flow of water and low heads than the Pelton [58,67]. The cross-flow turbine has an average efficiency for medium and large hydropower is up to 86% and usually 80% for small hydropower [67]. The efficiency increases with increasing number of blades [68,69].

4.5.2. Reaction turbine

Compared to impulse turbines, reaction turbines have better performance for high flow and low head sites [55,58]. The collective action of moving water and pressure improves the power of a reaction turbine in a small hydro plant. The water stream of a runner is located above the blades rather than striking each individually.

4.5.2.1. Propeller. For low head applications, propeller turbines are quite efficient [20,70]. A propeller turbine has three or six runner blades and is used for a constant flow of water. The runner would be out of balance if the propeller is not running with constant pressure [71]. The blade pitch may be variable or constant. In addition to the runner, the major components of a propeller turbine are the draft tube, wicket gate, and scroll case. The efficiency can be increased by adjusting the guide vane angles and turbine blades [72]. Several types of propeller turbines, such as Bulb turbine, Straflo, and Tube turbine have been used in SHPP [58,72,73]. Normally, the efficiency of these turbines is in the range, 55–74%.

4.5.2.2. Kaplan. For a run-of-the-river SHPP, Kaplan, with a head of 6–15 m and high rate of flow of water, is the most commonly used type of turbine [57]. This turbine is appropriate for fluctuating water volumes because both of its blades and wicket gates are adjustable, and it is employed for a variety of uses; its efficiency is 90% [65].

4.5.2.3. Francis. The Francis turbine is a primitive type of conventional turbine that is used mostly in SHPPs. The operating range of Francis turbines is between 1 m and 900 m for mini, medium or large hydro plants [74]. Generally, the Francis turbine uses nine or more fixed runner buckets (vanes). Above the runner, water flows and falls through it, causing it to spin. In addition, in the runner, the main components are the wicket gates, draft tube, and scroll case [75].

4.5.2.4. Free flow. Free-flow turbines are also known as kinetic energy turbines and they produce power from the kinetic energy of a volume of water rather than the potential energy from the height of water. The system can operate in oceans, tidal waters, rivers, and manufactured channel currents. The free flow turbine utilizes the natural pathway of the stream's water and does not involve the deviation of water through pipes, or riverbeds and man-made channels, even though they might have applications in such ducts. They do not require civil works because they are employed in prevailing structures, such as tailraces, channels, and bridges [76].

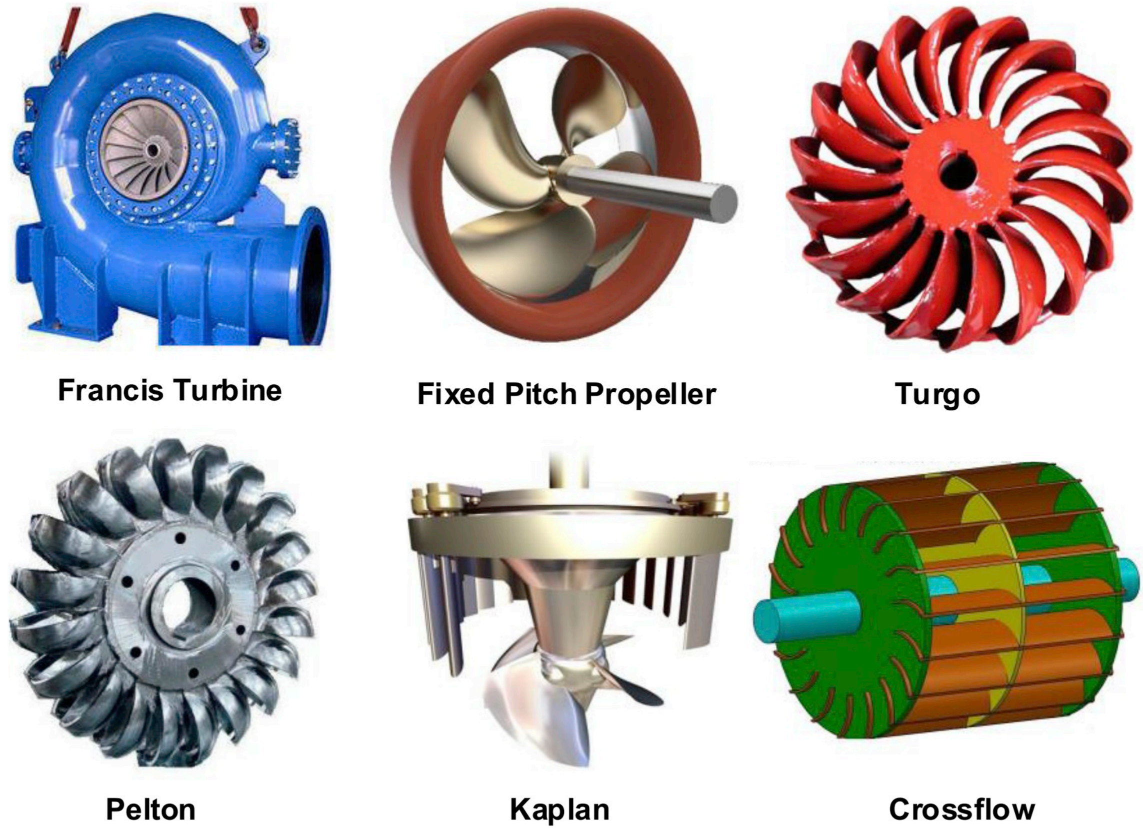

Fig. 8. Commonly used water turbines [50].

Table 6
Plant installed by PCRET [83].

