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Application of PV-Thermal Array for Pumping Irrigation Water as an Alternative to PV in Ghor Al-Safi, Jordan: A case study

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Abstract: In developing countries like Jordan, traditional energy resources are not available, so finding other sources to pump the water for irrigation and consumption is necessary. Renewable energy sources, particularly photovoltaic (PV), can play a vital role in providing potable water and irrigating crops in Jordan. Where there is a large amount of groundwater in most areas, while the water wells are deep and far from the national electricity grid. This article compares the Present Value Cost (PVC) for the monetary estimation of energy supply for water pumping systems (WPSs) in remote areas in Ghor Al-Safi/Jordan by two different sun-energy systems, Photovoltaic thermal (PV-T), and PV systems. Several factors are considered, including energy costs and expenses of the investments. The comparison is performed for a variety of variable values, including PV system peak power, and water pumping requirements. A case study is conducted at Ghor Al-Safi/Jordan. Evaluating two energy supply WPSs, which are designed to supply irrigation water for the entire year 2020. The obtained results showed that the average monthly electricity output efficiency for "PV and PV-T" was 12.7% and 10.86%, respectively. However, the total efficiency of the "PV-T" ranged from 41.3% to 55% which is higher than the PV system. The result concluded that the application of PV-T system in Jordan is promising for solving energy demand.

Keywords: photovoltaic thermal (PV-T), photovoltaic (PV), Ghor Al-Safi, alfalfa

1. Introduction

As the population in Jordan, as well as around the world increases, the demand for agricultural products is rising, and so agricultural technology is constantly being developed to cope with this rising demand, which, in turn, increases the need for more electrical energy. Current research shows the potential for using solar energy to overcome the conflicts in energy and water demands[1-7].

Solar energy is mostly gathered as electricity and heat through PV and thermal technologies, adequately[8-12]. A hybrid PV-T integrates a PV and a thermal catcher into one block. while the PV cells produce electricity, the combined thermal arrangement absorbs the remaining warmth power from the panels then decreases their temperature in the operation and as well increases their efficiency[13-14].

Like most other developing countries (DCs), Jordan's energy and water situation are extremely critical[15,16]. Thus, the agricultural sector's use of water for irrigation by electricity generated from renewable energy sources has merely grown in Jordan and DCs. These water supply systems reduce farmers' expenses by reducing energy consumption as the cost of irrigation is a significant factor in the total cost of agriculture. The main goal of this paper is to find the most appropriate, and cost-effective PV technology, so that solar radiation can be used to generate electricity and heat the water for domestic use. This can give important meaning to strategic alternative solutions to farmers' problems that affect many aspects of their lives. This study considers, the historical sun radiation data, water consumption, water reserves, and tool cost, to suggest a better configuration and optimization of the cost of the solar water drip irrigation system. In addition, it allows the evaluation of the feasibility of an on-site solar-powered drip irrigation system in a specific area. There are many systems for pumping water that is currently used in the world including diesel, and local generator WPSs. However, there are many problems associated with these systems as follows[16]:

1. Continuous growth in oil prices in recent years, so that, these techniques have become cost-expensive

leading to an increase in the price of water irrigation.

2. These systems have many moving mechanical parts and therefore require more maintenance.
3. These systems may be in isolated remote rural areas.
4. Most external environmental factors are frequently not thoroughly taken into account when determining the energy sources at which the WPS should be operated.

Therefore, this article's main idea is to adequately focus on the cost-effectiveness of using thermal and PV technologies. The PV-T panel is a combined unit of the solar thermal collector in addition to the PV cell, to produce hot water and generate electricity. The integrated thermal unit of PV-T accumulates the heat energy via its thermal collector from the solar panels, thus reducing their temperature and therefore improving their efficiency[13]. PV-T panels can have a net efficiency of both types, electrical and thermal, of up to 68%, while their electrical efficiency can only reach “15-18%”, and their thermal efficiency may exceed 50%[13,16]. In general, the energy payback time of PV-T is shorter than stand-alone PV systems, because it operates at 9% better efficiency[17,18].

2. Solar irradiation and weather conditions data/ Ghor Al-Safi-Jordan

Ghor Al-Safi (also known as Ghawar As-Safi) is a region in the Jordan valley, located in the Wadi al-Hasa. It is located between the Tafilah and governorates of Karak, southern Dead Sea[19].

Reviewing Jordan's solar atlas in Fig. 1, Jordan is split into five zone areas. The Southern zone has the largest solar irradiance in Jordan. The yearly average daily global irradiance is around “6.5 kWh/m²”. The Eastern zone (semi-desert) with a yearly global irradiance of around “5.75 kWh/m²”. The middle region with a yearly global irradiance is around “4.75 kWh/m²”, but with the largest annual daily average of diffused irradiance. The Northern zone with a yearly average daily global irradiance of around “5.5 kWh/m²”. The Western region represents the Jordan Valley area, which is located below sea level and with an average annual daily global irradiance below “4.5 kWh/m²”.

