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Engineering Solutions for Climate-Conscious Cultivation: Solar Energy's Role in Enhancing Agricultural Productivity in Punjab

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Abstract

The study investigates the use of solar energy and project management in the sustainable agriculture sector of Punjab, Pakistan. A 40-acre land with a solar-powered water reservoir supports up to 15-17 irrigation sets, demonstrating a strategic combination of reserve management and environmental stewardship. The agronomy of Onions, Cauliflower, Cucumber, and Brinjal on the farm could yield a profit between 6.99 and 7.23 million Rupees, with a breakeven point of 5 to 6 months. This model demonstrates profitable, eco-friendly agronomic practices, addressing water insufficiency and climate effect challenges. The research highlights the need for specific project management to fully utilize solar-powered tube wells for irrigation systems and set a precedent for future agronomy activities. Additionally, the research emphasizes the importance of implementing efficient water usage techniques and incorporating sustainable farming methods to mitigate the impact of climate change on agricultural productivity. By prioritizing the use of solar-powered tube wells for irrigation, the farm not only reduces its carbon footprint but also sets a positive example for other agricultural operations to follow suit. Overall, this model showcases the potential for profitable farming practices that prioritize environmental sustainability and resource management.

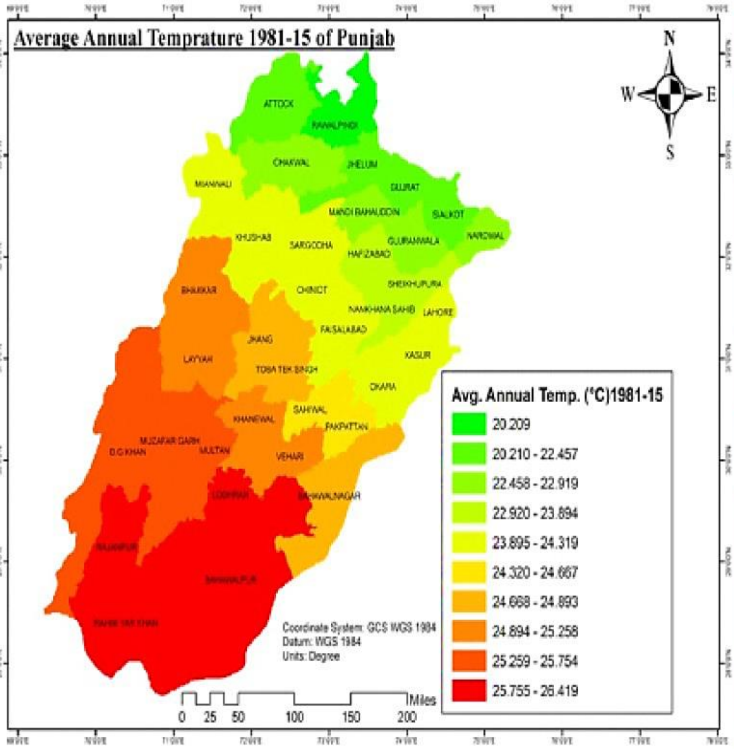
Keywords: *Agricultural Sector Punjab, Carbon footprint, Solar Energy.*

1. Introduction

Pakistan is an agricultural-based economy. Agriculture accounts for 20.9% of the GDP and provides livelihood to 43.5% of the rural population [1]. Agricultural GPD is derived from 4 major subsectors. Livestock is the biggest contributor to GDP accounting for 46.3%, at the second it's the crops accounting for 47.96%, similarly fishing and forestry account for 3.46% and 2.28% respectively. Punjab is the largest province of Pakistan in population and its contribution to the agricultural sector of Pakistan [2]. Agricultural-based products account for the 3/4th of Pakistan's total export which is about 60%. Punjab has a total geographical area of 20.63 million hectares which is 25.9% of the country's total area which makes it the Punjab's 2nd largest province.

As per the Census of Agriculture 2023, there are 7,894,963 agricultural farms in Punjab [3]. Around 76% of farms fell in the range of 1 hectare to 15 hectares. Agricultural performance is directly linked with suitable climate conditions where Punjab has different agro-climate zones offering the diversity to cultivate different types of crops [4]. Figure 1 shows the Punjab climate map, which shows the temperature increases from North to south region of Punjab. The average rainfall trend in Punjab decreases from north to south Punjab. Average rainfall in northern districts like Rawalpindi, and Sialkot is the highest. Similarly, Lahore and Faisalabad are lower in district and it continues to further decrease in southern districts like Bahawalpur and Multan.

Similarly, 88% of the total area of Punjab is irrigated whereas 12% is unirrigated, depending on the natural rainfall [5]. Shares of irrigated areas are different for the two cropping seasons. For the Rabi crops, it is 83.3% and for the Kharif crops, 93.8% area is irrigated. The agriculture sector of Punjab uses multiple modes of irrigation where 22.7% sown area is irrigated by canals and 18.7% by tube wells, While the remaining area uses both modes of irrigation [3]. The tube wells grew rapidly as the number of tube wells in 2014 was 1,028,424 and in 2021 it was 1224718 where Table 1 shows the division of tube wells in the entire Punjab on regional bases [6].



Districts	Temp ^{0}C
Rawalpindi	20.2
Attock	21.7
Jhelum	22.4
Gujrat	23.8
Rahim Yar Khan	26.4
Multan	26.1
Bahawalpur	26.0
Lodhran	26.1

Figure 1. Climate Region of Province Punjab

Table 1. Regional-based tube well division in Punjab's region.