Region	No of Plants Installed	Installed Capacity (kW)	Houses Electrified
KPK & FATA	553	8239.5	65,337
Gilgit	72	401.5	4010
Baluchistan	3	80	800
AJ&K	50	786	4758
Total	**678**	**9507**	**74,905**

4.6. Generators

Mechanical power produced at the shaft due to the flow of water is converted to electric power through electrical generators. In SHPPs, two types of generators used to convert mechanical power to electrical: asynchronous generator and synchronous generator [77,78].

4.6.1. Asynchronous generator

Asynchronous generators are suitable for SHPPs because they satisfy most of the requirements imposed by the users: relatively low cost, high reliability, high output voltage, easy maintenance, and simple design [77,79,80]. They are the source of isolated or distributed power [81]. A wide range of asynchronous generator is manufactured on the bases of generating capability, rotational speed, and form factor. Hence, these qualities allow us to design a machine that can be fit in any application.

4.6.2. Synchronous generator

This type of generator is used widely for the commercial purpose [77]. The synchronous generator used for the hydro plant has a salient pole rotor. These types of generators are driven by a low-speed prime mover. The major advantage of a synchronous generator is that it does not require a capacitor bank in parallel to provide the reactive power demand of a load [82].

5. Prospects of small hydro in Pakistan

The current energy crisis in Pakistan can be solved by the installation of SHPPs. Pakistan has the extensive potential of hydropower generation due to the abundant water resources in Khyber Pakhtunkhwa (KPK) province, Azad Jammu & Kashmir (AJ&K), Gilgit, and Baluchistan areas. Currently, different government and non-governmental organizations are working on the installation of SHPPs in the country [14]. PCRET installed 678 SHPP ranges from 5 to 100 kW across the country. These plants were installed from 1978 to 2016 and produce 9.507 MW of electric power [83]. Table 6 provides details of the plants installed by PCRET.

Among non-governmental organizations, SRSP has played an important role in providing electricity to remote areas that are not connected to the national grid. According to a survey conducted in Malakand Division KPK, 25% of the total population are still not electrified. SRSP has installed 166 SHPP in 12 years (2006–2014) with a cost of Rs. 1.25 million, which provide 9.6 MW of electric power to more than 0.242 million people. Whereas the number of plants installed has increased to 422 in two consecutive years due to the increase in demand. These 422 SHPPs generate 33 MW of electricity and electrify approximately 0.7 million people [84]. These plants are made operational with an expenditure of Rs.3.2 billion. PEDO is also working on SHPPs that will provide 2156 MW of electric power by 2020. Based on the completion time of the project, PEDO has developed an action plan consisting of short term, medium term, and long-term categories, which is summarized in Table 7.

The power plants installed by PEDO are expected to recover their total cost within 5 years. According to the report of the International Renewable Energy Agency (IRENA), the total power produced from the hydro resource is 7407 MW in 2017 [85,86]. This is only a 12.67%

Table 7
Hydropower development 2011–2020 [85].

Plan	Capacity (MW)	No. of Projects	Span of Project (Years)	Cost (Rs. Billion)	Expected Revenue/Annum (Rs. Billion)
Short Term	56	3	3	12	2
Medium Term	600	8	5	130.9	18
Long Term	1500	13	10	187.96	54
Total	**2156**	**24**		**331.3**	**74**

Table 8
Power produce since 2000 in MW [86].

Year	Small Hydro	Medium Hydro	Large Hydro	Total
2007	19	70	6485	6574
2009	19	86	6566	6671
2011	19	88	6638	6745
2013	21	94	6978	7094
2015	21	94	7108	7224
2016	21	94	7164	7255
2017	–	–	–	7407

increase since 2007, which is not appreciable. IRENA divided hydro plants into three categories: (1) Small hydro (< 1 MW), (2) Medium hydro (1–10 MW), and (3) Large hydro (> 10 MW). Table 8 shows the increase in hydropower generation capacity since 2000.

The increase in small, medium and large hydro since 2007 is 10.5%, 34.28%, and 10.47%.

6. Economical comparison

The electrical power in Pakistan is provided by a semi-government organization known as WAPDA. WAPDA charges their consumer Rs.12/unit during normal hours and Rs. 18 during peak hours. Apart from tariff charges, the consumer faces an 8-h power outage in urban areas while in rural areas, the duration of power outages can be 12–16 h [3]. While SHPP provides electricity 24/7 at a rate of Rs.4/unit for domestic purposes, the charge for commercial purpose is Rs.7 per unit [87]. Some local hotels in Kalam (Swat) reported Rs.100, 000 savings per month due to its connection with SHPP. According to the report of SRSP, all 422 units installed generate 33 MW electricity, which saves 114 million liters of kerosene oil worth Rs. 11 billion [84]. SHPP electricity is provided to businesses during the daytime. SHPP users can save time, cash, fuel, labor, and can be used for crop drying. In the swat area, SHPP electricity is used to dry fruit. The dried fruit is then marketed locally at Rs.440 per kg. Because of the dried fruit (Japanese fruit), the increase in income is more than 156% [87]. Extracting oil from mustard seed, milling, and hulling rice can also be done easily using electrical machinery. The power to these electrical machines is provided from SHPP. Using electrical machinery, 113 h, 31.4 h, and 31 h can be saved in exacting oil, hulling of rice, and milling process, respectively [88]. Table 9 lists the time required to complete the process in the traditional way and electrical machinery run by SHPP.

Table 9
Required time for mechanical work [88].

Mechanical Work	Using Traditional (Hours)	Using Hydroelectric power (Hours)
Extracting Oil	117.5	4.5
Hulling rice	32.5	1.1
Milling	32.2	1.2

In addition to the running cost and other benefits, the installation cost of SHPP is much lower than the solar and wind energy [89–91]. SHPP also has a high capacity factor compared to other renewable resources. Table 10 compares the different resources of electrical power generation. The leveled cost of electricity calculation was assumed to be 10% of the capital cost. SHPP and other renewable energy resources have made a large contribution to developing employment opportunities for technical and non-technical people. According to the report of SRSP, a single installed unit of SHPP provides jobs to three people [87]. Therefore, all 422 units installed by SRSP has economic benefits for approximately 1200 families [84].

