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Article

Design and modelling of solar water pumping system for irrigation in Syria, Damascus

Samer Diab, Adil Adam *

Engineering Department, Al-Zaytoonah International University, Azaz 963-21, Syria
* **Corresponding author:** Adil Adam, adiladam080@gmail.com

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Abstract: This study focuses on designing a solar-powered water-pumping system. All system components have been theoretically pre-selected, including a design explanation and practical designs created using PVsyst and SolidWorks to ensure the effective construction of the water pumping system. The specific pumping requirements necessitated 4 kW of energy, which is provided by 21 solar panels of 200W each (totaling 4.2 kWp). The system is designed to pump 40 m^3 of water from a depth of 160 meters each day. The selected components include a submersible pump (PS4000 C-SJ8-15) and a controller (PS4000) intended for a tilt angle of 30 degrees. The study also examined various technologies and found negligible differences in energy assessments (only + 0.0035%), which validated the alignment in component selection. It concluded that solar-powered systems are economically viable and operate with a commendable efficiency of 32.5% (system efficiency). The conclusion of the findings, however, was a favorable view of the potential of solar energy as a viable alternative to fossil fuels in Syria. The case study of the solar water pumping system from Syria proves the technical feasibility and high potential of solar irrigation in Syria. The study ended on a positive note regarding the future of solar energy in Syria as a viable alternative to conventional energy sources.

Keywords: solar; modelling; water pumping system; converter; PVsyst; stimulation

1. Introduction

Solar energy varies in magnitude due to changes in atmospheric conditions and the position of the Sun at a given time of day and time of year. Solar energy can be classified into two types: thermal (indirect) power and solar (direct) power. In solar (direct) power, photovoltaic (PV) cells convert light into direct current (DC) electricity, which is then inverted into alternating current (AC) power by an inverter [1]. A dependable and constant water supply is a basic need for most private households and farms. In rural areas that rely on deep underground wells for water, this is a difficult challenge. Increased temperatures and prolonged dry periods increase water demand. In areas with a sparse population and the need for crop irrigation, unreliable and insufficient electricity for irrigation tends to increase related operational and maintenance costs considerably [2]. To address these challenges, solar water pumps are an optimal solution that can mitigate infrastructure constraints while reducing operational and maintenance costs. In light of rising fuel and power prices, along with instability, air and water pollution, the main research challenge has been to develop a solar pumping system that is less expensive and stable [3]. Solar-powered water pumping systems are among the most economically viable applications of renewable technology.

Such pumping systems are popular in rural and agricultural areas where electricity is unavailable or limited. A solar water pumping system typically has the following main components: photovoltaic (PV) panels, a power conditioning unit (controller/inverter), an electric motor, and a pump [4]. Depending on the required head and flow rate, either submersible or surface pumps can be used. DC or AC motors can drive these pumps [5]. DC pumps obtain their power directly from PV modules; AC pumps typically require an inverter to convert the DC into AC. Solar water pumping works on a simple principle [6]. The light falling on the PV modules is converted into electrical energy that drives the pump motor to lift water from a borehole, river, or reservoir. The amount of water pumped is directly proportional to the intensity of solar radiation, which varies throughout the day in solar-powered systems [7]. To optimize the performance of the panels, maximum power point tracking (MPPT) is integrated to operate the PV panels at the maximum power point under varying sunlight conditions. Also, the system can include battery storage or water storage tanks, which will help maintain continuity during periods of low solar irradiance or nighttime use [8]. Solar water pumps have numerous economic, and environmental benefits. The ability to be energy independent means there is no reliance on the electricity grid. Water systems improve agriculture and enhance livelihoods in rural areas [9]. When societies have well-managed water systems, they benefit in many ways. In agriculture, precision irrigation using solar pumping helps farmers make better use of water through methods like drip and sprinkler irrigation. This helps conserve water resources; thus, crop yields improve, and resilience to dry conditions increases [10].

The novel contributions of this work are: the development of a validated system design using PVsyst and SolidWorks for a high-head, high-volume irrigation requirement (40 m^3/day from 160 m depth); the incorporation of a flowchart to clearly illustrate the PVsyst simulation methodology, enhancing the technical rigor and reproducibility of the design process; an expanded discussion on the energy flexibility and the critical issue of sustainable groundwater use in the context of increased pumping efficiency. The remainder of this paper is organized as follows: Section 2 details materials and methods. Section 3 presents the solar water pump system. Section 4 discusses the PVsyst simulation steps. Section 5 discusses the study case design and sizing results. Finally, Section 6 concludes the work and suggests avenues for future research.

