SOLAR WATER HEATING POTENTIAL FOR SUSTAINABLE TOURISM: A CASE STUDY OF GILGIT-BALTISTAN PAKISTAN

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THESIS ACCEPTANCE CERTIFICATE

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Dedicated to

To my Beloved Family

List of publications

Journal Paper

Muhammad Naveed Arif, Adeel Waqas, Asif Hussain Khoja, Kafait Ullah, Majid Ali *"Technical Assessment of Solar Water Heating Systems for Sustainable Tourism in Gilgit-Baltistan Pakistan", Alexandria Engineering Journal*, Impact Factor: 2.46 (Under Review).

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Abstract

The world is moving towards renewable energy sources due to environmental concerns. Pakistan has also been facing climate change problems, especially in recent years due to extensive usage of fossil fuel which produce harmful and toxic gases to the environment. From the mighty stretches of the Karakorams in the North to the vast alluvial delta of the Indus River in the South, Pakistan remains a land of high adventure and nature. Currently, tourism contributes over 5.9% to the total economy, worth a sum of Rs2.285 trillion, as reported by the World Travel and Tourism Council (WTTC) Pakistan 2020 Annual Report. Tourists in the norther region of Pakistan also use energy with a greater intensity, often to local detriment where scarcity exists. With renewables, sustainable energy and tourism can complement each other. Therefore, this study is aimed to examine the feasibility analysis of the solar water heating (SWH) system for sustainable tourism in the Gilgit-Baltistan (GB) region of Pakistan. Initially, climatic data have been collected for the above mentioned two locations. The tourism impact on energy demand, solar irradiance and sunshine hour were key parameters considered to investigate the potential of SWH systems for this case study. The potential of SWH systems was investigated using T*SOL. Three different types of solar collectors were investigated, based on solar fraction, maximum collector temperature and overall efficiency. The simulations were performed for the Gilgit and Skardu regions. Among these collectors, the evacuated tube collectors (ETC) show high solar fraction, efficiency and CO_2 emissions saved as compared to flat plate collectors (FPC) and unglazed collectors (UnGC). The results show that ETC has 75 % solar fraction, 40 % efficiency, and 676 kg CO_2 emission saved for Gilgit city and 84 % solar fraction, 36 % efficiency, and 756 kg CO_2 emissions saved for Skardu city. The most suitable systems for Gilgit and Skardu regions were presented and concluded that the utilization of solar energy in the colder region like GB can certainly contributes to ecotourism and sustainable development.

Keywords: *Gilgit-Baltistan; Solar thermal; Sustainable tourism; thermal collector; T*SOL;*

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Chapter 1

Introduction

1.1Research Background

Globally, the world moves towards renewable energy sources due to the decline in renewable energy costs, improving energy efficiency, and limited conventional energy sources [1, 2]. Renewable energy sources produce a low level of GHE emissions as compared to the non-renewable sources. Studies found that by the end of 2022 renewable energy sources will reduce the emission of carbon dioxide to $46405 \times 10^3 t$ [3]. Conventional sources like petroleum and natural gas also harm the global environment where the world facing severe climatic issues in the last few decades[4]. Due to the energy crisis and other negative impacts of conventional sources the global world moves towards sustainability in every sector. The tourism sector is also one of the fastest-growing sectors where the tourism activity increases at a rate of 3% to 4.5% yearly and contributes 10.2% of the world gross domestic product [5, 6]. Pakistan is the favourite destination of many tourists all over the world due to its utmost beauty and other famous cultural places [7, 8]. In 2020 Pakistan was declared the third highest adventure destination and also best holiday destination in the world. Tourism activities also increase in this region due to the development of the China Pakistan economic corridor [9, 10]. GB is the fifth province of Pakistan located in the northern areas of Pakistan which shares its border with China, India, Afghanistan, and Tajikistan. GB is home to five of more than eight thousand and fifty peaks above seven thousand meters including K2, Nanga Parbat, and other world-famous mountains. GB lies in the cold climate zone where locals and tourists face harsh cold weather. GB is one of the best tourist spots in Pakistan where millions of foreign and local tourists visit every year[11]. In the last few years, the number local and foreign tourists has been increasing at very high rate and multiples to come in future [12]. It is observed that tourism has also a negative impact on the ecosystem[13] and the clean environment of GB. Locals and tourists use conventional sources like wood and LP gas for heating purposes. This development has shifted the focus of the present government, the provincial as well as the federal government, towards ecotourism development in the region [14, 15]. So, it is a need of the hour to shift towards sustainability in the tourism sector. GB region is famous for its beauty, tourism, and local industries. Eco-friendly tourist activities in dispersedly populated areas not only benefit locals but also helpful in gaining carbon credits and improving financial activities in the national market [14, 16]. Owing to insufficient resources of electricity in GB, the people of the area use wood and LP gas to warm themselves which is very expensive leaving the people in serious environmental and health issues [17]. The significant increase in deforestation from 2000 to 2010 is about 75000 ha to 95000 ha in the northern part of Pakistan due to excessive use of wood [18]. Due to harsh cold weather in this region, locals need hot water throughout twelve months of the year, but the conventional sources do not fulfil the demand as per energy requirements. GB has profound solar potential and suitable weather conditions for harvesting solar energy. Recently solar energy has also been utilizing by individuals for domestic purposes such as lightening and water pumping in distant areas. The NASA data and Pakistan metrological department report show that this region has a good profile of solar radiation so by using a solar water heating system we will take one more step towards sustainable energy utilization[19].

The sun light is converted into heat by using collectors in solar water heating system. Solar heater use water only or sometimes uses water with a working fluid. For different environments and climates there are different types of solar collectors are available. Solar Water Heating System is used for domestic and industrial applications. In the last few years, solar water heating technology is one of the fastest growing technology in the whole world due to its reliability and efficiency [20, 21]. There are basically two types of solar heaters are available which are active solar heater and passive solar heater. These heaters uses sometimes water and sometimes both water and fluid. A direct sunlight is used to heat the collectors and sometimes they use mirrors to concentrate the heat. They also operate as a hybrid with gas or electric heaters. In large installations, the sunlight is concentrated by using mirrors [22, 23]. There are different types of solar collectors using according to the different locations, altitudes, and weather conditions. Evacuated tube and flat plate are mainly used collectors for solar water heating purpose[24].

Previously few studies carried out related to the contribution of solar heating in sustainable tourism but this is the first of its kind which is about the northern region of Pakistan [25-27]. In terms of renewable energy sources, Pakistan has a good solar energy profile. This region has a strong potential for solar power generation throughout the year.[28-30]. There is also not carry any experimental work about the solar potential of GB but on the other side of the border in Ladakh, India is installing world's biggest solar power production plant due to the high availability of solar energy in that region which has almost the same geographical and climatic condition with the GB region of Pakistan [31, 32]. Ladakh is located in the northern part of India with an altitude of 12000 feet here India is planting world's biggest solar power plant approximately 4 Gig watt because Ladakh has a good profile of solar radiation throughout the year [33, 34].

At the High Altitude Mountainous region, there is plenty of solar irradiance due to pollution-free environments especially in the Himalayan region (Northern part of Pakistan and India) [35, 36]. In high altitude areas, the sun is more bright and intense than plains. The sun's rays are intense and have good radiation power due to less pollution and a clear sky in the mountainous region. The researcher found that air pollution absorbs and disperse sunlight that reduces the potential of solar radiation in pollutant areas [37, 38]. Studies found that air pollution not only weakens the solar radiation power but also reduce solar energy systems performance [39-41]. According to recent research, the radiation power of solar is higher in the mountainous region as compared to hot desert areas [42]. Some types of solar collectors are performed better in cold arid high altitude regions as compared to hot areas due to low ambient temperature [43, 44]. Mostly the High altitude areas are mountainous and cold arid regions where less pollution as compared to plain polluted cities. Due to pollution-free and other environmental effects, high altitude areas are the best place for solar energy harvesting. In China and the northern part of Nepal main source of energy is solar due to their feasibility at these high-altitude areas [45, 46].

1.2 Problem statement/Rationale

The population of GB is spread thinly over mountainous terrain with 86% population inhabit in rural areas and engaged in very little economic activity. According to the Government of GB, about 90% of households (including hotels and commercial establishments) use firewood for cooking and heating, which contributes to the serious problem of deforestation and health. The main source of electricity is hydro while thermal used as a backup; the hydro-thermal energy mix ratio in GB is 99:1. The energy supply is low in winter due to reduction of water in rivers and streams but the energy demand remain high because of cold weather. In the last years, it is observed that the number of tourists has been increasing at a very high rate and more to come in the future. This rapid increase in tourism also harms the ecosystem of this region. Locals and tourists both use conventional sources to meet their heating demands. Deforestation and environmental complications emerge because of the extensive utilization of wood for heating, cooking, and lighting purposes. Apart from hydro this region has also the good potential of solar energy but no steps have been taken yet in exploiting these sustainable resources. Sustainable energy adaptation is a desperate need of this region to increase economic activities, reduce poverty, decrease GHG emission, and provide good investment opportunities for investors/developers.

1.3 Research objectives

Following are the objectives of current research.

- **1.** To analyse technical effectiveness of replacement of Solar Water Heating (SWH) system with conventional heating energy sources (LP gas, wood) for sustainable tourism.
- **2.** To analyse the solar potential of GB region and effect of using SWH system on deforestation and local climate of the study area.
- **3.** Modelling and sizing of the water heating system suiting the climatic conditions and affordability of the study area.

1.4 Scope and limitations of the study

1.4.1 Study was conducted only for the Gilgit and Skardu regions at the major tourist locations.

1.4.2 The water usage per day for all location is 350 ltr/day as per data from the Tourism Department of GB.

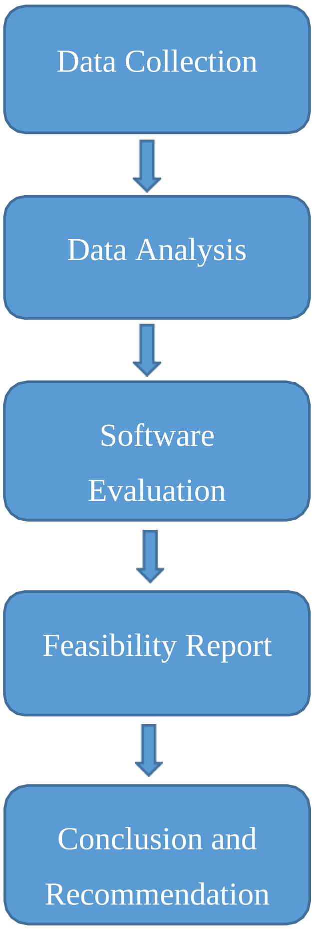
1.4.3 Tourist data was collected form the tourism department of GB for the last ten years.

1.4.4 Deforestation data was collected from the literature.

1.4.5 Climatic data was collected from the Metrological Department of the Pakistan.

1.5 Conceptual framework

The conceptual framework of research is presented in the following flow chart. First collected all the related to solar potential of GB. The data include solar radiation of GB, weather reports of last five years of this region and tourism data. These data have been acquired from concerned departments and other reliable sources. Completely analysis the data to examine the solar potential of GB. By using these authentic data performed a software evaluation work on T*SOL software to investigate the feasibility of solar water heating potential in this region. At the end, based on the obtained results conclusion and recommendations are proposed.



Summary

In the Introductory chapter discussed the background of study, problem statement, objectives and scope of the research. In the first section completely discussed all the aspects of solar water heating system in current energy scenario. In second section discussed the need of renewable energy like solar heating system in GB and its impact on local environment. Also discussed the impact of conventional energy utilization on the local environment and ecosystem of the study area. Finally, the objective, scope of solar heating system in GB and the conceptual framework of study are presented in section three and four.

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Chapter 2

Literature Review

2.1 Overview of energy Scenario in Pakistan

The energy sector of Pakistan has been facing several challenges during last decades resulting from insufficient production and mismanagements. Fig. 1 shows the energy sources of Pakistan [1]. The basic energy production sources of Pakistan are LP gas, petroleum oil, coal, hydro and nuclear energy. Pakistan mostly depends on Gas source which is about 44% of total energy sources. Oil is also biggest source in energy consumption which shares its part about 29%, Electricity sector shares 16% and Coal sector shares 10% of total energy sources. Pakistan has always been highly dependent on fossil fuels and other thermal sources. To import the petroleum oil Pakistan, spend 60% foreign exchange [2]. Although the petroleum fuels produce useful energy, but it has also a negative impact. These conventional sources are not only expensive but also harmful for the environment and ecosystem.

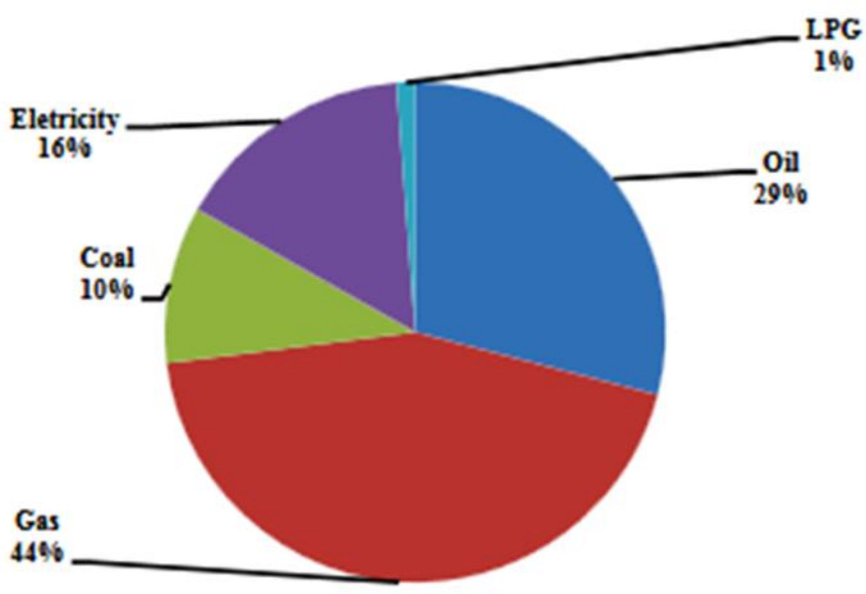

Fig. 1 Share of Sources in Energy Consumption [3].

