ENERGY AND CLIMATE
PANORAMA

Assessment of SOLAR TUBE WELL POTENTIAL In Balochistan

ABOUT US

Who we are

We are a dedicated team of researchers and experts who recognize the urgent need for action in addressing climate resilience and energy transition in Pakistan. Our mission is to develop and implement effective policies for cleaner, renewable energy sources like solar and wind, aligning with Pakistan's 2030 goal of 30% renewable energy in its electricity mix. As a multidisciplinary team, we leverage expertise in three key disciplines of study—Energy Systems Engineering, Thermal Energy Engineering, and Electrical Power Engineering—to drive our mission forward. We are united by a shared vision of creating a sustainable and resilient future for Pakistan, where cleaner energy sources play a pivotal role in reducing the nation's vulnerability to climate-related challenges.

What we do

We conduct in-depth, evidence-based research to analyze and improve energy policies in Pakistan. Our focus is on advancing renewable energy solutions and engaging stakeholders to ensure effective policy implementation. Our methodology involves a critical examination of current energy policies to pinpoint areas of improvement and formulate strategies for the widespread adoption of renewable energy sources across various levels.

In line with our commitment to fostering sustainable practices, we have established a fellowship program as part of our broader initiatives that aims to facilitate evidence-based research for promoting energy transition in Pakistan. Through research studies, surveys, and forecasting, we plan to assess various aspects of energy transition, including the adoption of renewable energy technologies and their impact on climate change. Our approach involves active engagement with stakeholders to address their concerns and facilitate the effective implementation of policies, fostering the growth of renewable energy manufacturing and marketing facilities.

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Executive Summary

Water is a vital resource with diverse applications, supporting livelihoods globally in activities such as household chores, drinking, power generation, and notably, agriculture. In Pakistan, particularly in rural areas like Balochistan, agriculture is a cornerstone of the economy, making water resources crucial. However, conventional electricity generation for agricultural needs contributes to greenhouse gas emissions, prompting a global shift towards renewable energy in line with the Paris Agreement. Balochistan faces the pressing issue of water scarcity, affecting its agriculture-dependent economy. With agriculture contributing significantly to Balochistan's GDP, dwindling water resources hinder productivity. Prolonged droughts, exacerbated by climate change, have led farmers to rely on diesel or electric tube wells, presenting challenges like rising fuel costs and carbon emissions. Despite these challenges, Balochistan's abundant solar energy potential makes it an ideal candidate for transitioning to solar-powered tube wells.

The report evaluates the feasibility of deploying solar-powered tube wells in Gawadar, Balochistan, emphasizing economic and technical considerations. Despite the positive environmental impact, challenges related to governmental policies and sustainable development goals must be addressed. Surveys involving government officials, experts, and local residents are conducted to gather insights into water availability, quality, energy crisis, and the effects of existing solar tube wells. Technical and environmental assessments using RETScreen software reveal that an 8.9KW solar tube well can be economically viable, with a 26.9KW photovoltaic system demonstrating a substantial benefit-cost ratio in off-grid scenarios. Adopting off-grid solar systems not only meets load demand but also significantly reduces greenhouse gas emissions, contributing to a pollution-free operation.

In conclusion, transitioning to solar-powered tube wells in Balochistan presents a promising solution to water scarcity, enhancing agricultural productivity and aligning with environmental sustainability. However, addressing barriers and policy challenges is crucial to fully realizing the potential benefits of this clean energy solution.

1. Introduction

Modern industrialization has made energy a fundamental human need and, therefore, essential for driving the global economy. But, due to the increase in population and ever-growing demand, the world is facing an energy crisis. Continuous production of electrical energy from fossil fuels causes an increase in GHG emissions which must be reduced. According to the Kyoto Protocol, the world must shift towards renewable energy resources for energy production to control the rise of atmospheric temperature due to increased CO2 amount and reduce the emissions of GHGs. Moreover, fossil fuel reserves are also being depleted, as in 2019, still, 84.3% of the energy is produced from fossil fuels, and generation from renewable energy only accounts for 11.4% [1]. Agriculture is an important sector that is responsible for the growing economy of Pakistan, provides food security, and reduces poverty. The climate of Pakistan is arid with four seasons having versatility in temperature, minimum humidity, and total arable land of 30.510 million hectares in 2021. In 2014, agriculture accounted for 21% of Pakistan's GDP while providing 44% of employment to the workforce[2]. Water is a necessity of the agricultural sector for proper irrigation to yield high-quality crops. In Pakistan, the agriculture sector requires 93% of water, 4% of water is utilized for households, and 3% is required for industries. However, the situation of the agriculture sector becomes adverse due to the prevailing energy crisis which relies on conventional resources for electricity generation but due to an increase in fuel prices, or limited reserves, changes the scenario of the world's economy[3]. Therefore, we are required to shift towards renewable energy resources such as wind, solar, or biomass to make better use of the power requirement in agriculture. Moreover, an increase in population size causes the intensified irrigation of land to maximize its cropping potential which in turn enhances the requirement of water for crop cultivation. Therefore, the issue of water scarcity, lack of proper irrigation, and inefficient farming techniques that affect crop productivity must be addressed. The main interest of our study is to analyze the above-mentioned issues in Balochistan, one of the provinces of Pakistan.

Apart from water scarcity or energy crisis, climate change is also an important aspect to be studied. Due to the rapid use of fossil-fuel-based resources, carbon emissions continue to increase which will further alter the environmental aspect of the world. Their use enhances the emissions of greenhouse gases, causes global warming, and affects the pattern of rainfall or crop production. Climate change has caused irregular rainfalls which urges nations towards increased use of groundwater to meet their agricultural needs. In turn, the depletion of groundwater increases due to the greater dependency of people on its extraction to fulfill basic requirements. People living in rural areas highly depend on the agriculture sector, so they spend a lot of money on diesel-based generators to produce water for irrigation purposes. But, due to flaring prices of diesel fuel and greater emissions of carbon that will adversely affect the climate, Pakistani farmers are showing less interest in the utilization of diesel generators. Electric-based generators are also not reliable for farmers due to less supply of electricity in rural areas and increased load shedding. hours affect their work. Therefore, due to the drying of natural resources, they have to depend on the extraction of underground water by installing tube wells or pumps[4]. Extensive pumping or extraction of water also has reduced the groundwater due to which feasible location must be selected for installation of tube wells to cope with groundwater depletion issues. Moreover, solar tube wells will be installed to reduce GHG emissions and global warming. This study investigated the technical feasibility of installing solar tube wells in Balochistan with an emphasis on the reduction of GHG emissions and analyzed the cost-effectiveness of the adopted methodology.

1.1 The geographical location of Balochistan

Balochistan is a province which is located in the southwestern part of Pakistan. The largest province by land area of Pakistan is Balochistan but it has the lowest population density. Despite covering 44% of Pakistan's land area, Balochistan contributes only 5% of its arable land due to its dry climate and rough terrain. It has a high temperature of 25.34ºC with very low annual rainfall of 6.95%. Balochistan has enriched potential for renewable energy (RE) resources and is considered the second largest supplier of natural gas in Pakistan. Balochistan experiences the highest solar radiation among all Pakistan's provinces with a yearly average daily solar radiation of 5.9-6.2 kWh/m2/day and while yearly average sunlight duration of 8-8.5 hours, according to World Bank studies[5]. Therefore, the RE potential of Balochistan must be exploited to achieve better sustainable goals.

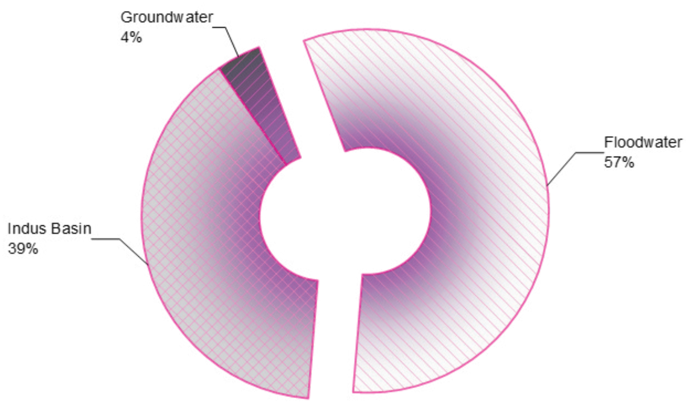

Fig 1. *Distribution of Water Resources in Balochistan*

People residing in rural areas of Balochistan account for about 75% of the Balochistan population due to which the majority of the workforce (60%) depends on agriculture for their livelihoods[2]. The agriculture sector contributes about 2/3 of the provincial GDP with 97% of water utilization for crop production. Balochistan has a total geographic area of 34.7 million hectares, of which only 2.07 million are farmed, while the other 54% is now uncultivated owing to a shortage of water. The three significant water sources are the Indus Basin, groundwater, and flood water with their distribution illustrated in Fig 1. Groundwater comprises springs, river flows, karezes, tube wells, and open surface wells [6]. Traditionally, Karezes were utilized for irrigation purpose that taps the water into underground water but the installation of tube wells have distorted this traditional system[3]. Moreover, as shown in Fig 1, floodwater contributes to a major portion of water resources in Balochistan, but water scarcity remains an issue due to the following reasons: lack of efficient flood control systems to utilize flood flows, impractical water management systems, absence of effective irrigation infrastructure, poor monitoring of water resources and nonexistence of proper water storage facilities such as dams.