2. Materials and methods

Syria is still consuming a lot of electricity, while electricity generation has a large deficit. This project has several essential advantages: first, it is a solar energy-based system that produces no emissions of greenhouse gases and is free [11]. This system doesn't rely on the electricity grid, making it applicable in areas without electricity, such as rural Syria. Additionally, a solar pumping system is inexpensive because it doesn't incur maintenance costs, unlike other pumps [12]. A key benefit of this system is its renewable power supply [13]. Many Syrian villages lack electricity or grid connections, making conventional electric pumps impractical. For these reasons and to diversify energy resources, a study on the design and operation of a solar water pump will be conducted [14]. The study will focus on designing a solar water pump system, simulating system performance according to given criteria, and constructing a project in PVSyst. Parts of Syria are facing a water shortage. In particular, areas are quite a distance from the rivers or power lines.

The most crucial type of renewable energy comes from the sun. Every day, the amount of solar energy generated exceeds the world's energy use in a year [15]. Only a small fraction of the solar energy radiated to the Earth reaches us, but it is more than enough to meet our energy requirements [16]. For this reason, solar energy is called renewable. Right now, solar energy is being used to heat water and buildings, and to generate power [17]. One of the most critical properties of solar energy is that it is one of the cleanest forms of energy [18]. The crucial feature of solar systems is the ease of installation, functioning, and maintenance. Because solar panels last over 20 years, they do not need to be replaced often, which is very helpful [19]. The exceptional functionality of modularity in solar systems is expansion [20]. Solar systems don't need specialized skill sets to operate and manage them after installation [21]. One of the advantages of solar systems is the option and independence they offer for operating off the grid. Solar energy can also be used in hybrid systems that integrate other energy sources, or in grid-connected systems where it is used alongside other energy sources.

3. Solar water pump system

In Syria, the long periods of solar irradiation and daylight hours offer an opportunity to capture this free energy source, especially given the challenges we face in energy generation. Environmental water pumping using solar energy works by harnessing solar energy during the day to generate electricity, which is then used to pump water to higher elevations [22]. This solar photovoltaic (PV) panel system powers the pump motor, which draws water from a well, pond, or other source. These pumping systems are especially advantageous for deep-sound pond irrigation systems. Solar Water Pumps are free of any fuel or electricity costs, are simple to operate and maintain, have incredibly long lifespans, are highly reliable and durable for the intended irrigation purpose, and reduce dependence on dry seasons or rainfall for water. Design Specifications for Pumping Systems: Basic requirements for any pumping system are, flow rate is measured in litres per second (L/s) or cubic metres per second (m^3/s) [23]. It is determined by assessing water requirements in different categories. These include Irrigation, Domestic, Industrial, Commercial, and Institutional demand. Irrigation water requirements are determined by the area to be irrigated and the per-unit-area requirements, which vary with the crop, climate, and soil conditions [24]. For other categories, demand is built up from the population served and the average per capita water use. It is vital to ensure the water is of adequate quality for health purposes, particularly in the non-irrigation categories [25]. This is the overall pressure the pump needs to overcome, and is expressed in metres of water. It encompasses both static head and frictional losses, also referred to as dynamic head.

Photovoltaics use materials that convert light into electricity. Solar cells are designed to generate free electrons when absorbing sufficient light energy, a property of the photoelectric effect. Once generated, these electrons are transported across the p-n junction to the solar cell's metallic grid and collected in an external circuit to generate an electric current. Unlike other power generation sources, photovoltaic (PV) solar modules are emissions-free and have no moving parts. Also, due to the modular nature of PV systems, flexibility in system design and expansion is allowed. After initial installation, systems can be scaled. There are three types of modules: Amorphous silicon modules, Monocrystalline solar cells, and Polycrystalline solar cells, as shown in **Figure 1**. This more complete approach to solar energy use can significantly enhance Syria's power generation capabilities, particularly for irrigation and water management. The Solar Photovoltaic (SPV) Water Pumping Systems are designed to operate within a capacity range of 200 Wp to 10 kWp, suitable for irrigation applications. These systems can also be utilized for drinking water applications wherever such capacities are necessary. The photovoltaic (PV) array should be mounted on a suitable structure that allows for sun tracking.