In contrast, worldwide solar PV is making the largest contribution to the job market, it produces approximately 2.5 million jobs globally. Similarly, small hydro provides employment for 209,000 people [86,92]. Table 11 lists the employment provided by different renewable energy sources and their power generation.

7. Barriers for using SHPP

Although several hydro sources are identified in Pakistan, which can make a huge contribution to the generation of electric power, there are several barriers that block or delay the propagation of SHPPs. These include strategy and monitoring framework, funding, policies and regulation for SHPPs, unavailability of data on hydro resources, and social barriers.

Table 11
Employment created by renewable resources [86,92].

Renewable Energy Source	Generation in MW	Employment (×1000)
Solar PV	175,305	2495
Liquid Biofuels	1633	1788
Wind Power	369,608	1027
Biogas	12,666	381
Small Hydro	134,368	209
Geothermal	12,414	154
Concentrated Solar Power	4334	22

Table 10
Cost comparison of different renewable resources [89–91].

Resources	Installed Cost (USD/kW)	Levelized Cost of electricity (USD/kWh)	Capacity Factor (%)
Large Hydro	1050–7650	0.02–0.19	25–90
Small Hydro	1300–8000	0.02–0.27	20–95
c-Si PV System	3800–5800	0.25–0.65	10–25
c-Si PV system with Battery storage	5000–6000	0.36–0.71	–
Onshore Wind Turbine	1850–2100	0.08–0.14	25–35
Offshore Wind Turbine	4000–4500	0.14–0.19	40–50

C: crystalline, Si: Silicon, PV: Photovoltaic.

7.1. Strategy and monitoring framework

A major barrier for using SHPPs is the lack of strategy and monitoring framework. In this regard, there is often insufficient structures and designs that can manage SHPP schemes efficiently [93]. Because of this inadequate regulatory framework, the developer does not have enough knowledge about the requirements of SHPP design and structure that should be applied and work in unreliable regulation [94].

7.2. Funding

A common challenge is the absence of adequate funding to improve the SHPP industry. Because the SHPP industry is dependent mostly on available funding, the allocated funds are normally spent on a specific community and area, which is not enough to address the issue of the energy crisis in the country [95]. Although some of the local community also invests in the development of an SHPP (< 1 MW), the generation of revenue is a positive step to expanding the SHPP industry [96]. Another solution is to find some other sources of funding, i.e., encouraging private investors to invest in this sector [93].

7.3. Policies and regulations for SHPP

Rural electrification is not possible without awareness and knowledge of the potential of SHPP. Political decision makers focus only on visible large hydropower systems while they are showing a cold response to the making, revision, and implementation of policies and regulation in support of SHPPs [97]. On the technical side, a plan for building and operating SHPPs is always missing. The insufficient supply of affordable generators and turbine parts is a barrier to the instantaneous and cost-effective development of an SHPP project. For the long-term development of this sector, it is necessary to make available the equipment and parts related to SHPPs at an affordable price throughout the country [98].

7.4. Unavailability of data on hydro resources

One of the barriers in the promotion of SHPPs is the unavailability of data related to hydro resources, such as seasonal variation in the flow of rivers and streams, electricity demand, geology, and geography [99,100].

7.5. Social barrier

The opposition of the local communities is also one of the important barriers to the SHPP. One of the causes is disagreement between the upstream and downstream villages on the sharing of water resources. Another common cause is that most of the community does not allow the local distribution line to pass through their land [101].

8. Environmental impacts

Small hydro has almost no negative impact on the environment and is all-green energy [102–108]. All other energy sources are contributing to global warming by producing Greenhouse Gases (GHG). Among all the energy sources, coal produces the highest amount of GHG while hydro is the lowest contributor to global warming. Table 12 lists the GHG emissions from various energy sources. One study [110] reported that the generation of 1 kWh hydroelectricity reduces carbon emissions by 0.42 kg and the use of kerosene oil is reduced by 0.48 L. By considering this value, 1100 SHPPs installed by PCRET and SRSP will produce 1020 MWh of energy per day. This will reduce 428 tons of carbon emissions and reduce the use of kerosene oil by 489.68 kL per day. In addition, it has been reported [24] that the use of SHPPs can save 120 million tons of coal or 83.3 billion liters of oil in a year. Furthermore, the use of SHPPs worldwide instead of coal can save 343 million tons of CO_2 emissions or 246.18 million tons of CO_2 can be saved by preventing the use of oil [111].

Table 12
Greenhouse gas emission by different power plants [109].

Energy Sources	GHG emission CO_2 (g/kWh)	SO_2 (g/kWh)	NO_x (g/kWh)
Coal (NOx) and FGD	987	1.5	2.9
Coal (best practice)	955	11.8	4.3
Oil (best practice)	818	14.2	4.0
Diesel	772	1.6	12.3
Natural gas (CCGT)	430	–	0.5
Solar photovoltaic	98–167	0.2–0.34	0.18–0.30
Solar thermal electric	26–38	0.13–0.27	0.06–0.13
Energy crops – current practice	17–27	0.07–0.16	1.1–2.5
Energy crops-Likely to improve to	15–18	0.06–0.08	0.35–0.51
Small hydro	9	0.03	0.07
Wind	7–9	0.02–0.09	0.02–0.06
Geothermal	7–9	0.02	0.28
Large hydro	3.6–11.6	0.009–0.024	0.003–0.006

g/kWh: gram/kWh, FGD: Flue-gas desulfurization, CCGT: Combined Cycle Gas Turbines.