As previously stated, statistical data assists in predicting and characterizing the site. As a result, this study was conducted for the 2020 year, and on the alfalfa crop, which is heavily reliant on water irrigation. To design a suitable PV drip irrigation system for a specific area, the following must be specified:

1. The complete information on weather conditions in the study area,
2. The underground water specifications, and
3. The amount of required water to irrigate the crop.

As illustrated in Fig. 2, the typical PV WPS generally includes:

- PV-array mounted on a fixed structure or tracking system;
- Pumping system (pump motor), which can be mounted on the surface/floating, or submersible;
- Power electronics devices, which typically consist of an inverter, converter, controller, etc.; and
- Water storage system.

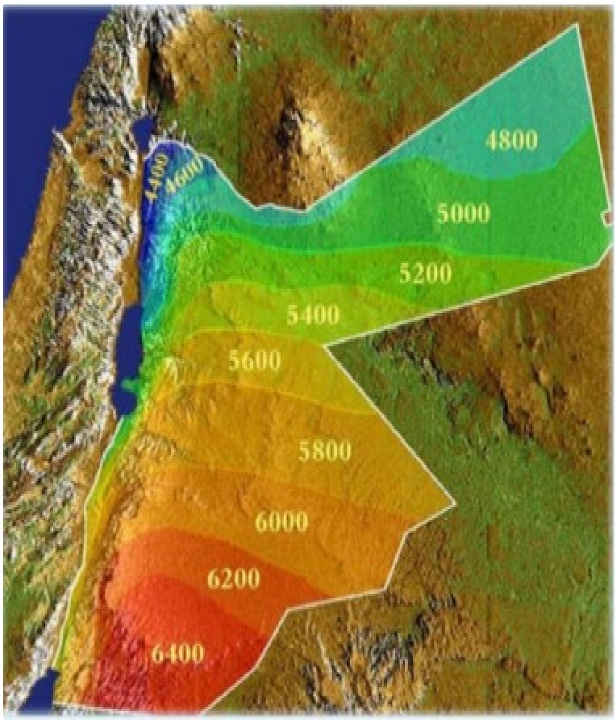

Fig. 1. Jordan Five Main Morphological Units[19].

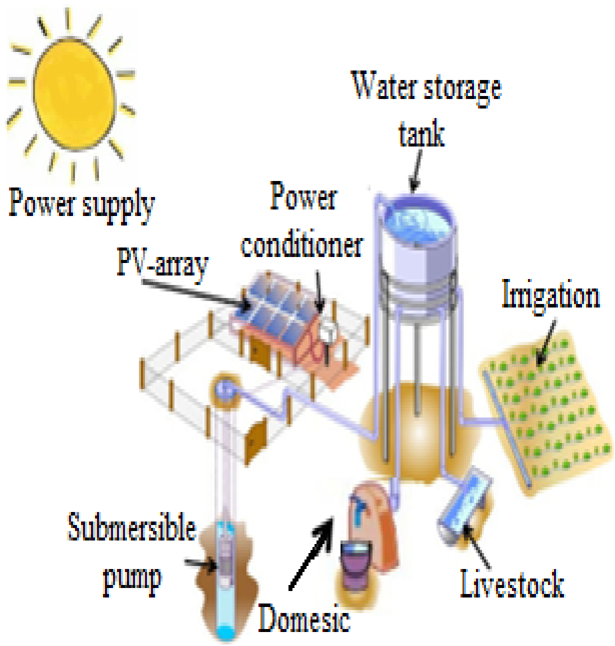

Fig. 2. Schematic diagram of PV pumping system[20]

The data of the groundwater well are specified in Table 1. The site condition, solar availability, and the most important atmospheric condition required for the design of any PV system are given in Table 2. The monthly variation of a measured average value of ambient temperature and horizontal radiation in Jordan is shown in Fig. 3 and Fig. 4 respectively. The highest average ambient temperature was recorded in July at "35.5 ^oC", while the minimum was recorded at "15.5 ^oC" in January[21]. It can also be seen that the highest average horizontal radiation of "7.27 kWh/m^2" was recorded in July, while the minimum is "3.02 kWh/m^2" per day in December[21].

Table 1. Groundwater hydrological data[2].

Depth of well	125 m.
Level of the static water	50 m.
Level of the dynamic water	25 m.
Productivity of the Well	$100\ m^3/h$.
Criteria of the design	$55\ m^3/day$.
Head of pumping	75 m

3. Irrigation water pumping system

Currently, PV WPSs are exceedingly applied globally and in Jordan due to solar radiation availability. Solar energy systems proved to be an efficient and reliable method for WPS in areas where surface water and electric grid systems are unavailable. Whilst, the traditional generating systems, and operating costs are. high[22-24].