CO_2 emission rate of fossil fuels are also very high which is responsible for ozone layer depletion and other environmental problems. Fig. 2 shows the increase in CO_2 emission due to non-renewable energy production of Pakistan [4]. Also, the rising oil prize creating additional pressure on power sector of country. Therefore, the Government of Pakistan try to focus onrenewable and non-conventional sources like solar, biomass and hydro. The supply and demand gap is increasing because of rapid increase in population and larger use of conventional sources. Because of industrial development and urbanization there is a rapid increase in consumer base electricity demand. If we observe the energy demand of last 15 years, it is analysed that 85% growth in electricity consumers. The energy demand will be three times increased in 2050 according to the estimation report. It is also a point of concern that the reserve of oil and gas are reducing at a very high rate and are available for 10 to 20 years. Pakistan is rich in natural resources which has abundance of coal reserves. This coal reserves can be used for next thousands of years but unfortunately have not been properly utilized. This energy crisis also effects the economic growth of the country as it can be observed from last few years' economic ups and downs due to energy shortfalls. If proper measures should not be taken than the energy deficiency will grow more rapidly in the upcoming years.

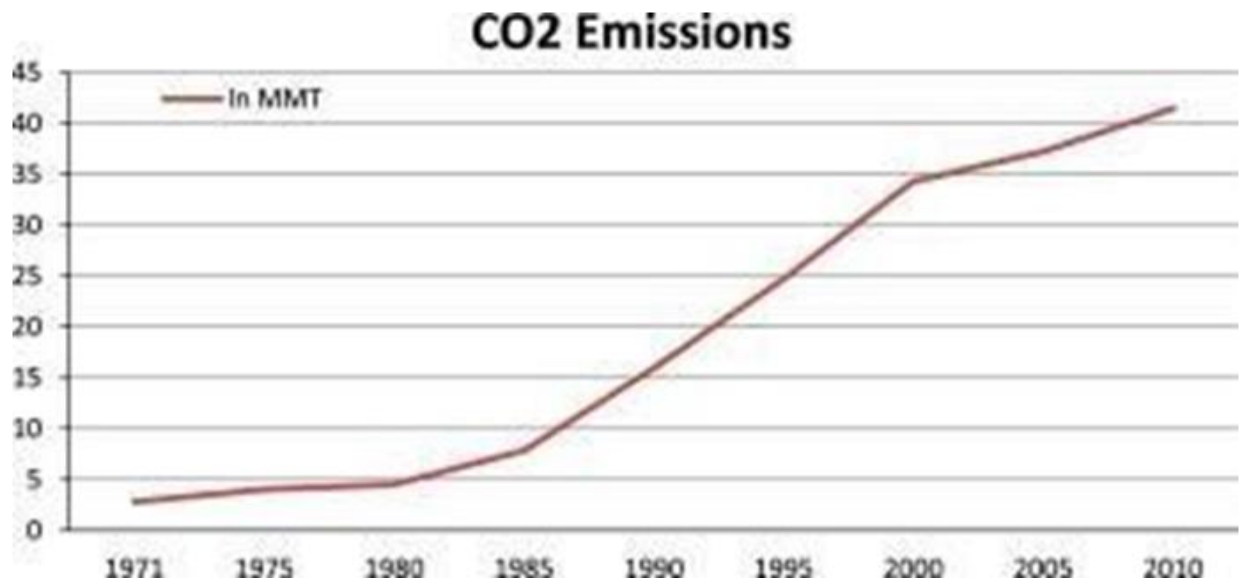

Fig. 2 CO_2 emissions of Pakistan [5].

The energy acquired from the natural sources like solar, wind and geothermal is known as renewable energy are best alternatives to replace with conventional energy sources. These energy sources are highly available and have very low level of Carbon emission which suit the global climate change scenario. So, it is a need of time to take strong steps in order to explore the utilization of these renewable energy production sources. This will create a new opportunity and also contribute in local economic development. This will generate revenues, also open a new door for investors and reduce unemployment. Fig. 3 represents generation of power from renewable energy sources in Pakistan. By utilizing solar and other renewable sources we can overcome the electricity short fall.

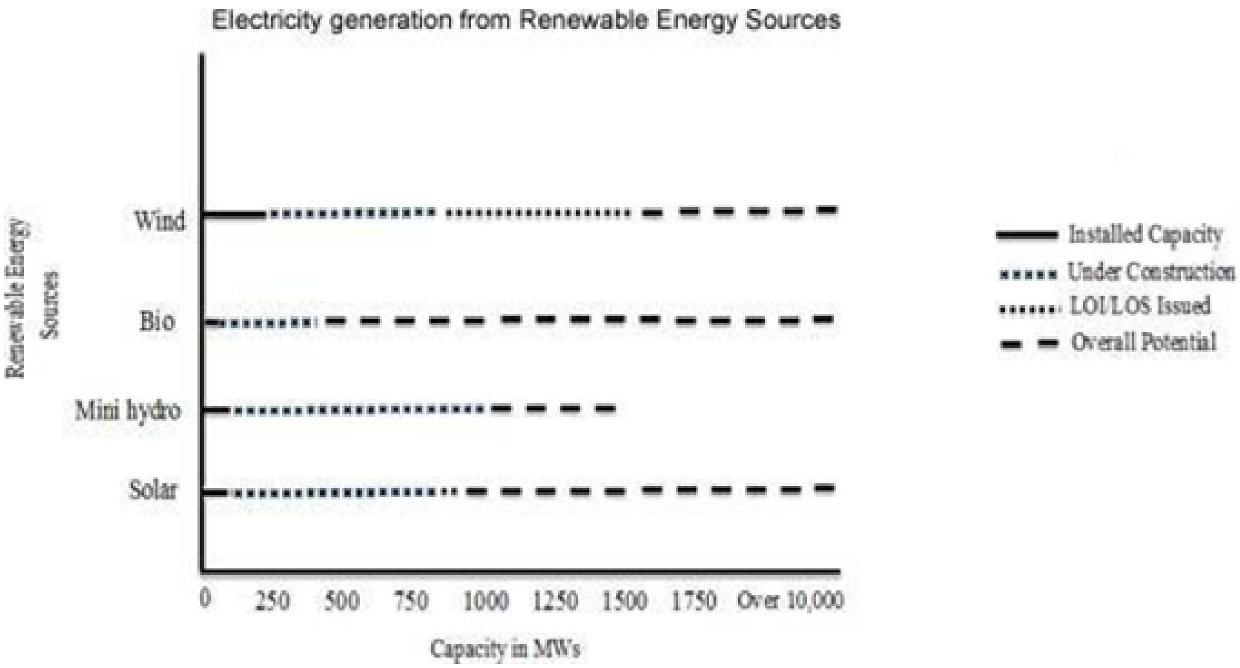

Fig. 3 Power generation from Renewable Energy Sources in Pakistan [6].

Fig. 4 shows Pakistan hydro power potential. According to the Pakistan Water and Power Department Authority the hydro potential of Pakistan is around 60,000 MW but the utilized power capacity is about 7320 MW [7]. The current working capacity of power in Pakistan is 17,000 MW, the high peak demand is 22,000 MW and short fall is about 5000 MW. According to sources, the electricity demand is increasing at a rate of 10% yearly when the other side the energy capacity addition is 7% [8]. During 2004 to 2005 the country had enough energy production to easily meet the demands. In 2006-2007energy shortage started and this short fall increased in upcoming years. In 2011 Pakistan faced a worst energy short fall which is almost 7000 MW. Pakistan Government should take several measures to overcome the current energy crisis and shift towards sustainable energy projects.

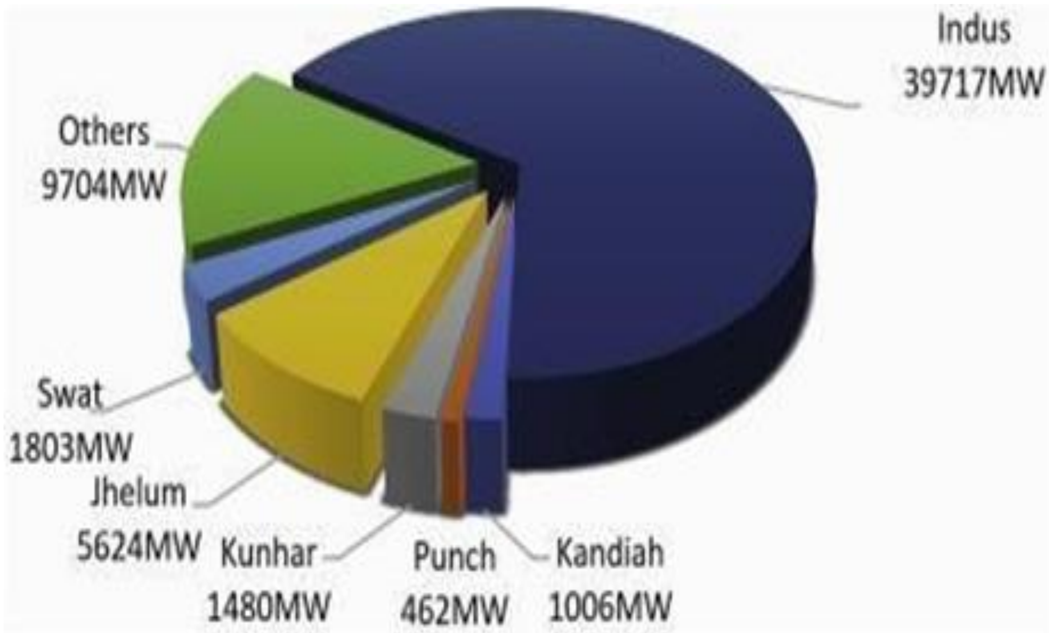

Fig. 4 Pakistan Hydro Power Potential [5].

2.2 Solar Energy prospective in Pakistan

Pakistan lies in those region where good radiation power of solar energy is available throughout the year [9]. Integration of renewable energy with national grid revives the dream of industrialization. In most areas of Pakistan, the daily average solar irradiance is more than 6 kWh in summer seasons. Due to the high availability of solar energy many projects are under development. Fig. 5 shows the cumulative capacity of solar energy in last few years. This figure exhibit that from 2012 to 218 the production of solar energy in Pakistan is sharply increase. In 2012 the total capacity of solar power generation is only 19 MW but in 2018 the solar generation capacity is increase up to1568 MW. According to the solar energy profile, Pakistan lies in the strong solar energy zone. In Baluchistan, upper part of Punjab and KPK the solar fraction is recorded about 90% which shows the handsome amount of solar radiation available in those regions. Currently on-going solar projects of Pakistan includes Quaid-e-Quaid e Azam Solar Park Bahawalpur Punjab, Solar Water Pump Gadap Karachi and CO-generation Power Plant at Rahim-Yar-khan and Ghotiki. Quaid-e-Azam Solar Park largest project in Pakistan which has a capacity of 1000 MW, CO-generation Power Plant at Rahim-Yar-khan and Ghotiki is 26 MW. Pakistan has also working on solar power stations and currently undergoing many research works related to utilization of solar energy. The first solar grid power plant is established in Islamabad on 29 May 2012.

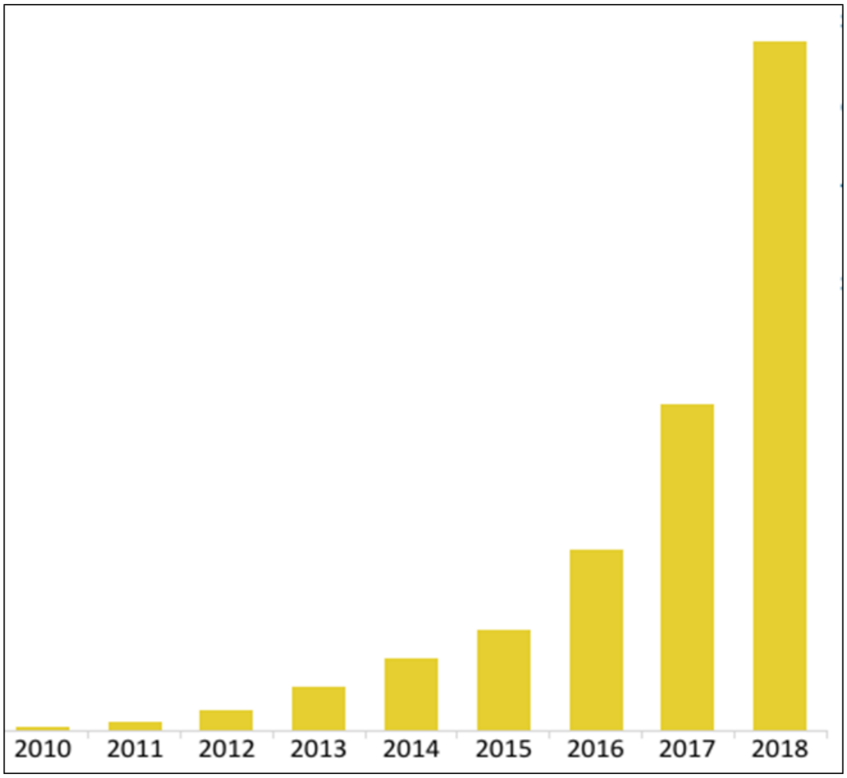

Fig. 5 Pakistan Cumulative Solar Power Capacity [5].

Fig. 6 shows the annual solar radiation map of Pakistan. From this figure it is observed that maximum solar radiation available in upper part of Baluchistan. Quetta city is the capital of Baluchistan province is the best place for solar energy harvesting because the daily solar radiation of Quetta city is more than 8 KWh per day [10]. The solar fraction of Quetta city is more 90% and overall solar energy performance is also good due to its climatic and geographic landscape. Punjab, upper Sindh, KPK and GB have also a good solar profile. The daily solar irradiance in this region is more than 6 KWh per day which can be a used for solar power projects. Overall the solar energy profile of Pakistan is best and up to the mark. Despite of good solar radiation available in this region, utilization of solar energy in Pakistan is very low as compared to other developing countries. Pakistan government should take strong measures to initiate more solar power projects to utilization of this renewable energy. It will not only to overcome the contemporary crisis but also provide clean and efficient energy.

