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Assessing the Feasibility and Techno-economic potential of Residential Solar Water Heating System in Hayatabad, a Township in Peshawar, Pakistan

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Abstract**—**Solar water heating technology is one of the cost-effective ways of heating water in domestic as well as commercial and industrial sectors. The use of Solar Water Heating (SWH) systems is motivated by the desire to reduce the conventional energy consumption (fossil fuels) and especially to reduce a major source of greenhouse gas (GHG) emissions. The purposes of the present paper consist in: assessing the solar potential; analysing the possibility of using solar energy to heat water for residential applications in Pakistan; investigating the economic potential of SWH systems; and their contribution to saving energy and reducing CO2 emissions. SWH installations and economic analysis of the proposed model was done by using System Advisor Model (SAM) software tool for Renewable Energy (RE) projects analysis. An empirical model is used for estimating the CO2 reductions due to SWH system implementation by replacing conventional water heating system. The result showed that if a SWH system replaces electricity, it can save 3741 KWh of electrical energy, similarly, by replacing natural gas, it can save 12.7549 MMBTU and reduces 1982.73 kg of CO2, 1.87 kg of SO2 as well as 3.37 kg of NOx. The annual mitigations of GHGs emissions by a single residential SWH system installation are also estimated for coal and crude oil used for electricity production in the country. This research also surveyed different single-family households in the study area with installed SWH system for real time observation and analysis.

Keywords**—** Solar Thermal Energy (STE), Solar Water Heaters (SWH), Techno-economic analysis, greenhouse gases (GHG) emissions, System Advisor Model (SAM), Payback Period.

I. Introduction

Energy resources are one of the most important factors for sustainable development **[1–3].** Energy consumption during the last century has greatly increased. It's expected that it will grow from 12 billion tonnes of oil equivalent (TOE) in 2010 to 17 billion TOE in 2030 with an average increase of 1.8% per year, whereas during the period 1990-2000, the increase was 1.4% per year **[4]**. Continuous use of conventional fuels everywhere for different purposes in the world which are going to create multiple threats, that includes: conventional fuel resources reduction, sustainability and rise in costs of fuels, environmental problems, global warming, armed disputes and geopolitical issues, etc **[5]**. Recently, sustainable, noise-free, and environmentally friendly solar energy has been developed at a steady pace around the world to replace fossil fuel resources **[6]**.

Solar energy has been exploited in several ways, such as producing electricity, thermal usages, water treatment systems, and solar water heating (SWH) systems. The SWH system is known as a common application of solar energy where the received radiation is changed into heat and then transferred into a circulated medium, mostly water and air [7]. SWH systems can cover a significant part of the hot water needs depending on local and seasonal climatic conditions **[8]**. They present both economic and ecological benefits. These systems use renewable energy for water heating and produce no direct emissions with greenhouse effect. Considering the whole life cycle, solar water heating (SWH) systems produce greenhouse gas (GHG) emissions although they are low compared to fossil reference systems, thus contributing to the reduction of GHG emissions and to the improvement of the air quality locally **[9–13]**. Moreover, SWH systems can substantially reduce fossil fuel consumption **[14]**.

Several studies (e.g., Haralambopoulos et al. **[15]**; Diakoulaki et al. **[16]**; Kaldellis et al. **[17]**) evaluated the applicability of various SWH development programs based on benefit–cost analyses, and solar radiation was the major factor considered by these studies. Total annual solar radiation was used to estimate energy production benefit. However, for an SWH, since solar energy captured today cannot generally be stored for later use **[15],** an analysis based on total annual solar radiation may overestimate energy production benefit.

"**Figure 1**" shows the cumulated installed capacity of glazed and unglazed water collectors in operation for the 10 leading markets in 2020 in total numbers. China remained the world leader in total capacity and a market dominated by evacuated tube collectors. The United States held its third position due to its high number of installed unglazed water collectors. Besides the United States, only Australia and, to some extent Brazil, have large numbers of unglazed water collectors installed. In the large European markets, Germany, Austria and Greece, flat plate collectors were the most dominant collector technology. In Turkey, over the past several years, there has been a strong trend toward evacuated tube collector technology **[18].**

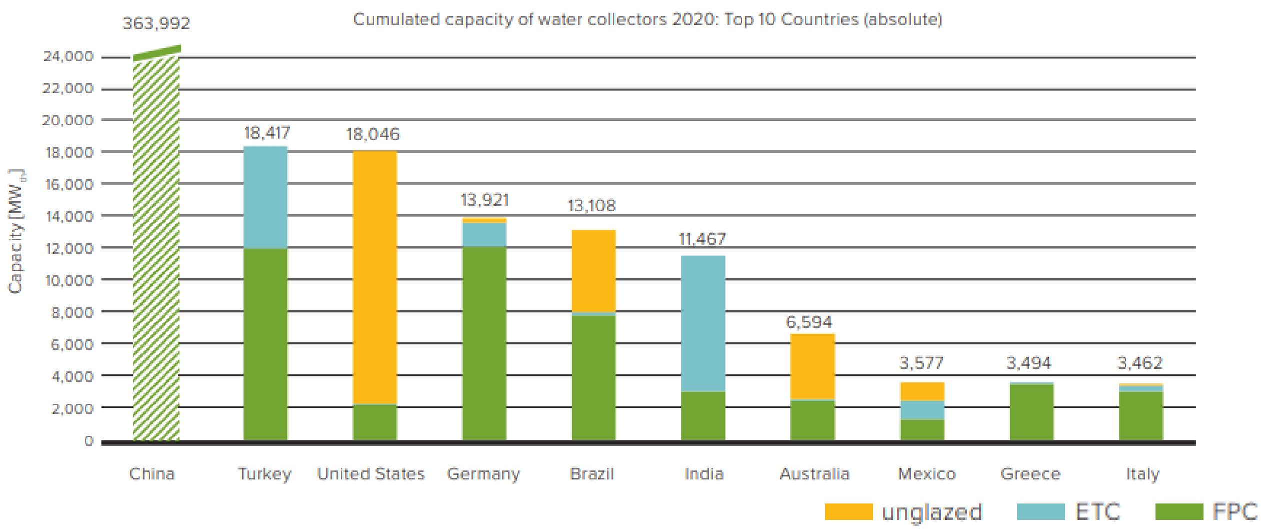


Figure 1: Top 10 countries of cumulated water collector installations in 2020 (absolute figures in MWh) **[18].**

Solar water heating systems are a fully mature technology. These systems have been used for several decades to provide heat energy to households. In most cases, solar systems can provide only a certain part of the energy needs, meaning a complementary heating system is required **[19].**

Domestic hot water systems dominate the solar market that is about 109 million solar thermal systems were in operation by the end of 2020. We can see "**Figure 2",** solar hot water systems for single and multi-family houses, tourism, and public buildings remained the dominant application, with an 86% share of new solar thermal installations in 2020 **[18].**

The majority of studies found that in terms of installation expenditures and energy cost over the total life of the system, solar water heating technology has proven to be cost efficient for several domestic and industrial applications, this being proved by analyses of the systems performances **[20].** This is the reason for the SWH systems widespread usage and applications in both domestic and industrial sectors. Shukla (2013) showed that SWH is not only environmentally friendly but also requires minimal maintenance and operation cost compared to other solar energy applications. SWH systems are cost effective with an attractive payback period of 2–4 years depending on the type and size of the system, and generate extensive researches performed to further improve the thermal efficiency of solar water heating **[21].**

Though policy support exists for energy production from renewable energy sources in Pakistan, lack of awareness by policy makers about SWHs economic potential to reduce the demand of imported oils, electricity and firewood make the utilization of SWHs insignificant.