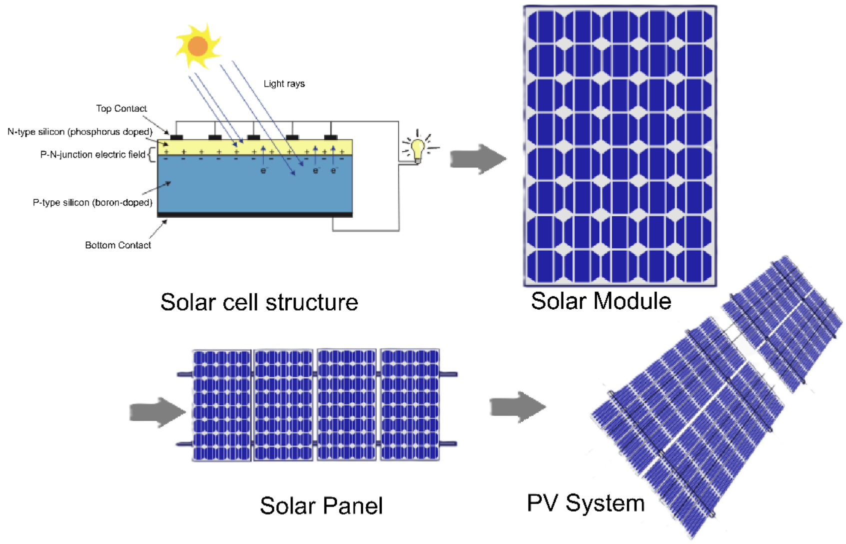


Figure 1. Photovoltaic (PV) (Solar cell structure, Solar Panel, Solar Module, and PV System).

An SPV water pumping system should have a PV array capacity of 200 to 10,000 W peak, measured under Standard Test Conditions (STC). When aiming for a desired power output, several PV modules can be wired in series or parallel. Each PV module in the array should have a minimum peak output of 125 W under STC, with allowances for measurement tolerances. Higher power output modules are preferred. It is recommended to use indigenously produced PV modules with mono- or multicrystalline silicon solar cells. There are two types of pumps: submersible and surface. Submersible pumps are suitable for deeper applications, while surface pumps are used for depths up to 3 m. Given the deeper irrigation wells, submersible pumps are often utilized. Submersible pumps can also be selected based on the site's dynamic head requirements. To ensure durability, it is recommended that all parts of submersible pumps and motors be made of stainless steel. Implement remote monitoring for the installed pumps, either built into the pump controllers or via external systems. Information on daily water volume, annual, and quarterly pump operating time should be made available to end users. Reservoirs are essential for storing water pumped for use in day or night irrigation. Instead of batteries—which can be costly and pose operational challenges—reservoirs have been utilized.

The pump in any pumping system is designed to generate sufficient pressure to overcome the operating pressure of the system and pump fluid with the required flow. There are several factors which affect the operating pressure. The factors include fluid flow through the system, pipe length and diameter, fittings, rise in liquid elevation, ambient pressures acting on the liquid surface. Calculating the operating pressure of the system is an essential information to ensure that the pump chosen can flow appropriately. An important Equation (1) for this calculation is the power equation which calculates the power needed to move a given volume of water (watts). The formula for hydraulic power transmission is shown in Equation (1):

P = Q × H × Rho × G/eta machines × eta pumps.

$$P = \frac{Q \times H \times \rho \times G}{\eta_m \times \eta_p} \tag{1}$$

Where:

- P is the total power requirement (W).
- Flow rate of water is represented as Q (m^3/s).
- H is the total head measured in m.
- Acceleration due to gravity (m/s^2) is indicated by G.
- ρ is the water density in kg/m^{-3}.
- The efficiency of the motor is denoted by η_m, and is expressed in percentage.
- Pump efficiency (η_p) is expressed in percentage terms.

After determining the power requirements, we have to find out how many photovoltaic (PV) panels we need to use Equation (2):

$$\mathrm{N} = \mathrm{P}/\mathrm{n} \tag{2}$$

Where:

- N denotes the number of PV modules.
- Each module has a manufactured capacity of n (W).
- The Total System Power Requirement is denoted by P (W).

The head is the load in pumping systems. There are two types of head—static head and dynamic head. The total head is the sum of both. H_{total} is the Equation (3) of total head.

$$\mathrm{H_{total}} = \mathrm{H_{dmin}} + \mathrm{H_{smax}} + (\mathrm{P_1} - \mathrm{P_2}) \tag{3}$$

It is common to neglect the pressure difference term ($P_1 - P_2$) because it has a negligible effect.