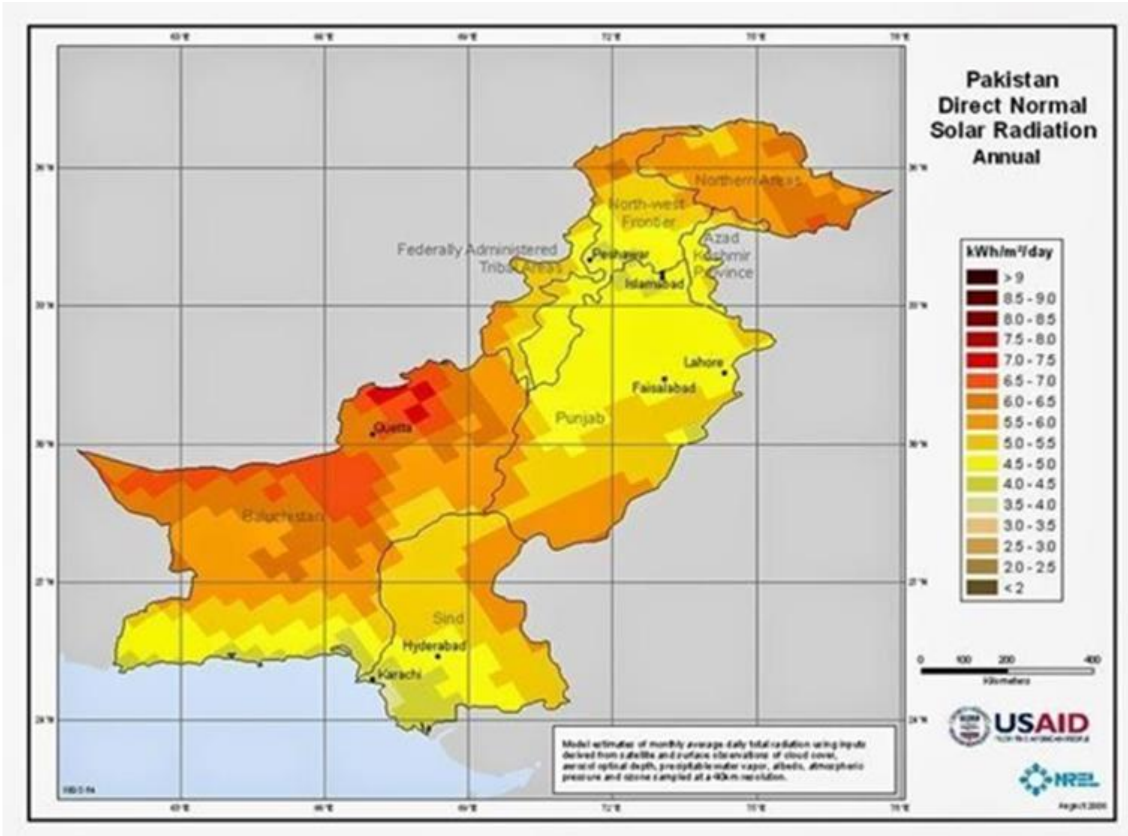

Fig. 6 Pakistan Solar Radiation Map [11].

2.3 Solar Energy prospective in GB

GB is located in the northern part of Pakistan which shares its border with India, China, Afghanistan and Tajikistan. The geo-strategic location of GB is very important as its share its border with four main countries. The world highest plateau named as Deosai plan is also located in this region. Three main mountain ranges the Karakorum, Himalayas and Hindu-Kash are also located in GB. GB is located in cold climate zone and also called roof of the world due to its highest elevation. This region has a harsh cold weather most of the year. The solar profile of GB is very strong and profound and can be used for energy development projects. According to the NASA source the daily solar radiation of GB is normally around 6 KWh per day. Solar irradiance in GB is very high and profound because this region has a very low air pollution as compared to other cities of Pakistan. This high altitude cold arid region is the best place for solar energy utilization because of its suitable environmental and climatic conditions. India has been planting the world biggest solar energy projects, which is almost 5 GW, in Laddak due to its amazing solar energy profile. Fig. 7 shows the daily average solar radiation of Ladakh, India. Ladakh is located on the other side of border which has almost same environmental condition and geographical landscape with GB region of Pakistan. From this figure it is observed that Ladakh has maximum solar radiation available in summer seasons [12]. Especially in the month of July, August and September the daily average solar radiation is about 7 kWh per day. The cold arid region of Ladakh is one of the best place in India for solar harvesting. Studies found that solar radiation power is higher at high altitude pollution free regions as compared to the plain region because the polluted gas present in atmosphere weaken the radiation power. Therefore, the northern part of Pakistan is best place for utilization of solar energy. Because this place has a dry arid region. Due to low the population and absence of any industrial activities this region is called pollution free areas. In a nutshell this region is a best place for utilization of solar energy because this region has a favourable climatic condition and geographical landscape for solar energy harvesting. This will not only provide cheaper clean and efficient energy to the whole region but also a way forward towards sustainable energy utilization.

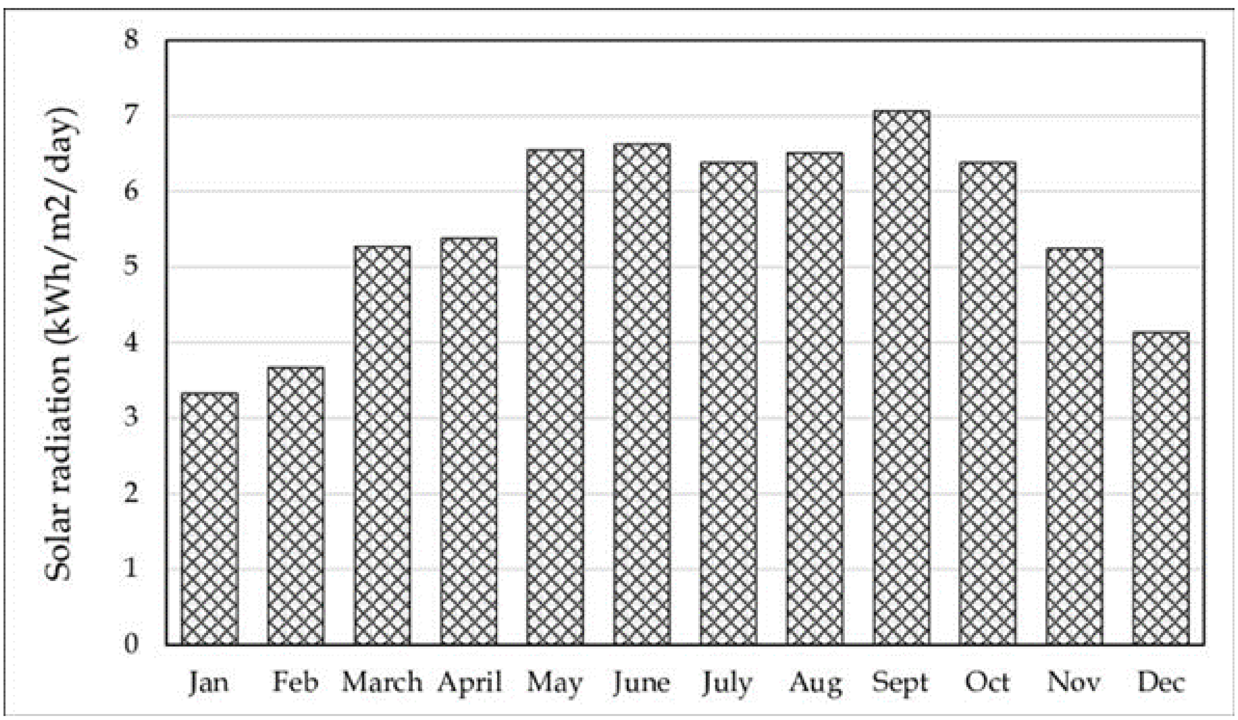

Fig. 7 Daily Average Solar Radiation of Ladakh, India [13].

GB region is famous for its beauty, tourism and local industries. World favourite tourist destination is situated in in this region include K2, Sadpara lake, Shangrila resort and Aata Abad lake. GB is famous all over the world due to its beautiful landscape and might mountains and colder weather in summer. The number of tourists visit this region increase day by day due to its utmost beauty and amazing locations. According to the tourism magazine GB is the one of the favorite destinations for tourists across the world. In 2019 more than two million tourists visit this region which include both domestic and foreign tourists. Table. 1 shows the number of domestic and foreign tourist visit this region from 2007 to 2015. According to the table, from 2007 onward the total number of tourists increased sharply. In 2007 the total number of foreign tourists are 10338 but in 2008 and onward this figure reduced. This development is due to the growth of terrorism activities in Pakistan. But from 2015 onward the interest of foreign tourist also increases in this region after the improved security condition. In 2015 the total number of tourists visit this region is 204733 which include 200651 domestic tourists and 4082 foreign tourists. Social and electronic media plays a very important role in the increase of tourism activities in this region. Locals and tourism companies use social media and other platforms to advertise the beauty of GB all over the world. A large number of domestic and foreign tourists visit this region is a blessing for the locals as its open new doors in local business market. China Pakistan Economic Corridor is one of the major developments in this decade. Increasing CPEC activities along the KKH route also create new business opportunities for the local people of GB. This will also create many job opportunities for the locals. This development not only strengthen the economy but also generate revenues.

Tourism plays also a very important role in the economy of this region. Tourism created many business opportunities in the local market in last few years. Due to the steps taken by Government, the flow of tourists increases in this region during the last few years. Government built standard hotels, tourist resorts, and cultural venues. The government has also been taking several steps to conserve the natural beauty of GB for the last few years. In this regard Government completely banned the hunting of Ibex, snow leopard, and other natural habitats. According to the FWO report, the population of these habitat increases which is a very positive development for the natural ecosystem. The infrastructure of GB has also improved in the last several years because Government has competed many projects include road constructions etc.

All these developments have created a major shift to increase the flow of tourists towards this region.

Table 1 No of tourists visit in GB [14].

Year	Total no of tourists	Foreign tourists	Domestic tourists
2007	34108	10338	23770
2008	62544	8504	54040
2009	62341	7739	54602
2010	53028	7728	45300
2011	66475	5242	61233

2012	33217	4324	28893
2013	56415	4501	51914
2014	53746	3442	50304
2015	204733	4082	200651

But on the other side this development also has many consequences. Due to the harsh cold weather of GB, locals and tourists use conventional energy sources to warm themselves. These conventional sources include mostly wood and LP gas. These sources are very expensive and also create environmental pollution. The excessive use of wood creates deforestation and other climatic problems. According to the report, in northern Pakistan deforestation rate is increasing exponentially due to the excessive use of wood for heating purpose. Use of LP gas is also very dangerous, polluted and health hazardous. Many incidents took place in this region in last few years due to use of LP gas. This conventional source release toxic gas in the air and responsible for increase carbon emission. So, it is a need of time to shift towards renewable energy sources to meet the heating demand to save the nature and promote ecotourism in GB. As GB has a strong solar energy profile so the solar energy can be used to meet the heating demand of this region. In winter we can use hybrid energy sources, in which solar is combine with electric or gas heaters, to meet the hating demand.

2.4 Solar Thermal Systems

Solar energy sources are the biggest renewable energy sources in modern world. Basically, there are two types of solar energy utilization which is PV cells and solar thermal system. Solar thermal Systems include both electricity generation and direct heating system. Electricity production is carried through solar thermal plants and collectors are used in the direct heating systems.

2.4.1 Solar Thermal plants

Solar thermal plants are used to generate electricity that use the energy from the sun to heat the working fluid and raise it temperature. After reaches at high temperature this working fluid later transfer the heat to water. After that water converted into a high heated steam. Then the turbine is run by using this superheated steam and this mechanical energy is converted in electrical energy in thermal power plants using electric generators. This generation is same as the steam power plant uses fossil fuels. But in this system the power plant uses direct sun light to heat the water without any fossil fuel combustion. Solar mirrors and solar collectors are used to focus solar radiation on common point to raise the temperature. There are three types of solar thermal on the basis of mirrors that focus the sun radiation on common point which include parabolic troughs, parabolic dishes and solar towers.

Fig. 8 shows the image of Parabolic Troughs. These troughs are composing of long reflector which in parabolic shaped that focus the sun rays on a pipe. These troughs are also called line focus collectors. To track the sun rays the solar collectors normally utilize a a solar tracking system which has single axis. Receiver pipe can reach 400°C temperature as trough track the solar radiation at 30 to100 times its common intensity. Theses solar troughs are properly placed in a row. When it runs into the pipe the working fluid is heated. This heat is transferred to the water when the working fluid returns to the heat exchangers. This converts the water into a superheated steam that moves in a turbine to produce electricity.

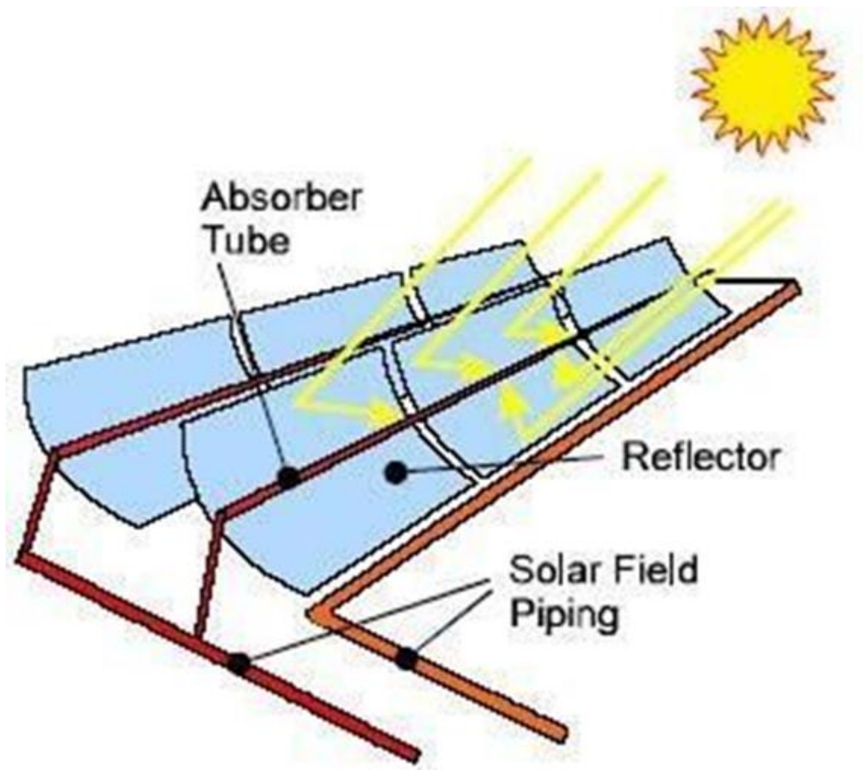

Fig. 8 Parabolic Troughs [15].