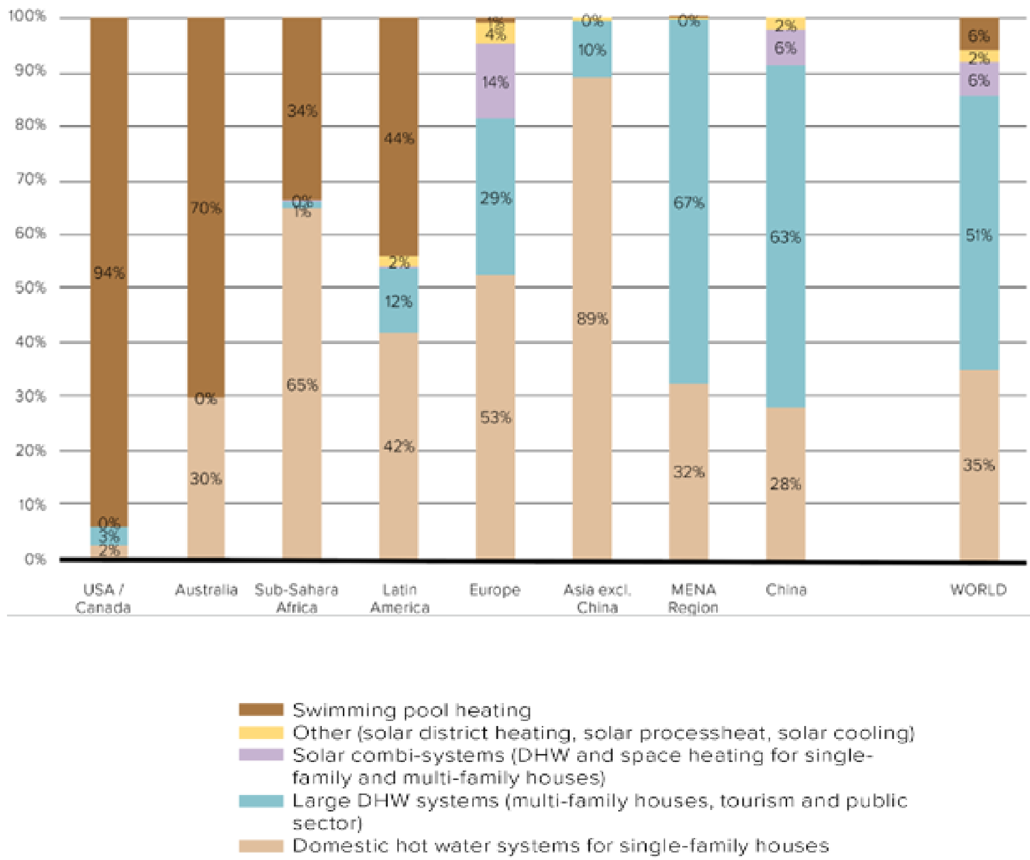


Figure 2: Distribution of Solar Thermal Systems by newly installed SWH collector capacity by economic region in 2020 **[18]**.

Thus, the purpose of this paper is to assess the solar potential and to analyse the possibility of using solar energy to heat water for residential applications in Pakistan. The present paper also aims at investigating the economic potential of solar water heating (SWH) systems and their contribution to saving energy and reducing CO2 emissions.

The present paper provides detail quantitative analysis of energy saving and this is the main focus of the study. The study is used SAM 2021.12.1 simulation software to estimate the energy output of a closed loop solar water heating system according to the environmental condition of the study area i.e. Hayatabad, Peshawar. Then annual financial saving per household and the payback period for initial investment cost of SWH system has been empirically calculated. Finally, mitigation in CO_2 emission due to replacement of conventional fossil fuels by SWH system is also estimated.

II. Global CO2 emissions (Carbon footprints)

Carbon dioxide emissions are the primary driver of global climate change. It’s widely recognised that to avoid the worst impacts of climate change, the world needs to urgently reduce emissions. The combustion of fossil fuel is the main cause of the rising greenhouse gas emission particularly in developing countries **[22]. “Figure 3”** shows the carbon dioxide (CO_2) emissions from fossil fuels and industry in Asia, Land use change is not included.

We observe that prior to the Industrial Revolution in the world, emissions were very low. Growth in emissions was still relatively slow until the mid-20th century. In 1950 the world emitted 6 billion tonnes of CO2 and by 1990 this had almost quadrupled, reaching more than 22 billion tonnes **[25]**. Emissions have continued to grow rapidly; we now emit over 34 billion tonnes each year in 2020. Pakistan emit about 235 million tonnes of CO2 each year [25].