WPS for water supply and irrigation for rural and remote areas by autonomous PV systems demonstrates a significant role[25-28]. WPS usually consists of a water source and PV array, water reservoir, and electrical pump motor as illustrated in Fig.5.

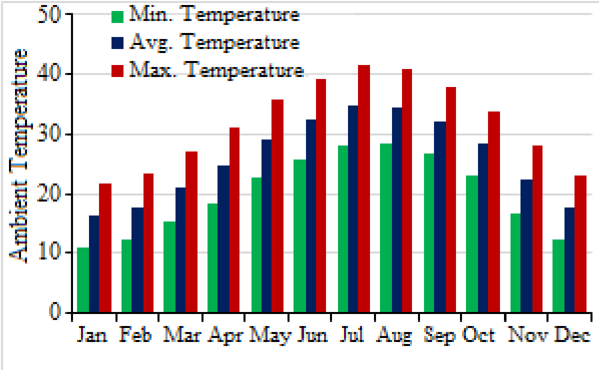

Fig. 3. Monthly variation of the ambient temperature in Ghor Al-Safi, Jordan[21].

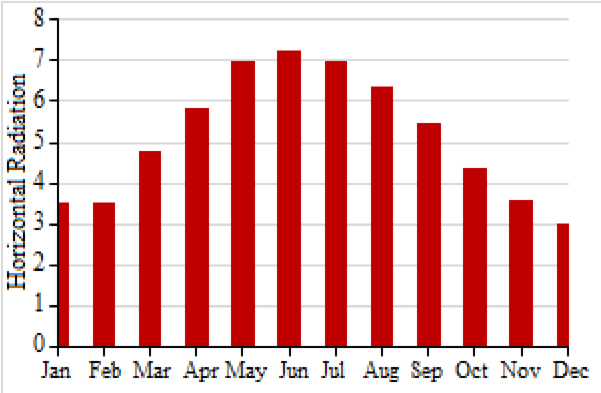

Fig. 4. Monthly variation of the horizontal irradiance in Ghor Al-Safi, Jordan[21].

Table 2. Solar radiation availability and site condition at Ghor Al-Safi Station[5, 14]

System Location:		**Latitude: 31° 2' 9N**		**Longitude: 35° 29' 19E**			
Month	**Site condition**			**Array Plane**			
	Ambient Temperature (˚C)	**Horizontal Irradiance**	×	**Tilt, azimuth Shadow factor**	=	**Irradiance**	
		"$kWh/m^2/day$"	×	**Fraction**	=	**"$kWh/m^2/day$"**	**"W/m^2"**
Jan.	15.5	3.54	×	1.4	=	4.956	175.0
Feb.	16.7	3.55	×	1.3	=	4.615	205.8
Mar.	20	4.8	×	1.2	=	5.76	230.0
Apr.	24.5	5.85	×	1	=	5.85	241.7
May	28	6.97	×	0.9	=	6.273	262.5
Jun.	31	7.27	×	0.9	=	6.543	281.3
Jul.	32	7	×	0.9	=	6.3	288.8
Aug.	32	6.36	×	1	=	6.36	304.2
Sep.	30.5	5.45	×	1.1	=	5.995	265.8
Oct.	27	4.39	×	1.3	=	5.707	232.9
Nov.	22	3.58	×	1.3	=	4.654	184.2
Dec.	17.8	3.02	×	1.5	=	4.53	175.0

3.1. Irrigation water requirements (IWR)

IWR is the amount of water needed for crop growth that depends on cropping patterns and the impact of climate change. Assessment of irrigation potential, based on soil and water resources, can only be done with the simultaneous assessment of irrigation water requirements (IWR). In this paper, the alfalfa crop is chosen as a case study for the research because it consumes large amounts of water[29-31]. Fig. 6 illustrates the net irrigation requirements for six field crops.

Fig. 5. PV WPS in Ghor Al-Safi –Jordan[2].

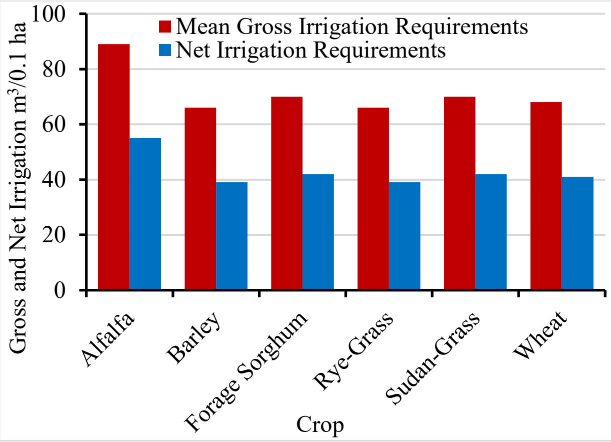

Fig. 6. The mean gross and net irrigation requirements for six field crops[33].