Fig. 9 shows parabolic type dishes which focus the sun by using motors. This motor ensures that on focal point they receive highest sun rays. The dishes have the ability to concentrate more sun's rays as compared to the parabolic troughs so, the working fluid in these dishes reaches the temperature at 750 °C. Stirling engine is used in this system. To compress the fluid this engine convert heat into mechanical form of energy.

Fig. 9 Parabolic Dishes [15].

Fig. 10 shows the image of solar energy towers. These towers are basically used as a central rays receiver. They are placed in middle of the mirrors which concentrate solar rays on single point. These sun tracking called heliostats. A mounted heat exchanger is in the tower which warmed the working fluid. This high temperature fluid produce steam which is used to run turbine for electricity production. These types of towers are used on a large scale power generation.

Fig. 10 Solar Towers [15].

2.4.2 Solar Water Heater

Solar water heating systems use solar thermal collector to heat the water. Solar heater is mostly used for domestic and commercial purposes. A collector that collects the sun rays on common point to heat the fluid which passes on the storage for later uses. Solar heaters are active and sometimes passive depend on their working principle. Active system uses more than one pump to run the fluid. Passive system uses sometimes heat pipes to run the working fluid. Solar water heater is also classified into direct and indirect system. Direct system is an open loop system that circulates potable water through the collectors. This system is less expensive as compared to indirect system but they have small overheat and protection from freezing. Indirect systems are closed loop which uses heat exchanger to heat transfer from HTF fluid to the potable water. Depending upon the collectors used, three main types of collectors which are Flat plate, Evacuated tube and Unglazed plat collector. Fig 11 shows the flat type of plate collector that consist of box which is insulated. By using hard glass this box is covered on the top. To increase absorption of solar energy this box also contains an absorber sheet that is coated with selective coating. Riser tubes which are made of copper that is placed with absorber and carry water for heated. After that, the cool water flow into the storage tank which fills and enter to collector and into the vertical riser tubes until absorber and the header are full of fluid. In riser tube the heat is absorbed and transfer to water. At the end, the high temperature water rises on the top of the pipe. This is called the Thermo syphon process. After the temperature of storage tank and collector is same this process is stopped. Now this high temperature water is stored and ready to use.

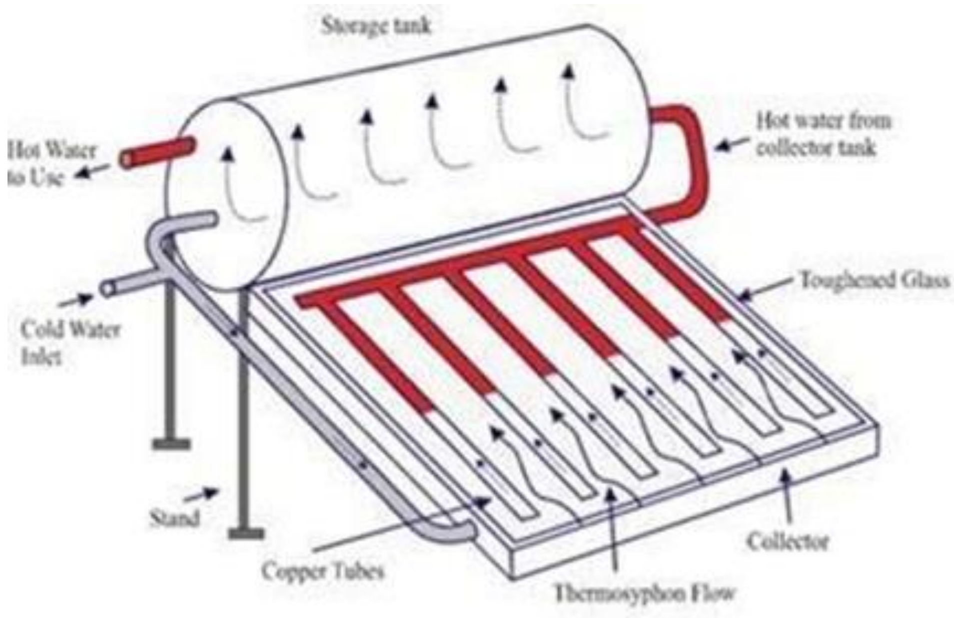

Fig. 11 Flat Plate Collector [15].

Fig. 12 shows the image of Evacuated tube collector. This collector consists with multi co-axial tubes of glass. For vacuum creation, these tubes are fused at both ends. This vacuum is basically act as insulation. For absorption of solar radiation, the surface is coated. Until all tubes are full the cool water is flowing into the storage tank and then enter the tubes. In inner tube the energy is carried and absorbed. As like flat plat collector the high temperature rises and flow into storage tank because it is lighter than cool water. This process continuous until the temperatures equalize.

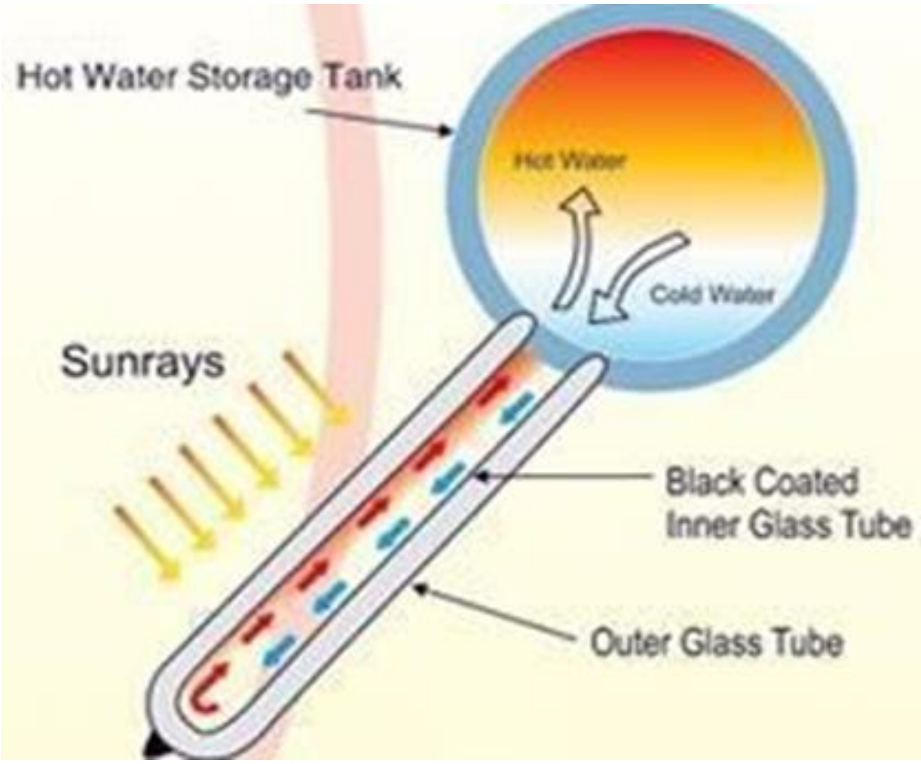

Fig. 12 Evacuated Tube Collector [15].

Fig.13 shows unglazed solar collector. Unglazed solar collector uses absorber type plate, so the absorber takes the heat. An unglazed solar type of collector composed of absorber which has no glass covering. Foe the need of temperature below 30°C these types of collectors are best suitable. These types of collectors are made up of a plastic which has the ability to bear ultraviolet solar radiations. If there is no glazing, most of solar radiations are absorbed by these collectors. Most of the heat is lost because these types of collectors are not insulated. When the ambient temperature is low are airy weather at outside it is more susceptible for heat loss. The efficiency of unglazed collector is normally high because it works near to the ambient temperature. It is more economical and efficient solar thermal systems available in the market. This type of collectors are mostly used in commercial sectors. The main application of this collector is HVAC. In South America and Asia these collectors are using for many domestic and industrial applications. Unglazed system has been used in commercial, agriculture and process application.

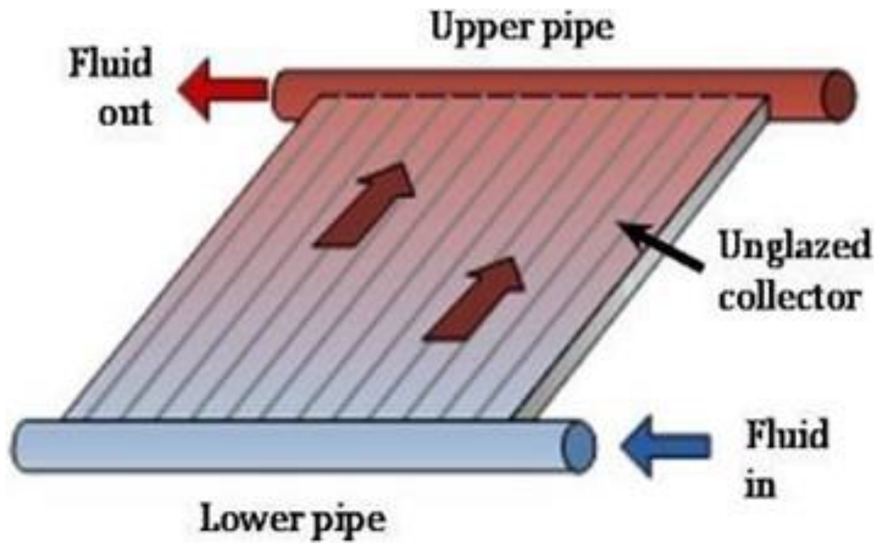

Fig. 13 Unglazed Collector [15].

2.5 Simulation Studies

To investigate the feasibility of solar water heating systems and selection of best optimum collector at GB region of Pakistan, used T*SOL software for modelling and simulations. T*SOL is a simulation program solar thermal systems evaluation. Simulates performance of energy and temperatures throughout the year. Both technical and financial analysis can be done through this simulation software. T*SOL is used for modelling and simulating the solar heating systems. Completely design domestic and commercial heating projects through T*SOL software. It includes hot water supply, heating of pool, industrial heating, and domestic heating systems. This simulation tool is used for different types of applications. T*SOL slows the designer to examine each component of a complete solar heating system. The result of T*SOL software can be analysed in table or graph format. The climate data management has been expanded by an export and import function. In this study, a tourist resort is assumed as a standard resort with a capacity of 4 people. A SWH system is installed on rooftop of the resort. Fig. 14 presents the schematic diagram of the SWH system for tourist resort and Table 2 shows the SWH system specifications. The total gross area of the collector is about 5 m^2 and tilt angle is 45°. The water storage tank volume is 500 litres and the thickness of its insulation is 100 mm. The temperature of storage tank was placed at 45°C and daily usage of water was 350 L/day. Target solar fraction for collector was set at middle (60%). The piping inside the resort is 5 m, outside is 1 m and 200 mm between the collectors. The thermal conductivity of insulation for these three parameters is 0.045 $W/(m.k)$. The volume flow rate of the collector is 40 $(L/h/m^2)$. Auxiliary heating is provided during cloudy days or non-availability of sufficient solar energy.

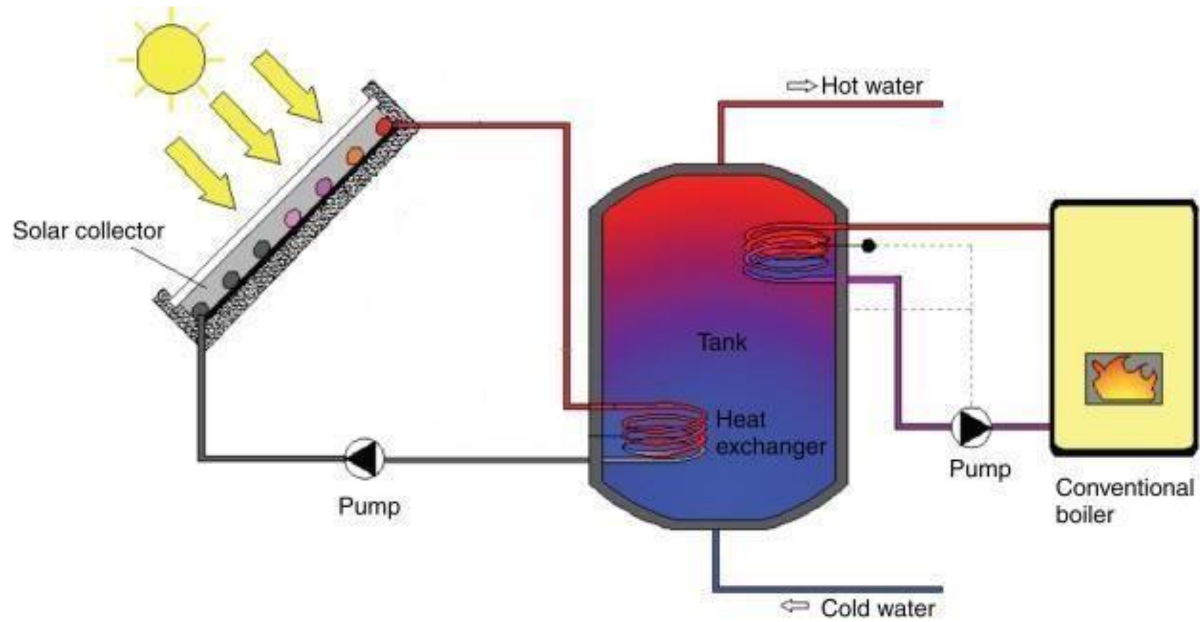

Fig. 14 Schematic Diagram of T*SOL Software [16].

Table 2 SWH system specifications for an assumed tourist resort.

Category	Specification
Installed collector power	4.0 kW_{th}
Installed solar surface area (gross)	5 m^2
Volume Flow rate of collector	40L/h/ m^2
Usage of hot water	350 L/day
Desired temperature for storage tank	45°C
Insulation thickness of storage tank	100 mm

Following are the foundational basis of T*SOL software.

2.5.1 Basic Construction of Solar System

The important part of solar heater is collector which converts the sun rays into the heat. Later this heat is transferred to the storage tank through via piping systems. For supply of high temperature of water, the tank compensates for ups and downs in energy supplies and needs at different times of 24 hours. In big solar thermal system, an underground storage tank is usually constructed in order to bear the variations in solar rays and energy requirements. A controller is used to monitors working of solar thermal system and ensure the use of solar radiations. To ensure heat transport to the storage tank, turn on the circulation pump in loop to check any difference in temperature is occur between storage tank and collector.