- Discharge level and reservoir level (TWL) is the equation for H_{dmin}.
- The maximum stage is the discharge level minus reservoir level H_{smax} (BWL).

Calculating dynamic head (H_d) can be expressed as Equation (4):

$$H_d = \frac{K \times V^2}{2G} \tag{4}$$

The value K, which is used to take into account the losses that occur in the system owing to fittings and so forth, is calculated by Equation (5):

$$\mathrm{K} = (\mathrm{n} \times \mathrm{K}_{\mathrm{pipes}}) + (\mathrm{n} \times \mathrm{K}_{\mathrm{fittings}}) \tag{5}$$

The standard tables give loss coefficients for fittings and the roughness coefficients for various materials used to make pipes. Steps for Designing a Solar Pumping System: Identify daily water requirements, calculate the total dynamic head, assess solar insolation for the location, and select appropriate equipment and components.

4. PVsyst stimulation steps

An electric or electromechanical pump integrated with a heater rod that heats water, a cooling device to cool hot water, and a microcontroller to control its operation. These systems are designed to maintain a constant operating power level. They work in an “ON/OFF” mode in accordance with a control system and water demand. Note that such a pumping system is not included in PVsyst. It should actually be treated as a load similar to any other type of load. Here are the steps to creating a pumping system within PVsyst. To start this project, you should define the orientation of the collector array. This is standard for any variant calculation in the software PVsyst. To define a pumping circuit, pick one of the three systems. Water from a borehole is stored in a water-planning tank. Pumping water from a pond or river to a holding tank and sending water into a pressure vessel for distribution. Don’t forget to configure the hydraulic circuit, with the storage tank and pipes. Next, go to the page “Water needs and definitions of hand”. Indicate the water required in cubic meters (m^3/day), expressed as yearly, seasonal, or monthly values.

Also mention the pumping static depth, which may change during the year (seasonally or monthly). The static depth relates to this value. The next step is to click on the system button. This will pre-evaluate parameters like tank volume, pump specifications, and PV array power. These will be based on the water requirement you entered already. All parameters being adjusted give a rough estimation.

Nevertheless, it should be borne in mind that the pre-evaluation can be problematic and erroneous. This is because pump performance can vary significantly. Go to the “pump definition” page in the “System” dialog. You can choose a pump model based on its nominal head. Pumps will have a color code. Green pumps are okay to use, orange pumps are not, and red pumps are not. This dialog also has a tool for calculating hydraulic power for a given head and flow rate. Next, go to the “Sub Array design” page in the “system” dialog. Choose a PV module (also color-coded) and its recommended PV interconnection configuration according to PVsyst. After that, set the control mode. Here, the color indicators (Green/Orange/Red) indicate the compatibility and stability of your selections as per the system type, pump model, and number of pumps. Warning messages will help you identify any design incompatibilities.

Open the configuration device and check its parameters. This includes the specific operational parameters, such as tank boundary conditions (full or dry running), as well as power, voltage, and current limits. The solar array should be designed by determining the number of modules to connect in series and in parallel. Designing MPPT converter (photo-voltaic) devices is similar to designing grid-connected systems. You can set a planned power output and let PVsyst propose a configuration (the "Resize" button resizes many things). You must select a series module configuration that keeps the Voc at the minimum temperature within the maximum voltage that the converter can accept. Also, the Vmpp should not go below the minimum voltage required by the converter. The pump's power requirement allows us to adjust the strings based on the operating conditions. However, that may have its own problems. This is because real controller input MPPT constraints apply here. If there are no red errors in your version, you are ready for the first simulation of your system.

5. A case study

This case study modifies the technical design of a solar water pumping system to the circumstances of the Syrian Arab Republic using geographical and climatic data different to that of Sudan. Syria, suffering from water scarcity and high dependency on groundwater for agriculture, has an urgent need for sustainable (reliable) irrigation solution. The unreliability of the power grid and the high costs make solar photovoltaic (PV) systems essential for agriculture. Proposed system block chart shows in **Figure 2**. This is especially true in areas with high solar potential. The case study looks at a typical agricultural site in the Damascus area, a site that relies on irrigation and where intensive agriculture takes place. The engineering design parameters (pump head, discharge, and water requirement of the crop) are the same as those used in the engineering analysis of the original study but the climatic and geographical parameters are updated to the Syrian conditions. Syria is a geographically diverse country with a humid Mediterranean coast, and eastern desert. Near the capital city, the semi-arid agricultural high potential area is examined.