Division/	Electric Tube well			Diesel Tube well			Run by Tractor		
District	Govt.	Private	Total	Govt.	Private	Total	Govt.	Private	Total
THE PUNJAB	**980**	**184568**	**185548**	**112**	**864393**	**864505**	**32**	**175757**	**175789**
RAWALPINDI DIV:	**69**	**10330**	**10399**	**6**	**10001**	**10007**	**0**	**1750**	**1750**
Attock	34	4160	4194	2	797	799	0	200	200
Rawalpindi	34	209	243	0	618	618	0	111	111
Islamabad	-	-	-	-	-	-	-	-	-
Jhelum	0	662	662	4	5586	5590	0	1162	1162
Chakwal	1	5299	5300	0	3000	3000	0	277	277
SARGODHA DIV:	**238**	**6089**	**6327**	**31**	**98106**	**98137**	**27**	**18790**	**18817**
Sargodha	13	2171	2184	0	35137	35137	0	6307	6307
Khushab	82	846	928	6	14012	14018	1	726	727
Mianwali	89	1709	1798	4	9946	9950	12	3261	3273
Bhakkar	54	1363	1417	21	39011	39032	14	8496	8510
FAISALABAD DIV:	**87**	**33911**	**33998**	**12**	**113814**	**113826**	**4**	**33804**	**33808**
Faisalabad	25	5923	5948	4	21923	21927	4	6885	6889
T.T.Singh	36	4346	4382	0	10872	10872	0	7524	7524
Jhang	26	16532	16558	8	69456	69464	0	18226	18226
Chiniot	0	7110	7110	0	11563	11563	0	1169	1169
GUJRANWALA DIV	**7**	**46076**	**46083**	**9**	**257779**	**257788**	**0**	**4074**	**4074**
Gujrat	0	5733	5733	0	24843	24843	0	356	356
M.B.Din	1	3092	3093	9	49331	49340	0	671	671
Sialkot	2	10398	10400	0	63934	63934	0	916	916

Narowal	2	4789	4791	0	46308	46308	0	605	605
Gujranwala	2	15964	15966	0	52253	52253	0	1516	1516
Hafizabad	0	6100	6100	0	21110	21110	0	10	10
LAHORE DIV:	**50**	**19863**	**19913**	**0**	**58864**	**58864**	**0**	**13316**	**13316**
Sheikhupura	0	6156	6156	0	31486	31486	0	1438	1438
Nankana Sahib	0	3914	3914	0	15728	15728	0	989	989
Lahore	4	2146	2150	0	2088	2088	0	559	559
Kasur	46	7647	7693	0	9562	9562	0	10330	10330
SAHIWAL DIV:	**178**	**23648**	**23826**	**7**	**36792**	**36799**	**1**	**16569**	**16570**
Okara	24	8067	8091	4	25580	25584	0	4846	4846
Sahiwal	85	4414	4499	3	6536	6539	0	8463	8463
Pakpattan	69	11167	11236	0	4676	4676	1	3260	3261
MULTAN DIV:	**71**	**27072**	**27143**	**0**	**11385**	**11385**	**0**	**27342**	**27342**
Multan	21	6013	6034	0	4347	4347	0	3821	3821
Lodhran	3	5848	5851	0	35	35	0	4633	4633
Khanewal	37	5512	5549	0	6559	6559	0	9240	9240
Vehari	10	9699	9709	0	444	444	0	9648	9648
D.G. KHAN DIV:	**21**	**6153**	**6174**	**47**	**183009**	**183056**	**0**	**32189**	**32189**
Muzaffargarh	0	2918	2918	0	67594	67594	0	6047	6047
Layyah	14	1220	1234	2	59176	59178	0	17057	17057
D.G. Khan	0	1152	1152	0	22017	22017	0	2140	2140
RajanPur	7	863	870	45	34222	34267	0	6945	6945
BAHAWALPUR DI	**259**	**11426**	**11685**	**0**	**94643**	**94643**	**0**	**27923**	**27923**
Bahawalpur	0	2694	2694	0	25791	25791	0	9397	9397
R.Y. Khan	0	2694	2694	0	25791	25791	0	9397	9397
Bahawalnagar	259	6038	6297	0	43061	43061	0	9129	9129

In the last decade, it has been observed that in agricultural land in Punjab, there has been a shift from fuel-powered tube wells to electric tube wells for several reasons:

1. **Energy Efficiency and Cost Reduction:** Electric tube wells are more energy-efficient compared to diesel-powered ones. By using electricity, farmers can reduce their energy costs and improve overall efficiency [7].
2. **Environmental Considerations:** Diesel tube wells contribute to air pollution and greenhouse gas emissions [8]. Switching to electric tube wells helps mitigate environmental impact by reducing emissions.
3. **Government Initiatives:** The Punjab government has taken steps to promote renewable energy sources. They have allocated funds to convert electric tube wells to solar power, aiming to reduce the burden on the exchequer, decrease power demand, and save the environment [9].
4. **Sustainability and Food Security:** Groundwater sustainability is crucial for agriculture. While private tube wells have aided wheat production, unregulated growth of these wells could jeopardize groundwater

resources and food security [10]. Policies are needed to limit private tube well expansion.

Recently, Punjab has allocated Rs12 billion to convert tube wells to solar power, emphasizing energy cost reduction for farmers and environmental benefits. This transition aligns with global trends toward cleaner energy sources, figure 2 shows the number of electric tube-wells in Punjab in respective Punjab divisions.