2.5.2 Working of Collector

A collector is a device that collects and absorbs radiation from the sun and later this heat energy transfers to the storage tank through piping. Solar thermal collectors are concentrating or non-concentrating. Concentrated solar collectors are normally used for generating electricity by heating a fluid and generate a steam to drive a turbine. Non-concentrating collectors are used in domestic and commercial areas. The collector is made up of plastic or it is made up of a metal with a black surface. Collectors are active part in the solar thermal systems. A flat plate collector contain an absorber fitted with a very clear cover and a heat insulation its side. Thermal insulation decreases heat losses and the cover decreases radiation to outside environment. Flat plate type collectors are present in different shapes and sizes. Evacuate collectors have an absorber which is placed in evacuated glass type tubes. Vacuum portion in evacuated tube ensure that het losses are minimum and enabling a temperature of 200 to be reached. Evacuated tube collectors are used in heating service water, space heating and cooling of residential areas.

2.5.3 Task of the Storage Tank

Basic task of storage tank is to equate the highest demand. It also compensates the time difference between energy produces and hot water needs. It placed the exchanger at the lower side that the medium transfers to the attached storage tank. Additionally, heated the upper area of storage tank when it is needed. The biggest solar heating systems use a series of storage tank that is placed one by one in a sequence. From this sequence the last storage tank is used for reheating.

2.5.4 Working of Controller

Solar thermal system uses a differential controller. The system compares temperature storage tank and absorber. If the temperature is above the storage tank the pump is switched on. The heat is transferred in to the storage tank when the energy is converted. When temperature of absorber is same to the tank the supply is stop and the switched is off.

2.5.5 Economics of Solar Thermal Systems

To analysis of economics of thermal system, the costs of investment are placed to overall system, consider maintenance and operating cost and simple interest. The price of heating for the KWH is same as the high temperature water generation from electrical current, noticeably lower for the larger systems as compared to the smaller systems. The amount which is saved from costs of burning fossil fuels is not considered in this case.

Summary

The section of literature review comprises of current energy perspective of Pakistan, solar energy potential of Pakistan and GB, solar thermal systems, and simulation studies. Completely studied and analysed all the field of knowledge related to this current research work. Currently, Pakistan is working toward renewable energy generation to meet the energy demand and overcome the energy gap between generations and requirements. Pakistan has profound potential in renewable energy generation. The solar potential of Pakistan is very profound and strong and can use for large scale energy production. GB is situated in northern region of Pakistan, is famous for its beauty and tourism. In last few years, the number of tourists visit this region has been increasing exponentially. This development strengthens the economy of this region and generate revenues. But the rapid increase in tourism also has a negative impact on the natural biodiversity and environment of this region. Basically, GB is located in the cold climate zone therefore locals and tourists both use conventional sources for heating purpose. These conventional sources include wood and LP gas which creates many environmental problems. So, utilization of solar energy is the best alternative to replace the conventional energy sources. GB has a very strong solar energy profile which can be used for heating system and other power generation. Solar thermal collectors are one of the best and efficient equipment for commercial and domestic heating purpose. The commonly used collectors are flat type plate collectors, evacuated collectors, and unglazed collectors. Each has its own features and uses for different applications.

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Chapter 3

Research Methodology

This study consists of two phases. During the first phase collected theoretical and empirical data from different sources related to GB climatic and geographic conditions and the GB tourism sector. Also, acquired data about energy production and utilization of this region and made a complete feasibility report. In 2nd phase based on these collected data performed a software evaluation work using T*SOL software. The rest of this study is arranged accordingly. Section 2 shows data accusation and also discusses the simulation tools for solar water heating systems. Results and discussion will be present in section 3 which include both feasibility analysis and simulations of solar water heating system. Section 4 concludes the results.

3.1 Data Accusation

To carry our work towards solar water heating for sustainable tourism, collected more accurate data from reliable sources. For this purpose, acquired all related data from concerned departments of the GB government includes the metrological department, tourism department, and power department GB.

According to the GB tourism department, more than two million tourists visit this region in 2019 include foreign visitors from all over the world. In 2019 the number of domestic tourists is about 2508020 and foreign tourists are 31000. In the last few years, due to the influence of social media and other platforms, the number of tourists visit this region increases exponentially [1, 2].

Table 3-4 shows the monthly average data of Gilgit and Skardu city of the year 2019. Solar irradiance is the key factor to measure the solar potential in any region. Skardu and Gilgit are two major cities of the GB region, a favourite place for tourists all over the world due to its absolute beauty[3], have a strong solar profile. Table 3-4 comprises the weather data of Gilgit and Skardu city include the temperature of ambient air, daily average solar radiation, humidity, pressure of atmosphere, and wind speed. The Tables show the monthly average data and also calculates annual data of the weathering profile.

Table 3 Climatic data Gilgit city [4].

Months	Air temperature °C	Relative humidity %	Daily solar (h) radiation kWh/m²/d	Atmospheric pressure kPa	Wind speed m/s
Jan	-11.3	80.0%	3.44	64.6	5.0
Feb	-12.3	80.3%	4.07	64.5	5.0
Mar	-1.1	79.7	5.01	64.7	4.9
Apr	3.4	75.1%	5.88	65.0	4.8
May	12.2	64.6%	6.86	65.0	4.9
Jun	22.1	53.4%	7.48	65.0	5.2
Jul	31.9	48.5%	7.38	65.0	5.6
Aug	30.3	53.5%	6.94	65.1	5.6
Sep	13.3	51.9%	6.36	65.2	5.7
Oct	6.5	56.0%	5.29	65.2	5.6
Nov	-2.7	63.8%	4.16	65.1	5.1
Dec	-9.4	74.8%	3.34	64.9	5.0
Annual	6.90	65.0%	5.517	64.9	5.2

Table 4 Climatic data Skardu city [4].

Months	Air temperature °C	Relative humidity %	Daily solar (h) radiation kWh/m²/d	Atmospheric pressure kPa	Wind speed m/s
Jan	-17.6	76.0%	3.31	59.6	5.6
Feb	-15.9	76.6%	3.75	59.6	5.5
Mar	-12.2	78.0%	5.21	59.8	5.4
Apr	-7.6	77.9%	5.31	60.1	4.9
May	2.5	70.6%	6.64	60.3	5.0
Jun	13.9	60.1%	6.72	60.3	5.3
Jul	18.1	57.7%	6.54	60.3	5.3
Aug	14.8	61.7%	6.60	60.4	5..2
Sep	3.8	57.8%	7.12	60.4	5.3
Oct	-2.8	54.8%	6.45	60.3	5.2
Nov	-9.8	61.6%	5.18	60.2	5.4
Dec	-15.3	71.5%	4.19	59.9	5.7
Annual	-2.34	67.0%	5.585	60.1	5.3

Table 5-6 represents the sunshine hour of Gilgit and Skardu region for the year 2019. To carry this research selected two main cities of GB named Gilgit and Skardu. Acquired data about a sunshine hour of Gilgit and Skardu city during the last five years from the Pakistan metrological department. Gilgit and Skardu city has mostly sunny days throughout the year. In summer, the days are long and dry and in winter the days are shorter. The intensity of solar radiation is very high and profound due to the climatic conditions and landscape of this region. The availability of solar energy is also high due to longer sunny days.

Table 5 Sunshine hour Gilgit [4].

Days	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.9	6.0	6.3	7.1	8.8	11.5	5.9	7.9	2.8	9.2	6.7	2.1
2	5.8	0.8	4.0	6.2	10.2	8.9	3.4	8.1	6.3	9.0	4.2	5.8
3	0.2	0.0	2.1	9.1	9.7	10.9	7.1	8.7	9.0	9.1	4.7	5.8
4	1.2	1.7	5.8	7.0	0.0	11.0	11.3	7.2	9.7	8.1	6.5	5.8
5	1.2	0.0	4.2	1.5	0.0	9.0	11.5	3.6	10.0	8.0	6.5	5.8
6	0.2	0.0	3.9	6.9	9.3	11.4	9.6	9.4	10.0	6.9	6.2	5.7
7	1.3	0.0	4.5	0.8	10.2	11.6	10.2	10.1	9.8	1.9	5.9	0.0
8	1.1	0.0	8.3	1.9	10.2	11.4	6.8	7.6	9.4	2.4	5.2	0.0
9	0.5	5.7	7.2	2.3	6.6	11.4	3.3	5.5	9.6	5.4	5.3	0.5
10	0.2	5.8	4.7	1.0	2.5	11.4	3.7	2.6	10.6	7.7	6.0	1.8
11	5.5	5.5	7.2	5.4	5.9	11.5	2.7	5.7	10.6	8.6	1.5	0.0
12	4.6	5.8	8.4	0.9	4.6	8.8	3.8	1.2	6.2	8.5	5.5	4.6
13	5.7	6.9	8.2	6.7	6.9	9.3	11.6	6.0	3.6	8.6	0.0	5.6
14	6.1	3.6	8.3	1.7	6.6	8.4	9.1	2.8	7.6	2.3	2.2	4.9
15	4.9	7.1	8.6	1.0	7.7	4.7	5.6	3.3	5.3	0.0	6.1	0.7
16	3.5	6.9	6.0	2.1	6.8	4.9	9.6	0.9	8.1	7.6	6.1	0.0
17	1.7	3.1	0.5	9.3	4.7	7.4	5.6	7.2	9.1	7.9	5.0	0.0
18	1.5	7.5	5.7	9.8	4.9	7.4	11.5	6.2	8.3	7.9	2.9	3.4
19	1.4	7.6	8.7	8.6	5.0	11.5	11.7	10.0	10.0	7.8	4.4	0.0
20	5.0	7.8	7.1	8.4	10.3	11.3	7.5	7.6	10.2	5.6	3.1	0.0
21	3.8	4.3	7.3	9.7	10.0	11.7	10.3	7.6	8.5	7.6	5.9	1.0
22	0.1	2.3	4.5	7.4	4.7	11.5	9.5	2.8	9.3	5.8	0.0	4.8
23	0.2	3.8	7.5	5.5	5.7	11.3	10.3	9.2	3.0	7.4	4.2	5.6
24	5.0	5.0	8.7	8.6	7.4	11.4	10.8	7.5	9.0	7.1	6.2	5.6
25	6.1	6.0	8.4	4.3	1.3	11.3	9.5	7.7	9.4	4.9	6.1	0.0
26	3.4	8.1	6.7	4.4	4.6	10.0	11.6	7.3	9.4	7.0	3.8	5.6
27	6.2	8.2	4.6	10.0	6.2	4.0	11.6	5.4	9.3	7.1	6.0	5.6
28	6.1	8.1	6.0	10.1	1.5	6.8	9.9	8.1	3.4	0.7	2.2	5.3
29	5.8		6.3	8.9	9.8	4.5	11.5	9.7	7.5	5.6	2.4	0.0
30	6.1		5.0	9.1	5.7	1.2	4.4	6.0	8.6	2.1	5.3	3.9
31	0.3		5.4		8.4		8.2	6.1		6.5		5.6
SUM	86.1	135.8	190.1	175.7	196.2	277.4	259.1	193.7	243.6	194.3	136.1	95.5

Table 6 Sunshine hour Skardu [4].

Days	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	5.6	6.3	2.6	5.4	9.9	10.5	9.2	7.8	6.1	7.3	6.1	3.1
2	0.7	1.2	6.1	0.7	7.9	10.4	6.4	0.0	7.1	8.5	6.5	5.3
3	0.0	4.4	3.0	6.3	3.4	9.8	4.2	1.2	2.7	8.5	5.7	0.0
4	0.1	0.2	0.0	9.9	4.1	8.1	0.0	8.3	0.8	0.0	6.6	5.7
5	4.6	0.0	5.9	4.9	2.7	10.2	10.0	9.1	9.9	5.4	4.3	2.6
6	4.4	0.7	7.0	3.0	6.8	2.9	8.1	10.1	8.9	6.6	6.2	1.2
7	5.5	5.3	1.3	0.0	11.2	11.8	10.8	10.2	8.5	7.8	1.8	5.4
8	5.7	6.8	0.0	1.0	5.6	11.8	8.1	10	9.4	5.1	0.0	2.7
9	4.3	0.2	2.2	2.7	4.7	11.7	8.2	2.3	9.4	2.8	0.2	0.0
10	2.7	0.1	9.1	9.9	2.1	11.4	6.6	8.2	9.3	6.3	5.6	3.3
11	6.0	5.7	9.2	8.2	6.5	11.6	9.1	9.1	9.2	6.2	6.2	3.6
12	6.0	0.0	9.2	3.5	10.2	1.5	7.3	0.2	7.9	6.3	6.2	0.0
13	2.7	0.0	9.1	4.0	10.3	7.7	8.2	2.6	3.1	6.7	6.2	3.6
14	3.0	2.5	9.3	1.3	10.2	3.6	5.9	8.9	7.8	1.6	6.2	1.0

15	0.6	5.9	9.2	0.2	3.9	1.9	10.3	9.9	7.6	5.9	5.8	0.7
16	0.0	7.2	2.8	9.7	7.7	4.2	10.0	2.3	2.7	6.6	3.0	3.1
17	1.4	1.9	6.3	7.4	10.1	6.1	9.6	7.2	5.7	7.1	5.2	3.5
18	0.0	7.4	2.6	9.7	10.1	8.0	7.4	7	6.9	5.0	6.0	5.7
19	2.1	6.1	5.4	9.8	6.6	10.8	6.9	10	9.0	7.3	6.0	5.1
20	5.4	0.5	3.2	2.8	5.0	11.4	6.3	9.6	9.0	7.5	6.0	0.0
21	6.0	5.5	3.1	3.5	5.9	11.9	4.4	9.3	7.4	6.2	6.1	0.6
22	5.0	2.3	1.5	7.7	5.3	11.9	4.4	8.6	8.4	6.2	5.1	4.8
23	6.6	2.8	1.7	5.3	9.2	11.3	3.5	8.5	8.5	6.3	6.2	5.3
24	0.2	6.5	1.8	7.7	5.6	12.1	10.1	10	5.8	7.0	6.0	5.6
25	0.0	7.8	0.1	9.3	3.5	12.1	6.8	10.9	8.6	6.9	4.2	5.6
26	0.1	6.2	7.2	0.5	10.4	10.4	10.2	10.3	8.2	6.8	6.0	5.5
27	0.3	4.8	1.2	5.4	8.3	0.4	10.3	10.2	5.9	6.3	0.0	0.1
28	6.8	8.1	4.4	6.0	10.3	7.1	7.1	9	7.3	0.0	3.6	5.6
29	0.4		2.5	9.3	8.7	1.4	3.3	8.2	8.5	1.8	6.0	3.8
30	6.3		5.0	10.0	10.2	5.9	7.2	2	8.5	6.7	0.2	4.8
31	6.3		9.4		9.9		8.1	6.5		6.6		5.0
SUM	98.8	106.4	141.4	165.1	226.3	249.9	228.0	227.3	218.1	179.3	143.2	102.3

The population of GB is spread thinly over mountainous terrain with 86% population inhabit in rural areas and engaged in very little economic activity. According to the water and power department of GB, the total energy demand of this region is 270 megawatts (MW). To meet this demand there are about 128 Hydro stations in GB and collectively hydropower generation capacity is 145.934MW, thermal backup is 11MWand other production is about 3 MW.