9. Case study

The SHPP situated at Tarpatar (Upper Dir, Khyber Pakhtunkhwa), which is 5021 ft above the sea level, was selected for a case study. The global coordinates for this SHPP are 35° 09′ 42″ N and 72° 06′ 13″ E. The location of SHPP can be accessed through the given link (https://earth.app.goo.gl/73rY6C). The snapshot from google earth shows the location of SHPP as depicted in Fig. 9.

The water channel is shown by the red line and the mainstream are shown by a green line. While the forebay and SHPP are encircled in blue shown in Fig. 9.

The catchment area of SHPP is spread over the area of 26.2 km^2. The main source of water is glacial melt. The snowfall in the catchment area varies from 1 inch to several feet. The glacial melt and spring collect to form a stream carrying 20–22 cusecs of water. The stream is known as Aligasar Khwar (stream).

The water is diverted from the stream through a 1600 feet channel to produce a head of 75 feet. The diverted water collected in a forebay. The forebay is used to control water flow during the flood and trap the debris and sediment from flow through the penstock. Finally, penstock passes the water to the turbine for generation of electric power. The specification, length, dimension of civil work and other items given in Table 13.

A 3-phase (Stamford 100 kW) generator is used in SHPP that produces a power of 80 kW. The power produce from SHPP is used to electrify approximately 210 houses. The generation voltage of the plant is 400 V while the rotor of generator rotates at speed of 1500 RPM to produce a frequency of 50 Hz. The voltage fluctuation at the consumer terminal is controlled by the installation of an Electric Load Controller (ELC). Apart from ELC, a programmable logic controller (PLC) is installed for automation of system. The generator operates for 16 Hours daily which generates 38,400 kW-hours of energy in a month. The overall efficiency of SHPP is 76.8%. The average load demand per consumer in the area is approximately 100 units per month. The electricity in the area is used mostly for lighting during the night while during the daytime the power is used to run flour mills for grinding wheat and maize crops.

Fig. 9. Snapshot of SHPP location from google earth.

Table 13
Specification of civil work.

Description	Unit/Dimension
The dimension of the channel (without free-board)	(2.17 × 2.17) square feet
Dimension of fore bay	15 × 10 × 10 Cubic feet
Dimensions of turbine foundation	1.5 × 10 x 5 Cubic feet
Length of penstock	140 feet
Diameter of penstock pipe	20 inches
Diameter of inlet valve	20 inches
Type of Valve	Sluice
Type of turbine	X-Flow T15
Diameter of runner	11.8 inches
Flush value sluice with 10 feet pipe	6 inches

Table 14
Specification of the different item used in local transmission line.

Item	Specification	Quantity	Unit
Electrical pole Cylindrical type (HT)	30 ft	35	No
Electrical pole Cylindrical type (LT)	20 ft	35	No
Aluminum Conductor (HT)	GNAT	6000	Meter
Aluminum Conductor (LT)	GNAT	6000	Meter
Insulators with U-clamp and Nutt Bolts	D-shackle	120	No
Poles Stay wire set	Steel Wire 5/8 (30′ft)	3	No
Step-up Transformer	100 KVA	1	No
Step-down Transformer	75 KVA	1	No
Step-down Transformer	50 KVA	1	No
Pin insulators	11 KV	110	No
Disc insulators	11 KV	55	No
4 core insulated cable	16 mm square	20	Meter

The generated power is transferred from SHPP through a local distribution line. The distribution line is spread in both directions of SHPP. Initially, the voltage is stepped up to 11 kV and then distributed to the scattered consumers. The high voltage is stepped down to 220 V for domestic use. The specification of different items used in the transmission line is given in Table 14.

The average load demand per consumer in the area is approximately 100 units per month. The electricity in the area is used mostly for lighting after dusk while during the day light the power is used to run flour mills for grinding wheat and maize. Apart from these applications it's is also utilized for small scale commercial use after the dawn. Fig. 10 (a) presents the SHPPs installed by SRSP for local communities. Fig. 10 (b) depicts a flour mill run by hydroelectricity for commercial purpose while Fig. 10 (c) shows the internal setup, i.e. turbine, generator, and control panel used in SHPP Tarpatar (Upper Dir).

The community is charged Rs. 100 per house per month for electricity. This is quite inexpensive and economical compared to the electricity provided by WAPDA. In addition, WAPDA provides electricity for 12 h per day with a voltage of 60–100 V at 50 Hz. While the SHPP provides electricity for approximately 16 h except during repair. The SHPP provides 38,400 kWh of energy in a month to the consumers. One operator and 5–6 members of the community are responsible for normal routine maintenance while major problems are handled by service providers.

The SHPP has given the many benefits to consumer such as availability of low cost electricity, economy to fuel wood, accessibility to electronic media, social uplift by improving living standard, and boosting in income.

10. Conclusion

Unlike other non-renewable energy resources, SHPP is a source of greener energy that makes a low contribution to global warming. The source of the hydro resource should be fully utilized to overcome the energy crisis in the country; whereas any surplus energy can be sold to the neighboring countries. The study presented shows that SHPP is environmentally friendly and has a good impact on society in terms of the availability of jobs and cheaper energy. The government should develop policies to promote renewable energies, particularly small hydro plants. Besides the policies, the availability of new advanced technology will be needed to extract electric power efficiently from water. Furthermore, the other barriers should also be addressed to encourage private investment in renewable energy resources and the local community to contribute positively to the development of SHPP.

(a): SHPP Tarpatar (Dir Upper)

(b): Flour mill running on SHPP

(c): Turbine, generator, and control system of SHPP

Fig. 10. (A): SHPP Tarpatar (Dir Upper). (b): Flour mill running on SHPP. (c): Turbine, generator, and control system of SHPP.