However, due to the increase in population, adverse dry weather, dehydration of natural water resources, low rainfall due to climate change, and higher dependency of inhabitants on the agricultural sector, the government provides subsidies to install tube wells for the removal of underground water. The excess use of tube wells has also depleted the groundwater due to inefficient water management or storage systems, which is a major issue for the province. This study explored the RE potential of Balochistan to install solar tube wells at feasible locations with deeper levels which will be environmentally friendly as well as cost-effective in meeting the provincial demand.

1.2 Objectives of the study

The main aim of the proposed study is to examine the technical and economic feasibility of employing solar tube wells in Balochistan. The main objectives are described as

1. To address the water scarcity issue in Balochistan and analyze the current situation of an energy crisis, droughts, as well as depletion of groundwater.
2. To access the environmental impact of shifting towards solar energy in Balochistan and its influence on the Sustainable development goal (SDG 13) that accounts for climate action.
3. To accomplish the Sustainable development goal (SDG 6) of providing clean and adequate water in Balochistan by installing solar tube wells.
4. To explore the various barriers, government policies, and technical challenges that must be tackled for the implementation of solar tube wells in Balochistan. Apart from several challenges, optimal solutions for the installation of solar tube wells are also proposed despite various grid or transmission system issues.

1.3. Limitations of the Study

1. There is a limited amount of available and reliable data on water scarcity, tube well specification, energy crisis, and solar potential which will affect the results.

1. The geography, climate, and socioeconomic conditions of Balochistan vary greatly. Therefore, findings from one area may not be fully applicable to others, posing a problem of generalizability.
2. Several factors could impact our proposals' effectiveness, including technical limitations, maintenance challenges, as well as the suitability of various solar technologies in certain areas.

2. Sources of Literature Review

For organizing my report, I have read many articles and journals explaining the water depletion issue, the situation of the energy crisis, and the condition of already installed electric as well as solar tube wells in Balochistan. I also extract significant information from websites. I also gather the declarations of expert people from the internet. Several questions based on the study's purposes have been revised by the supervisor after the draft questionnaire was constructed. I go through so many newspapers to collect much valuable information. I also gather reviews from survey forms on questionnaires from government officials, residents, and community members for writing my paper.

2.1 Literature Review

This report [7] gives an overview of current practices in the use of renewable energy technology in Balochistan. It examined the various challenges, institutional government, and organizational setup involved in utilizing RE in various projects of Balochistan as well as provided various recommendations along with efficient planning for increased utilization of RE resources. The study [3], [8] investigated the water scarcity issue in Balochistan which results in long-term droughts and effect their agricultural sector and livestock. It evaluated the cause of the water depletion issue after conducting detailed qualitative and quantitative research and concluded that lack of installation of storage dams or improper water management facilities are major reasons behind these issues. Authors in [9] studied the groundwater depletion issue occurring due to uncontrolled groundwater usage in the Kuchlagh district of Balochistan. It evaluates the depletion of the alluvial aquifer in a particular district that occurs due to its intensive use by more than 300 agricultural tube wells for many decades. Pakistan is enriched with solar potential so the study [10] examined the potential of installing a solar system for off-grid and grid-connected networks. It compared three types of PV modules of the same size for comparing their energy output which are thin-film, premium, and standard.

Instead of the traditional karez system used for irrigation purposes in Balochistan, the study [11] provided a detailed analysis of replacing Karezes with tube wells, which can efficiently be used for irrigational purposes and improving their rural economy. The researchers in the study[4] examined the impact of installing tube wells on the water table and discharge rate of the Quetta Valley aquifer and also performed an economic analysis of employing a solar pumping system in contrast to the typical traditional WASA tube wells. They analyzed the cost-effectiveness of employing solar PV tube wells in their proposed methodology using RET Screen software and determined their CB ratio to find the most optimal capacities of solar pumps. The research [6] conducted the solarization of electric tube wells in Balochistan to reduce carbon emissions thus assessing the environmental impact of installing solar tube wells. Moreover, it also performed financial analysis, reduced electrical subsidies provided by governments, and provided recommendations to improve the current situation in Balochistan. It concluded that solarization of electric tube wells can save up to 850-900 MW which can be sold to other sectors. The purpose of the study [12] is to investigate how electricity subsidies affect tube well owners and water buyers from a financial perspective and to propose alternative subsidy policies that would balance efficiency and equity.

Conventionally, diesel-based tube wells were used for irrigation purposes so the authors in the study [13] proposed a solar-based irrigation system in Pakistan to utilize clean energy. It conducted a detailed analysis to determine the number of solar panels, capacities, and amount of GHG emissions reduced by using a solar-based irrigation system. It has been found that 8960.3-kilo Tons of carbon emissions is reduced by operating solar system. The cost analysis of the PV water pump is performed using RETScreen software in research [14] which provided the result that installation of a 4.48KW PV pump causes a 7MWh reduction in annual peak load. Moreover, the installation of PV pumps also reduces the issue of load shedding faced by farmers during irrigation. Authors in [15] studied the long-term effect of economic expansion, increased use of electricity in the agricultural sector, financial development, and population on the environmental condition of Pakistan from 1980-2016. They concluded that a 1% rise in economic expansion will improve the environmental condition of Pakistan by 0.45%. Mostly, the regions with plenty of renewable resources face water scarcity issues, therefore the paper[16] utilized the abundant solar energy potential in Pakistan and promoted the traditional irrigation system to a drip or sprinkle irrigation structure. It was observed that water and desalination demand will be reduced by 54% and 80%, respectively, when the country's total irrigation efficiency is enhanced to 90% by 2050.

An investigation of solar energy harnessing potential was conducted in the Upper Indus Basin(UIB) region of Pakistan to assess its suitability for the adoption of solar-powered irrigation systems (SPIS)[17]. For this analysis, they considered the various climatic and geographical aspects of the Hindukash, Himalayas, and Karakoram regions. Although the initial cost of PV is expensive as compared to diesel generators, they require less maintenance and labor costs. Introduced various indicators (EIR, ESI) in [18] to determine the sustainability of agricultural productivity, environmental, and economic aspects in various provinces of Pakistan. Authors in [19] investigated the isolated DC system which is capable of meeting the demand of de-centralized domestic households by using HOMER Pro software. They performed the technical and cost analysis on the designed CHP system depending on renewable energy resources. The study [20] assessed the technical and economic feasibility of installing a solar water heating system in Skardu and Gilgit. ETC, FPC, and UnGC solar collectors were determined based on their maximum temperature and efficiency. It was proposed that ETC indicated 75% solar fraction, 40% efficiency, and 676 kg carbon dioxide emissions as compared to FPC.

The supply of electricity in rural areas is a major hindrance, so the study [21] analyzed the effectiveness of the proposed design considering PV/biomass using HOMER Pro to meet the electric demand in the small village of Layyah. The cost of energy (COE) and net present cost (NPC) of the system were examined for analyzing the technical aspect of the design and performed sensitivity analysis by utilizing solar irradiance, biomass price, and potential of biomass as sensitivity input parameters.

A feasibility and cost study of a PV-based solar water pumping system was performed in research[22] for a site located in Rahim Yar Khan. It was watered by 5 pumping systems and an optimized design was selected by using HOMER Pro, which provided a PV of 52.8KW and a power converter of 8.31KW as the optimal capacity of the proposed system. The study [23], [24]examined the feasibility of installing solar tube wells in Bakhar Punjab due to its shorter payback length of 1.42 years as compared to diesel-based generators.

3. Research Methodology

This report analyzed the technical and financial feasibility of implementing solar-based tube wells in Balochistan using RETScreen software. The detailed cost-effectiveness analysis of solar-based tube wells and their comparison with conventional diesel-based generators in off-grid and grid-connected scenarios are conducted in a related study. Moreover, the environmental impact of installing solar tube wells in reducing greenhouse gas emissions is also evaluated using RETScreen software. To conduct this research, the Gawadar district has been chosen for data collection. Primarily interviews, questionnaires, and literature review are used to conduct this study. The steps adopted in the proposed methodology are described in Fig 2.