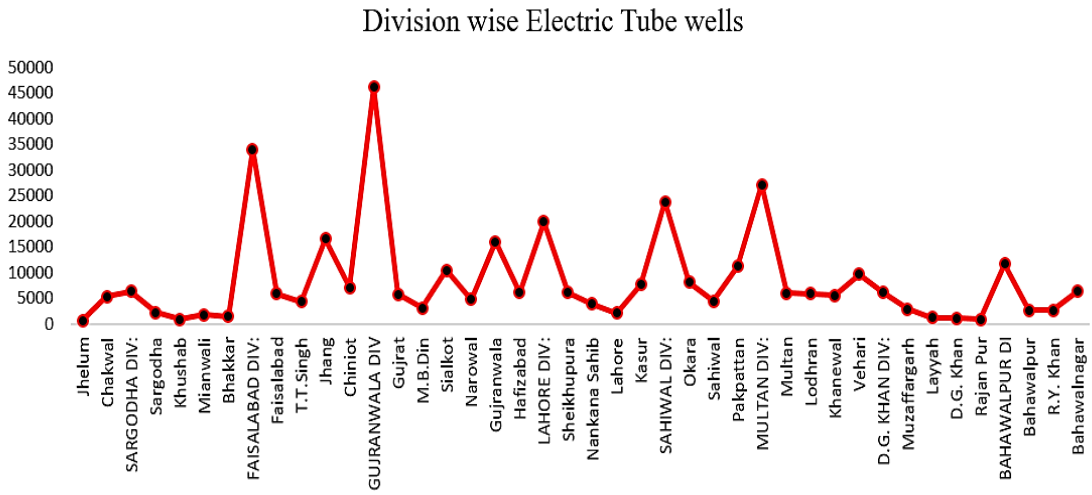


Figure 2. Division Wise Electric Tube Wells

Pakistan is at a turning point in its history as the energy crisis has long eclipsed the country's advancements in social and economic spheres. Because of the continuous outages and growing need for electricity, the nation is resorting to other energy sources to stay warm [11]. This shift in course demonstrates the nation's perseverance in using the power of the natural world to reveal the future in addition to being a matter of policy [12]. Every residence is urged to join this energetic insurgency as the cry for achievement reverberates in every house, farm, and business. This thorough synopsis delves deeper into Pakistan's energy situation, covering both opportunities and challenges. It looks at the limitations of solar, wind, and hydroelectric technologies and analyzes how they can alter the nation's electrical supply [13], [14]. It examines the issues surrounding fossil fuels, where the search for gas and oil has become a monopoly and a detrimental activity to the environment. The narrative then shifts to the plains that are buffeted by wind and sun, where the prospect of wind and solar energy is alluring [15]. Despite the dearth of wind energy resources, this outline identifies the probable locations where aero-generators could eventually turn steadily and supply towns with electricity. It offers a happier illustration of solar energy, with Pakistan's abundant sunshine offering a timely and well-planned remedy for the nation's energy deficit. This argument, though, focuses on the creation of power. It also highlights the threat that climate change poses to Pakistan's many ecosystems. The primer provides a grim assessment of agricultural commerce, pointing out that inadequate management practices and a lack of water supplies significantly harm food sanctuary.

The introduction makes the case for a comprehensive strategy that combines solar energy with water-saving measures to revitalize Pakistan’s parched lands. It imagines a time when drip irrigation systems and solar-powered pumps are commonplace, every drop of water is valued, and every ray of sunlight is harnessed. The argument gains pace as the word count increases. The introduction highlights the advantages of renewable energy for the economy, the environment, and society while outlining a plan for sustainable development. To reverse the course of the energy crisis, everyone must work together and combine grassroots efforts with official policy.

The rest of the paper is organized as follows: following an introduction to our prospects, a section on related work includes comparable projects in Pakistan's agriculture sector. Following this, a section on work analysis is completed to demonstrate the project's entire workflow, including methodology, cost-benefit analysis, and solar design for the necessary system. Finally, a conclusion is developed to encapsulate the research findings and workflow dissemination.

2. Literature Review

Pakistan's solar energy potential is investigated in this study, with a focus on Punjab's agricultural sector. The writers' primary concerns and challenges include the technical, economic, social, and environmental elements of installing solar energy systems. The research also makes recommendations for how to resolve these problems and maximize the solar energy potential in the region. A project management schedule for the installation of solar energy structures in Pakistan's agricultural sector is similarly presented in [16] and [17]. The writers go over the important aspects of project management, such as the technical, financial, social, and environmental aspects. A case study of a solar-powered irrigation system that was installed in the area is also included in the article, along with a discussion of the project's lessons learned. This study [18] assesses the feasibility of solar-powered irrigation systems in Punjab, Pakistan. The authors use a techno-economic framework to determine the key factors supporting the viability of solar-powered irrigation organizations and to estimate the likelihood of solar energy being used for irrigation. The study also discusses the benefits and drawbacks of setting up solar-powered irrigation systems nearby. The study [19] also looks at how solar-powered irrigation systems (SPIS) affect the technical efficiency (TE) of wheat production in rural Baluchistan, Pakistan.

The researchers employed a stochastic frontier production function and data from 1080 wheat farms to estimate the TE of wheat production. Furthermore, an endogenous switching regression model is being developed to mitigate the potential for self-selectivity bias. The data shows that 13.7% of wheat farmers used SPISs and that employing SPISs increases the TE of wheat cultivators by 6.657%. The study also shows that wheat producers with larger farms and more farming experience benefit more from using SPISs in terms of TE. The findings highlight the need for additional research into evidence-based best practices for SPIS solutions to boost sustainable agronomy and lessen dependency on fossil fuels [19].

This research investigates the relationship between food security, nutrition, and climate change [20]. The study highlights how the negative effects of climate change on food and nutrition security are exacerbated by poverty and social inequality. The main ways that climate change affects food and nutrition security are through production, price volatility, accessibility, and nutritional quality. The paper offers suggestions for mitigation and adaptation strategies to address the impact of climate change on food security and nutrition. The geographic distribution of publications on the topic indicates the focus on Africa and Asia, two continents recognized for their socioeconomic disparity and poverty [21]. The findings emphasize how urgently more money needs to be spent globally on related investigations, research, and public policy.

Situation Analysis

Energy's supply and demand have never been in balance. Pakistan's energy shortfall was 5500 MW in 2015, or almost 45% of the nation's overall demand [22]. To keep supply and demand in balance, load shedding is frequently used for eight to ten hours each day. It's been ten or fourteen hours since the previous year.

Synopsis of Technologies

Presently, China has the top spot in the international market for PV modules, and the global photovoltaic industry is growing at a rate of up to 30%. In 2010, China exported 23,000 MW of solar panel consumable power. Only solar transactions from China made up 75% of all transactions worldwide in 2010 [23]. An increasing number of domestic and international enterprises are created annually as a result of the growing demand for solar modules. The intense competition in the market is causing prices for PV modules to drop every day [24].