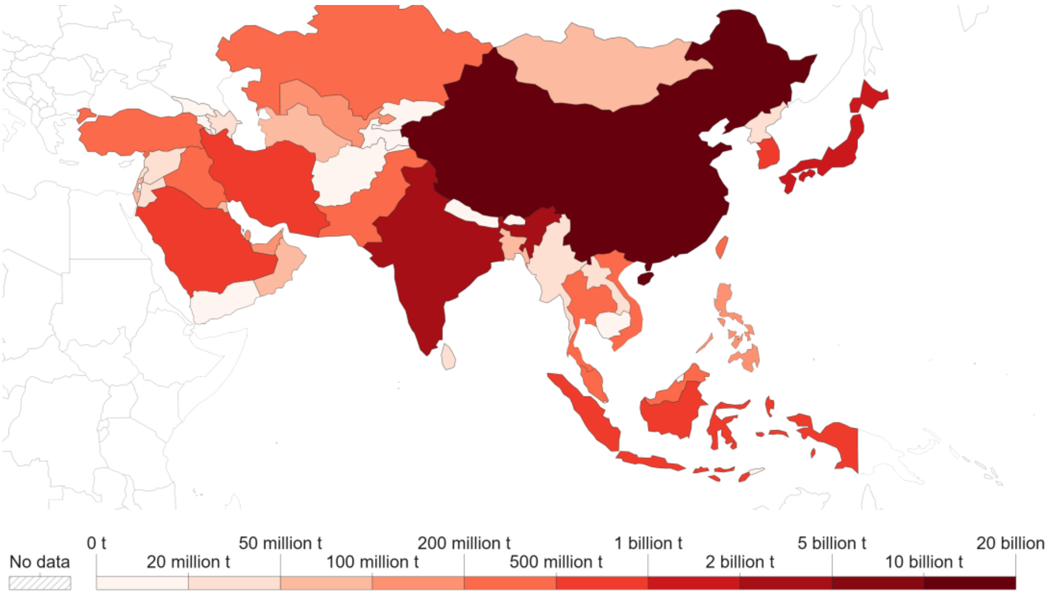


Figure 3: Annual Carbon dioxide (CO_2) emissions 2020, from fossil fuels and industry in Asian Countries **[23-24].**

Emissions growth has slowed over the last few years, but they have yet to reach their peak. We can see from "**Figure 4"** that until well into the 20th century, global emissions were dominated by Europe and the United States. In 1900, more than 90% of emissions were produced in Europe or the US; even by 1950, they accounted for more than 85% of emissions each year **[23].** But in recent decades this has changed significantly. In the second half of the 20th century we see a significant rise in emissions in the rest of the world, particularly across Asia, and most notably, China. The US and Europe now account for just under one-third of emissions as we can see from "**Figure 4".**

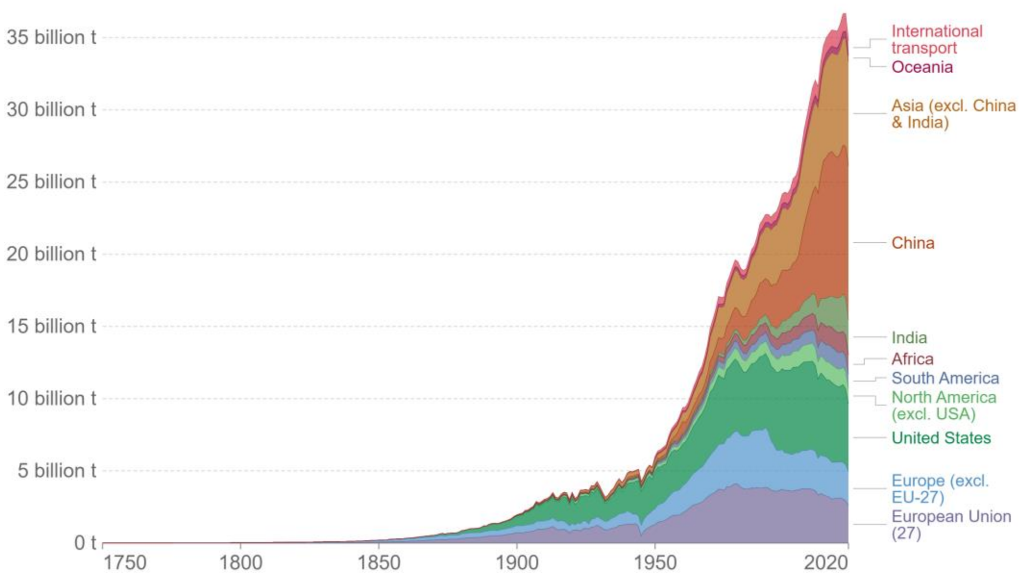


Figure 4: Annual Carbon dioxide (CO_2) emission from fossil fuels, by region **[23]**.

Now it is very essential to control the GHGs emissions which is only possible by taking necessary action as well as making policies regarding implementation of renewable energy technology and reduction of fossil fuel combustion. Increasing SWH system installation can significantly contribute to CO_2 reduction. This research will also estimate the mitigation of GHGs emissions due to Implementation of SWH system technology in the study area.

III. Solar energy resources in Pakistan

In Pakistan, PMD started measuring solar radiation data for five meteorological stations and sunshine duration data for 37 stations from 1957. WRDC centrally collects and archives the global solar radiation data, which is the only reliable source to access long-term measured solar radiation data for Pakistan; the other source is PMD. The solar radiation data for Pakistan measured by PMD have been reported by many researchers **[26–29]** to estimate the solar energy potential of Pakistan. The U.S. Agency for International Development (USAID), South Asia Regional Initiative for Energy Cooperation (SARI/E) program, promotes regional integration of energy systems and enhances Cross Border Energy Trade in South Asia. The SARI/E program includes eight countries: Pakistan, India, Bangladesh, Sri Lanka, Bhutan, Nepal, Afghanistan and Maldives. . The development of high resolution solar and wind resource data is one of the activities of the program.

The USAID under the SARI/E program contracted the National Renewable Energy Laboratory (NREL) to carry out renewable energy resource assessment (solar and wind) and to develop resource maps for selected countries. NREL has developed the Climatological Solar Radiation (CSR) Model to estimate the daily solar radiation at a spatial resolution of 40 km for Pakistan as shown in **“Figure 5” [30]**.