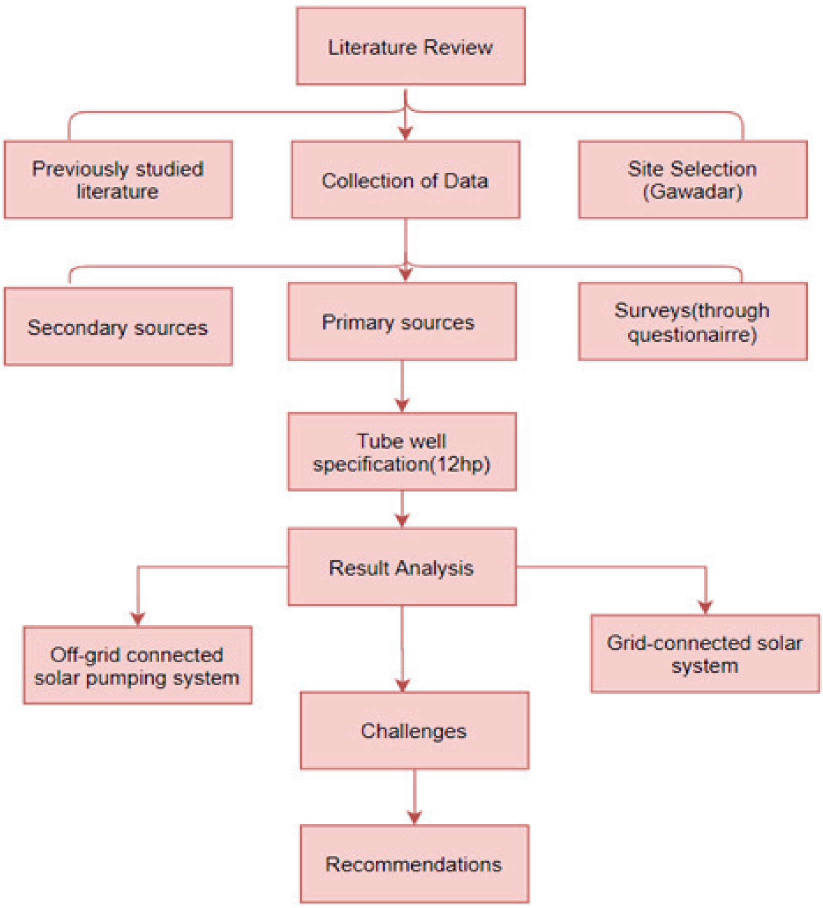

***Fig 2.** Steps in Proposed Methodology*

3.1 Study Area

Gwadar, a famous coastal city in Pakistan's Balochistan region, is located on the southern Arabian Sea coast, with coordinates of 25.1390° N latitude and 62.3295° E longitude. The city is distinguished by its unique soil composition, which consists mostly of sandy and gravelly soils and might offer difficulties for some types of construction and agricultural activity. Gwadar's extraordinary sun intensity is one of its distinguishing traits, owing to its geographical location near the equator and very clear sky. As a result, the city is an excellent site for harvesting solar energy via photovoltaic systems. The region's abundance of sunlight and high levels of solar insolation offer a favorable environment for solar power generation, contributing to the region's potential for sustainable energy solutions. Gwadar has a hot desert environment, which is typical of Balochistan's dry areas. Summers in the city are hot, with temperatures frequently surpassing 40°C (104°F), but winters are cooler, with temperatures averaging around 18-20°C (64-68°F). Because of the low yearly precipitation, water supply is a critical factor for the city's growth. Despite the difficult climate and geography, Gwadar's strategic position, developing port facilities, and renewable energy potential make it a focus point for economic growth and regional connection activities. The lack of dam or reservoir construction in Gawadar is one of the major challenges that poses water scarcity issues in respective areas which motivates us to address the above issue by implementing solar tube well installation in Gawadar.

Growth of Tube wells in Balochistan

The number of tube wells in Balochistan was 5000 in 1980 but it increased to over 45,000 in 2015 due to the introduction of electricity with subsidized flat rates. The increased development of tube wells has also affected the availability of groundwater. Although residents in respective provinces highly depend on groundwater but lack of efficient monitoring and storage systems highly affected their utilization. The total number of diesel and electric-based tube wells already installed in Balochistan in 2018 is given in Table 1[6].

Tube wells in Balochistan	Diesel operated	Electric operated	Total
	15,449	30,387	45,836

Table 1. *Total number of Tube wells installed in Balochistan [6]*

3.2 Collection of data

Data are collected from two sources; these are as follows:

Primary data sources:

- Conduct with knowledgeable residents and relevant authorities in Balochistan.
- Through consulting with technical experts.

- Gather valuable information from government officials.
- Members of different areas and communities.

Secondary data sources:
- Research journals.
- Different websites.
- Collected data from newspaper articles. Gathered information through reports and books.

3.3 Sampling Procedure

Sampling has been accomplished on a random basis. A total of 40 samples were taken based on random sampling. The respondents of this research were 26 to 68 years old. I have selected stratified random sampling required to choose the respondents. In this case, technical experts, and officers both male and female gave their opinions about the water scarcity issue, the feasibility of installation of solar tube wells, and their impact on reducing greenhouse gas emissions in Balochistan. The members of different areas and communities in Balochistan also give their views on the research.

3.4 Questionnaire for Survey

As part of this research, the questionnaire was designed based on the objectives of the study. Several closed-ended and open-ended questions have been included in this survey.In total, there are 20 questions in the questionnaire, with most of them being open-ended.

3.5 Sample size or number of the respondents

The total number of respondents is 200 which includes various government officers, senior citizens, technical experts, relevant authorities, and different community members chosen using the above-mentioned sampling methods.

4. Analysis of Survey

The researcher employed an open-handed questionnaire with technical experts, government officials, and residents of Balochistan as a collection of primary source data. Several questions were asked regarding Balochistan's financial, environmental, and water scarcity issues. Some of the analyses from the survey are provided here:

1. The researcher asked questions from participants which factors are more responsible for the water scarcity issue in Balochistan. After analysis, they found that 29.7% of people considered human beings responsible for water scarcity, 15.6 percent considered environmental factors for water depletion in Balochistan and48.4% declared both man-made as well as environmental factors for the water crisis, as depicted in Fig 3. Thus, from the results, it is concluded that man-made factors as well as environmental factors contribute much to the water scarcity issue in Balochistan.

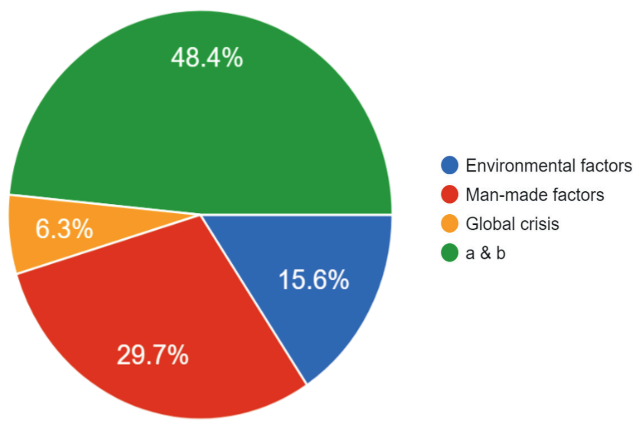

***Fig 3.** Percentage Distribution of the Factors Contributing to the Water Crisis*

2. The researcher asked questions from participants that if man-made factors are responsible for the water scarcity issue, then how? After analysis, they found that 4.7% of people declared lack of planning as an important factor responsible for water scarcity, and 20.3 percent considered government negligence for water depletion in Balochistan while 6.3% of individuals specified improper training and awareness among people as significant factors for water shortage as depicted in Fig 4. Thus, from the results, it is concluded that 68.8% of individuals contribute to the involvement of all mentioned factors that result in water scarcity due to human actions.

3. The researcher asked questions from participants, Do you believe that installing a solar tube well system would benefit your community? After analysis, they observed that most of the people strongly agreed with the installation of solar tube wells which will meet the water needs as well as reduce the energy crisis faced by residents which is 50 percent, 46.9 percent agreed with the installation of solar tube wells while 1.6 percent disagreed with solar tube wells installation due to its adverse impact on reducing groundwater from excessive water extraction, as depicted in Fig 5. Thus, from the results, it is concluded that the installation of a solar tube well system would be beneficial for residents of Balochistan.