Recent surveys and studies show that the average cost per watt of PV modules has decreased from $1.61 to $0.8 in just four years. This stands in stark contrast to the nation's increasing electricity prices during that same time frame [25]. Table 2 shows the solar plant installation capacity of the top 10 countries.

Table 2: Top 10 Countries by Solar Installed Capacity 2024

Rank	Country	Installed Capacity (MW)
1	China	609,920.8
2	USA	139,205.3
3	Japan	87,068.0
4	Germany	81,739.0
5	India	73,109.3
6	Brazil	37,449.2
7	Australia	33,683.0
8	Spain	31,016.3
9	Italy	29,795.3
10	Republic of Korea	27,0462.2

When it comes to PV installation, China leads the world. Pakistan currently has a meager 1000 MW of installed solar energy, placing it in 23rd place on the list. Pakistan is situated in a region that is ideal for solar energy production, receiving an average of 10–11 hours of sunlight each day during the summer and 6–7 hours during the winter. The earth receives 1.259 KW/m2 of energy on average from the sun; on a clear day, up to 80% of this energy is delivered to the globe. Generally speaking, clouds, fog, and moisture block the sun, which lowers solar radiation [26]. Pakistan has a special geographic location since it is perfectly positioned to receive the maximum amount of solar radiation possible throughout the year [27]. Several locations in southern Pakistan, including Quetta, and areas in central and southern Punjab, including Lahore, Faisalabad, Multan, Bahawalpur, and Rahimyar Khan, receive the most sun radiation year-round. Pakistan receives 6.8 to 8.3 KMJ/m2 yearly on average, with 7 to 9 hours of sunlight each day [28].

Pakistan is a market with dynamic tendencies due to its rapid national growth. The local market is ready to adopt and exploit new technologies. Because solar energy is cheap, easy to deploy, and quick to harvest, Pakistan has a lot of potential for alternative energy sources in general and solar energy in particular [29]. Considering their quick payback times and high rate of return, it’s likely that commercial, industrial, and agricultural sectors would benefit from solar systems more than residential, commercial, and agricultural sectors would. For households, the payback period is considerable. The cost per watt of solar PV modules, both national and international, is displayed in Table 3. Solar firms and the size of the solar frame are the two factors that affect the cost per watt of solar energy as well as the cost of installation [30]. The solar panel provider you select will determine the cost of the panels. The pricing will differ from business to company for anything from the solar equipment system itself to installation fees and add-ons. The first step is to research the top solar providers in your area. In a similar vein, the size, weight, and quantity of panels all affect their dimensions. How many solar panels you'll need depends on several factors, including the size of your property, the efficiency of the panels, and the quantity of sunshine [31].

Table 3: National and International Cost per Watt of Solar Panel Types.

Solar Technology	International Cost per Watt $	Local Cost per Watt Rs
Monocrystalline	1 to 1.50	45 to 58
Polycrystalline	0.90 to 1.50	37 to 50
Thin-film	0.50 to 1.50	39 to 45

Higher-efficiency panels are a better choice when maximizing energy output from limited rooftop areas in a nation like Pakistan that receives an abundance of sunshine. However, large-scale commercial installations or projects like solar farms or industrial installations where space is not a barrier can benefit from the use of thin-film panels [32]. Table 4 presents a prospective comparison of several types of solar panels.

Table 4: The Comparison of Solar Panel Types

Factors	Monocrystalline	Polycrystalline	Thin-Film
Life span	25+ years	25+ years	10-15 years
Cost	Comparatively Expensive	Average	Cheap
Advantages	• Highest Efficiency • Better Performance • Longer Lifespan • Occupy less space	• Good Efficiency • Low Cost • Longer Lifespan	• Lower Efficiency than Monocrystalline
Drawbacks	• Expansive • Heavy	• Occupy more Space	• Lower Efficiency • Require more Space • Shorter Lifespan

Figure 3 presents a statistical depiction of the society average rate per unit in PKR/kWh for the various sectors, including residential, commercial, industrial, agricultural, and others. One of the reasons why consumer-end tariffs are rising is because of this supply-demand imbalance. A low base impact of hydel fuel prices and various subsidies given to end users means that household and commercial consumers pay the lowest average rates across all sectors, whereas commercial and industrial consumers pay the highest average tariffs.

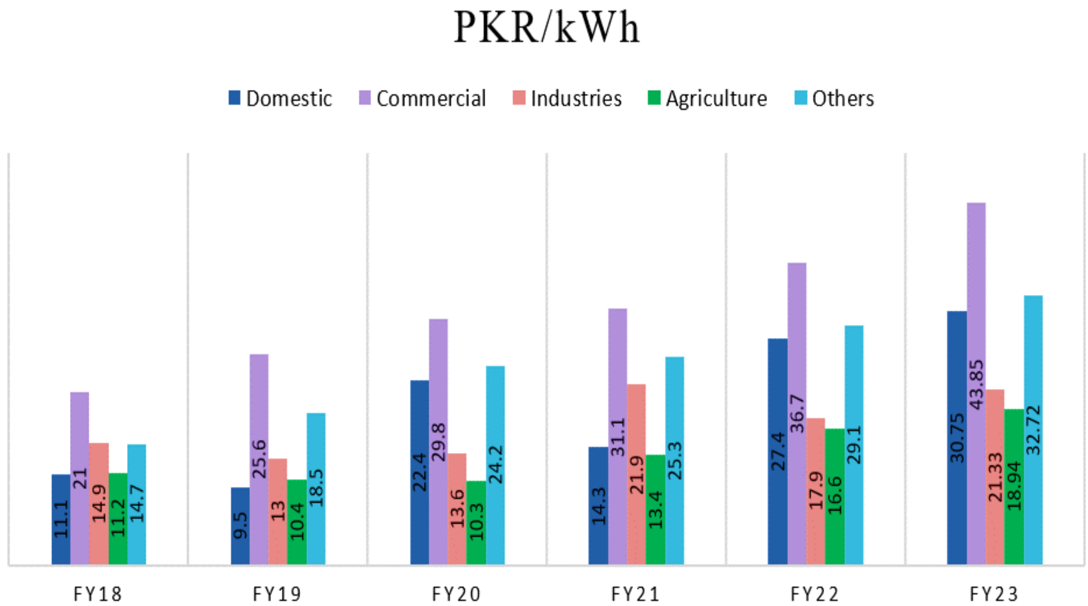


Figure 3: Sectoral Average Tariff Rate per Unit

- **Problem Synopsis**

Power requirements must be satisfied while accounting for power interruptions and other constraints to lower system costs and payback periods. A factor in decision-making is the capacity of the power plant.