4. Analytical study and calculations

In this paper, a simple and accurate approach was chosen for the calculations and sizing of PV and PV-T arrays, and this approach relies on the accurate determination of the nominal power of the pump the required water from the well to the storage tank, which is then used for irrigation purposes. Likewise, it depends on the sizing of the PV system elements required to operate the pump.

For hydraulic sizing, the user provides basic information, for example, the required daily water intake, the total pumping head, a variety of daily pumping times, the pipe grade material, length of pipe, rated pressure, and pump effectiveness, then the hydraulic requirement of the WPS is determined by using Eq. 1[34, 35].

$$P_m = \frac{\rho g\,(h + \Delta H)Q}{\eta_b \eta_e} \qquad (1)$$

where P_m is the pump input power [kW]; ρ is the water density "$1000\ \mathrm{kg/m^3}$", g is the gravity acceleration, "$9.81\ \mathrm{m/s^2}$"; h is the pump head, "m"; ΔH is the hydraulic losses in "m"; Q is the water rate flow, "$\mathrm{m^3/s}$", η_b is the pump efficiency, and η_e is the electrical motor efficiency.

The required hydraulic energy "kWh/day" is expressed in Eq. 2[2].

$$E_h = \rho \mathrm{ghV} = \eta_s E_{pv} = \frac{\mathrm{V(m^3/day)} \times h(m) \times \rho \times \mathrm{g}}{3.6 \times 10^6} = 2.7222 \times 10^{-3} \times \mathrm{V} \times h \qquad (2)$$

where V is the required water volume, "$\mathrm{m^3/day}$" and η_s is the subsystem (pump, motor, and the power electronic circuits) efficiency, and E_{pv} is the energy of the PV array.

4.1. Sizing of the PV array

An autonomous PV WPS sizing includes the determination of the PV power required to meet predictable load requirements. It is standard to use a PV size safety factor to compensate for the energy losses due to heat, dust, aging of panels, etc.[34].

The quantity of the PV power is determined based on irradiance energy[7] as expressed in Eq. 3.

$$P = S_{pv} G_r \eta_r \qquad (3)$$

where P is the power of the PV panels, [Wp]; S_{pv} is the useful surface area of the PV panels, [$\mathrm{m^2}$]; G_r is the irradiance at "25^oC", "$1000\ \mathrm{W/m^2}$"; η_r is the PV panel efficiency at "25^oC".

The energy daily produced by the PV is expressed by Eq. 4[7]:

$$E_{pv} = S_{pv} G_T \eta_{pv} \qquad (4)$$

Where "G_T is the daily irradiance" on the PV array surface, "$\mathrm{kWh/m^2}$"; η_{pv} is the efficiency of the PV array under operational conditions. The PV array area can be obtained from Eq. (2) as expressed in Eq. 5.

$$S_{pv} = \frac{\rho g h V}{G_T \eta_{pv} \eta_s} \qquad (5)$$

Thereby, the required size of the PV array is expressed by Eq. 6.

$$P_{pv} = \frac{E_h}{G_T \times F \times E} \qquad (6)$$

where F is the panel mismatch factor and is defined as the ratio of a PV panel's output power, under the working conditions to its power output at the maximum power point. The typical acceptable value of the PV system design is between "0.85 and 0.90" on average, and "E is subsystem daily efficiency 0.2–0.6 typically"[34,36].

Finally, the overall efficiency of the proposed system is determined by Eq. 7.

$$\eta_O = \frac{P_h}{P_{in}} = \frac{\rho g\, h\, V}{A_{pv} G_T} \qquad (7)$$

4.2. Comparison between PV and PV-T efficiency

Solar panels are manufactured in two forms: "PV-T" and "PV". The "PV-T" panel produces electricity plus heat, while the "PV" panel produces electricity only. Therefore, the cell' temperature is reduced, which improves its performance[13]. Corresponding characteristics of the "PV-T" and the "PV" panels are shown in Table 3.

The recorded temperatures of the "PV" panels at daylight hours are relatively higher than that of common "PV-T" panel temperatures. Table 4 shows the rising ratio, which starts from 3% in January to 6.5% in June. This means that "PV-T" panels produce better electricity because of their lower temperature and heat absorption ability.

Fig. 7a shows the differences in the temperatures of the "PV" and "PV-T" panels during daylight hours. Fig. 7b shows that the highest recorded operating panel temperatures recorded on 3 September 2020 for the reference period were "70.6 ^oC" for the "PV" panel and "60.5 ^oC" for the "PV-T" panel, respectively.