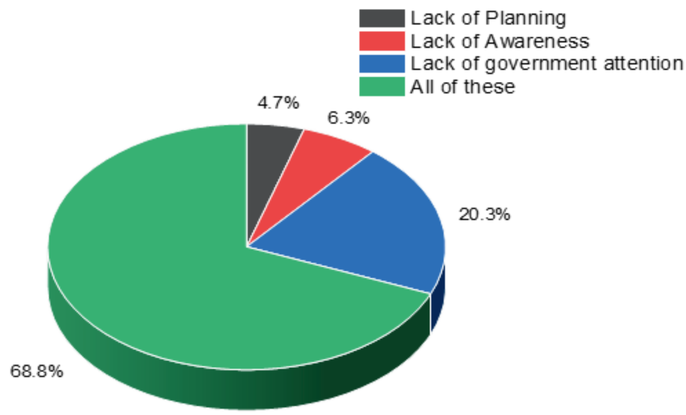

***Fig 4**. Percentage Distribution Related to the Man-made Factors Contributing to the Water Crisis.*

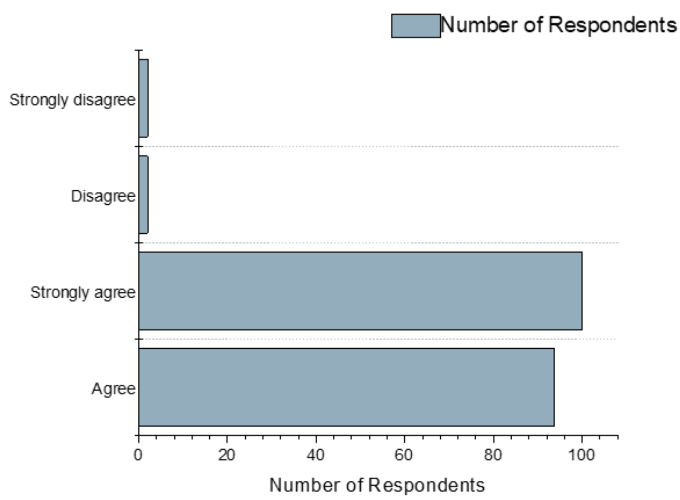

***Fig 5.** Percentage Distribution Concerning, do you believe that installing a solar tube well system would benefit your community?*

5. The researcher asked questions participants what benefits they would expect from the installation of solar tube wells in Balochistan. After analysis, they examined that 53.1% of people expected access to clean water with the aid of solar tube wells, most of the people considered that greenhouse gases emissions could be reduced by adopting solar tube wells which are 6.3 percent, while 10.9 percent considered water-borne diseases can be reduced which will improve overall health by implementing solar wells installation in Balochistan, as depicted in Fig 6. Thus, from the results, it is concluded that access to clean water is easily available for farmers and residents with a reduction of GHG emissions and improved community health due to solar tube wells installation.

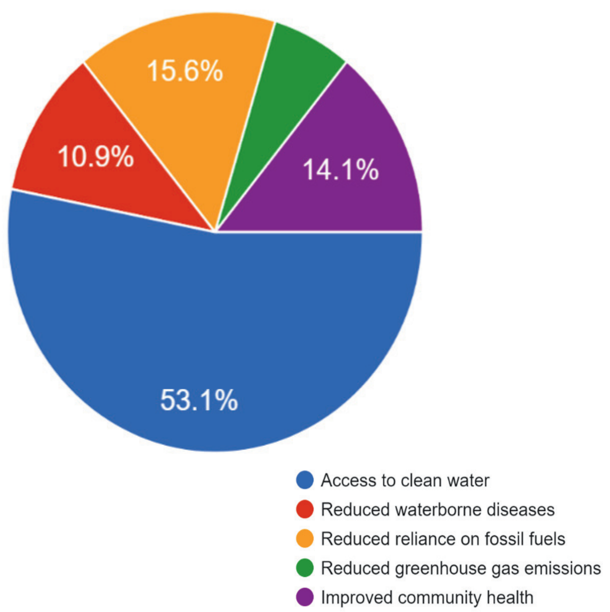

***Fig 6.** Percentage Distribution Regarding, which benefits the participants will expect from the installation of solar tube wells in Balochistan?*

6. The researcher asked questions from participants about which factors must be considered to improve the water scarcity situation in Balochistan. After analysis, they evaluated that 6.3% of people considered efficient water management systems for reducing water scarcity, 10.9% considered the adoption of modernized irrigation systems to reduce water wastage while 15.6 percent reflected the construction of water storage facilities for mitigating water depletion in Balochistan, as depicted in Fig 7. Thus, from the results, it is concluded that 67.2% declared the efficient irrigation system, proper water management facilities and construction of storage dams to be updated for improving the current situation of the water crisis in Balochistan, thus improving quality of life and agricultural productivity.

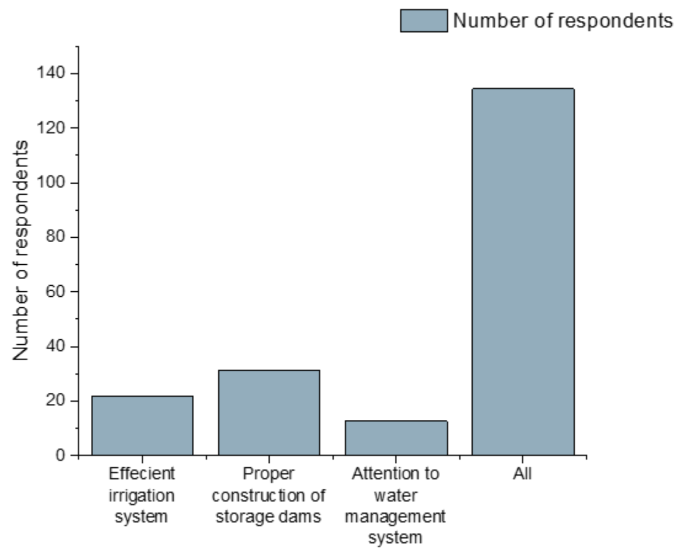

***Fig 7.** Percentage Distribution Regarding, which factors must be considered to improve the water scarcity situation in Balochistan?*

7. The researcher asked questions from respondents whether the implementation of a solar tube well system can improve the sustainability of the agricultural sector in Balochistan or not. After analysis, they evaluated that 14.8% of people strongly agreed with the solar tube well installation for the agricultural sector, 33.6% agreed that implementation of solar tube wells increases agricultural productivity, while only 0.8% disagreed with their installation, as depicted in Fig 8. Thus, from the results, it is concluded that the installation of solar tube wells may increase agricultural productivity by providing consistent water to farmers.

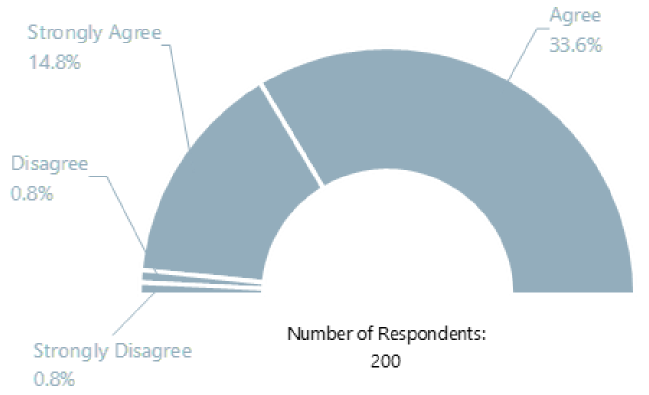

Fig 8. *Do you agree that the implementation of a solar tube well system can improve the sustainability of the agricultural sector in Balochistan?*

8. The researcher asked questions from respondents whether they think that the community can afford the initial cost of setting up a solar tube well system or not. After analysis, they evaluated that, only 29.7% of people think that Balochistan can cope with the initial cost of setting up the solar tube wells and 28.1% don't think that the Balochistan community deal with the initial cost of starting the solar tube wells, as depicted in Fig 9. Thus, from the results, it is concluded that the majority of people (42.2%) are not sure about whether the investors handle the initial cost of installation of solar tube wells or not.

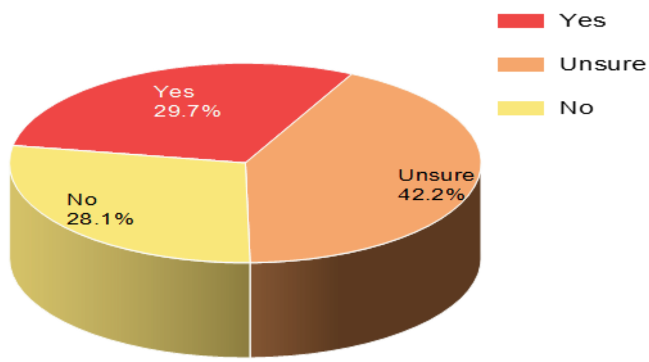

Fig 9. *Can your community afford the initial cost of setting up a solar tube well system?*

5. Technical and environmental assessment

5.1 Off-grid Solar Pumping System

The high amount of solar radiation up to 6.46 KWh/m2/day as depicted in Fig 10 motivated us to replace the diesel tube well installed in Gawadar to be converted to a solar system for the efficient production of water. A diesel-based tube well of 8.9KW (12hp) installed in Gawadar has been converted to a solar-based system. A 26.9KW capacity of photovoltaic is selected that would be 300% higher than the total load, delivering an energy of 11,163 KWh. A total hydraulic head of 25 meters was achieved by the tube well discharge of 25mm3 per second. A borehole that is 110 feet deep under the earth is made up of a blind borehole (50 feet) and a screen borehole (60 feet) with a diameter of 12.7 cm (5 inches). A three-stage submersible pump with a diameter of 15.24 cm (6 inches) was inserted into a borehole to a depth of 65 feet. A submersible pump is powered by 72 solar panels rated at 360 watts each. The battery involved for the purpose of energy storage is installed in a system which is 40% photovoltaic capacity. A brief comparison of an off-grid solar pumping system and a grid-connected system is analyzed