Funding

This work was supported by BK21PLUS, Creative Human Resource Development Program for IT Convergence.

References

[1] Planning Commission of Pakistan, [Online]. Available: http://www.pc.gov.pk/, Accessed date: 12 February 2019.
[2] The Express Tribune, [Online]. Available: https://tribune.com.pk/story/974259/cpec-group-forecasts-energy-shortfall-to-increase-to-10844mw/, Accessed date: 12 February 2019.
[3] W. Uddin, B. Khan, N. Shaukat, M. Majid, G. Mujtaba, A. Mehmood, et al., Potential of Biogas for Electric Power Generation in Pakistan, Renew. Sustain. Energy Rev. 54 (2016) 25–33.
[4] K. Zeb, S.M. Ali, B. khan, C.A. Mehmood, et al., A Survey on waste heat recovery: electric power generation and potential prospects within Pakistan, Renew. Sustain. Energy Rev. 75 (2017) 1142–1155.
[5] Ministry of Finance, Government of Pakistan, Pakistan economic survey 2009-10, [Online]. Available: http://finance.gov.pk/survey, Accessed date: 12 February 2019.
[6] The Express Tribune, [Online]. Available: http://tribune.com.pk/story/208495/dark-days-ahead-electricity-woes-to-worsen-in-future/, Accessed date: 12 February 2019.
[7] U. Zafar, T.U. Rashid, A.A. Khosa, M.S. Khalil, M. Rashid, An overview of implemented renewable energy policy of Pakistan, Renew. Sustain. Energy Rev. 82 (2018) 654–665.
[8] H. Zameer, Y. Wang, Energy production system optimization: evidence from Pakistan, Renew. Sustain. Energy Rev. 82 (2018) 886–893.
[9] M. Kamran, Current status and future success of renewable energy in Pakistan, Renew. Sustain. Energy Rev. 82 (2018) 609–617.
[10] G. Fernandes, L.L. Gomes, L.E.T. Brandao, A risk-hedging tool for hydro power plant, Renew. Sustain. Energy Rev. 90 (2018) 370–378.
[11] M.A. Hannan, R.A. Begum, M.G. Abdolrasol, et al., Review of baseline studies on energy policies and indicators in Malaysia for future sustainable energy development, Renew. Sustain. Energy Rev. vol. 94, (Oct 2018) 551–564.
[12] S. Sharma, J. Waldman, S. Afshari, B. Fekete, Status, trends and significance of american hydropower in changing energy landscape, Renew. Sustain. Energy Rev. 101 (2019) 112–122.
[13] John F. Mongillo, A Student guide to energy, Wind Energy, Oceanic Energy and Hydropower, vol. 3, Greenwood Publishing Group, ABC-CLIO, LLC, California, USA, 2011.
[14] The ministry of water & Power, Government of Pakistan, Hydropower Resources of Pakistan Feb-2011, [Online]. Available: www.ppib.gov.pk, Accessed date: 13 February 2019.
[15] S.P. Adhau, R.M. Moharil, P.G. Adhau, Mini-hydro power generation on existing irrigation projects: case study of Indian sites, Renew. Sustain. Energy Rev. 16 (2012) 4785–4795.
[16] Recep Bakis, Ayhan Demirbas, Sustainable Development of Small Hydropower Plants (SHPs), Energy Sources 26 (12) (2004) 1105–1118.
[17] Fred Schwartz, Rajani Pegallapati, Mohammad Shahidehpour, Small hydro as green power, IEEE Power Engineering Society General Meeting, 2005, pp. 1–8.
[18] Abdul Waheed Bhutto, Aqeel Ahmed Bazmi, Gholamreza Zahedi, Greener energy: issues and challenges for Pakistan-hydel power prospective, Renew. Sustain. Energy Rev. 16 (2012) 2732–2746.
[19] Umar K. Mirza, Nasir Ahmad, Tariq Majeed, Khanji Harijan, Hydropower use in Pakistan: past, present and future, Renew. Sustain. Energy Rev. 12 (2008) 1641–1651.
[20] David Kilama Okot, Review of small hydropower technology, Renew. Sustain. Energy Rev. 26 (2013) 515–520.
[21] Herman Jacobus Vermaak, Kanzumba Kusakana, Sandile Philip Koko, Status of micro-hydrokinetic river technology in rural applications: a review of literature, Renew. Sustain. Energy Rev. 29 (2014) 625–633.
[22] M. Hossain, A.S.N. Huda, S. Mekhilef, et al., A state-of-the art review of hydropower in Malaysia as renewable energy: current status and future prospects, Energy Strat. Rev. 22 (Nov. 2018) 426–437.
[23] Naveen Kumar Sharma, Prashant Kumar Tiwari, Yog Raj Sood, A comprehensive analysis of strategies, policies and development of hydropower in India: special emphasis on small hydro power, Renew. Sustain. Energy Rev. 18 (2013) 460–470.
[24] A. Demirbas, Focus on the world: status and future of hydropower, Energy Sources B Energy Econ. Plan. Pol. 2 (3) (2007) 237–242.
[25] Olayinka S. Ohunakin, J. Sunday, Ojolo, O. Ajayi Oluseyi, Small hydropower (SHP) development in Nigeria: an assessment, Renew. Sustain. Energy Rev. 15 (2011) 2006–2013.
[26] R. Bakis, The current status and future opportunities of hydroelectricity, Energy Sources B Energy Econ. Plan. Pol. 2 (3) (2007) 259–266.
[27] Mukesh Kumar Mishra, Nilay Khare, Alka Bani Agrawal, Small hydro power in India: current status and future perspectives, Renew. Sustain. Energy Rev. 51 (2015) 101–115.
[28] Pannathat Rojanamon, Taweep Chaisomphob, Thawilwadee Bureekul, Application of geographical information system to site selection of small run-of-river hydropower project by considering engineering/economic/environmental criteria and social impact, Renew. Sustain. Energy Rev. 13 (2009) 2336–2348.
[29] S. Kaunda Chiyembekezo, Energy situation, potential and application status of small-scale hydropower systems in Malawi, Renew. Sustain. Energy Rev. vol. 26, (2013) 1–19.
[30] Pakistan: Mining,Minerals and Fuel Resources, [Online]. Available: http://www.azomining.com/Article.aspx?ArticleID=150, Accessed date: 13 February 2019.