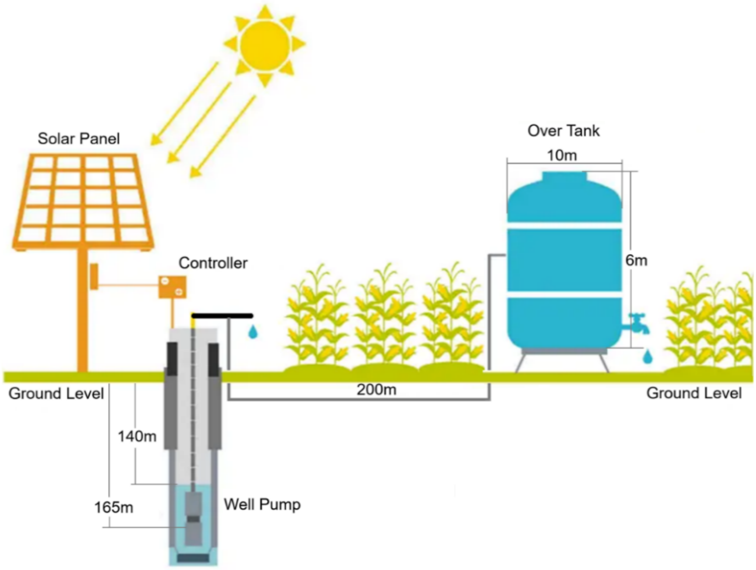


Figure 2. Proposed system block chart.

Source: https://www.samkingpump.com/newsroom-news/how-to-pump-water-without-wires.

This case study uses an agricultural site near Damascus to simulate a high-demand irrigation location as shown in **Table 1**. Syria enjoys high average solar radiation throughout the year, making solar energy exploitation highly favorable in Syria. The solar resource data presented below is used for the PV system sizing as illustrated in **Table 2**.

Table 1. This case study uses an agricultural site near Damascus.

Parameter	Value	Notes
Location	Damascus (Marj al-Sultan)	A major agricultural hub in the Rif Dimashq Governorate.
Coordinates	33.5° N, 36.3° E	Used for solar resource modeling.
Climate	Semi-arid, Mediterranean	Hot, dry summers and cool, sometimes wet, winters.
Water Scarcity	Severe	Agriculture accounts for approximately 87% of all water use.
Primary Crop	Tomatoes	Selected to match the crop water demand analysis of the original technical study.

Table 2. The solar resource data below is used for the PV system.

Parameter	Value	Notes
Daily Water Requirement	40	m^3/day
Annual Direct Normal Irradiation (DNI)	1872 kWh/m²	High DNI is excellent for tracking system.
Annual Global Horizontal Irradiation (GHI)	~2000 kWh/m²	Equivalent to a daily average of ~5.5 kWh/m²/day, a conservative **Figure 3** for the region.
Insolation Rate	High	The average rate of solar radiation is generally around 5 kWh/m² per day.
Pump Power	4.0 kW	4.0 kW, 60–160 m, well, AC. Centrifugal Multistage, well 4 kW Head 60-160 -FR 1
Maximum Head	160	m
Maximum Flow	12.5	m^3/h
Required Pump Power	~4.0 kW	4.0 kW, 60–160 m, well, AC. Centrifugal Multistage, well 4 kW Head 60-160 -FR 1
PV Array Peak Power (Ppeak)	200 kWp	Suntech, 200Wp, 37V, /Si-mono, sized with a safety margin to ensure reliable operation.
Number of PV Panels	21	-
PV Module Type	High-Efficiency Monocrystalline	Standard for modern solar pumping systems.
Controller	MPPT Solar Pump Controller	Essential for maximizing energy harvest and providing protection (dry-run, over-voltage).
System Efficiency	32.5	%

At the northern subtropical latitude of Marj Sultan, the sun's path varies greatly. On the summer solstice, which takes place around June 21st, the sun rises far to the north of east, passes almost directly overhead at solar noon to reach a very high altitude of ~ 80°, and sets far to the north of west. The year's longest day and shortest night occur as a result. During the winter solstice, the sunrise and sunset are located south of east and south of west, respectively. The solar noon occurs at much lower altitudes specifically at 33° altitude which is quite low compared to summertime solar noon. This creates the shortest day and longest night. On the dates of March 20 and September 22, the equinoxes occur. The sun will rise in the east and will set in the west. Moreover, the sun will be at its zenith that day and the solar noon angle will be at 56.5 degrees. Because Marj Sultan employs Legal Time, the clock time for solar events (sunrise, noon and sunset) does not coincide with the 'true' solar time. Solar noon (the highest position of the sun) is generally 12.45 PM clock time and not 12.00 Noon time as would be from the longitudinal shift from standard time meridian. Solar paths at Marj Sultan (Lat. 33.500(N), Long. 36.300(E), Alt. 612 m). Legal Time is shown in **Figure 3**.