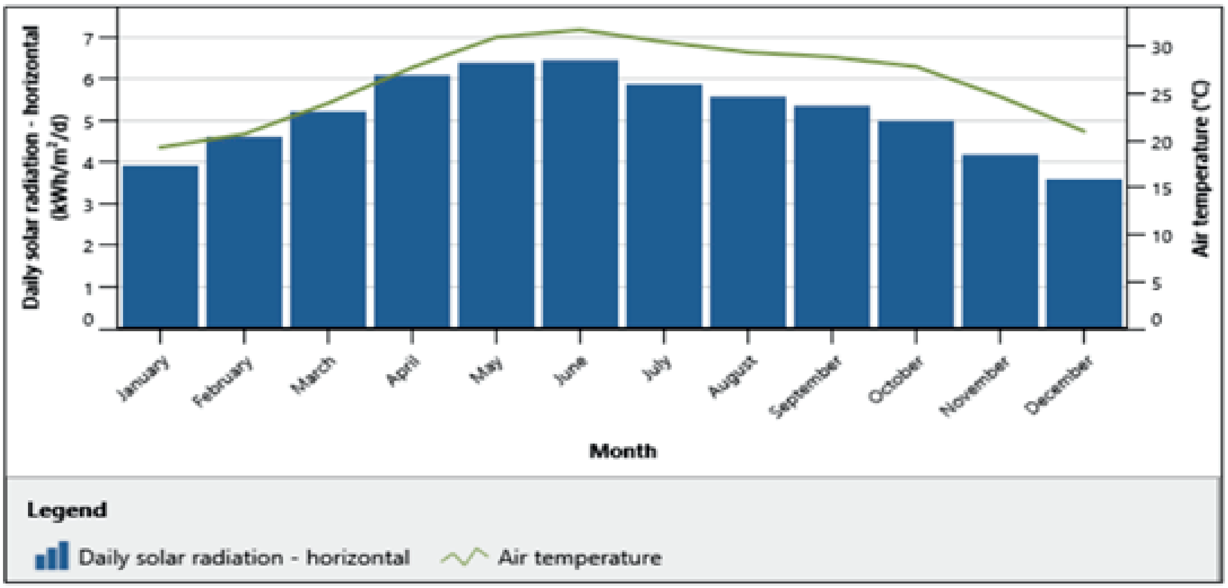

Fig 10. *Solar Radiation intensity in each month in Gawadar*

in RETScreen software concerning carbon dioxide emissions, benefit-cost ratio, payback period, and net present value. In an off-grid solar pumping system, the base case consists of diesel operating the tube well and the proposed case involves the photovoltaic operating the tube wells.

5.1.1 GHG Emissions Reduction

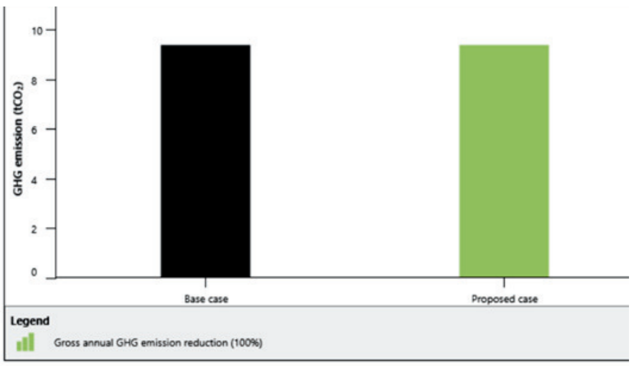

Fig 11. *GHG Emission reduction*

In the case of a base case involving diesel-based generators, 9.4tCO2/yr GHG emissions are produced which are annually reduced to 0 with the use of a solar-based system given in Fig 11. Therefore, solar pumping systems are environmentally friendly with zero emissions.

Annual revenue

GHG reduction revenue		
Net GHG reduction	tCO_2/yr	9
Net GHG reduction - 21 yrs	tCO_2	197
GHG reduction credit rate	$\$/tCO_2$	362
GHG reduction revenue	$	3,404
GHG reduction credit duration	yr	0
Net GHG reduction - yrs	tCO_2	
GHG reduction credit escalation rate	%	

We also analyze the total revenue generated from GHG reduction. As we have already observed total GHG emissions are 9.4tCO2/yr, then for 21 years it will be 197tCO2. From the results, it is examined that 3404$ GHG reduction revenue is generated by providing a substantial GHG reduction credit rate to customers.

5.1.2 Impact of input parameters on Net Present Value (NPV)

A project's net present value is the sum of all future cash flows discounted at the discount rate in today's currency. The NPV approach compares the present value of all cash inflows against the present value of all cash outflows connected with the project. Positive NPV numbers indicate that a project is theoretically feasible. The NPV generated for our off-grid project is 22,174$. The total initial costs of operating the solar-based system are 6717$ in our analysis with O&M costs of 349$ given in Table 2.

Total operational cost of PV	349$
The total initial cost of PV	6,717$
Total off-grid diesel initial cost	8000$
Total operational cost of off-grid diesel	3298$
Total operational cost of PV	349$
The total initial cost of PV	6,717$
Total off-grid diesel initial cost	8000$
Total operational cost of off-grid diesel	3298$

Table 2. *Costs of equipment in the project*

5.1.3 Total Annual saving and Revenue

An 8% inflation rate and,10.5% discount rate is considered with a project life of 21 years for financial analysis. Total costs and revenue generated after the installation of solar tube well systems are analyzed in this section. Annual savings and revenue generated will be 6702$ illustrated in Fig 12.

5.1.4 Sorted by impact

The effect of input parameters on NPV is given in Fig 13. It is observed that the impact of base-case fuel cost is greater than that of other parameters on NPV. Increasing fuel cost will improve NPV, whereas increasing initial cost will decrease it.

Initial costs			
Power system	100%	$	6,717
Total initial costs	100%	$	6,717
Yearly cash flows - Year 1			
Annual costs and debt payments			
O&M		$	349
Debt payments - 15 yrs		$	516
Total annual costs		$	865
Annual savings and revenue			
Fuel cost - base case		$	3,298
GHG reduction revenue - yrs		$	3,404
Other revenue (cost)		$	0
Total annual savings and revenue		$	6,702

Fig 12. *Annual Savings and Revenue*

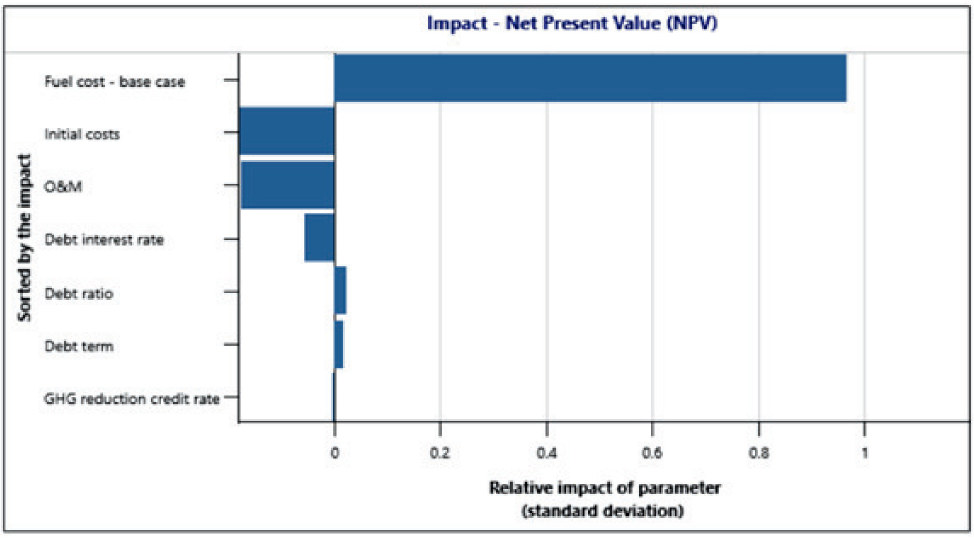

Fig 13. *Impact of input parameters on NPV*

5.1.5 Distribution Graph

The histogram shows the distribution of possible values for the financial indicator. Depending on the width of each bar, the height of each bar represents the frequency (%) of values falling within that range. The X-axis plots the value that corresponds to the middle of each range.

5.1.6 Benefit-cost Ratio

The benefit-cost ratio reflects the project's relative profitability. The model computes the net Benefit-Cost ratio, which is defined as the ratio of the project's net benefits to expenses. Profitable initiatives have ratios larger than one. In our proposed case, a Benefit-Cost ratio of 12 is achieved.

5.1.7 Payback Period

The simple payback is the number of years it takes for the cash flow (excluding debt payments) to equal the total investment (which includes both debt and equity). The payback period for our project is 1.1 years in the case of an off-grid solar-based pumping system depicted in Fig 15.