3. Agricultural Case Study

Because agriculture has always been the backbone of our country, 75% of pumping units are located in remote areas or in regions without grid connectivity. Voltage variations and unstable grid circumstances lead farmers to use expensive fuel-based and energy-generating technologies to operate their tube wells for irrigation systems [33]. A solo solar energy system for water pumping works only during the day and solely employs solar energy as its primary source. Knowing how long a system will take to pay for itself will be helpful to our farmers.

The limitations remain the same as those mentioned in the method section. The variables related to generator choices, such as fuel usage, generator sizing, and grid purchases, are not significant in this scenario because there is no grid electricity. Rather, the size of the solar array is the deciding factor. Results: 77 solar modules with a 1000W capacity are used in this project.

1. Economic Analysis

The payback time, replacement costs, and system expenses are covered in this kind of study. The only power source for this off-grid setup is solar power; a pump is utilized to drill water for the irrigation system. While the overall project cost, including the cost of installing panels, building tanks, channels, tube wells, and land, is around 3.5 to 3.8 million Rupees, the estimated profit for the 40-acre area used to produce all of these crops would be 6.99 million to 7.23 million Rupees. The true profit-generating phase would start after the breakeven period.

2. Solar Panel

As is well knowledge, the solar panel gets its energy from the sun and is expressed as follows:

Ppv(t) represents ηpv×Apv×Irr(t)×(1−0.005(Temp(t)−25)) (1)

Where Ppv is the amount of electricity generated hourly by solar panels. The solar panel's efficiency and area are denoted as ηpv and Apv, respectively. For a given period, t, the variables Irr(t) and Temp(t) represent the sun irradiance and outdoor temperature, respectively [28].

3. Electricity Cost

Numerous power tariffs, such as DAP, TOUP, PP, and RTP, are available to specify the pricing of electricity for a certain day [34]. RTP was employed in our model. Every hour, the price of power in RTP fluctuates and then stays the same for another hour. The daily electricity bills for shift-able and non-shift-able appliances are displayed by T EcP and EdP, respectively; these figures are computed by [35].

EcP=EdP=EtotP=∑t=124(∑M=1m(Ecm∈M(t)×Xcm∈M(t)×PRTP(t)))∑t=1 24(∑N=1n(Edn∈N(t)×Xdn∈N(t)×PRTP(t)))EcP+EdP (2)

where the on/off states of shift-able and non-shift-able appliances are represented by Xcm∈M(t) and Xdn∈N(t), respectively. In a given timeslot t, M denotes shift-able appliances and N denotes non-shift-able appliances, where EtotP stands for the total cost of electricity. The electricity cost at any given time slot t is represented by EP(t), which accounts for both ESS and RESSs.

$$EP(t)=(Ec(t)+Eb(t)-EPV(t)-SE(\tau))\times PRTP(t). \quad (3)$$

where τ represents the time slot between $t20$ to $t24$ having the highest electricity bill. The ESS is discharged because the PV is not available in those slots.

4. Solar System Design

The irrigation infrastructure's operational requirements, which require about four 15 HP Solar tube wells with pole mounting with around 54 to 60 KW of electricity, are a prime example of the shift to renewable energy. An array of 37 to 40 solar panels, each rated at 1500W, easily meets this requirement, highlighting the project's dedication to renewable energy. This solar project with a channel and motor for tube wells will cost between Rs. 3,500,000 and Rs. 3,800,000, which is a calculated investment in long-term sustainability. The 25-year project lifespan is calculated from the lifespan of the solar panels. Although solar panels don't need maintenance, because of their long lifespan, the system charger has to be replaced regularly.

5. Cost-Benefit Analysis of Potato, Onion, and spinach Crops in Punjab

The water scarcity areas of Punjab present unique facilitations for agriculture. However, by meticulously evaluating costs and benefits, we can make informed decisions to maximize profitability and sustainability. Our analysis focuses on the cultivation of four essential crops: brinjal, cauliflower, onion, and cucumber.

A. Fixed Costs (FC)

- **Land Lease or Mortgage Payments**: The cost associated with securing the 40-acre land is an average of 37,000/acre in Punjab.
- **Infrastructure Maintenance**: Expenses for maintaining irrigation channels, fencing, and other infrastructure its around 6-11k/acre.
- **Depreciation of Machinery and Equipment**: Calculating the wear and tear on tractors, plows, and another farm equipment is approximately 15-16k/acre.

Variable Costs (VC)

- **Seeds**: The cost of high-quality seeds for each crop.
- **Fertilizers and Pesticides**: Necessary inputs for healthy crop growth.
- **Labor**: Wages paid to workers for planting, weeding, and harvesting.

- **Watering**: Includes electricity costs for pumping water from wells or other sources.
- **Transportation**: Includes the essentials for harvesting and product to market.

B. Total Cost (TC)

The total cost of production (TC) is the sum of fixed costs (FC) and variable costs (VC): **TC=FC+VC**

Benefit

Yield: Estimate the expected yield (in 40 kilograms) for each crop per acre.

Market Price (P): Determine the prevailing market price for each crop.