[31] Zulfiqar Ahmad, Mohsin Hafeez, Iftikhar Ahmad, Hydrology of mountainous area in the upper Indus Basin, Northern Pakistan with the perspective of climate change, Environ. Monit. Assess. (2012), https://doi.org/10.1007/s10661-011-2337-7.
[32] Triple Bottom-Line Sustainability Advocacy “The Feasibility of Renewable Energy in Pakistan”, [Online]. Available: http://www.tbl.com.pk/the-feasibility-of-renewable-energy-in-pakistan/, Accessed date: 13 February 2019.
[33] Pakistan Press International, Wind power and solar energy in Pakistan, [Online]. Available: http://ppinewsagency.com/wind-power-and-solar-energy-in-pakistan/, Accessed date: 5 January 2017.
[34] List of Power Stations in Pakistan, [Online]. Available: https://en.wikipedia.org/wiki/List of_power_stations _in _Pakistan, Accessed date: 13 February 2019.
[35] “Ministry of Planning & Development, Govt of Pakistan, China-Pakistan Economic Corridor (CPEC), [Online]. Available: http://cpec.gov.pk/energy, Accessed date: 13 February 2019.
[36] Ministry of Water and Power, Government of Pakistan, Private Power and Infrastructure Board. 960 MW Tarbela 4th Extension Hydropower Project, (2006) [Online]. Available: , Accessed date: 13 February 2019.
[37] Chiyembekezo S. Kaunda, Cuthbert Z. Kimambo, Torbjorn K. Nielsen, Potential of small-scale hydropower for electricity generation in sub-Saharan Africa, ISRN Renewable Energy (2012) 132606, https://doi.org/10.5402/2012/132606.
[38] Marek Adamowicz, Ryszard Strzelecki, Cascaded doubly fed induction generator for mini and micro power plant connected to grid, 13th International Conference on Power Electronics and Motion Control (EPE-PEMC 2008), 2008.
[39] L.J. Bracken n, H.A. Bulkeley, C.M. Maynard, Micro-hydro power in the UK: the role of communities in an emerging energy resource, Energy Policy 68 (2014) 92–101.
[40] G.P. Patel, Purushottam Singh, Pankaj Kulshreshtha, Vivek Atreya, Jaipal Singh, “Generating Equipment” International Conference on Hydropower for Sustainable Development Dehradun, (Feb 05-07, 2015), pp. 548–562.
[41] Bilal Abdullah Nasir, Design of micro-hydro-electric power station, Int. J. Eng. Adv. Technol. 3 (3) (February 2014) 388–396 ISSN: 2249 – 8958.
[42] S. Khurana, Anoop Kumar, Small hydro power – a review, Int. J. Tumor Ther. 1 (1) (December, 2011) 107–110.
[43] Small hydro system, Energy Efficiency and renewable energy clearinghouse (EREC), [Online] Available: www.eren.doe.gov/consumerinfo/, Accessed date: 13 February 2019.
[44] Celso Penche, Layman's guidebook on how to develop a small hydro site, Published by the European Small Hydropower Association (ESHA), second ed., Belgium, June, 1998.
[45] “Guide to Hydro Power” An Introduction to Hydropower Concepts and Planning, [Online] Available: http://www.canyonhydro.com/guide/Guide%20to%20Hydropower.pdf, Accessed date: 13 February 2019.
[46] Lea Kosnik, “The Potential for Small Scale Hydropower Development in the US” Energy Policy vol. 38, (2010), pp. 5512–5519.
[47] G. Ardizzon, G. Cavazzini, G. Pavesi, A new generation of small hydro and pumped-hydro power plants: Advances and future challenges, Renew. Sustain. Energy Rev. 31 (2014) 746–761.
[48] Tasneem Abbasi, S.A. Abbasi, Small hydro and the environmental implications of its extensive utilization, Renew. Sustain. Energy Rev. 15 (2011) 2134–2143.
[49] Dilip Singh, Micro-hydro-power, Resource Assessment Handbook, An Initiative of the Asian and Pacific Center for Transfer of Technology, September, 2009.
[50] Water Turbines, [Online] Available: http://waterturbines.wikidot.com/, Accessed date: 14 February 2019.
[51] European Small Hydropower Association, Guide on how to develop a small hydropower plant, [Online] Available:www.esha.be/fileadmin/esha_files/documents/publications/publications/Part_1_Guide_on_how_to _develop_a_small_hydropower_plant-_Final.pdf (2004).
[52] K. Ghosh Tushar, A. Prelas Mark, Energy Resources and Systems. Renewable Resources vol. 2, Springer, Netherlands, 2011 (chapter 3).
[53] O.B. Yaakob, Yasser M. Ahmed, A.H. Elbatran, H.M. Shabara, A review on micro hydro gravitational vortex power and turbine systems, Jurnal teknologi (Sci. Eng.), 69 (7) (2014) 1–7.
[54] A.H. Elbatran, O.B. Yaakob, Yasser M. Ahmed, H.M. Shabara, Operation, performance and economic analysis of low head micro-hydropower turbines for rural and remote areas: A review, Renew. Sustain. Energy Rev. 43 (2015) 40–50.
[55] Edy E. Jiménez, “Final Study Report, Achievable Renewable Energy Targets for Puerto Rico's Renewable Energy Portfolio Standard” Puerto Rico's Energy Affairs Administration, (2009) Available: http://www.uprm.edu/aret/ (chapter 8).
[56] A.R. Wallace, H.W. Whittington, Performance Prediction of Standardized Impulse Turbines for Micro-hydro, Elsevier B.V., U.K, 2008 Sutton., Int. Water Power & Dam Construction.
[57] [online]Available:http://www.renewables-made-in-germany.com/en/renewables-made-inGerman y/technologies/hydropower/hydropower/technologies-and-applications.html , Accessed date: 14 February 2019.
[58] L. Barelli, L. Liucci, A. Ottaviano, D. Valigi, Mini-hydro: A design approach in case of torrential rivers, Energy 58 (2013) 695–706.
[59] Davis Scott, Micro, Clean Power From Water, 2nd printing, New Society Publisher, Gabriola Island, Canada, 2005.
[60] Voith Hydro Pelton Turbines 〈http://voith.com/en/products-services/hydropower/turbines/pelton-turbines-563.html〉 [Accessed 14 February 2019].
[61] U.S. Department of Energy, Energy Efficiency and Renewable Energy, Small Hydro