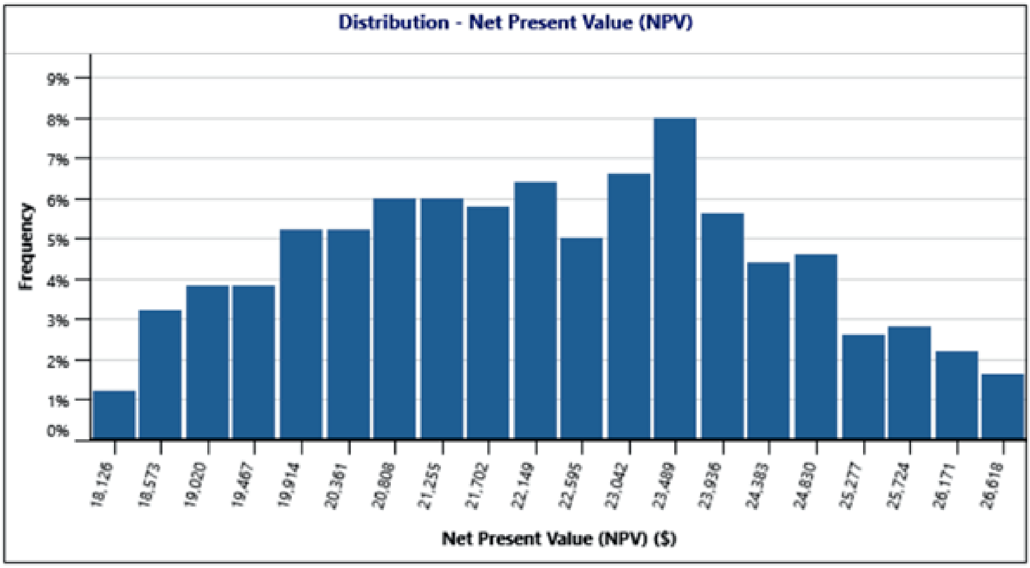

Fig 14. *Distribution graph of NPV*

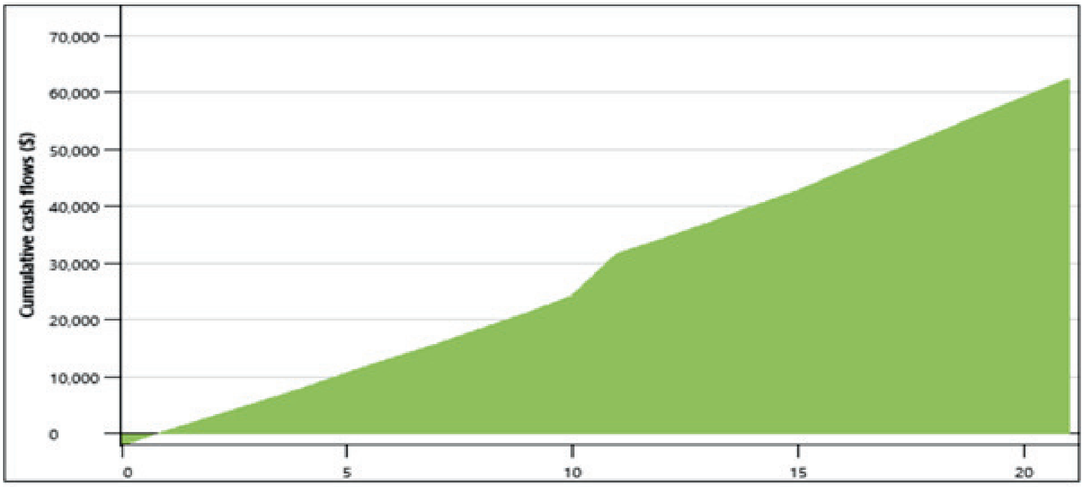

Fig 15. Cumulative cashflow graph

5.2 Grid-connected Solar Pumping System

In grid-connected solar system, a grid having a capacity of 26.865KW with annual O&M costs of 500$ is required to operate a tube well in the base case while in the proposed case, solar is used to operate the tube well. The cost of operating the PV and grid-based system in the project is given in Table 3.

Total operational cost of PV	349$
The total initial cost of PV	6,717$
Total grid initial cost	8000$
Total operational cost of grid	1616$

Table 3. *Costs of equipment in the project*

5.2.1 GHG Emissions Reduction

In the case of a base case involving diesel-based generators, 4.7tCO2/yr GHG emissions are produced which are annually reduced to 0 with the use of a solar-based system given in Fig 16. Therefore, solar pumping systems are environmentally friendly with zero emissions.

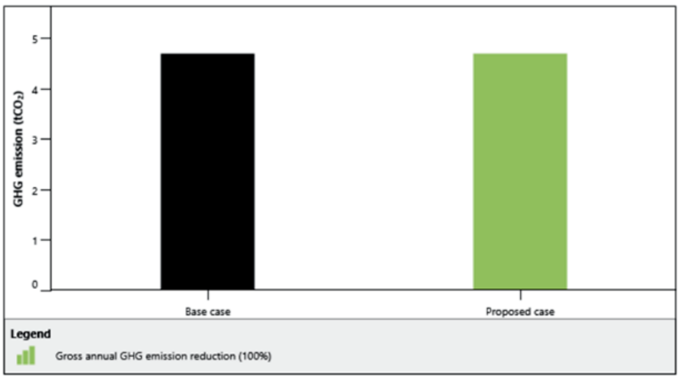

Fig 16. *GHG Emission reduction*

We also analyze the total revenue generated from GHG reduction. As we have already observed total GHG emissions are 4.7tCO2/yr, then for 21 years it will be 99tCO2. From the results, it is examined that 1702$ GHG reduction revenue is generated by providing a substantial GHG reduction credit rate to customers.

Annual revenue		
GHG reduction revenue		
Net GHG reduction	tCO_2/yr	5
Net GHG reduction - 21 yrs	tCO_2	99
GHG reduction credit rate	$\$/tCO_2$	362
GHG reduction revenue	$	1,702
GHG reduction credit duration	yr	0
Net GHG reduction - yrs	tCO_2	
GHG reduction credit escalation rate	%	

5.2.2 Impact of input parameters on Net Present Value (NPV)

The NPV approach compares the present value of all cash inflows against the present value of all cash outflows connected with the project. Positive NPV numbers indicate that a project is theoretically feasible.

The NPV generated in the case of the grid-connected system is 5751$.

5.2.3 Total Annual saving and Revenue

An 8% inflation rate and,10.5% discount rate is considered with a project life of 21 years for financial analysis. Total costs and revenue generated after the installation of solar tube well systems are analyzed in this section. Annual savings and revenue generated will be 3,318$ illustrated in Fig 17.

Initial costs			
Power system	100%	$	6,717
Total initial costs	100%	$	6,717
Yearly cash flows - Year 1			
Annual costs and debt payments			
O&M		$	349
Debt payments - 15 yrs		$	516
Total annual costs		$	865
Annual savings and revenue			
Fuel cost - base case		$	1,616
GHG reduction revenue - yrs		$	1,702
Other revenue (cost)		$	0
Total annual savings and revenue		$	3,318

Fig 17. *Annual Savings and Revenue*

5.2.4 Sorted by impact

The effect of input parameters on NPV is given in Fig 18. It is observed that the impact of base-case fuel cost is greater than that of other parameters on NPV. Increasing fuel cost will improve NPV, whereas increasing initial cost will decrease it.

5.2.5 Distribution Graph

The histogram (Fig 19) shows the distribution of possible values for the financial indicator. Depending on the width of each bar, the height of each bar represents the frequency (%) of values falling within that range. The X-axis plots the value that corresponds to the middle of each range.