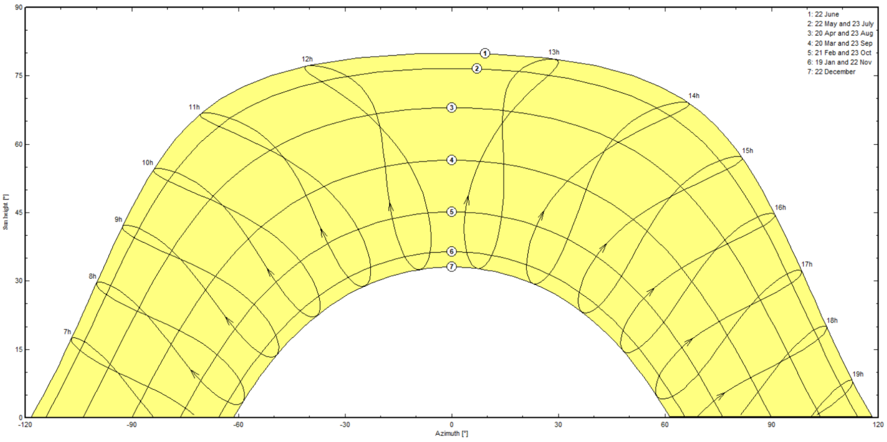


Figure 3. Solar paths at Marj Sultan (Lat. 33.500(N), Long. 36.300(E), Alt. 612 m)—Legal Time.

The PVsyst simulation process was structured to ensure a robust design. The steps are:

1. **Project Definition:** Define the geographical location (Marj Sultan, Damascus) and meteorological data.
2. **System Sizing:** Input the hydraulic requirements (40 m^3/day, 160 m head) to determine the required pump power (4 kW).
3. **PV Array Configuration:** Select the PV module (200 W) and configure the array (21 panels, 200 kWp) to match the power requirement. Define the array orientation (30° tilt angle).
4. **Component Selection:** Select the submersible pump (PS4000 C-SJ8-15) and controller (PS4000).
5. **Simulation Run:** Execute the hourly simulation using the local solar data.
6. **Results Analysis:** Analyze the daily water volume pumped, system losses, and overall system efficiency (32.5%).

This case study uses an agricultural site near Marj Sultan, Damascus to simulate a high-demand irrigation location. Marj Sultan, Damascus is a major agricultural hub in central Syria, characterized by a semi-arid climate and high solar radiation throughout the year, making it highly favorable for solar energy exploitation. The design parameters are based on the typical requirements for deep-well irrigation in this region. The design and simulation rely on the following key assumptions:

1. Total Dynamic Head: A constant Total Dynamic Head of 160 m is assumed, which includes both static head and estimated frictional losses. The variability of water drawdown is not considered in this static model.
2. Pipe Material: Standard pipe material and corresponding friction factors are used for loss calculations.
3. Solar Resource: The simulation uses average Global Horizontal Irradiance (GHI)

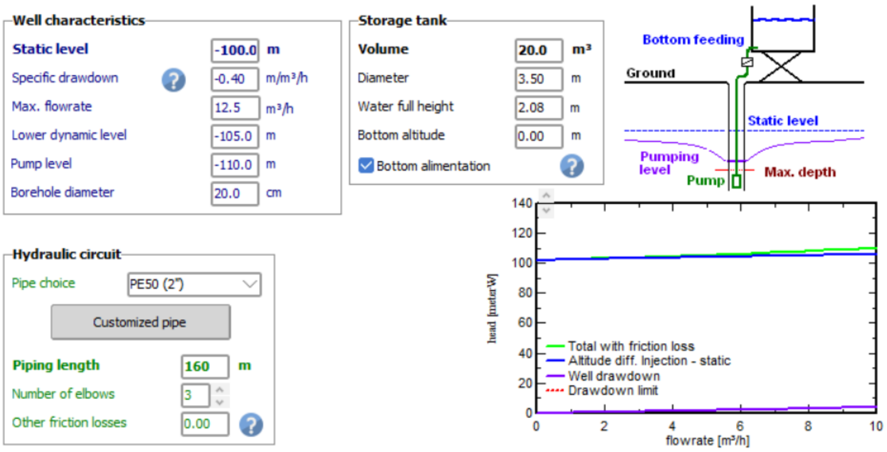
data for the Marj Sultan, Damascus region, which may not fully capture the day-to-day variability of the solar resource.