Revenue: Calculate the total revenue from selling all crops: **R = P × Yield**

C. Net Benefit (NB)

The net benefit (NB) is the difference between revenue and total cost: NB=R−TC

4. Benefits and Costs

The expenditures of buildings, infrastructure, and equipment needed for sustainable farming are included in the investment costs associated with crop growing. Regardless of farming, depreciation, and interest are often fixed expenditures. The straight-line approach is used to compute the depreciation. Operating expenses are associated with the day-to-day operations of farming and are contingent upon the quantity of water used per irrigation, the frequency of irrigation, the amount of fuel consumed, and the total irrigated area [36]. Labor costs are the most significant variable costs because they are used for land cultivation, irrigation, upkeep, and harvesting. The price of fertilizer and seeds is included in the material expenses. The yearly expenditure for upkeep and repairs would amount to 6% of the irrigation system's original cost. There are finite amounts of water. The quantity of water applied for irrigation, using crop irrigation norms and an ecological and economic assessment of water, is how water loss is calculated [37]. The income from crops, higher yields from the irrigation system, land rental income, labor and water savings, and social insurance are all advantages of irrigated farming. The whole cost flow for the crop's costs per acre is displayed in Table 5 and Table 6 respectively for fueled and electric solar-based tube wells.

Table 5. Cost-benefit Analysis of the entire project at the regular practice of irrigation system by fueled tube wells.

Cost	**Production per Acre**			
Variable Cost	**Cauliflower**	**Onion**	**Brinjal**	**Cucumber**
Cost of Land Preparation	14,084	12,364	12,692	11,732
Cost of Seeding & Sowing	29,975	20,904	13,896	52,497
Cost of Irrigation	17,374	20,890	28,106	35,756
Cost of Fertilizer	30,057	20,163	28,628	21,867
Cost of Drug	N/A	1,673	N/A	N/A
Cost of Pesticides	12,660	4,716	35,481	38,494
Cost of Weedicides	8,353	5,342	56,860	8,026
Cost of Harvesting	19,720	9,805	26,320	26,846
Cost of Transport	24,919	9,675	33,235	42,047
Cost of Land	40,000	45,000	25,000	25,000
Fixed Cost				
Cost of Fuel, Motor Pump with tube well construction 142,560				
CostBenefit Analysis	**Cauliflower**	**Onion**	**Brinjal**	**Cucumber**
Production Cost	344,701	288,093	402,777	404,826
Revenue Expected	306,471	263,940	374,609	364,710
Profit	38,230	24,153	28,168	40,116
Indicative price per 40kg	750	1,450	1,822	1,157

Table 6: Cost-benefit Analysis of the entire project a solar-based electric irrigation system by tube wells.

Cost	**Production per Acre**			
Variable Cost	**Cauliflower**	**Onion**	**Brinjal**	**Cucumber**
Cost of Land Preparation	14,084	12,364	12,692	11,732
Cost of Seeding & Sowing	29,975	20,904	13,896	52,497
Cost of Irrigation	17,374	20,890	28,106	35,756
Cost of Fertilizer	30,057	20,163	28,628	21,867
Cost of Drug	N/A	1,673	N/A	N/A
Cost of Pesticides	12,660	4,716	35,481	38,494

Cost of Weedicides	8,353	5,342	56,860	8,026
Cost of Harvesting	19,720	9,805	26,320	26,846
Cost of Transport	24,919	9,675	33,235	42,047
Cost of Land	40,000	45,000	25,000	25,000
Fixed Cost				
Cost of Solar, Motor Pump with tube well construction 95,000				
CostBenefitAnalysis	**Cauliflower**	**Onion**	**Brinjal**	**Cucumber**
Production Cost	297,141	240,533	355,217	357,266
Revenue Expected	246,357	203,826	314,495	304,598
Profit	50,784	36,707	40,722	52,668
Indicative price per 40kg	750	1,450	1,822	1,157

In the long term, the solar-powered electric irrigation system appears to be a more economical and ecologically friendly choice, as indicated by the tables. In terms of lower operating expenses, higher profit margins, and environmental advantages, it provides a substantial gain. The increased initial cost of the solar system, however, may be a deterrent for many farmers. The price for a fuel-based irrigation system costs around Rs 5,702,400 annually for the entire land of 40 acres, which means the price for each acre is Rs 142,560. Similarly, for the solar-based irrigation system, it's going to be about Rs 3,500,000 to 3,800,000 for a whole year for the entire land where Rs 95,000 is for each acre of land for the whole year.

Figure 5 shows that the average yield varies significantly between divisions. The average yields in some divisions, including Lodhran, Vehari, Bahawalpur, and Faisalabad, are greater than in others. Professionals in agriculture and any individual curious about Pakistan's cucumber production scene would find this information to be very helpful. It offers information on regions under cultivation, production variances, and possible areas for improvement. Farmers in the region like Gujrat, Gujranwala, and Sialkot have to investigate the reasons behind the lower yield. Factors that should be focused on for the higher yield are pest management, seed quality, irrigation practice, and most importantly soil quality.