The nominal "PV" and "PV-T" efficiencies listed on the nameplate are 16.60% and 15.08%, accordingly to Table 3. The efficiencies of "PV-T" and "PV" were calculated at special values for panel temperatures. From the results presented in Table 5 and Fig. 8, the efficiency of "PV" systems ranged between 10% and 17.38%. Meanwhile, the electrical efficiency of "PV-T" ranged from 8.09% to 13%. Moreover, the thermal efficiency of "PV-T" varies widely from 23.56% to 40.94%.

4.2.1. Temperature of the panel

The maximum or nominal power of the PV panel is obtained at "standard test conditions (STC)", which include solar radiation of "$1\ \mathrm{kW/m^2}$", the temperature of the panel being "25^oC", and an air mass ratio of "AMR $=$ 1.5 ". Though in the open-air actual situations, the circumambient is differentiated from these STC, and therefore, the output power of the PV panel would differentiate at the nominal power. The temperature of the cell, " $T_{cell}, ^o C$ " at any circumjacent temperature "$T_{amb}, ^o C$" is expressed in Eq. 8.

$$T_{cell} = T_{amb} + \left[G_p\left(\frac{ROCT - 20}{800}\right)\left(\frac{9.5}{5.7 + 3.8\omega}\right)\right] \quad (8)$$

where ω is wind speed $(\mathrm{m/s})$, "ROCT is the nominal operating cell temperature", and G_p is the irradiance in the PV system site "$\mathrm{W/m^2}$". Therefore, the impact of the "solar irradiance, ambient temperature, and wind speed" on the PV panels can be evaluated by their effect on the PV panel temperature.

4.2.2. Performance ratio and efficiency of PV-T and PV panels

In general, the performance of photovoltaic systems is assessed using numerous specified performance indicators, including energy yield (EY), performance ratio (PR), and efficiency. The EY is defined as the normalized output over the nominal capacity of the PV panel. It defines how many hours per day the PV array needs to run at full power to produce the same quantity of energy as estimated. It is calculated by:

$$EY = \frac{E_{d.avg}}{P_{nominal}} \qquad (9)$$

where EY is the energy yield by the array, "$\mathrm{kWh/kW_p/}$ day", $E_{d.avg}$ is the daily average of the panel, "$\mathrm{kWh/day}$", and $P_{nominal}$ is the panel nominal electrical power, "$\mathrm{kW_p}$" at STC.

The performance ratio (PR) estimates, the overall influence of the energy losses on the nominal energy output of the PV array. It indicates how its performance is close to ideal performance during its operations time. The PR is important in order to compare the panels that receive different amounts of irradiance, particularly due to geographical location and/or inclination of PV. It is calculated by:

$$PR = \frac{E_{d.avg}}{P_{nominal} \times H_d} \qquad (10)$$

where H_d is the panel average daily peak sunshine hours, "$\mathrm{h/day}$".

The performance of PV and PV-T systems may also be tested using the efficiency of both units. The efficiency of the PV panels is obtained by Eq. 11.

$$\eta_{PV} = \frac{100 \times E_{dc}}{A_m \times G_p}\ \% \qquad (11)$$

where A_m is the total panel absorber surface area of the panel, "$\mathrm{m^2}$", and E_{dc} is the DC power generated by the panel, "kW".

Concerning a PV-T panel, its total efficiency is given as a combination of the electrical efficiency of PV cells and thermal efficiency. Thermal efficiency is related to thermal energy extracted from a PV cell by a thermal fluid (water or air) as it is cooled by this fluid that flows through the tubes inside the cells. Thus, the thermal efficiency of the PV-T panels is obtained by Eq. 12.

$$\eta_{th} = \frac{100 \times E_{th}}{A_m \times G_p} \times \% \qquad (12)$$

$$E_{th} = M_\omega \times c_p \times (T_2 - T_1) \qquad (13)$$

where M_{ω} is the mass of water flow rate (kg/s), c_p is the water-specific heat "$\mathrm{kJ/kg}\,^{o}\mathrm{C}$", and T_1 and T_2 are the inlet and outlet water temperature, respectively.

By merging Equations 9 and 10, the overall efficiency of the PV-T panels becomes as in Eq. 14.

$$\eta_{PVT} = \frac{100}{A_m \times G_p}(E_{dc} + E_{th}) \qquad (14)$$

4.2.3. Design of the PV-T and PV array

The variation in cell temperature, maximum power, and efficiency of the PV and PV-T units were recorded considering the influence of climatic conditions including hydrological data of the site[31]. The results of the above equations become:

$E_h = 11.38\ \mathrm{kWh/day}$

By applying Eq. 6, assuming the mismatch factor of the array $F = 0.9$, and $\eta_s = 0.5$, then the required solar power is

$$P_{pv} = \frac{E_h}{G_T \times F \times E} = \frac{11.24}{5.25 \times 0.9 \times 0.5} = 4.82\ kWp$$

where E_h is defined as the hydraulic energy required to pump the water, and P is the power generated by the solar PV array. A major factor that greatly affects the performance of solar PV systems is the safety factor. This factor has a value of 1.2 as described in[29].