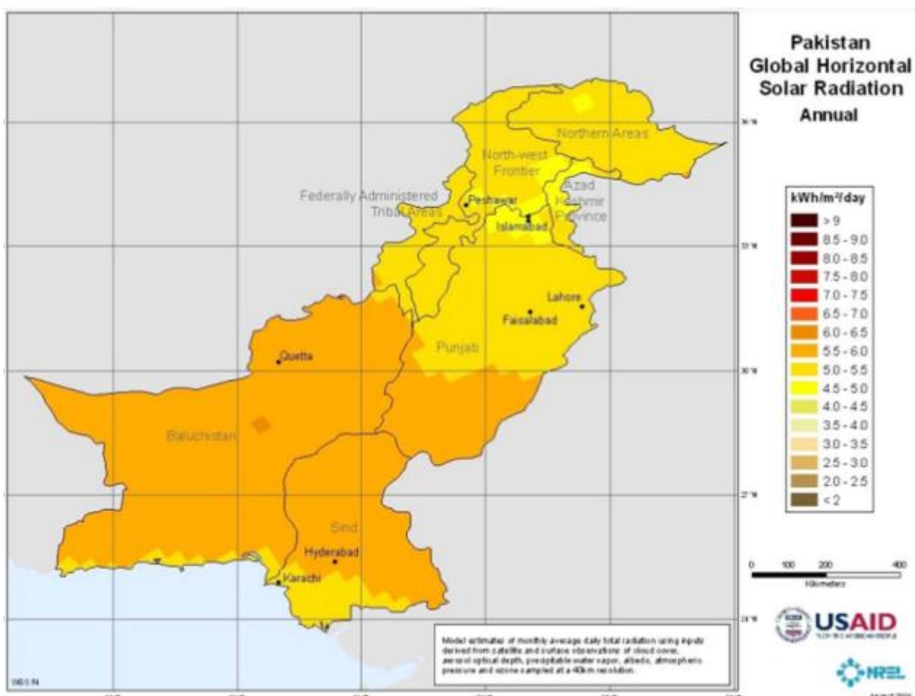


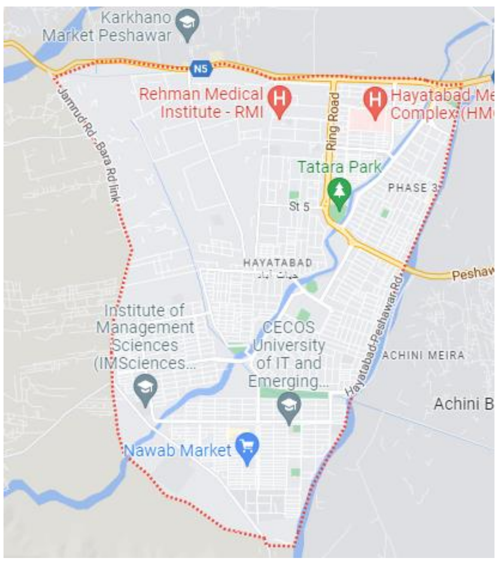
Figure 5: Annual mean daily solar radiation (kW h/m^2) using NREL's CSR model (GHI) **[31]**

We see that the average GHI values in Baluchistan, Sind and southern Punjab are ranges from 5.5 to 6.0 kWh/m^2/day. In the rest of Pakistan, the GHIs values ranges from 5.0 to 5.5 kWh/m^2/day. Hence it shows that Pakistan has a lot of solar resources which make it a favorable candidate for solar energy technologies especially solar water heating (SWH) system.

IV. STUDY AREA

A small township Hayatabad is located at 34° N and 71° E with altitudes between 0–3000 m, benefiting from a substantial amount of sunshine. The average daily solar radiation is between 2–7 kWh/m^2 and the annual average solar radiation is 2132 kWh/m^2. As the applicability of SWH system mainly depends on the potential of solar radiations at the location of interest, hence based on the geographical parameters of study area, the local and seasonal variation of solar irradiations at Hayatabad are considered. To find the total energy saved per household by implementing SWH system in Hayatabad region we needs daily average value of Global Horizontal Irradiance (GHI) at that region. "**Figure 6 (b)"** shows the minimum, maximum and average GHI values for study area.

There is a wide variation of hot water consumption in Pakistan, e.g., the lowest and highest sets in summer and winter times, respectively. This leads to a great electricity demand and associated costs for providing this hot water by conventional heating systems at most times of the year. Further, we consider the average hot water consumption in study area is 50 L/person, requiring a hot water of 250L/household/day, if we consider average family consist of 5 person. More than 67% of the national energy is generated using imported fossil fuels, which causes an incline in energy bills. This leads to an increased economic dependency to the international oil price changes which affects public finances notably **[32].** Pakistan aims at achieving 5-6% of its total on-grid electricity supply from renewables (excluding large hydropower) by 2030 **[33].**



(a)

Peshawar (Hayatabad)		
Min	**Max**	**Mean**
3.02	7.30	5.16
2.68	7.05	4.99
2.64	6.63	4.65
2.40	6.44	4.65
2.92	7.37	5.05
2.92	7.36	5.05

(b)

Figure 6: Study Area (a) Map of Hayatabad (b) Min and Max GHIs values **[34].**

Daily Global Horizontal Irradiance for Study Area

This research work is a case study for a small township named Hayatabad situated in Peshawar, Pakistan. Hayatabad region consist of seven phases and blessed with abundant solar radiation which can be utilised with solar energy technologies especially solar water heating (SWH) system. **"Table 1"** shows that the latitude and longitude in study area are 34.00° N and 71.52° E respectively, altitude is about 359 m from sea-level. The daily minimum and maximum solar insolation are about 3.02 to 7.30 kWh/m^2, so the average GHI value is 5.16 kWh/m^2 which is enough for SWH system implementation.

Table 1 Solar radiation data for study area i.e. Hayatabad, Peshawar.

Station	WMO index	Latitude (°N)	Longitude (°E)	Altitude (m)	Solar insolation (kW h/m²)		
					Minimum	Maximum	Annual
Peshawar	41,530	34.00	71.52	359	3.02	7.30	5.16

V. DATA AND METHODOLOGY

The efficiency of SWH system principally depends on the availability of solar thermal energy at desired position on the earth surface. Therefore in order to conduct a Cost-Benefit Analysis of SWH system, both the cost and associated benefits need to be analysed based on the available solar energy potential at study area. For our research work we acquired the required data from different sources. The nature of data and sources acquired for this study is given in **"Table 2".**

Table 2 Nature and source of central data used in the study

S.r.NO	Nature of Data Acquired	Source of Data
1	SWHS Specifications (Maintenance cost, Operational cost, Tank Capacity, Material of construction) for the study area	Nizam Solar Energy, Karkhano Market, Peshawar, Pakistan
2	Pricing and Tariff of Natural Gas, Annual price variation rate (2019 to 2021)	Oil And Gas Regulatory Authority (OGRA)
3	Domestic natural gas consumer's data of Islamabad region (2019 to 2021)	Sui Northern Gas Pipelines Limited (SNGPL)
4	Monetary Statistics, Average Inflation Rate & Discount Rate of Pak (FY, 2019 to 2021)	Published reports, Economic Data File, State Bank of Pakistan
5	SWHS local market Prices in Pakistan (2016)	Paktron Pvt Ltd, Pakistan
6	Pricing and Tariff of Electricity & annual price variation rate (2019 to 2021)	National Electric Power Regulatory Authority (NEPRA)

The main source of SWH system is the solar thermal energy, so SWH system efficiency largely depends on its availability. In our study as we are mainly focusing on the benefit analysis of SWH system so all the benefits have to be analyzed on the basis of solar energy at study area. For the estimation of benefit and cost analysis of SWH system adaptation in the Hayatabad, Peshawar, Pakistan at residential sector. We use the radiation data from SWERA website which can be accessed SAM solar resource library.