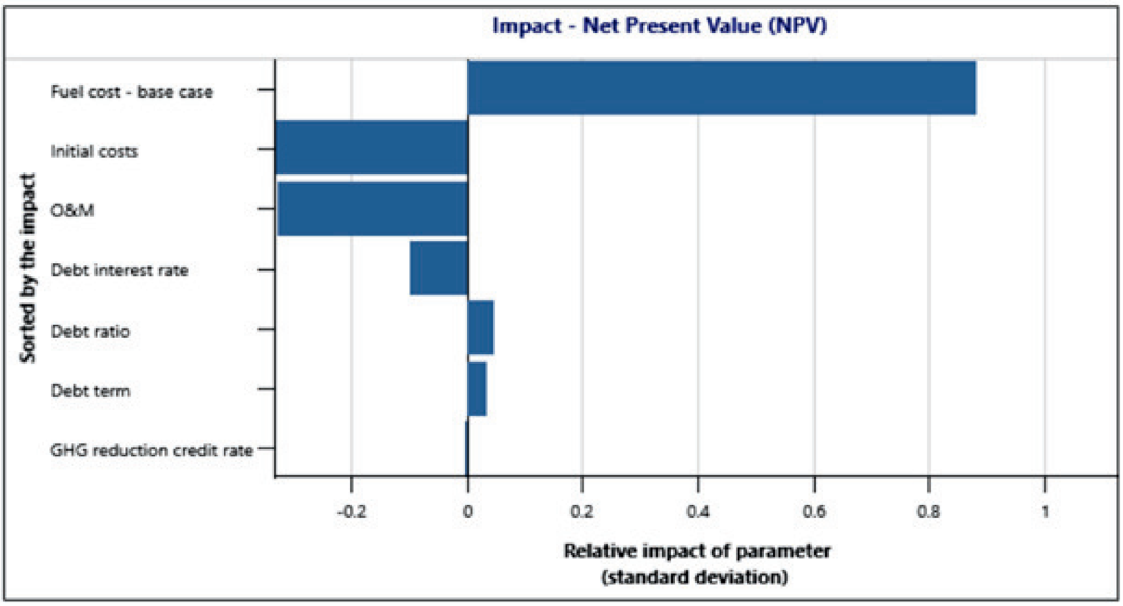

Fig 18:. *mpact of input parameters on NPV*

5.3 Benefit-cost Ratio

The benefit-cost ratio reflects the project's relative profitability. The model computes the net Benefit-Cost ratio, which is defined as the ratio of the project's net benefits to expenses. Profitable initiatives have ratios larger than one. In our proposed case, a Benefit-Cost ratio of 3.9 is achieved.

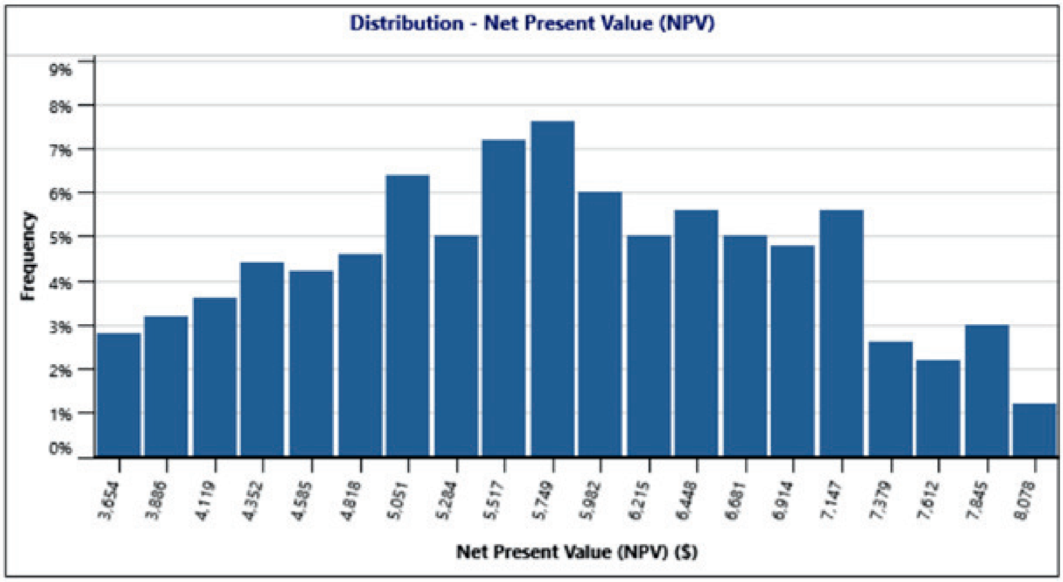

Fig 19. *Distribution graph of NPV*

5.4 Payback period

The simple payback is the number of years it takes for the cash flow (excluding debt payments) to equal the total investment (which includes both debt and equity). The payback period for our project is 2.3 years in the case of an off-grid solar-based pumping system depicted in Fig 20. The total revenue generated in the grid-connected case is less due to which it takes more time to recover investment as compared to the off-grid case.

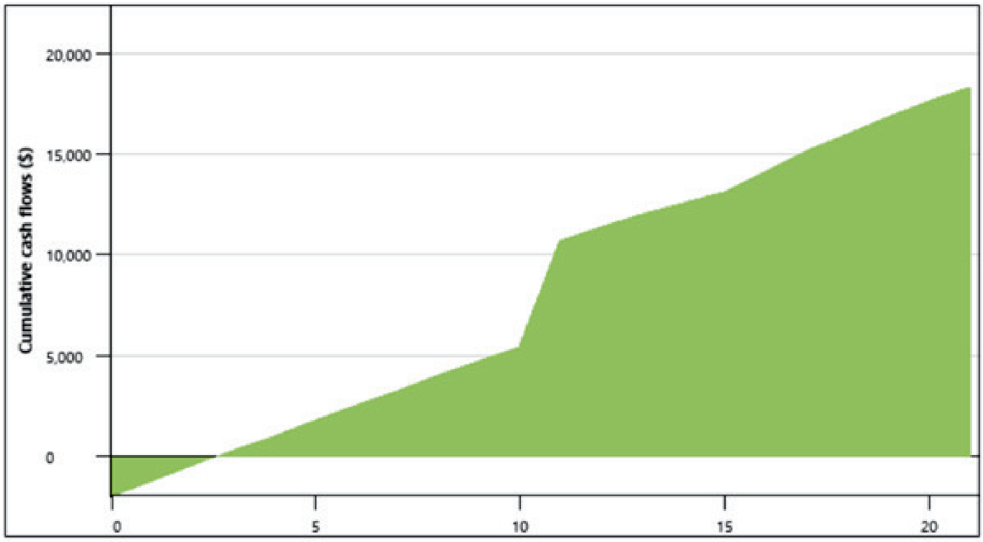

Fig 20. *Cumulative cashflow graph*

6. Key challenges

There are various policy barriers, government schemes, and technical challenges that hinder the efficient operation of solar tube wells in Balochistan. These challenges must be addressed, and efficient solutions must be proposed for the extensive adoption of solar tube wells to meet the energy need, minimize water depletion issues, increase agricultural productivity, and improve climate action, Fig 21depicts a few of them.

6.1 Policy Barriers

Solar tube wells may confront several governmental obstacles in Balochistan, limiting their widespread implementation. Among these policy barriers are:

- Balochistan might lack specific policies dedicated to promoting solar energy, such as solar tube wells. Incentives may not be sufficient to encourage the adoption of solar technology under generic energy policies.
- Under existing energy policies, there is limited incentive support for solar tube well projects. Farmers and investors may be discouraged from investing in solar technology due to the lack of financial support.
- Solar tube well approval processes can be lengthy and convoluted, thus deterring potential investors. It can take a long time for projects to develop due to unclear regulations and bureaucratic hurdles.
- A net metering system allows excess solar energy to be fed back into the grid, incentivizing solar adoption. The regulatory absence of net metering can discourage investors from installing solar tube wells.
- Investors may find it difficult to estimate the return on investment accurately due to uncertainty in solar electricity's pricing and tariff structure.
- Ambiguous land use policies and regulations can lead to confusion over the allocation of land for solar tube well installations. Developing a project can be hampered by unclear guidelines and land ownership issues.
- Many local communities have difficulty obtaining loans and financing options for solar tube well projects. The lack of financial support can impede the implementation of a project.
- Farmers may not consider solar as a viable alternative due to limited awareness about the benefits of solar tube wells and a lack of government incentives.
- In the absence of coordination between relevant government departments, such as agriculture, energy, and rural development, policies can be fragmented and poorly integrated.

- Lack of proper infrastructure, such as training centers, maintenance support, and repair services, can hinder the effectiveness of solar tube wells.

6.2 Government Schemes

- Providing highly subsidized electricity to farmers may reduce their incentive to invest in solar tube wells, which require an upfront investment but are cost-effective in the long run.
- In contrast to conventional grid-connected pumps, solar tube wells lack targeted incentives to encourage the community to install them.
- A lack of government programs that promote renewable energy solutions for agriculture might discourage farmers from considering solar tube wells as an effective option.
- Solar tube wells may not be supported adequately if the government prioritizes grid expansion over off-grid solutions.