Power Systems, (July 2001), p. FS217.
[62] S.J. Williamson, B.H. Stark, J.D. Booker, Performance of a low-head Pico-hydro turgo turbine, Appl. Energy 102 (2013) 1114–1126.
[63] S.J. Williamson, B.H. Stark, J.D. Booker, Experimental optimization of a low-head Pico hydro turgo turbine, Proceedings of the 3rd IEEE International Conference on Sustainable Energy Technologies, (2012), pp. 322–327.
[64] R. Cobb Bryan, V. Sharp Kendra, Impulse (Turgo and Pelton) turbine performance characteristics and their impact on pico-hydro installations, Renew. Energy 50 (2013) 959–964.
[65] Microhydro, [online] Available: https://en.wikipedia.org/wiki/Micro_hydro#cite_note-vlh-11, Accessed date: 14 February 2019.
[66] S. Khosrowpanah, A. Fiuzat, M. Albertson, Experimental study of cross flow turbine, J. Hydraul. Eng. 114 (3) (1988) 299–314.
[67] Ossberger GmbH Co, The Ossberger Turbine, (2011) Bayern, Germany http://www.ossberger.de/cms/en/hydro/the-ossberger-turbine-for-asynchronous-andsynchronous-water-plants/, Accessed date: 14 February 2019.
[68] V.R. Desai, N.M. Aziz, An experimental investigation of cross-flow turbine efficiency, J. Fluids Eng. 116 (3) (1994) 545–550.
[69] H. Motohashi, M. Goto, Y. Sato, Development and field test of open cross flow type micro-water turbines, Nihon Kikai Gakkai Ronbunshu, B Hen/Trans. Jan. Soc. Mech. Eng. Part B 76 (763) (2010) 371–373.
[70] F. Round George, Incompressible Flow Turbo Machines, Butterworth-Heinemann, Burlington, 2004 (chapter 3) (turbines).
[71] M. Ramos Helena, Simao Mariana, A. Borga, Experiments and CFD analyses for a new reaction micro hydro propeller with five blades, J. Energy Eng. 139 (2013) 109–117.
[72] Small Hydropower Technology and Market Assessment, (2009) http://www.oregon.gov/energy/renew/hydro/docs/SmallHydropowerTechnology-and-Market_Assessment.pdf, Accessed date: 15 February 2019.
[73] Brookshier Peggy, Encyclopedia of Energy, Hydropower Technology, Elsevier, New York, 2004, pp. 333–341.
[74] Voith-Siemens, Francis Turbines, Hydropower Generation, Voith, (2013) http://voith.com/en/Voith_Francis_/turbines.pdf, Accessed date: 15 February 2019.
[75] Romeo Susan-Resiga, Sebastian Muntean, Peter Stein, François Avellan, Axisymmetric swirling flow simulation of the draft Tube vortex in Francis turbines at partial discharge, Proceedings of the 24th Symp. on Hydraulic Machinery and System, 2008.
[76] Fergal O Rourke, Fergal Boyle, Anthony Reynolds, Tidal energy update 2009, Appl. Energy 87 (2010) 398–409.
[77] Jahidul Islam Razan, Riasat Siam Islam, Rezaul Hasan, Samiul Hasan, Fokhrul Islam, A comprehensive study of micro-hydropower plant and its potential in Bangladesh, ISRN Renew. Energy (2012) 635396, https://doi.org/10.5402/2012/63539610 pages.
[78] Azhumakan Zhamalovich Zhamalov Alaibek Dhumabekovich Obozov, Murat merkebekovich kunelbayev ruslan isaev and balzhan abylkanovna chakenova" selection of generator for the micro hydro power Plant, Am.-Eurasian J. Sci. Res. 8 (3) (2013) 104–108.
[79] T.S. Bhatti, R.C. Bansal, D.P. Kothari (Eds.), Small Hydro Power Systems, Dhanpat Rai and Sons, Delhi, India, 2004.
[80] Kanzumba Kusakana, A survey of innovative technologies increasing the viability of micro-hydro power as a cost effective rural electrification option in South Africa, Renew. Sustain. Energy Rev. 37 (2014) 370–379.
[81] M.G. Simoes, F.A. Farret, Renewable Energy Systems: Design and Analysis with Induction Generators, CRC Press, New York, USA, 2004.
[82] S.P. Adhau, A comparative study of micro hydro power schemes promoting self-sustained rural areas, Proceedings of the 1st International Conference on Sustainable Power Generation and Supply (SUPERGEN '09), April 2009, pp. 1–6.
[83] "Ministry of science and Technology, Govt. of Pakistan, Pakistan council of renewable energy Technology (PCRET), [online] Available: http://www.pcret.gov.pk/, Accessed date: 16 February 2019.
[84] Government of Khyber Pukhtunkhwa, Sarhad Rural & support Program, [online] Available: http://web.srsp.org.pk/, Accessed date: 16 February 2019.
[85] "Government of khyber Pukhtunkhwa, Pakhtunkhwa energy Development Organization, [online] Available: http://pedokp.kp.gov.pk/, Accessed date: 16 February 2019.