$P = 1.2 \times 4.82 = 5.78\ kWp$

Table 3. PV-T and PV panels technical specifications[14].

Parameters	PV-T	PV
Panel Dimension	$160.1 \times 82.8 \times 9\ \mathrm{cm}^3$	$164 \times 99.2 \times 4.5\ \mathrm{cm}^3$
Panel Aperture Area	$1.326\ \mathrm{m}^2$	$1.45\ \mathrm{m}^2$
Panel Absorber Area	$1.193\ \mathrm{m}^2$	-
Weight	24.4 kg	18.14 kg
Rated electrical power (P_{rated})	$200\ Wp$	$270\ Wp$
Rated thermal power	$630\ W$	-
Rated current (I_{mmp})	5.43 A	8.6 A
Short Circuit Current (I_{SC})	5.67 A	9.31 A
Rated voltage (V_{mmp})	37.89 V	31.4
Open-Circuit Voltage (V_{OC})	45.26 V	38.3 V
Efficiency of panel	"15.08%"	"16.6%"
Zero Loss Solar Thermal Collector Efficiency (%)	"0.48"	-
Temperature Constant of (I_{SC}) (α)	$0.06\ (\%/^{o}\mathrm{C})$	$0.05\ (\%/^{o}\mathrm{C})$
Temperature Coefficient of the Open Circuit Voltage (V_{OC}) (β)	$-0.34\ (\%/^{o}\mathrm{C})$	$-0.34\ (\%/^{o}\mathrm{C})$
Temperature Coefficient of the Maximum Output Power (P_{max}), (δ)	$-0.45\ (\%/^{o}\mathrm{C})$	$-0.45\ (\%/^{o}\mathrm{C})$
$Rated\ Operating\ Cell\ Temperatur\ (ROCT),^{o}\ C$0C	"45 ± 2^{0} C"	"45 ± 2^{0} C"
"PV Absorber Surface"	"mc-Si"	"mc-Si"
"Thermal Absorber Surface"	"Copper"	-

Table 4. panel temperatures and weather data for PV-T and PV cells[2].

Month	Ambient Temperature (^{o}C)	Radiation ($\mathrm{W/m^2}$)	ω (m/s)	T cell (˚C)	
				PV	PVT
Jan.	10	175.00	3.5	12.73	12.36
Feb.	12	205.83	3.5	15.22	14.77
Mar.	18	230.00	3.5	21.59	20.96
Apr.	22	241.67	3.5	25.78	25.03
May	27	262.50	3.5	31.10	30.20
Jun.	31	281.25	3.5	35.39	33.23
Jul.	34	288.75	4.5	37.76	35.46
Aug.	36	304.17	3.5	40.75	38.27
Sep.	28	265.83	1.5	34.92	33.91
Oct.	19	232.92	1.5	25.07	24.34

Nov.	17	184.17	1.5	21.80	21.16
Dec.	11	175.00	1.5	15.56	15.10

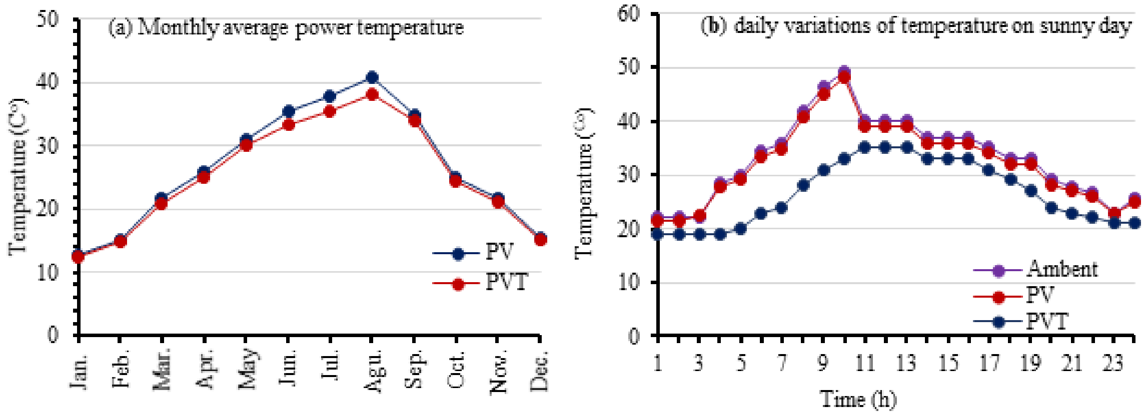

Fig. 7: panels Temperature of PV and PV-T[2].