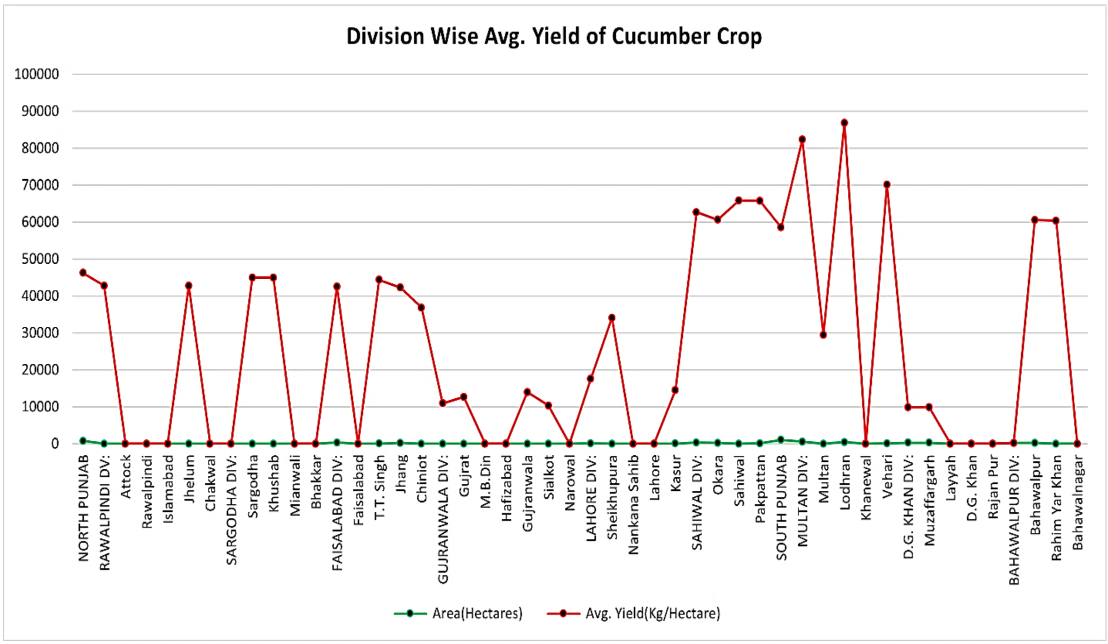


Figure 5. Punjab Sub-Division Wise Yield of Cucumber Crop

Similarly, figure 6 shows the average yield of brinjal varies significantly between Punjab divisions. The average yields in some divisions, including Kasur, Vehari, Lahore, and Khushab, are greater than in others. Farmers in the region like Gujrat, Multan, and Khanewal have to investigate the reasons behind the lower yield. Factors that should be focused on for the higher yield are pest management, seed quality, irrigation practice, and most importantly soil quality.

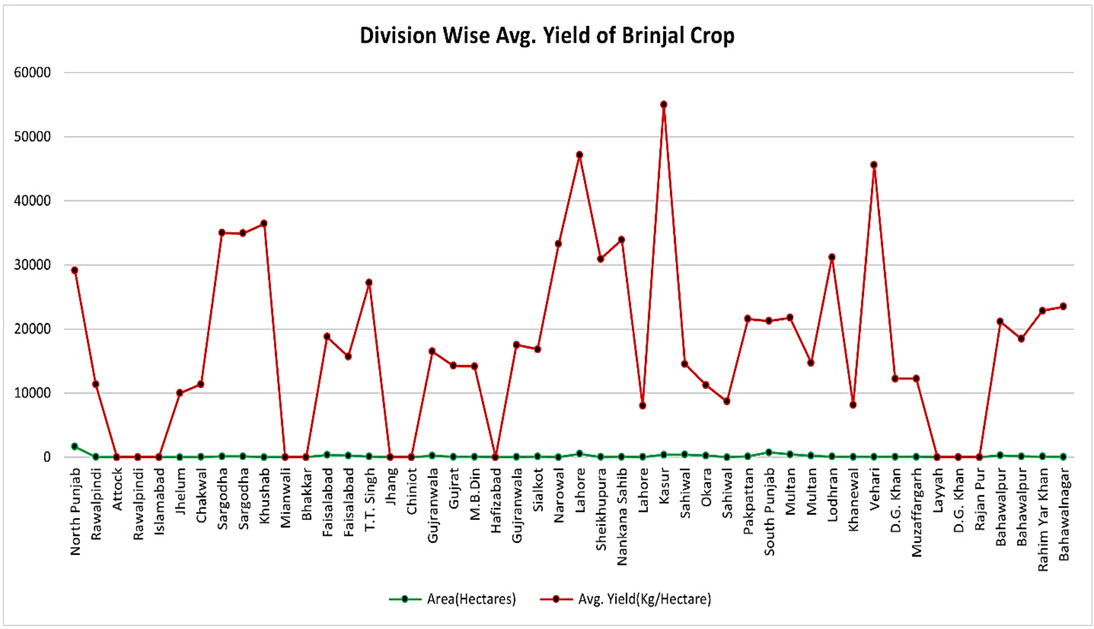


Figure 6. Punjab Sub-Division Wise Yield of Brinjal Crop

Figure 7 shows that the average yield varies significantly between different divisions of Punjab. The average yields of Cauliflower in some divisions, including Vehari and Sahiwal, are greater than in others. Whereas the divisions Attock and Gujrat are not so suitable for the higher production in the field of cauliflower. Individuals curious about Pakistan's cauliflower production scene would find this information to be very helpful. It offers information on regions under cultivation, production variances, and possible areas for improvement.