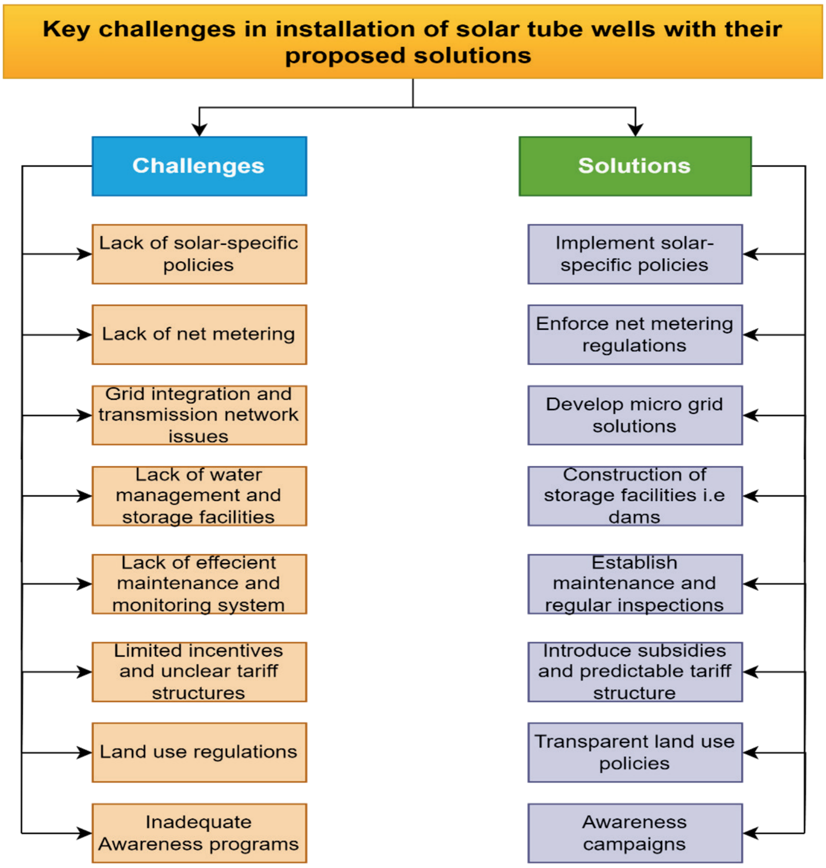

__Fig 21__. Some Key challenges during solar tube wells installation along with their proposed solutions

- Insufficient awareness and understanding of government programs related to renewable energy and solar tube wells may prevent investors from taking advantage of available assistance.
- The implementation of renewable energy initiatives can be difficult for farmers/investors when there is no clear framework at the local level.
- Lack of efficient water management resources and storage facilities may result in water scarcity issues in Balochistan.

6.3 Technical Challenges

- The generation of solar power depends on the availability of sunlight, resulting in intermittent power supply. When solar energy is not available, such as on cloudy days or at night, this intermittent generation might pose problems. Balancing water pumping requirements with solar power may be difficult.
- Solar tube well maintenance and monitoring can be challenging, especially in remote areas.
- Local communities may have an insufficient technical understanding of solar tube well technology.
- Solar tube wells might not be able to be connected to the grid due to limited grid connectivity and transmission network problems in Balochistan. There might be a limited capacity of Balochistan's
- existing grid to accommodate additional solar generation from tube wells, whose integration into existing grids may help minimize the energy crises.
- Remote places where tube wells are commonly built may have minimal grid infrastructure. Connecting these locations to the grid can be costly and time-consuming

6.4 .Recommendations &Solutions

- The recommendations and solutions that must be proposed to address the above-mentioned barriers to the implementation of solar tube wells in Balochistan are:
- Create and implement policies that provide financial incentives, tax breaks, and subsidies for solar tube well installations and operations.
- Ensure that net metering regulations are introduced and enforced, allowing solar tube well owners to sell excess energy to the grid, resulting in a higher return on investment.
- Educate communities about solar tube well schemes, grants, and subsidies available from the government for encouraging the installation of solar tube wells.
- Utilize energy storage solutions, such as batteries, to store excess solar energy during peak sunlight hours to reduce the intermittent nature of solar energy.

- Training should be provided to local technicians in the maintenance and troubleshooting of the system. Maintain a regular inspection and maintenance system to prevent downtime. Training centers for local technicians should be established to teach them how to maintain and repair solar tube wells.
- Provide farmers with training programs and workshops regarding how solar tube wells work, their benefits, and how to maintain them.
- Create microgrid solutions for solar tube wells, enabling them to operate independently of the main grid.
- Developing a comprehensive solar energy policy that outlines incentives, regulations, and support mechanisms targeted specifically for the installation of solar tube wells.
- Reducing bureaucratic hurdles and delays for solar tube well installations by simplifying and accelerating the regulatory approval process.
- To enable investors to calculate their return on investment accurately, solar-generated electricity tariffs should be clear and predictable.
- Establish guidelines for allocating land for solar tube well projects, ensuring transparency and minimizing land ownership disputes.
- Provide low-interest loans and flexible repayment terms for solar tube well projects through a dedicated financing scheme or loan facility.
- Ensure that relevant government departments, energy agencies, agricultural bodies, and rural development organizations must collaborate.
- Create a system for monitoring and reporting solar tube well progress to ensure continuous improvement.
- Financing options that cater to various scales of installations can be provided, making it feasible for smallholders as well as larger enterprises.
- Solar tube wells should be regarded as an essential tool for sustainable agriculture through the alignment of renewable energy policies and agricultural development strategies.
- Maintain effective and supportive policies to promote the adoption of solar tube wells by periodically reviewing and updating them.
- Upgrade grid infrastructure to accommodate distributed solar generation and improve overall reliability.
- Proper water storage facilities such as dams should be constructed to store water despite wasting it, due to a lack of proper water management facilities.
- To prevent water waste, the irrigation system must be modernized and expanded to ensure agricultural productivity.
- A drip irrigation system must be adopted by farmers to reduce the wastage of

- water, hence improving agricultural productivity.

7. Socio-economic Significance of the Study

Some of the socio-economic significances of the propped study are

1. It can help to ensure clean and appropriate water availability for Balochistan communities by establishing solar tube wells. This has the potential to immediately improve public health and quality of life by lowering the burden of waterborne illnesses and boosting general well-being.

2. Adequate water supply using solar tube wells can enhance agricultural output in the region. Farmers would be able to irrigate their crops more effectively, resulting in higher yields, more diverse crop options, and possible revenue increases for rural households.

3. Solar tube well construction and maintenance might generate local job opportunities. This might include roles in installation, maintenance, technical assistance, and community participation, all of which contribute to improved livelihoods.

4. The shifting towards solar energy accords with climate action goals (SDG 13) and supports environmental sustainability. Reduced greenhouse gas emissions and increased usage of renewable energy will make Balochistan's communities more resilient to the effects of climate change.

5. The usage of solar tube wells can aid in the sustainable management of groundwater supplies. This might help to alleviate the problem of groundwater depletion, which is frequently caused by over-extraction for agricultural and household uses.

6. Solar tube wells that are successfully implemented can draw investment and assistance from a variety of stakeholders, including government agencies, non-governmental organizations, and private sector enterprises. This, in turn, has the potential to generate regional development and economic progress.

7. The findings and recommendations of the proposed study might give significant insights for policymakers, assisting them in developing more effective policies and strategies to address Balochistan's water and energy concerns.

8. Conclusion

In the context of implementing solar tube wells in Balochistan, a comprehensive questionnaire was administered to gather primary source data from a diverse group of participants, including technical experts, government officials, and residents of

Balochistan. The survey aimed to explore various aspects related to Balochistan's financial, environmental, and water scarcity challenges. The findings revealed that human-induced factors significantly contribute to the water scarcity issue in Balochistan. Government negligence, the absence of storage dams, and an inefficient water management system were identified as key culprits behind the depletion of groundwater. These issues also have far-reaching consequences, including energy crises, diminished agricultural productivity, and reduced household functionality. Additionally, the study conducted a thorough technical and environmental analysis of implementing an 8.9KW solar tube well in Gawadar using the RETScreen software, assessing both off-grid and grid-connected systems. The results indicated that a 26.9KW photovoltaic system had the capacity to meet the load demand with a commendable benefit-cost ratio of 12 in the case of an off-grid solar system. A higher benefit-cost ratio signifies greater project profitability. Notably, the adoption of an off-grid solar system eliminated 9.4tCO_2/yr emissions associated with a diesel generator, reducing them to zero. This transition to a solar pumping system resulted in higher revenues, amounting to $3404 in GHG emission reductions. Furthermore, the economic feasibility of solar tube wells was highlighted, with a payback period of 1.1 years for off-grid systems and 2.3 years for grid-connected solar-based systems. This eco-friendly solution not only curtailed emissions of hazardous gases but also generated annual savings and revenues of $6702 in the case of a grid-connected system.

In contrast, the grid-connected system required a 26.865KW grid capacity and incurred annual operation and maintenance costs of $500 in the base case. However, the proposed case, utilizing solar energy to operate the tube well, yielded positive results, with a benefit-cost ratio of 3.9. Emissions of 4.7tCO_2/yr in the base case of the grid-connected system, involving a diesel generator, were entirely eliminated with the adoption of a solar pumping system. This transition also led to revenues of $1702 from reduced GHG emissions. Nevertheless, the total revenue generated in the grid-connected case was relatively lower, necessitating a longer investment recovery time of 2.3 years compared to the off-grid scenario.

In light of these findings, it is strongly recommended to promote the use of solar-based tube wells for irrigation, household, and agricultural purposes to bolster Balochistan's sustainability and enhance the country's environmental outlook. Effective government policies should incentivize investors to embrace solar tube well installations. Moreover, the adoption of an efficient water storage and management system is crucial to mitigate water scarcity issues in Pakistan. To prevent water wastage, modernizing and expanding the irrigation system is imperative to ensure sustained agricultural productivity.

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