Table 5. The efficiency of PV-T and PV[2].

Month	η_{PV}	PV-T		
		η_{el}	η_{th}	η_{PVT}
Jan.	17.38	13.00	40.94	53.94
Feb.	14.77	11.05	34.81	45.86
Mar.	13.22	9.89	31.15	41.04
Apr.	12.58	9.41	29.65	39.06
May	11.58	8.66	27.29	35.96
Jun.	10.81	8.09	25.47	33.56
Jul.	10.53	7.88	24.81	32.69
Aug.	10.00	7.48	23.56	31.03
Sep.	11.44	8.56	26.95	35.51
Oct.	13.05	9.77	30.76	40.53
Nov.	16.51	12.35	38.90	51.25
Dec.	17.38	13.00	40.94	53.94

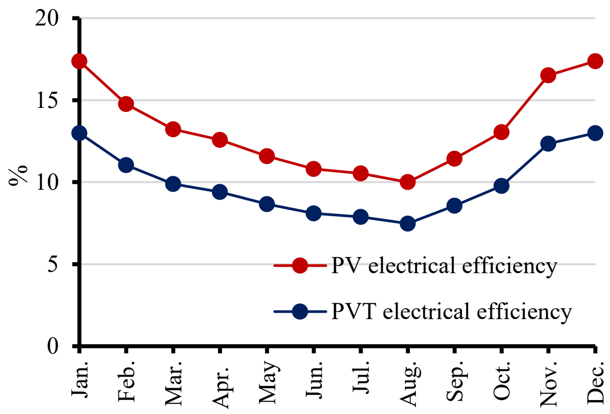

Fig. 8: Comparison between PV-T and PV electrical efficiency[2].

5. Study of results

5.1. The case study

The suggested methodology has been utilized to investigate an autonomous PV-T WPS designed to feed water for irrigation and domestic uses in Ghor Al-Safi, Jordan.

The PV-T WPS was installed in the Ghor Al-Safi station, and it contains PV-T panels, an inverter, a pumping motor, and “two storage tanks”. WPS components in this study are shown in Fig. 5.

The PV-T array contains a 30-panel type SM55/Siemens with a maximum power of 6 kW. The technical specifications of the used panels are shown in Table 3. The total area of 39.78 meters square.

The pump motor used in this WPS is 2EC132S-4 m, “5.5 kW”. The technical specifications are shown in Table 6.

The “DC/AC inverter” is an S5-GR3P5K-LV manufactured by Solis-China, with a nominal power of “7.5kVA”. The technical specifications are shown in Table 7.

All PV WPSs require a water storage system. To store water instead of storing electrical energy in batteries, thus lowering the expense and complication of the entire system. The common is to provide "water tanks" with sufficient capacity to store water for not less than two days.

The storage system includes "two water tanks" for an overall capacity of 100 m^3. This WPS is prepared to feed a small community of farmers and irrigate their crops with around “40 m^3/day” of water.

Table 6. Specifications of the pump motor[37]

Type	2EC132S-4
Rated power	5.5 kW
Flow	8 m3/h
Rated voltage	$230/400V(\Delta/Y)$
Rated current	$18.6/10.76A(\Delta/Y)$
Efficiency η	89.6%

Table 7. Specifications of the inverter[38]

Type	S5-GR3P6K-LV
Input voltage:	330V
Output voltage	230/400 V
Recommended max. PV power:	9 kW
Rated output power:	6 kW
Max. output power:	6.6 kW
Rated voltage:	230/400V
Rate frequency:	50 Hz / 60 Hz
Max. output current:	16.7 A
Max. Efficiency:	98.09%

5.2. Economical cost study

The payback period and the total cost of the generated power are used to evaluate WPS economically. The life cycle cost (LCC) of the two systems (PV or PV-T) includes the cost of design, installation, site preparation, and operating and maintenance costs. The life cycle cost is obtained as follows:

$$LCC = C_{capital} + \sum_{T=1}^{n} C_{O\&M} \times R_{pw} + \sum_{1}^{n} C_{replacement} \times R_{pw} - C_{salvage} \times R_{pw} \quad (15)$$

$$LCC = C_{capital} + \sum_{T=1}^{n} \frac{C_n}{(1+I)^n} \quad (16)$$

where $C_{capital}$ is the capital cost, $C_{O\&M}$ is the operational and maintenance cost, $C_{replacement}$ is the replacement cost, $C_{salvage}$ is the salvage value, C_n is the "annual cost".