Initially, we downloaded the weather files using SAM's library for study area. The applicability of SWH system at a specific region is dependent on seasonal variations of solar radiations. Therefore, we consider the estimated solar intensity for the complete one year for the study area. Proposed SWH system model have two collectors and each collector area of 4 m^2, the tilt angle and azimuth angle are putted in the SAM according to the latitude and longitude of study area. Another factor regarding the applicability of SWH system is the desired hot water outlet temperature; hence the desire temp is set along with other parameters. After entering the entire required parameters and data, next step is to simulate and get the result in the form of annual energy reduction per year. The energy reductions and benefits analysis of SWH system were explored in view this data. The overall benefits of SWH system adaptation can be analyzed from difference of cost savings due to installation of SWH system reduces conventional water heating resources and environmental impacts, Although for domestic purposes the reduction in the use of conventional energy is considered as total net saving in this study.

The payback period and annual cost savings for SWH system are calculated on the basis of reduction in the use conventional energy sources i.e. electricity and natural gas substitution. For study area, the simulation gives useful energy outputs gives the annual energy reductions by replacing the traditional sources, however for benefit analysis which includes both cost analysis and reduction in the outflow of greenhouse gases and environmental hazardous gases were calculated empirically using Error! Reference source not found. and Error! Reference source not found..Based on the financial savings due to reduction in the use of traditional energy sources, the payback period is calculated empirically.

VI. SWH SYSTEM MODEL & ITS SIMULATION

i. Solar Radiation Data used for simulation

There is an average solar radiation intensity ranges from 1500 W/m^2/day to 2750 W/m^2/day for 10 hours per day in Pakistan **[35].** There are many sources from where we can get the measured solar data for a specific location of Pakistan but we can also find solar radiation data from SWERA database for simulations which can be access from SAM resource library. The annual global horizontal irradiance (GHI) values for Peshawar, Pakistan are shown in **"Table 3"**.

Table 3 Data for study area from SWERA weather database

REGIONS	Station ID	Latitude	Longitude	Annual GHI values (KWh/m^2/day)
Peshawar	15140	34.05	71.55	4.97

ii. SWH System Model and its useful energy outputs

The approximate energy outputs of proposed SWH system model are calculated using SAM simulation tool for study area of Pakistan i.e. Hayatabad, Peshawar. Vacuum Tube Solar Collector prepared by Zhejiang Shentai Solar Energy Co. Ltd. with brand name Suntask and model No. SR30 (**"Figure 7"**) which is certified from Solar Rating & Certification Corporation (SRCC) is installed to calculate annual average solar thermal energy produced by SWH system in the study area.

Figure 7: Installed SWH system on rooftop of a house in Hayatabad, Peshawar.

Table 4: Characteristics of Proposed SWH system Model

SWH SYSTEM PARAMETERS	QUANTITATIVE VALUE
Company name	Zhejiang shanti solar energy Co. LTD.
Brand name	Suntask

Model no.	SR30
Solar collector area	4(m^2)
Y- intercept	3.85(W/m^2.C)
Tank size	250(L)
Desire water temp	65 (°C)
Efficiency	50(%)
SRCC number	2009004C

For simulation purpose data of typical meteorological year (TMY) of different years is used and it is obtainable from solar resource library of SAM for specific area under consideration.

The proposed system model optimal sizing was developed on the basis of factors such as the hot water requirement of a 4 to 5 family members per household, necessary solar fraction, economic features, location vise solar energy supplies, and other weather-related aspects. It is estimated that an average household (typical) can consumed 250 litres of hot water per day. Required collector area of solar plates is 64.2 L/m2 which provide water temperature of 65 oC with collector efficiency of 0.50 as mentioned in "Table 4". The common insulating material polyurethane foam is used for storage tanks of hot water, with thermal conductivity of 0.52 Watt/ (m2. K), for 50 mm of thickness.
The recommended thickness of insulation for the 19 mm diameter pipes that are used in SWH system is 6 mm, which have a thermal conductivity of 0.03 W/ (m.C).

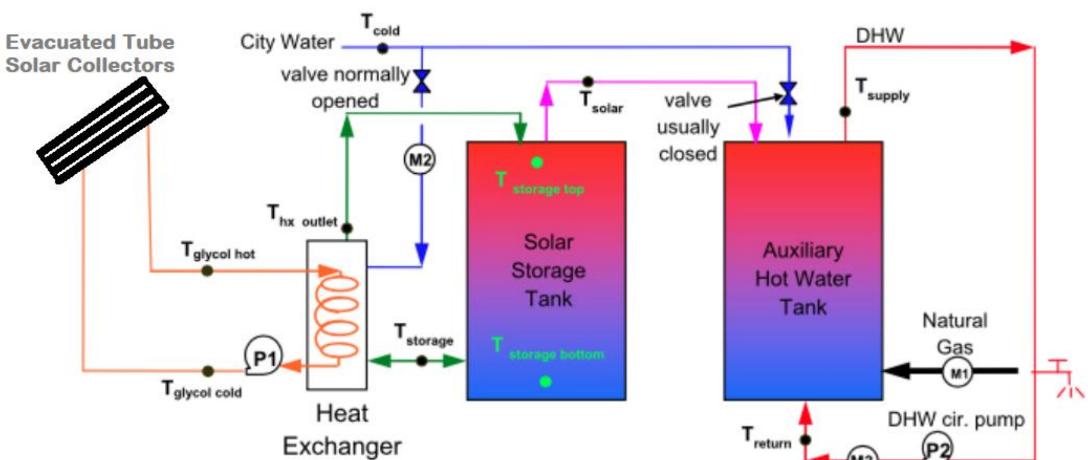


Figure 8: Schematic Diagram of proposed Residential (Domestic) SWH system Model

The system model in SAM indicated in **"Figure 8"** showing a SWH system of closed loop system consists of two evacuated tube collector and tilt angle equal to latitude of the respective location, azimuth angle of 180 °, 45 W pump with 85% efficiency, heat exchanger effectiveness of 75% and one storage tank with commercially available auxiliary electric heater of volume 0.3 m^3, height to diameter ratio of 2.8, heat loss coefficient of 0.52 W/ (m^2.K) and a maximum water temperature of 95 ° C. The outlet set temperature is 65 °C and the mechanical room temperature is 25 ° C. The length of pipe is 10 m with 0.019 m diameter of and insulation thickness of 0.006 m with 0.03 W/ (m.C) insulation conductivity. The characteristics of collector of the used SWH system model i.e. total/gross area and optical gain (Y-intercept) is shown in **"Table 4".**

It is assumed that collectors are connected in parallel and the major inputs of SWH system which we are taking in our consideration are the working fluid flow rate and the incident angle modifier (IAM) in SAM.

The potential benefits of SWH system include cost savings (financial benefit) through the use of renewable energy sources for water heating rather than traditional ones, as well as reductions in the emissions of greenhouse gases (GHGs). Here we have analyzed these benefits on the basis of potential of solar thermal energy (STE) and the magnitude of global horizontal irradiance (GHI) in the specific region under consideration.