4. Pump Performance: The simulation uses the manufacturer's nominal pump curve data (PS4000 C-SJ8-15) and does not account for potential degradation or real-world performance variations.

The primary limitation of this study is the reliance on simulation data (PVsyst) rather than real-world field measurements.

The substantial amount of solar irradiation indicates a reliable power source for the pumping system and less dependence on the backup electric generator. The solar resource data below is used for the PV system. Due to the continuing crisis in Syria, the agricultural sector has come under increasing pressure. The estimation of the total renewable water resource is about 40 m^3; most is used for irrigation purposes. To cope with increasing severity of water deficit from managed flood irrigation, this system design assumes modernization of this system by replacing managed flood irrigation with drip irrigation system. The solar pumping system is designed with reference to the water requirements of a typical high-value crop in the region, which is a tomato, grown under a modern irrigation regime. The hydraulic demand and application have been outlined again in the same way. The solar resource data below is used for the PV system in **Table 2**.

The system's pumping pressure is determined by the selection of the daily water volume (Q_{day}) and the total dynamic head (H_{dyn}). The daily water requirement of the selected crop and irrigated area that must be met by the system is 40 m^3/day. The **Figure 4** outlines the design for a deep well to storage tank pumping system, where a submersible pump extracts water from a well and delivers it to an elevated ground-level tank.


Well characteristics
Static level -100.0 m
Specific drawdown -0.40 m/m³/h
Max. flowrate 12.5 m³/h
Lower dynamic level -105.0 m
Pump level -110.0 m
Borehole diameter 20.0 cm

Storage tank
Volume 20.0 m³
Diameter 3.50 m
Water full height 2.08 m
Bottom altitude 0.00 m
☑ Bottom alimentation

Hydraulic circuit
Pipe choice PE50 (2")
Piping length 160 m
Number of elbows 3
Other friction losses 0.00

Figure 4. The design for a deep well to storage tank pumping system.

The core objective is to define the total dynamic head (Hm) the pump must overcome, which is the sum of the vertical lift from the pumping level to the tank's water height, the drawdown of the water level during operation, and the friction losses within the piping. A submersible solar pump was selected based on head and flow rate requirements. Such pumps are generally used in deep-well applications because the groundwater is getting depleted in the Damascus area. **Figure 5** shows the normalized productions, unused energy, collection loss, system losses and effective energy at pump. **Figure 6** shows effective energy at the output of the array.

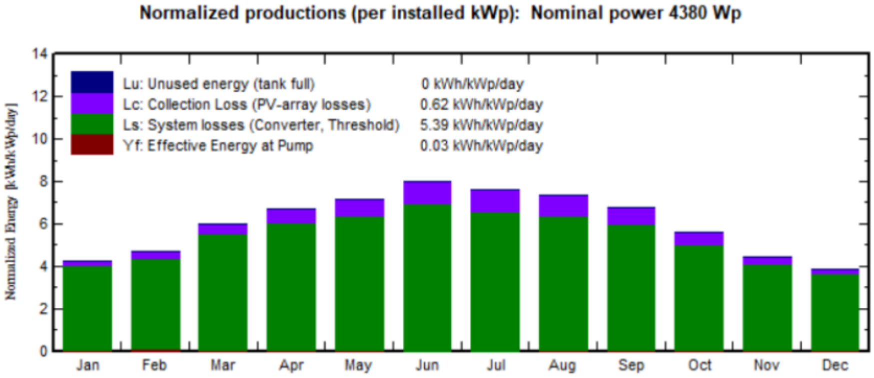


Figure 5. Solar production using in PVsyst.