[86] International Renewable Energy Agency (IRENA), Renewable Energy Capacity Statistics 2015, [online] Available: http://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Capacity _Statistics_2016.pdf.
[87] Atif Zeeshan Rauf, A decade of SRSP efforts in provision of renewable and sustainable energy, [online] Available: http://web.srsp.org.pk/.
[88] Cromwell Godfrey, What makes technology transfer? small-scale hydropower in Nepal's public and private sectors, World Dev. vol. 20, (7) (1992) 979–989.
[89] International Renewable Energy Agency (IRENA), "Renewable energy technologies: Cost analysis series" Wind Power Volume 1: Power Sector Issue 5/5 2012, Available: www.irena.org.
[90] International Renewable Energy Agency (IRENA), "Renewable energy technologies: Cost analysis series" Hydropower Volume 1: Power Sector Issue 3/5 2012, Available: www.irena.org.
[91] International Renewable Energy Agency (IRENA), "Renewable energy technologies: Cost analysis series" Solar Photovoltaics Volume 1: Power Sector Issue 4/5 2012, Available: www.irena.org.
[92] International Renewable Energy Agency (IRENA), Renewable Energy and Jobs Annual Review 2015 IRENA_RE_Jobs_Annual_Review_2015, Available: www.irena.org.
[93] United Nations Development Program, Energy and Poverty in Nepal: Challenges and the Way Forward, UNDP Regional Center, Bangkok, 2007.
[94] http://kerea.org/wp-content/uploads/2012/12/Policy-and-regulatory-framework-conditions-for-small-hydro-power-in-Sub-Saharan-Africa.pdf.
[95] S. Banerjee, A. Singh, H. Samad, Power and People: the Benefits of Renewable Energy in Nepal, South Asia Energy Unit, World Bank, Washington, DC, June, 2010.
[96] S. Pokharel, Promotional issues on alternative energy technologies in Nepal, Energy Pol. 31 (2003) 307–318.
[97] World Bank, Nepal Power Development Project. Integrated Safeguards Data Sheet, World Bank, Washington, DC, May 16, 2003 Report Number AC76.
[98] Wim Jonker Klunne, "Current Status and Future Developments of Small and Micro Hydro in Southern Africa" Hidroenergia, (2012), pp. 1–11.
[99] R.H. Sharma, N.M. Shakya, Hydrological changes and its impact on water resources of Bagmati watershed, Nepal, J. Hydrol. 327 (2006) 315–322.
[100] Run of river Hydroelectricity[online], Available: https://en.wikipedia.org/wiki/Run-of-the-river_hydroelectricity#cite_note-five-9 , Accessed date: 16 February 2019.
[101] Benjamin K. Sovacool, Saroj Dhakal, Olivia Gippner, Malavika Jain Bambawale, Halting hydro: a review of the socio-technical barriers to hydroelectric power plants in Nepal, Energy 36 (2011) 3468–3476.
[102] T.V. Ramachandra, R.K. Jha, V. Krishan, B.V. Shruthi, Spatial decision support system for assessing micro, mini and small hydel potential, J. Appl. Sci. 4 (2004) 596–604.
[103] BHA (British Hydropower Association), A Guide to UK Mini-Hydro Developments, (2006) http://www.british-hydro.org/mini-hydro, Accessed date: February 2019.
[104] M. Borota, Mini Hydro Power Plants 'Green' Power for Uses, (2008) [online] Available: http://www.balwois.com/balwois/administration/full paper/ffp-903.pdf, Accessed date: 15 February 2019.
[105] A.O. Tunde, Small hydro schemes—taking Nigeria's energy generation to the next level, Proceedings of the Inaugural IEEE PES 2005 Conference and Exposition in Africa, 112 2005.
[106] V.R. Reddy, J.I. Uitto, D.R. Frans, N. Matin, Achieving global environmental benefits through local development of clean energy? The case of small hilly hydel in India, Energy Pol. 34 (2006) 18–4069.
[107] O. Yuksek, M.I. Komurcu, I. Yuksel, K. Kaygusuz, The role of hydropower in meeting Turkey's electric energy demand, Energy Policy 34 (2006) 17–3093.
[108] A.B. Chhetri, G.R. Pokharel, M.R. Islam, Sustainability of micro-hydrosystems—a case study, Energy Environ. 20 (2009) 4–567.
[109] International Energy Agency, Benign Energy? the Environmental Implications of Renewables, OECD, Paris, 1998, pp. 15–45.
[110] Muhammad Hamayun, Sumera Afzal Khan, Abdul Latif Khan, Wood as a fuel source in the hindukush: a case study of utror and gabriel valleys, northern Pakistan, Pakhtunkhwa J. Life Sci. 01 (02) (2013) 94–99.
[111] "U.S energy information Administration Independent statistic and analysis", Available: https://www.eia.gov/coal/production/quarterly/co2_article/co2.html, Accessed date: 16 February 2019.