A. Benefits analysis of SWH system in HAYATABAD, Pakistan

i. Energy reduction by replacing conventional energy resources with SWH system

The generated energy of SWH system replaces the conventional energy sources for water heating purpose. The useful energy outputs for study area are obtained using SAM simulation on a particular SWH system as indicated in **"Table 5"**.

The energy reduction outputs from SAM simulation for Hayatabad, Peshawar is 3741 kWh. The substituted traditional energy sources for water heating in Pakistan include natural gas and electricity mostly. Total annual Energy Reduction (ER) for a single user of a SWH system by replacing traditional energy source (Electricity, Natural gas) are presented in **"Table 5"**. The results of annual energy reduction were quite similar with the results of **[36]** which are done for Islamabad.

Table 5 Annual Energy Reductions (ER) through SWH system by substituting conventional source

Region	Electricity(KWH)	Natural gas(MMBTU)
Hayatabad, Peshawar	3741	12.7549

ii. Benefit-Cost analysis of SWH system

The cost savings associated with SWH system are estimated using the annual energy reductions for a single household in the particular study area. Considering the average of annual energy tariff of conventional sources and the total annual averaged energy savings due to SWH system, the financial savings were calculated empirically using **"E.q(1)"**. The Cost savings due to SWH system for different regions of Pakistan are determined **[37]** .

$$(CS)_S = ER_S . ET_S \qquad \textit{E.q(1)}$$

CS_s represent annual cost savings due to SWH system by replacing particular previous source "s", ER_s is the total annual energy reductions per household and ET_s is energy tariff for substituted energy source. Energy tariff are taken from respective government bodies websites **[38], [39]**, given in **"Table 6"**.

Table 6 Energy Tariffs of conventional sources.

Fiscal year	Electrical power Tariff (USD/KWh)	Natural gas Tariff (USD/MMBTU)	LPG Tariff (USD/Kg)
2019	0.15	9.45	0.69
2020	0.14	9.41	0.74
2021	0.14	9.45	0.94

Graph is generated for cost saving when the conventional energy source is replaced by SWH system. From **Table 7**, we can see that if the natural gas is replaced by SWH system, it can save 120.53 US dollars ($) of energy cost per annum per household in Hayatabad, Peshawar. Similarly if the SWH system replaces electric power heating system, it can save 523.74 US dollars ($) of energy cost per annum per household in study area as shown in **"Table 7".**

Table 7 Cost savings if previous sources were replaced by SWH system.

Region	Electricity($)	Natural gas($)
Hayatabad, Peshawar	523.74	120.53

iii. Mitigation in the emissions of GHG and environmental hazardous gases

As in the earlier discussions we have mentioned that the main source for SWH system is solar energy, so SWH system implementation will reduces fossil fuels combustion which gives mitigation in the GHGs emissions and environmental hazardous gases. The emission factor of various pollutants emitted during fossil fuels combustion has fixed values which are used for water heating or electricity generation as listed in **"Table 8"** [36].

The estimated value of various air pollutants gases i.e. CO_2, SO_2, NO_X reduced annually due to substitution of traditional water heating system by SWH system are shown in **"Fig"**. The mitigations in pollutants are determined on the basis of coal, natural gas and crude oil used for direct water heating and the electricity generation, monthly energy produced by SWH system and the emissions rates of each pollutant. **"E.q(2)"** is used for the assessment of pollution reduction using SWH system **[37].**

$$RP = ER * EF \qquad \textit{E.q(2)}$$

In the above equation RP stands for the reduction in pollution , ER are the energy reductions and EF is the emission factors of different sources as mention in **“Table 8”.** From **“Table 8”** we concluded that coal has the highest CO2 emission rate of 1.18 Kg per kWh of energy generated. As a result we can say that, if a resident of specific region replaces coal as previous source by SWH system then there is a huge potential to reduce the GHGs emissions as well as other environmental polluted gases like Sulphur dioxide (SO2) and Nitrogen oxide (NOx). As we know that in Pakistan, 67% of power is produced from fossil fuel (coal, natural gas and crude oil) [40]. So, if a householder replaces an electric water geyser with a SWH system, there is an indirect decrease in fossil fuel combustion used for generation of electricity and, as a result, a reduction also occurs in GHGs emissions.

Table 8 Emission factors

S/No	Sources	Emission rates (Kg/KWH)		
		CO_2	SO_2	NO_X
1.	Natural gas	0.53	0.0005	0.0009
2.	Coal	1.18	0.0139	0.0052
3.	Electric power	0.00	0.0000	0.0000
4.	Crude oil	0.85	0.0164	0.0025

The adoption of a single SWH system mitigates 1982.73 Kg of Carbon dioxide (CO_2), 1.87 Kg of sulphur dioxide (SO_2) and 3.37 Kg of Nitrogen oxide (NO_x), annually per household in study area if substituted source is Natural gas.

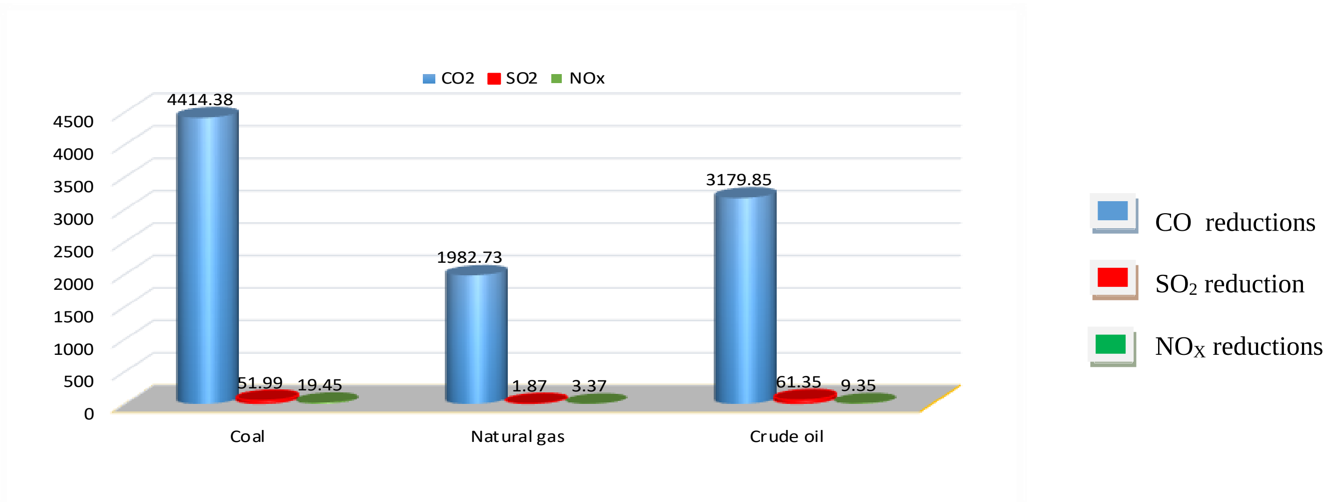


Figure 9: Mitigations in GHGs emissions by a residential SWH system implementation (Kg/year/SWH)