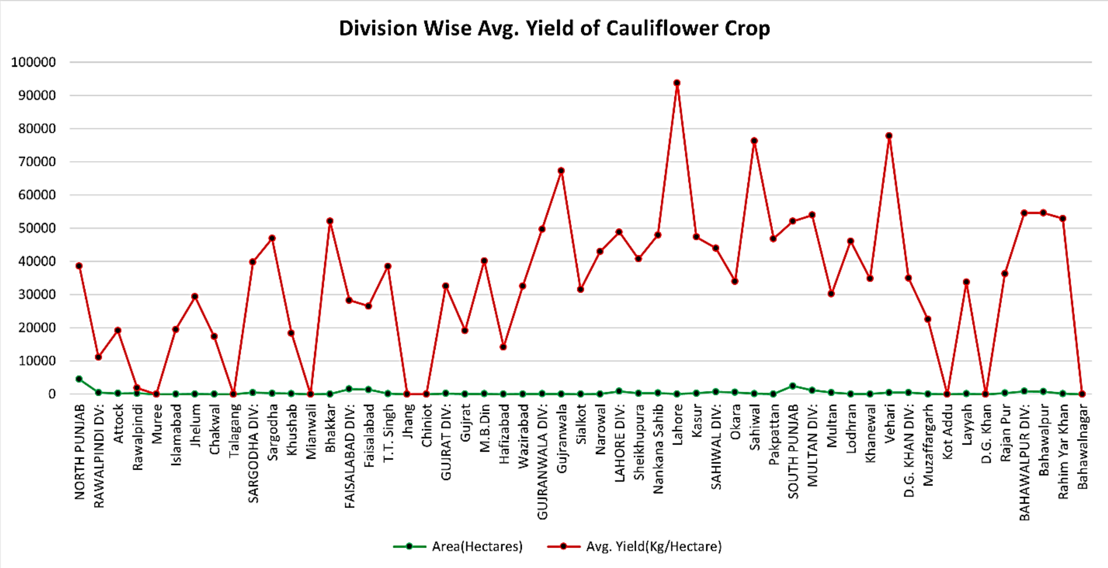


Figure 8. Punjab Sub-Division Wise Yield of Cauliflower Crop

Similarly, figure 9 shows the average yield of Onion varies significantly between Punjab divisions. The average yields in some divisions, including Sialkot, Chakwal, and Attock, are greater than in others. Farmers in the region like Hafizabad, Jhang, and Vehari have to investigate the reasons behind the lower yield. Factors that should be focused on for the higher yield are pest management, seed quality, irrigation practice, and most importantly soil quality.

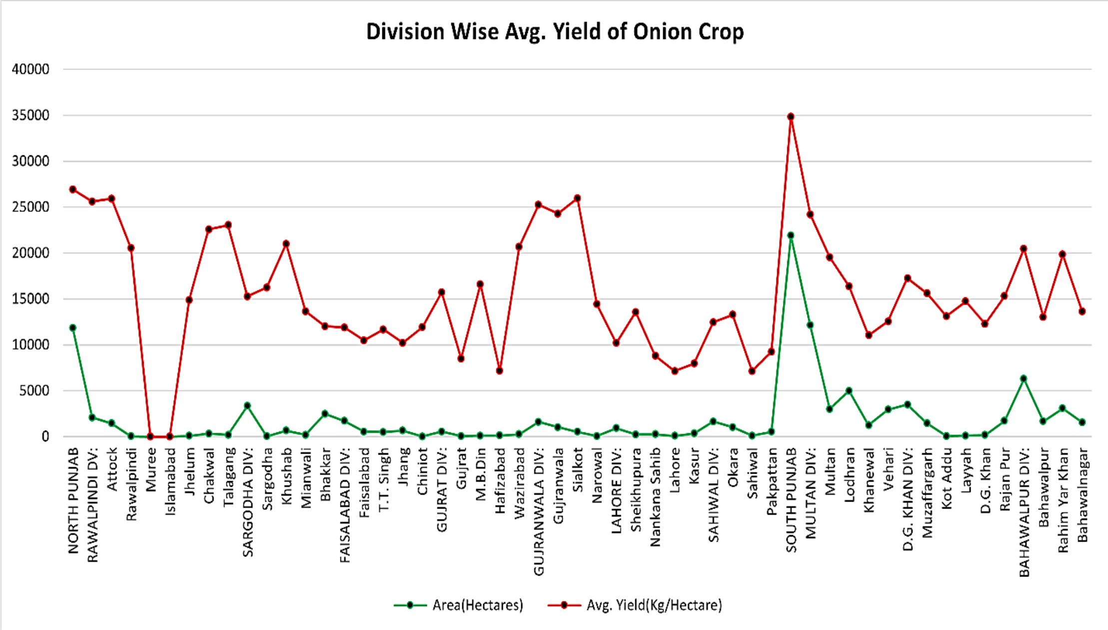


Figure 9: Punjab Sub-Division Wise Yield of Onion Crop

The incorporation of a well-planned water tank sized with a tube well for a 40-acre plot of land is a demonstration of sustainable farming methods in the fields of project management and solar energy production. This reservoir is a perfect example of the cooperation between resource management and environmental care since it can irrigate the land up to fifteen to seventeen times. To speed up the irrigation process, four to seven panels are installed for electric tube wells with tube well construction, motor, and channel infrastructure to the entire land which would cost about ₨790,000. Economically speaking, the production of onions on this property brings in ₨ 36,707 per acre, while the production of cauliflower, brinjal, and cucumber brings in ₨ 50,784, 40,722, and 398,495 per acre, respectively.

These numbers demonstrate the project's potential for scalable expansion in addition to its financial feasibility. The agronomic schedule is in line with the seasonal cycles, which have Onion and Cauliflower harvesting from January to April and then August to December, Similarly Brinjal and Cucumber cultivation from April to November respectively, guaranteeing a steady flow of produce. While the overall project cost, including the cost of installing panels, building tanks, tube wells, channels, motor, and land price, is around 3.5 to 3.8 million Rupees, the estimated profit for the 40-acre area used to produce all of these crops would be 6.99 million to 7.23 million Rupees. The true profit-generating phase would start after the breakeven period, which happens after around 5 to

6 months. It's all due to the harvesting of the most productive crops in the region with the annual production of crops calendar.

5. Conclusion

In conclusion, the agriculture industry in Punjab has a revolutionary chance with several advantages when solar-powered power systems are used. On the other hand, project management is required for the effective implementation and ongoing sustainable operation of these solar-powered systems. Agronomists can reduce their dependency on operational costs and waste fuels by mitigating the issues caused by unstable electrical networks through the use of solar energy. Furthermore, water efficiency is increased by solar-powered irrigation systems, which is crucial for addressing Pakistan's water scarcity problems and management. Efficient project management techniques guarantee that solar solutions are tailored to the distinct needs of Pakistan's agricultural landscape, optimizing impact and resource availability consequently. Implementing solar technology also promotes ecological sustainability, which is in line with global initiatives to slow down climate change. Cooperation amongst investors is encouraged by project management, and this includes private investors, public officials, and local communities. This promotes the widespread use of solar-powered power systems, empowering farmers and raising agricultural productivity. In the end, through strategic planning, efficient execution, and continuous monitoring, project management helps Pakistan attain a resilient, energy-independent, and environmentally conscientious agricultural industry.

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