3.2 Simulation tools for Solar Water Heating Systems

To examine the feasibility of solar water heating and selection of optimum collector at high altitude cold arid region of GB, used T*SOL software for simulation. T*SOL is used for designing and modelling of solar heating systems. Previously it is used to investigate the solar heating systems feasibility in different climate conditions [5]. In this simulation software, we can completely design domestic and commercial solar heating systems with supply of hot water, space building heating, domestic heating, commercial heating, and big-scale systems. This software use Meteosyn climate data for simulation at different locations. Both technical and financial calculations can be done through this simulation software. Some calculation basis of T*SOL are given below.

3.2.1 Calculation for Energy Balance

Eq. 1 is employed to estimate and calculate temperature changes. This balancing is accomplished for the individual system's components. Mean Temperature Difference (MTD) is calculated using Eq. 1.

$$MTD = \frac{TotalEnergy_{(input)} + TotalEnergy_{(output)}}{Total\ heat\ capacity} \quad (1)$$

This balancing is carried out for the individual systems components.

3.2.2 Calculation of Irradiation

Irradiation on horizontal plane is presented in W/m^2 (Watts per square meter) in available climate files. The solar and collector azimuth angle and tilt angle are calculated based on the peak of sun.

3.2.3 Calculating Collector Thermal Losses

The energy absorbed by the collector is calculated using Eq. (2).

$$P = G_{dir}.\eta_{\circ}.F_{IAM} + F_{IAM_{diff}}.G_{diff}.\eta_{\circ} - k_{\circ}.(T_{cm} - T_A) - k(T_{cm} - T_A)^2 \quad (2)$$

Whereas G_{dir} is part of solar irradiance and G_{diff} is a dispersed solar radiation hitting the tilted surface, T_{Km} is average collector temperature, T_A is temperature of air, F_{IAM} is modifier for incident angle.

3.2.4 Calculation of CO_2 Emissions

For calculation of CO_2 emission reduction following emissions factors are used.
Emissions factors by fuel type are used to calculate the CO_2 emissions of a heating system. The following emission factors are used in T*SOL.

Table 7 Emissions factors used in T*SOL

Fuel	Heating value	Emissions factor
Oil	36722 kJ/l	7.32748 g CO2/kJ
Gas	41100 kJ/m³	5.14355 g CO2/kJ
Wood pellet	15490 kJ/kg	CO2-neutral

3.2.5 Efficiency and Solar Fraction

The collector loop efficiency is defined by

$$Collector\ loop efficiency = \frac{Energy\ output\ from\ collector loop}{Energy\ irradiated\ on\ to\ the\ collector\ area} \quad (3)$$

The system efficiency is defined by

$$System efficiency = \frac{Energy\ output\ from\ the\ solar system}{Energy\ irradiated\ on\ to\ the\ collector\ area} \quad (4)$$

The solar fraction is defined by

$$Solar fraction = \frac{Energy\ supplied\ to\ the\ standby\ tank\ from\ solar\ system}{Total energy supplied to\ the standby tank (Solar system + Auxiliary\ heating)} \quad (5)$$

Summary

Research Methodology is completely discussed in this chapter. First acquired all the data related to the climate and environment of GB from concerned departments. Analyzed the data regarding solar potential of the study area. To examine the feasibility of solar water heating system at GB using T*SOL software. The acquired data have been used in this software evaluation work and finally made a complete report about the solar potential and solar heating system feasibility in northern areas of Pakistan.

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Chapter 4

Results and Discussion

4.1 Solar Water Heating System Feasibility Analysis

4.1.1 Tourism impact

Fig. 15 represents the tourist activities from 2012 onward. From 2012 to 2015 tourism growth is normal but from 2015 onward tourist activities in this region growing rapidly. The information acquired from the tourism department of GB depicts that more than two million tourists visit this region in 2019, making it the most attractive destination for visitors all over the world. The rate of tourists has been exponentially increasing in the last few years and multiple to come in the future due to betterment in infrastructure and other services provided by the government and locals. The increase in tourism is also due to the influence of social and electronic media in this region [1]. This development has strengthened the economy of this region and generate revenues. But the rapid increase in tourists in this region also has negative impacts. The energy demand in this region is increasing rapidly due to tourism activities. Tourists use conventional sources for heating purposes. Because of less focus on environmental problems, it is observed that tourism activity is badly affecting the eco-system and natural resources of this region [2]. So, it is need of the hour to take necessary measures towards sustainable tourism to provide better service for tourist and increase eco-friendly tourism in GB. In this regard, the solar water heating system is optimal solution to overcome the heating requirements and one more step towards ecotourism.

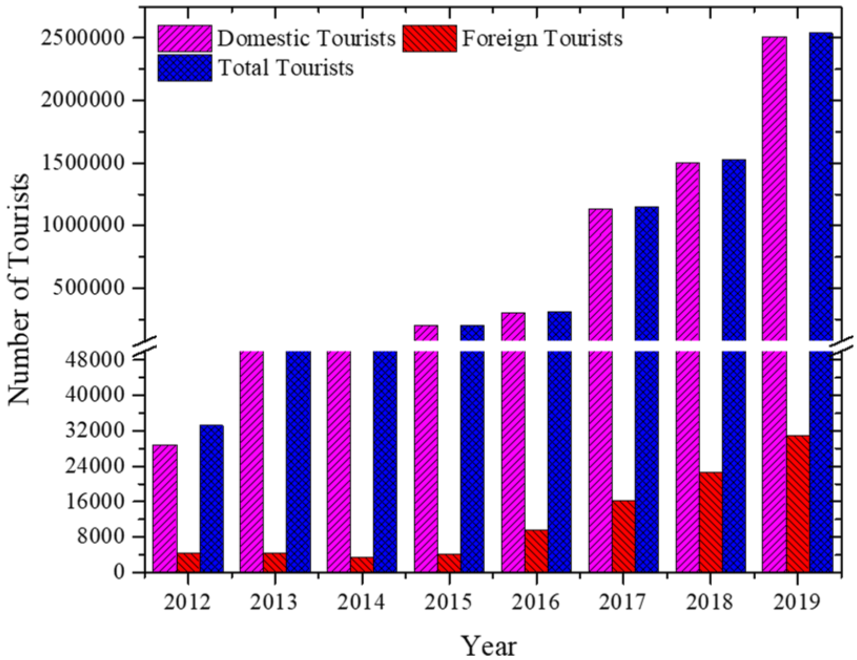

Fig. 15. No of tourists visit in GB.

4.1.2 Solar Irradiance

Fig. 16 represents the solar daily solar radiations of Gilgit and Skardu city. The average solar radiation in Pakistan is 5.30 kWh/day and at GB approximately 5.6 kWh/day. The solar map of Pakistan represents that Northern Pakistan receives a sufficient amount of solar irradiation as compared to other parts of Pakistan. Solar radiation available in GB is plenty. Average annual solar radiation is about 5.54 kWh/day however the maximum amount of radiation is received during the month of September according to NASA sources. The cold arid region of the country located at Gilgit and Skardu receives the highest amount of radiation, which is about 7-7.5 kWh/day [3]. At Skardu, the maximum amount of radiation is received during the month of June is 7.48 kWh/day. In addition, most of days in GB are clear and sunny according to the reports as 300 days are sharp clear in a year according to the Pakistan metrological climate report.

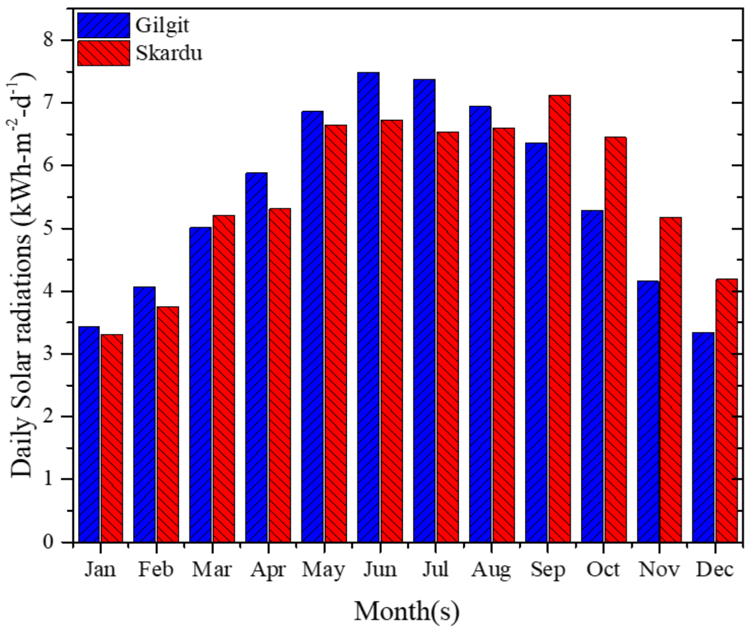

Fig. 16. Daily solar radiations (monthly average) for Gilgit and Skardu City.

In the month of January, February, and December solar irradiance is about 3 to 5 kWh/day. In the mid-winter season, the efficiency of solar collectors will be decreased due to low solar irradiance. To overcome this problem, we can use a hybrid heating system like gas or power electric heater to supply require heating because in winter season the heating demand also increases due to the harsh cold weather. In the month of March, April, and November the radiation potential is normal and can meet the collector demands. In the summer season, the availability of solar irradiance is very high and profound.

4.1.3 Sunshine hour

Fig. 17 represents the monthly average sunshine hour of the Gilgit and Skardu region. The data represents in Table 3-4 reflect that GB has mostly sunny days throughout the year. Also analysed the weather report for the last five years. From these data, it is analysed that the monthly average of this region is three to four days cloudy, and the rest of the days the sky is almost clear. The longest day recorded in Gilgit is in July which is almost eleven hours and the longest day recorded in Skardu is in June. Most of the place in GB has very clear and pleasant weather and receive good solar radiation.

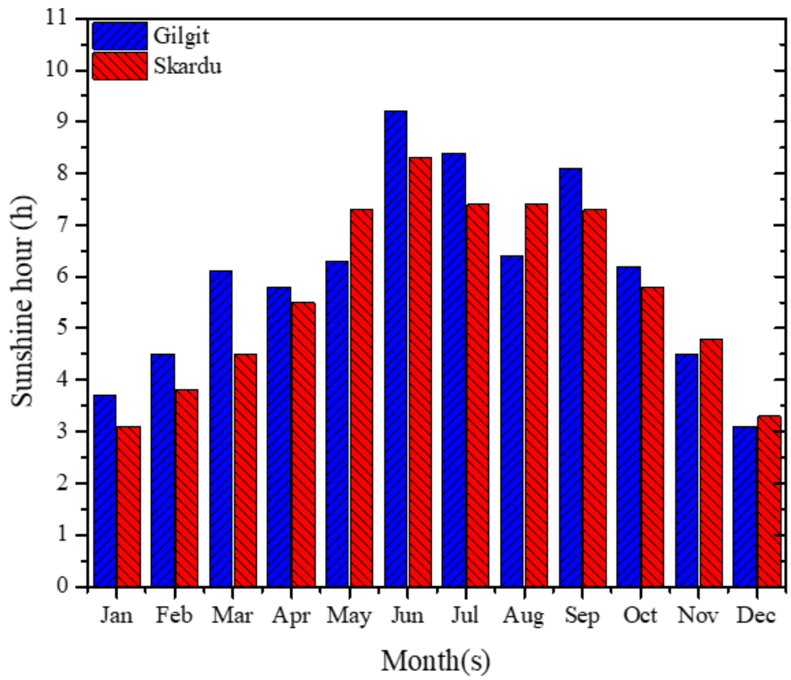

Fig. 17. Daily sunshine hour (monthly average) for Gilgit and Skardu City.

Especially in summer, the ambient temperature is about 22 °C but solar irradiance is more than 6 kWh/day. In summer there are more shining hours as compared to winter months. But from the Table 3-4 reflect that in winter we also have adequate sunny days. Mostly tourists come to this region in the summer seasons and fewer in winter so, in the winter season we can use a hybrid

heating system to achieve our heating requirements in the absence of sunny days. For this purpose, we can use LP gas or other conventional sources with a solar water heating system.

4.2 Solar Water Heating Systems Analysis

In the 2nd phase of the study, performed simulation-based experiments to investigate the efficiency of the solar water heating system at GB. Mostly worked with T*SOL and also collect real-time climatic values from Meteonorm Software. Using different types of collectors at different locations of GB, analysis their results, and select the best optimum collector for heating purposes. Complete the project of solar heating for a tourist resort, schools and also did a simulation for domestic purposes. Evaluate the results and completely analysed the efficiency of solar thermal heating in this region from different aspects. To obtain optimum collector for GB performed many simulations on T*SOL software. All the data acquired in the first phase used in this software work for more accurate and efficient results. By using a different type of collector investigate solar fraction, overall efficiency, and other factors on T*SOL software. For this work, used three types of solar collectors include flat, evacuated, and unglazed type collectors and selected the best collector which suits the environmental conditions of GB. The current study focused to analyse the performance of a solar water heater at GB towards the goal of sustainability in the tourism sector. For this work, performed simulations at different locations in GB for tourist resorts and domestic households. Simulation is conducted for two major cities of GB named Gilgit and Skardu. Following are the simulation results of the tourist resort at Gilgit and Skardu.