The results also shows that if the coal is replaced by SWH system then it can reduce the GHGs emission by 4414.38 kg of CO_2, 51.99 Kg of SO_2 and 19.45 kg of NO_x annually by a single household adoption in the study area. Similarly, we also see the results for crude oil used for electricity production saved by SWH implementation in **“Figure 9”.**

B. Payback Period Analysis of SWH System

The payback period is calculated using a detailed analysis of the financial advantage obtained from monthly energy savings based on annual costs and benefits. It goes without saying that the economic benefits can offset the SWH system's entire capital cost although; the ecological benefits of SWH system’s application on the user's end remain unnoticed. The overall financial benefits of SWH system are heavily influenced by the pace of change in tariffs for fossil fuels used for water heating. The domestic tariff changed for natural gas is 11.94% in fiscal year 2019 to 2021**[38].** Similarly, electricity annual price changed by 5.54% in fiscal year 2019 to 2021 **[39].** It is noteworthy here that once the payback period is attained, then the subsequent benefits of SWH system will be included in the overall resident’s monthly income.

In this study the proposed model has system cost of 896$, balance cost of 111$ and installation cost of 97$. The net capital cost (annual cost) for proposed SWH system is estimated as shown in **“Table 9”**.

Table 9 Costs

Direct capital cost($)			Indirect capital cost (%)	Average Inflation Rate of Pak, 2020) (IR)	Net capital cost ($)
System cost	Balance cost	Installation cost	5	10.74	1160.69
896	111	97			

SAM have different variables on the Costs page SWH System which are used to calculate the project installation cost (investment) and annual maintenance costs reported in the project cash flow and used to calculate cost metrics. Collector cost ($\$/m^2$) is the cost of collectors used in the system. Labor costs for installation of collectors can be included in collector cost or it can be separately incorporate in the installation cost category. Storage cost ($\$/m^3$ or $/Unit) is the cost of the solar storage tanks for water or fluids.

The balance of system ($) is a fixed cost that accounts for items costs such as mounting racks and pipes that aren't included in the collector and storage cost categories. Installation cost ($) is a fixed cost that can be used to account for labor or other expenses that are not covered by the other cost categories**.** Sometime we should take contingency costs in our calculation but here we can’t consider it. Contingency (%) is a percentage of the sum of the collector, balance of system, installation and storage costs to account for anticipated uncertainties in estimates of direct cost. Indirect costs are those that can't be traced back to a particular piece of equipment or installation service **[41]**.

The overall annual cost is compared with annual benefits to estimate the payback period for residential SWH system. “Table 10” shows the calculation of annual cost for an operational year. Similarly, the annual Cost Savings (CS) of SWH system is evaluated on the basis of savings due to substitution of previous energy resources.

Simple payback period for the proposed system is calculated using **“**
E.q(3**)”** as mentioned below **[42].**

$$Pb(y) = \frac{ln(\frac{IC * iF}{ER * ET} + 1)}{ln(1 + iF)} \qquad \text{Eq (3)}$$

In the above equation, IC represents the initial costs of the system and IF is the inflation rate of Pakistan for year 2020 which is 10.47 **[43]**, ER represents the energy reductions and ET is the energy tariff. Simple payback period is calculated for the five regions as mention in Table 8.

Table 8 Payback period calculations of SWH system applications in selected area.

Region	Payback time (Yrs) if SWH system replaces	
	Electricity	Natural gas
Peshawar	2.0	6.9

Conclusions

This study examines the potential and significance of SWH system to alleviate the challenges of unmet electricity demand, imported oils dependency and unsustainable supply of fossil fuels in Pakistan.

Analyses of SWH system were performed in this study which is proposed on the basis of the annual cost savings, net capital cost and payback time. In our study area we estimate the reduction in the conventional energy consumption at residential sector as an application of SWH system, subsequently the reduction in the negative impacts of fossil fuels consumption. Efficiency of SWH system is taken as 50% which is a considerable value aims to avoid overestimation of households financial saving.

From this study we can easily conclude and examine the potential and importance of SWH system to mitigate the challenges regarding the shortfall of electricity and dependence on imported fossil fuels in Pakistan. The total output energy of a SWH system consists of two collectors for specific study region of Pakistan is estimated using SAM. The energy reductions due to SWH system in residential sector are calculated for Hayatabad Township. The results show that if SWH system replaces natural gas it can save 120.53 US dollars ($) of energy cost per annum per household for Hayatabad township in Peshawar. Similarly, it can save 12.652 MMBtu of natural gas if SWH system is installed in Peshawar. If the SWH system replaces electric power and

LPG the energy reductions and cost analysis are also calculated showed above in tables and graphs.

In study area, the SWH systems application in residential sector reduces the consumption of conventional energy sources, as well as a significant amount of mitigation in the GHG and environmental polluted gases produced due to fossil fuels combustion can be realized but the present SWH system utilization in Pakistan is very low. The main barriers which come across the promotion of SWH system include the lack of budgetary support of stakeholder's and also lack of sensitivity of public as well as policy makers for SWH system, absence of regulatory framework and high initial capital cost of SWH system.

REFERENCES

[1] Alayi R, Shamel A, Kasaeian A et al. The role of biogas to sustainable development (aspects environmental, security and economic). J Chem Pharm Res 2016;8:112–8.

[2] Alayi R, Kasaeian A, Atabi F. Thermal analysis of parabolic trough concentration photovoltaic/thermal system for using in buildings. Environ Prog Sustain Energy 2019;38:13220.

[3] Zhang N, Lior N, Jin H. The energy situation and its sustainable development strategy in China. Energy 2011;36:3639–49.

[4] A. Håkansson et al. (Eds.): Sustainability in Energy and Buildings, 2013, SIST 22, pp. 787–796. DOI: 10.1007/978-3-642-36645-1_70

[5] M. Kumar, "Social, Economic, and Environmental Impacts of Renewable Energy Resources," Wind Sol. Hybrid Renew. Energy Syst. [Working Title], pp. 1–19, 2020, doi: 10.5772/intechopen.89494.

[6] Dehghan, M.; Pfeiffer, C.F.; Rakhshani, E.; Bakhshi-Jafarabadi, R. A Review on Techno-Economic Assessment of Solar Water Heating Systems in the Middle East. Energies 2021, 14, 4944. https://doi.org/ 10.3390/en14164944

[7] Sadhishkumar, S.; Balusamy, T. Performance improvement in solar water heating systems—A review. Renew. Sustain. Energy Rev. 2014, 37, 191–198.