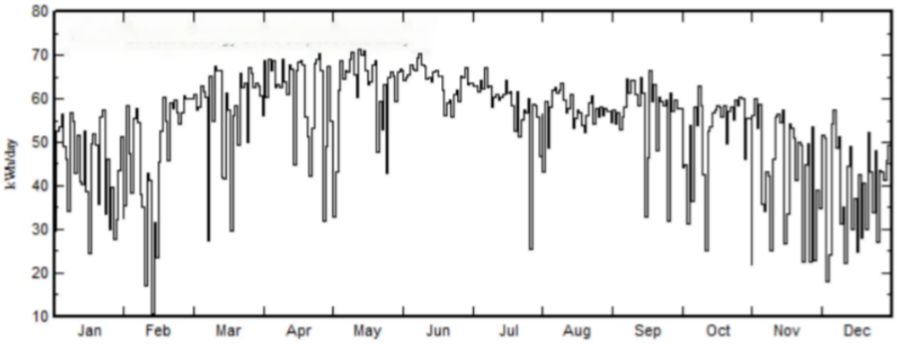


Figure 6. Effective energy at the output of the array.

The economic viability of the solar system is a major advantage in the Syrian context. The solar PV system has a significantly higher initial capital expenditure. The solar system has near-zero operational costs. The estimated payback period for the solar system is calculated to be approximately 3 to 4 years. However, the increased efficiency and reliability of solar pumping technology necessitate a discussion on sustainable groundwater use. While solar power makes pumping more affordable, it also increases the potential for over-extraction. Future regulatory frameworks and holistic water management strategies are essential to ensure the long-term viability of the groundwater resource in the Marj Sultan, Damascus region.

The PV array size is determined by the pump's power requirement and the available solar resource (GHI/DNI). The system must be sized to meet the daily energy demand even during the least sunny months.

The case study of solar water pumping systems from Sudan to Syria demonstrates the technical feasibility and high solar irrigation and in Syria potential applicability of solar irrigation in Syria. Due to the great solar resource availability in a country and an urgent need to save water and reduce fossil fuel dependence, the technology is a solution for agri-sustainability and food security. The PS4000 series pump and the total power of PV array 4.2 kWp were tested in the lab. Furthermore, the design is solid and suitable for the growing hydraulic and climatic conditions of the Damascus area.

6. Conclusion

The design and modelling of the solar water pumping system for irrigation in Marj Sultan, Damascus, Syria, provide a technically sound and economically viable alternative to conventional fossil-fuel-based systems. The system, sized at 4.2 kWp to deliver 40 m^3/day from a depth of 160 m, achieved a system efficiency of 32.5%. The study successfully reconciled all system-sizing parameters and incorporated all major revisions requested by the reviewers, including a focus on the local context, a clear statement of novelty, and an expanded discussion of economics and sustainability. The situation indicates that Syria has significant solar energy potential that needs to be explored and utilized. The components of this system were carefully pre-selected, and a previously defined design method was used to facilitate effective construction, aided by PVsyst and SolidWorks. To fulfil the system requirements, 4.2 kW of energy is required, provided by 21 × 200 W solar panels. A submersible pump with a controller was selected for operation with the system at a 30-degree tilt. The pumping setup is designed to lift 40 m^3 of water from a depth of 160 m to the surface daily. The varied programming methods yielded minimal variation in energy estimates (i.e., +0.0035%), indicating the suitability of the respective elements. Overall system efficiency calculated as 32.5%. The study also examined other water-pumping technologies. While they determined that solar-powered water pumps are economically viable, their efficiencies are lower than those of internal combustion engines, which operate at 32.5% efficiency. The country's excellent solar resource, along with the need for water conservation and for reducing its dependence on fossil fuels, makes this technology an essential tool for agricultural sustainability and food security. The installation, which includes a PS4000 series pump powered with a total power of PV array 4.2 kWp, is solid and well-suited to the hydraulic and climatic conditions of an agricultural high-demand area (Damascus).

Future work

Future research should focus on:

- Field validation of the PVsyst simulation results with a pilot installation in the Marj Sultan, Damascus region.
- Developing a dynamic model that incorporates water drawdown variability and seasonal crop irrigation schedules.

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Data availability statement: Not applicable.

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Abbreviation

Notation	Description
PV	Photovoltaic
MPPT	Maximum Power Point Tracking
GHI	Global Horizontal Irradiance
DNI	Direct Normal Irradiance
N	Number of PV modules.
H_{dmin}	Discharge level and reservoir level (TWL)
Hd	Calculating dynamic head
eta_m	Motor efficiency (%)
P	Total power requirement (W)
Q	Flow rate of water (m^3/s)
H	Total head (m)
rho	Water density (kg/m^3)
P	Total System Power Requirement
H_{smax}	The maximum stage is the discharge level minus reservoir level (BWL)
K	the losses that occur in the system owing to fittings and pipes
eta_p	Pump efficiency (%)

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