4.2.1 Solar Energy Consumption

Solar energy consumption is the act of using solar energy to run the system. Fig. 18 represents the solar energy consumptions of different plates throughout the year. These results show that solar consumption is high in summer seasons and moderate in winter seasons. In the winter season can use auxiliary heating with the solar heater to fill the consumption gap. For the Gilgit region, solar consumption is low in Jun, July, and August because the system is not in operation in those months. In these months the weather of Gilgit is warm and does not need hot water. But for Skardu city we need hot water throughout the year therefore solar consumption of Skardu city is high in July which is about 350-kilowatt hour per month. In Skardu, solar energy consumption in Jun, July, and August is maximum and sufficient for solar heating demands. Fig. 18 also represents the solar consumption of flat plate collector (FPC), evacuated tube collector (EC), and unglazed collector (UnGC) explicitly. For Gilgit, the highest consumption is in May which is about 330 kWh for FPC, 340 kWh for EC, and 250 kWh for UnGC. The lowest consumption is in February during operation, which is about 230 kWh for FPC, 250 kWh for EC, and 160 for UnGC. For Skardu, maximum solar consumption is in July which is about 350 kWh for FPC, 360 kWh for EC, and 260 kWh for UnGC. In winter minimum solar consumption of Skardu is in February, which is about 220 kWh for FPC, 240 kWh for EC, and 150 for UnGC. This simulation results represent that the evacuated tube collector has maximum solar consumption as compared to a flat plate and unglazed collector. The solar radiation power of northern Pakistan is strong and highly intense which increases solar energy consumption [4]. Solar energy consumption in GB is high as compared to plain areas of Pakistan due to pollution-free and clean environment. The solar energy consumption of evacuated tube collector is high because this collector performs better in high altitude cold regions [5]. It depicts that heating performance of the evacuated type collector is better which suits the environmental conditions and geographical landscape of this region.

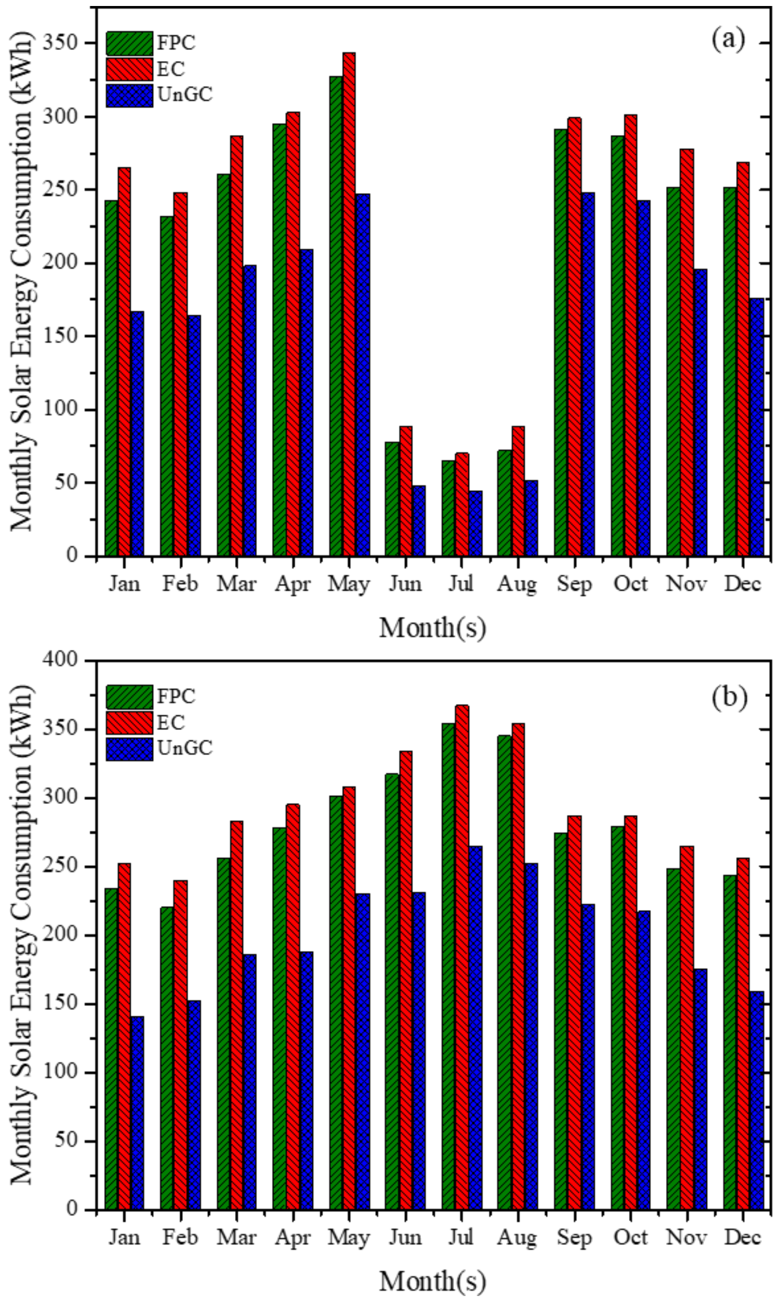

Fig. 18. Overall solar energy consumption (a) Gilgit (b) Skardu.

4.2.2 Daily Maximum Collector Temperature (Monthly Average)

Collector temperature is the key factor for efficient solar heating systems. Fig. 19 represents the monthly average of daily maximum solar collector temperature for Gilgit and Skardu regions. In the summer season, the collector receives maximum radiations because the days are longer and sunny so collector temperature is high in the summer season as compared to the winter season.

For Gilgit and Skardu region the maximum collector temperature reaches more than 80° in July and it is lowest in January which is about 50° for evacuated tube and flat plate collectors. Fig.19 represents the daily maximum collector temperature of different types of collectors include FPC collector, EC collector, and UnGC collector. For the Gilgit region, the daily maximum collector temperature is highest in July which is 82° for FPC, 85° for EC, and 63° for UnGC collector. The daily maximum collector temperature is lowest in January which is 55° for FPC, 58° for EC, and 33° for UnGC collector. For the Skardu region, the daily maximum collector temperature is also highest in July which is 80° for FPC, 83° for EC, and 60° for UnGC collector. The daily maximum collector temperature is lowest in January which is 53° for FPC, 57° for EC, and 32° for UnGC collector. Collector temperature depends on both intensity of radiations and ambient temperature [6]. The solar radiation potential of Gilgit and Skardu is almost equal but the ambient temperature is cooler in the Skardu region. Therefore, the maximum collector temperature of Gilgit city is slightly higher as compared to Skardu city. From these results, it is observed that the evacuated tube collector receives maximum collector temperature more than flat plate and unglazed type collectors. It means that efficiency of the evacuated tube collectors are better than other collectors in this geographical landscape. Evacuated tube collector performs efficiently both in winter and summer seasons due to its better output and minimal heat losses [7]. So, an evacuated tube collector is the best option to achieve the desire collector temperature for the solar heating system in this high-altitude mountainous region.

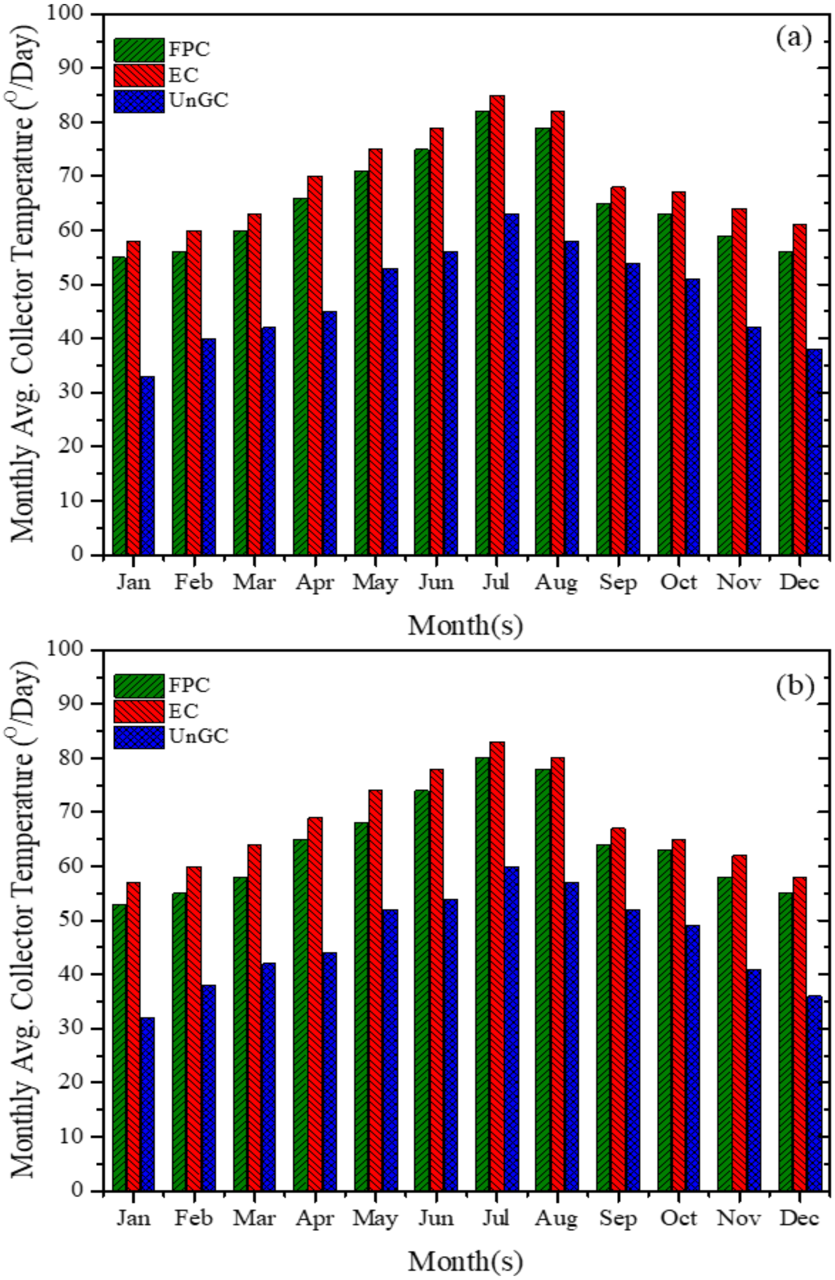

Fig. 19. Daily maximum collector temperature (monthly average) (a) Gilgit (b) Skardu.

4.2.3 Overall efficiency performance

To examine the efficiency of different collectors at Gilgit and Skardu location used three types of collectors for this simulation. Individually performed simulations with a flat plate evacuated tube and unglazed collector and analysed their results. Obtained simulation results are in Figs. 20, 21

& 22. These results include solar fraction, solar contribution to hot water, CO2 emissions avoided, and overall system efficiency of solar heating system.

Fig. 20 represents simulation results of the flat plate collectors. From flat plate simulation results, it is observed that the solar fraction is 66% throughout the year for Gilgit and 74% for Skardu. Yearly solar contribution is 1864 kWh for Gilgit and 2116 kWh for Skardu.. Total CO2 emissions avoided for the Gilgit region are 585 kg and the Skardu region is 659 kg for the whole year. The system efficiency of flat plate collector for Gilgit is 34 % and Skardu is 31%.

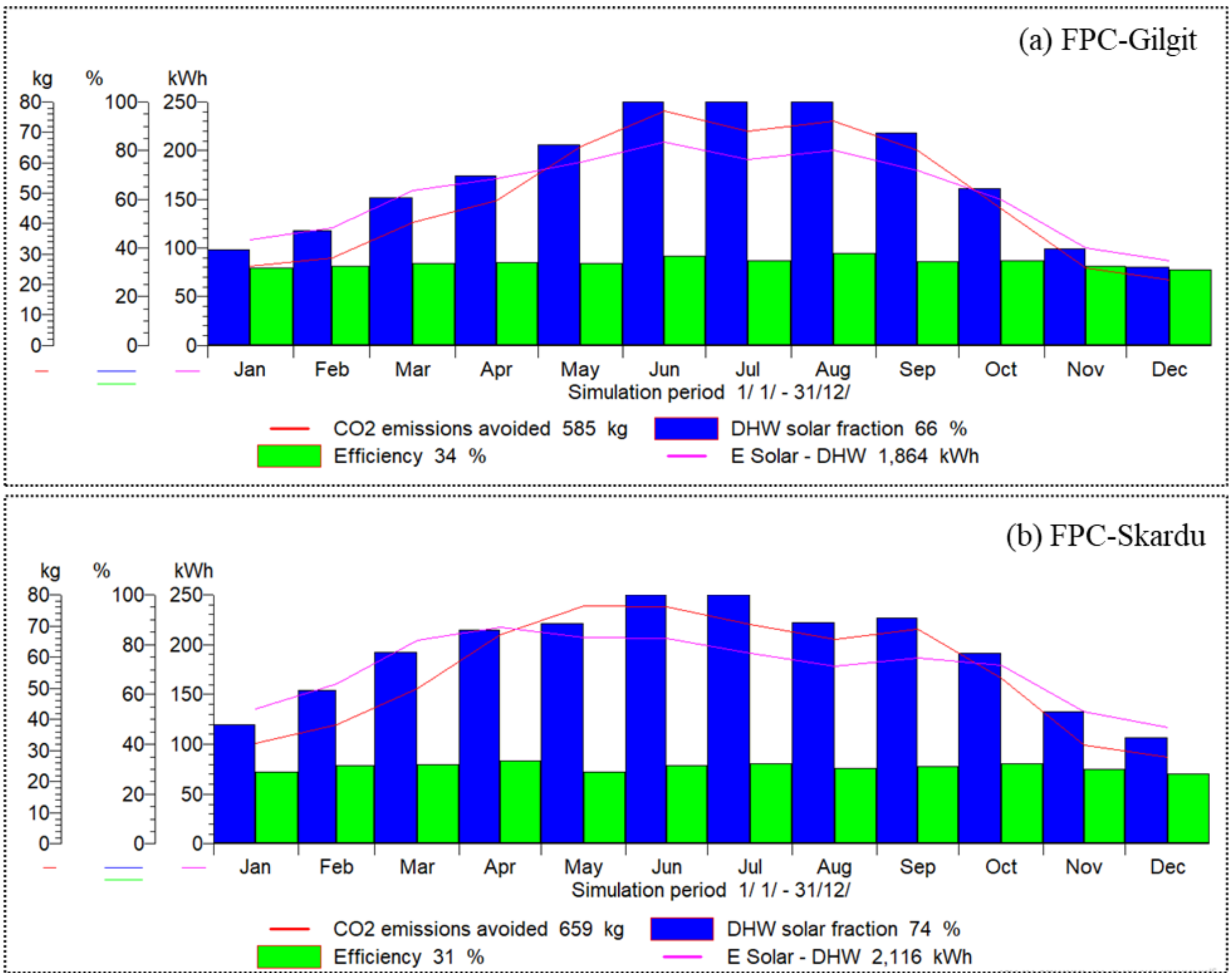

Fig. 20. T*SOL simulation results of flat plate collectors (a) Gilgit (b) Skardu.