[8] Majdi, H.; Nabiha, N.; Issam, A.; Abdelhamid, F. Solar water heating systems feasibility for domestic requests in Tunisia: Thermal potential and economic analysis. Energy Convers. Manag. 2013, 76, 599–608.

[9] Vanessa, M.T.B.; Racine, T.A.P. Reduction of carbon dioxide emissions by solar water heating systems and passive technologies in social housing. Energy Policy 2015, 83, 138–150.

[10] Zhang, L.; Xia, J.; Thorsen, J.E.; Gudmundsson, O.; Li, H.; Svendsen, S. Technical, economic and environmental investigation of using district heating to prepare domestic hot water in Chinese multi-storey buildings. Energy 2016, 116, 281–292.

[11] Fuentes-Cortés, L.F.; Ma, Y.; Ponce-Ortega, J.M.; Ruiz-Mercado, G.; Zavala, V.M. Valuation of water and emissions in energy systems. Appl. Energy 2016, in press.

[12] Denholm, P. The Technical Potential of Solar Water Heating to Reduce Fossil Fuel Use and Greenhouse Gas Emissions in the United States. Available online: http://images.hw.net/IAPMO/GreenPlumbers_education_preview/data/downloads/national%20renewable%20energy%20laboratory%20technical% 20report.pdf (accessed on 09 July 2022).

[13] Hackett, M.J.; Gray, N.F. Carbon Dioxide Emission Savings Potential of Household Water Use Reduction in the UK. J. Sustain. Dev. 2009, 2, 36–43.

[14] Jorge, A.R.F.; Dionicio, R.F.; José, L.F.Z. Potential energy saving in urban and rural house holds of Mexico by use of solar water heaters, using geographical information system. Renew. Sustain. Energy Rev. 2016, 53, 243–252.

[15] Haralambopoulos D, Paparsenos GF, Kovras H. Assessing the economic aspects of solar hot water production in Greece. Renewable Energy 1997;11: 153–67.

[16] Diakoulaki D, Zervos A, Sarafidis J, Mirasgedis S. Cost benefit analysis for solar water heating systems. Energy Conversion and Management 2001;42:1727–39.

[17] Kaldellis JK, El-Samani K, Koronakis P. Feasibility analysis of domestic solar water heating systems in Greece. Renewable Energy 2005;30: 659–82.

18] Werner Weiss, Monika Spörk-Dür Solar Heat Worldwide Available online: http://www.iea-shc.org/solar-heat-worldwide (accessed on 28 Aug 2022)

[19] Alexandru Serban et al. Economic and Environmental Analysis of Investing in Solar Water Heating Systems Sustainability 2016, 8, 1286; doi:10.3390/su8121286.

[20] Islam, R.M.; Sumathy, K.; Samee, U.K. Solar water heating systems and their market trends. Renew. Sustain. Energy Rev. 2013, 17, 1–25

[21] Shukla, R.; Sumathy, K.; Erickson, P.; Gong, J. Recent advances in the solar water heating systems: A review. Renew. Sustain. Energy Rev. 2013, 19, 173–190.

[22] Ali, K., Bakhsh, S., Ullah, S. et al. Industrial growth and CO2 emissions in Vietnam: the key role of financial development and fossil fuel consumption. Environ Sci Pollut Res 28, 7515–7527 (2021). https://doi.org/10.1007/s11356-020-10996-6

[23] Global Carbon Project. (2021). Supplemental data of Global Carbon Project 2021 (1.0) [Data set]. Global Carbon Project. https://doi.org/10.18160/gcp-2021.

[24] Andrew, Robbie M., & Peters, Glen P. (2021). The Global Carbon Project's fossil CO2 emissions dataset [Data set]. Zenodo. https://doi.org/10.5281/zenodo.5569235.

[25] https://ourworldindata.org/co2-emissions

[26] Sukhera MB, Pasha MAR, Naveed MS. Solar radiation over Pakistan – comparison of measured and predicted data. Sol Wind Technol 1986;3:219–21

[27] Raja IA, Twidell JW. Distribution of global insolation over Pakistan. Sol Energy 1990;44:63–71.

[28] Raja IA, Twidell JW. Statistical analysis of measured global insolation data for Pakistan. Renew Energy 1994;4:199–216.

[29] Ahmad I, Akhter P, Zaidi Z. Solar radiation over Pakistan. Appl Sol Energy 1995;31:41–50.

[30] George R, Maxwell E. High-resolution maps of solar collector performance using a climatological solar radiation model. Golden, CO (US): National Renewable Energy Lab.; 1999.

[31] National Renewable Energy Laboratory USA. Pakistan resource maps and toolkit; 2016.

[32] Z. T. Ebrahim, "No Title Pakistan faces an unexpected dilemma: too much electricity." p. 1, 2021.

[33] https://energypedia.info/wiki/Pakistan_Energy_Situation

[34] Tahir, Z.u.R., Renewable and Sustainable Energy Reviews (2017), http://dx.doi.org/10.1016/j.rser.2017.06.090 S

[35] Adnan, A. Hayat Khan, S. Haider, and R. Mahmood, "Solar energy potential in Pakistan," J. Renew. Sustain. Energy, vol. 4, no. 3, May 2012, doi: 10.1063/1.4712051.

[36] M. Sadiq, "Solar water heating system for residential consumers of Islamabad, Pakistan: A cost benefit analysis," J. Clean. Prod., vol. 172, pp. 2443–2453, 2018, doi: 10.1016/j.jclepro.2017.11.166.

[37] T. C. Pan, J. J. Kao, and C. P. Wong, "Effective solar radiation based benefit and cost analyses for solar water heater development in Taiwan," Renew. Sustain. Energy Rev., vol. 16, no. 4, pp. 1874–1882, 2012, doi: 10.1016/j.rser.2012.01.014.

[38] OGRA, "Sale_Price_Notification_Dated_October_23_2020.Pdf." 2020.

[39] NEPRA, "National Electric Power Regulatory Authority Islamic Republic of Pakistan." 2020.

[40] Z. T. Ebrahim, "No Title Pakistan faces an unexpected dilemma: too much electricity." p. 1, 2021.

[41] "Home - System Advisor Model (SAM)."

[42] S. A. Kalogirou, "Solar Energy Engineering: Processes and Systems: Second Edition," Sol. Energy Eng. Process. Syst. Second Ed., pp. 1–819, 2014.

[43] Statista.com, "• Pakistan: Inflation rate 2014-2024 | Statista," 2021.

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