When PVC for various alternative technologies is equivalent, the "Annual Equivalent Cost (AEC)", is a significantly relevant economical factor to estimating projects. The AEC is obtainable as follows[30]:

$$AEC = LCC \frac{I\,(1+I)^n}{(1+I)^n - 1} \quad (17)$$

The AEC is the total cost of irrigation water "JD/m^3", which includes both the capital cost of WPSs and operational costs, and is used to compare the costs of PV-T and PV WPS. Meanwhile, the particular water discharge cost allows for a comparison of various pumping systems, even for locations with varying pumping heads and levels of use[39].

The LCC will be evaluated as follows for the existing PV WPS. The projected life span (n) of the system components is 25 years, which corresponds to the predicted life span of the PV panels. Also, the inflation rate in Jordan at 5.3, and the market discount rate (d) is at 10%[40-42].

The initial cost of the PV and PV-T WPSs including the PV/PV-T arrays, inverter, pumping motor, and auxiliaries are:

$$C_{capital(PV)} = 12{,}000\,JD.$$

$$C_{capital(PV-T)} = 15{,}000\,JD.$$

$$C_{O\&M(PV)} = 0.02 \times C_{capital} = 0{,}02 \times 12{,}000 = 240\,JD$$

$$C_{O\&M(PV)} = 0.02 \times C_{capital} = 0{,}02 \times 15{,}000 = 300\,JD$$

By utilizing Eq. 15, AEC for the PV and PV-T respectively are:

$$LCC_{(PV)} = 12{,}000 + \sum_{n=1}^{25} \frac{240}{(1+0.1)^{25}} = 14178.5\,JD$$

$$LCC_{(PV-T)} = 15{,}000 + \sum_{n=1}^{25} \frac{300}{(1+0.1)^{25}} = 17723\,JD$$

By utilizing Eq. 14, LCC for the PV and PV-T respectively are:

$$AEC_{(PV)} = 14178.5 \times \frac{0.1(1+0.1)^{25}}{(1+0.1)^{25}-1} = 1562\,JD$$

$$AEC_{(PV-T)} = 17723 \times \frac{0.1(1+0.1)^{25}}{(1+0.1)^{25}-1} = 1952.5\,JD$$

The specific irrigation water costs (IWC) are:

$$IWC_{PV} = \frac{1562}{14600} = 0.107\,JD/m^3$$

$$IWC_{PV-T} = \frac{1952.5}{14600} = 0.134\,JD/m^3$$

where $14600m^3$ is the total pumping water through the year.

5.3. Comparison of PV and PV-T Installations

The daily average production of the proposed solar systems is "3.21 kWh" PV system, compared to 2.72 kWh/kWh of the PV-T system, and this indicates that the productivity of the PV system is better than that of the PV-T system for the electrical energy. This is consistent with all previous studies[43]. The summary of the output parameters of the systems is shown in Table 8. The production of the PV system was 25.55% higher than that produced by the PV-T in this research. Nevertheless, the PV-T system remains better than the PV system because it produces thermal in addition to electrical energy.

Table 8. A summary result of "PV" and "PV-T" performance.

Parameters	PV-T	PV
Nominal Power of the panel "Wp"	200	270
The system's yearly output "kWh/year"	6513.06	7767.81
The annual daily average energy output of the system "Wh/day"	18172	21230
The total yearly irradiance "kWh/m²"	2260	2260
The annual average daily irradiance "kWh/m²/day"	5.84	5.84
Daily System Yield "kWh/kWp/day"	3.03	3.57
The average Efficiency %	10.86	12.7
The total Efficiency %	51.3	12.7

6. Conclusion

This article proposes and investigates the application of a WPS using an autonomous PV project based on PV or PV-T technology used for irrigation purposes in the Ghor Al-Safi. To prepare a suitable statistical and comparative study, the lowest values of solar radiation have been chosen with a relatively water-intensive harvest in Jordan during the year. The main objective of choosing the lowest radiation with a relatively high-water consumption value is to provide a highly efficient system so that agricultural areas are used for different types of crops and in all months of the year.

This research compares the performance of PV and PV-T panels-based water irrigation, which are built using the same "mc-Si" technology. In January 2020, the highest recorded panel temperatures were 70.6 C and 65.5 C for PV and PV-T panels, respectively. While the average temperature of the PV panel was about (1.34-7.1%) higher than that of the PV-T panel.

The total annual daily mean electrical EY for the "PV and PV-T" were 3.57 and 3.03 " kWh/kWp/day ", respectively.

The average monthly electricity output efficiency for "PV and PV-T" was 12.7% and 10.86%, respectively. While the thermal efficiency of the "PV-T" ranged from 31.3% to 45%, and the total efficiency of 51.3%.

Thus, the comparative study of both systems shows that a WPS with PV panels can be more profitable if it is solely used to produce electricity. As soon as the use of thermal energy is required to provide the population with hot water and for other needs, such as air conditioning systems, PV-T is preferred over conventional PV systems.

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