Fig. 21 represents the simulation results of evacuated tube collectors. Simulation results include total solar fraction, solar contribution to hot water, CO2 emissions avoided, and total system efficiency. From Fig. 21, it is noticed that the total solar fraction of the ETC for Gilgit city is 75% and Skardu city is 84 %. Overall solar contribution to hot water for Gilgit city is 2185 kWh and Skardu city is 2468 kWh. Total CO2 emissions avoided for the Gilgit region are 676 kg and the Skardu region is 756 kg for the whole year. The system efficiency of evacuated tube collector for Gilgit is 40% and Skardu is 36%.

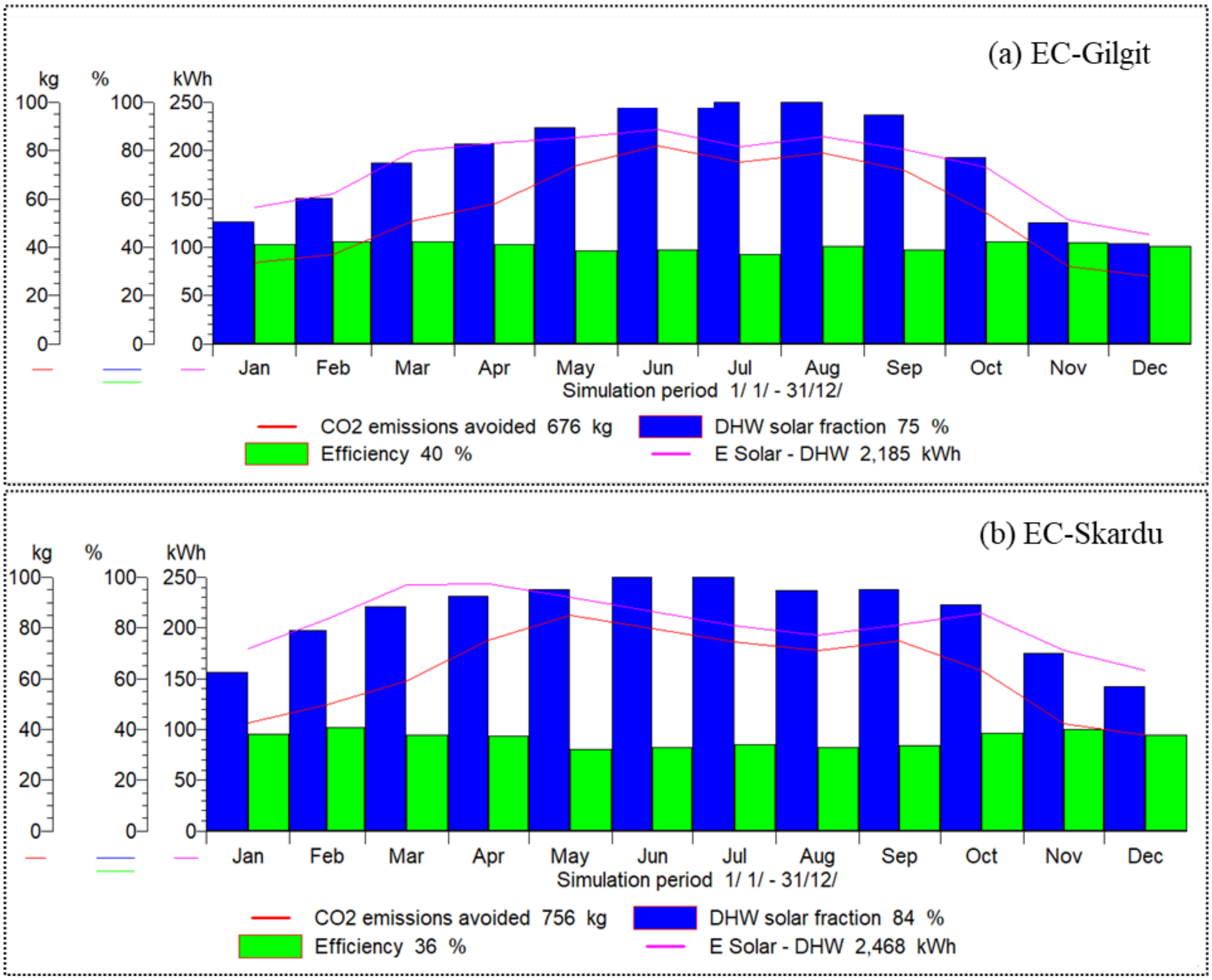

Fig. 21. T*SOL simulation results of evacuated tube collectors (a) Gilgit (b) Skardu.

Fig. 22 represents the simulation results of unglazed collectors. These simulation results also include total solar fraction, solar contribution to hot water, CO2 emissions avoided and, total system efficiency. From the results in Fig. 22, it is observed that the solar fraction of the unglazed collector for the Gilgit region is 38% and the Skardu region is 42 %. Solar contribution to hot water for Gilgit city is 967 kWh and Skardu city is 1115 kWh for the whole year. The

Total CO2 emissions avoided for Gilgit city are 318 kg and Skardu city is 365 kg. The overall system efficiency of the heating system is 17.8% for Gilgit and 16.3% for Skardu.

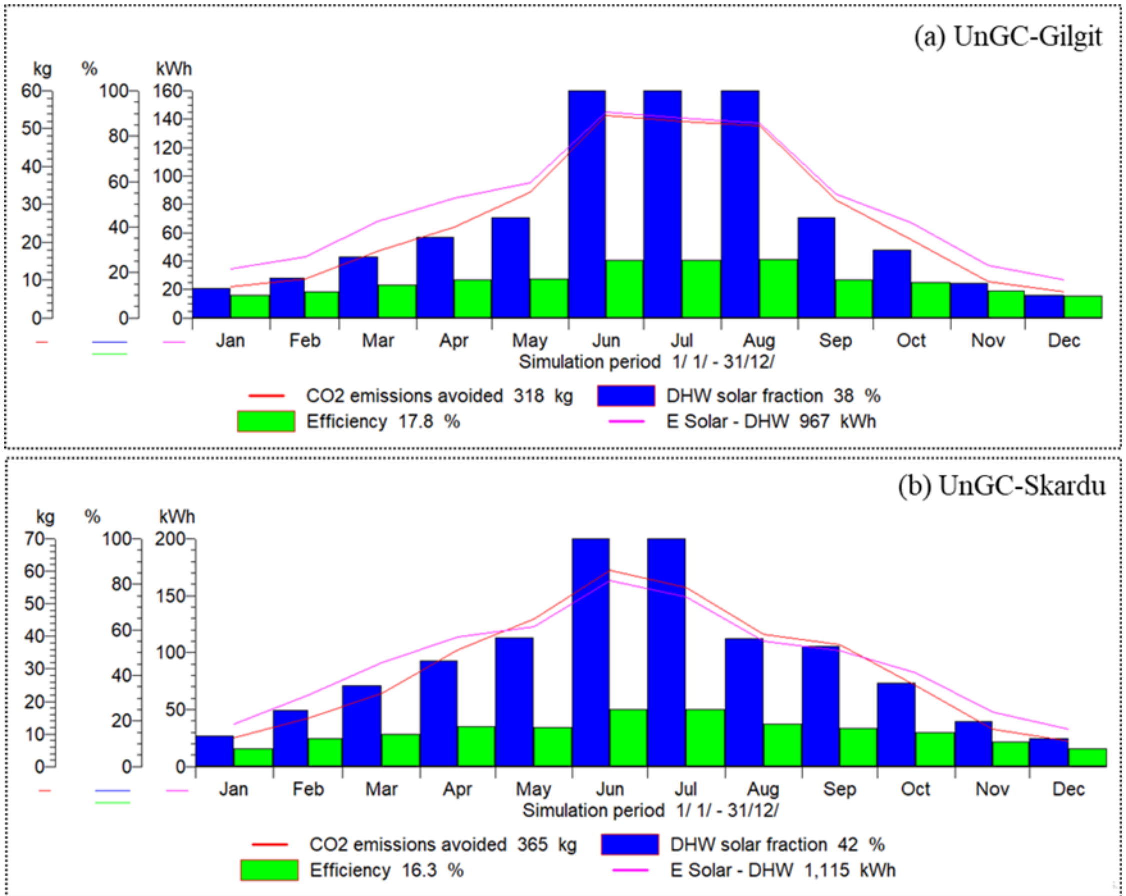

Fig. 22. T*SOL simulation results of unglazed collectors (a) Gilgit (b) Skardu.

A solar fraction is the energy supplied by the sun to the overall energy needed by systems. The solar fraction of the Skardu region is maximum than the Gilgit region because the solar heating system is not in operation during Jun, July, and August for the Gilgit region. In Jun, July and august solar fraction are very high due to the maximum solar radiation available in these months. During extreme summer the temperature is normal in Gilgit city and does not need hot water but Skardu city needs hot water twelve months of the year. Solar contribution is also high in Skardu due to the consumption of solar energy for the whole year. The CO2 emissions saved by solar heating system in Skardu region are slightly maximum than in Gilgit city. System Efficiency means the total efficiency of solar water heating system which considers all types of losses include thermal losses and piping losses. The overall System efficiency of Gilgit City is slightly higher than the Skardu city because the maximum collector temperature and solar energy consumption of Gilgit city are a little bit higher than the Skardu city.

Table 8 Final comparison for three different collectors at Gilgit and Skardu cities.

Collector Type	Gilgit City			Skardu city		
	Solar fraction (%)	Efficiency (%)	CO2 emissions avoided (kg)	Solar fraction (%)	Efficiency (%)	CO2 emissions avoided. (kg)
FPC	66	34	585	74	31	659
ETC	75	40	676	84	36	756
UGC	38	17.8	318	42	16.30	365

Table 9 Comparison Performance of FPC and ETC Collector at Gilgit, Skardu and Dublin, Ireland

Parameters	Flate Plate Collector			Evacuated Tube Collector		
	Gilgit	Skardu	Dublin	Gilgit	Skardu	Skardu
Installed solar surface area	5 m²	5 m²	2.04 m^2	5 m²	5 m²	2.04 m^2
Ambient Temperature September	13.3 °C	3.8 °C	14 °C	13.3 °C	3.8 °C	14 °C
Ambient Temperature October	6.5°C	2.8 °C	11 °C	6.5°C	2.8 °C	11 °C
SWH System Efficiency September (%)	32 %	29 %	27 %	40%	35 %	46 %
SWH System Efficiency October (%)	32 %	30 %	31 %	42 %	36 %	47 %
Maximum Outlet Temperature September(°C)	65 °C	64 °C	67 °C	68 °C	67 °C	70 °C
Maximum Outlet Temperature October(°C)	63 °C	63 °C	64°C	67 °C	65 °C	67°C

Table 8 shows the comparison of solar fraction, efficiency and CO_2 emissions prevented for three different collectors at Gilgit and Skardu regions. Table 9 shows the comparison performance of FPC and ETC collector at Gilgit and Skardu with Dublin, Ireland.

From these results, it is observed that Gilgit and Skardu region is feasible for the deployment of the SWH systems. Compared the results of GB with Dublin, Ireland which has almost similar climatic conditions also showed the similar results. The overall efficiency of both Gilgit and Skardu city is high for ETC that FPC and UGC. It depicts that the thermal performance of the ETC is better which suits the environmental conditions and geographical landscape of this region. The ETC perform better in cold climate areas because it has minimum thermal losses [8]. It is reported that; ETC has high outlet temperature with reduced dispersion of heat as compared to FPC and UGC. In term of solar collectors, the ETC has a much higher solar fraction, CO_2 emissions reduction, and system efficiency. The final comparison clearly shows that ETC is the most suited collector for the cooler climate of GB because the overall system efficiency of ETC is about 40 %. The specifications and designing of ETC are more suitable for cold climate regions. FPC and UGC are more susceptible to ambient heat loss as compared to ETC. ETC is more suitable in the GB region of Pakistan because it performs better than FPC and UGC at high altitude and cooler climate areas.

Summary

In this chapter, completely discussed the feasibility of solar water heating system at GB. In the first part, tourism impact, solar irradiance and sunshine hour of GB are analysed. From the analysed result, it is observed that the tourism in GB has been increasing sharply during the last few years and GB has a very strong solar profile throughout the year. In the second part, analysed the feasibility of solar water heating system using T*SOL software. Discussed the solar energy consumption, daily maximum collector temperature and overall efficiency performance of different solar collectors from the obtained results. Compared results of FPC, ETC, and UGC collectors and concluded that ETC collector is best for the high-altitude cold climate of GB.

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Chapter 5
Conclusion and Recommendations

5.1 Conclusion

The study concluded the SWH system feasibility for two cities of Gilgit-Baltistan. The collected data from various sources have been analysed to investigate its suitability for SWH system in GB. The data is then utilised to investigate for the different solar collector for simulation to check the collector temperature, CO_2 emissions and overall efficiency of the system. The harsh cold arid region of GB is the best place for solar energy harvesting as ETC showed a better overall performance for both cites with a significant reduction in CO_2 emissions. SWH systems more feasible for Skardu due to the cold climatic conditions and requirement of hot water throughout the year. Specifically, ETC is well suited to the geographical landscape and environmental conditions of GB. It is analysed that solar fraction and overall system efficiency are higher for both Gilgit and Skardu regions. So, the performance of the SWH system in GB is best and up to the mark. SWH system can provide better facilities for tourists, increase eco-friendly tourist activities in GB, and can be an effective alternative to the conventional non-renewable sources.

5.2 Recommendations & Future Work

Every research opens a new opportunities for future researchers. There are also some recommendations needed to carry this work more useful and efficient. A proper experimental work is required in GB to find the more accurate and real time data related to solar potential and other climatic factors. Now this time there is not carried any proper research about the solar potential and energy of this region. Also needed a proper survey about the environmental degradation which include deforestation, climate changes, destruction of ecosystem and other heath related problems due to excessive use of woods and LP gases. For more accurate result more real time data needed therefore it is necessary to conduct a proper survey in GB about the feasibility of solar heating system. If proper research is carried out, then there will be a good opportunity in near future that not only strengthen the economy but also provide a clean and efficient energy in this region.