(05-041) - Self-consumption solar installation for the extraction of drinking water and service to the city council of Titaguas (Valencia).

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The rising cost of energy has led to the development of increasingly affordable solar installations. Thus, solar photovoltaic technology is being implemented in industry for multiple applications. In self-consumption applications, it is common to use the roofs of buildings to superimpose solar panels. However, there are other equally useful but less known applications. In this article we are going to present an isolated solar installation, without interaction with the electrical grid, for pumping drinking water from an existing well. During sunny periods the installation generates enough energy to pump water to the reserve tanks in the Valencian town of Titaguas. This is an energy saving installation. We will study its configuration and the economic result of it.

Keywords: solar photovoltaic ; pumping well ; engineering projects

Instalación solar de autoconsumo para extracción de agua potable y servicio al ayuntamiento de Titaguas (Valencia).

El aumento del coste de la energía ha propiciado el desarrollo de las instalaciones solares cada vez más accesibles. Así la tecnología solar fotovoltaica se está implantando en la industria para múltiples aplicaciones. En las aplicaciones de autoconsumo es habitual utilizar las cubiertas de las edificaciones para superponer placas solares. Sin embargo, hay otras aplicaciones igualmente útiles pero menos conocidas. En este artículo vamos a presentar una instalación solar aislada, sin interacción con la red eléctrica para bombeo de agua potable desde un pozo existente. En los periodos soleados la instalación genera la suficiente energía para bombear agua a los depósitos de reserva en la población valenciana de Titaguas. Se trata de una instalación para ahorro energético. Vamos a estudiar su configuración y el resultado económico de la misma.

Palabras clave: solar fotovoltaica ; pozo de bombeo ; proyectos de ingeniería

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1. Introduction

The rising cost of energy and the growing awareness of climate change and the need to reduce greenhouse gas emissions have led to an increase in the use and development of photovoltaic installations in recent years. According to the International Energy Agency (IEA), the installed capacity of photovoltaic (PV) energy worldwide has increased more than 50-fold in the last 10 years, reaching over 580 gigawatts (GW) in 2021. This figure is expected to continue growing in the coming years as more efficient photovoltaic technologies are developed and installation costs continue to decrease (IEA, 2021).

Another key factor driving the increased use of photovoltaic installations is the decrease in the costs of solar energy installation and production. In recent decades, the costs of solar panels and other photovoltaic components have dropped significantly, making solar energy more affordable and competitive compared to conventional energy sources (IRENA, 2021).

Solar photovoltaic technology has a wide range of applications, with electricity generation in the residential sector being the most well-known. However, there are other equally useful but lesser-known applications in various sectors. This includes agricultural uses and diverse pumping systems, such as the one we will discuss in this paper.

This paper presents the design and implementation of a photovoltaic powered water pumping system to supply drinking water to the town of Titaguas, a small village in Valencia province, Spain. The paper details the PV system design, water demand assessment, and the economic and environmental analysis of the project. We present a solar installation for pumping drinking water from an existing well. During sunny periods, the installation generates enough energy to pump water to the reserve tanks. This is an energy-saving installation, and we will study its configuration and the economic outcome of the project.

Water scarcity is a growing concern in many regions worldwide, and it is particularly evident in Spain's Mediterranean regions, including the Valencia province. Access to safe and reliable drinking water is essential for human health and socio-economic development. To address these challenges, renewable energy technologies, such as photovoltaic systems, can provide an environmentally friendly and sustainable solution to power water pumping systems.

The objective of this study is to design a PV-powered water pumping system to supply drinking water to a small village in Valencia province, Spain. The system's performance, economic viability, and environmental benefits will be assessed to demonstrate its potential in contributing to a sustainable water supply.

A detailed analysis of the village's water demand, solar irradiation, and the available water resources was conducted to size the PV system accurately. The system comprises a PV array, a pump controller, a submersible pump, and a water storage tank. A backup battery system was considered for times when solar irradiation is insufficient. The water demand was estimated based on the population, daily per capita water consumption, and water losses during transportation.

A cost-benefit analysis was performed to assess the economic viability of the PV-powered water pumping system compared to a conventional diesel-powered system.

The proposed PV-powered water pumping system was found to be capable of meeting the village's water demand, with the appropriate sizing of the PV array and storage capacity. The system's performance will only require backup power during July and August.

2. Regulatory Framework for Small-Scale Photovoltaic Installations in Valencia, Spain

The successful implementation of a small-scale photovoltaic (PV) installation, such as the one proposed for pumping drinking water in Titaguas, requires compliance with the relevant regulations in Spain and the Valencia region. This section outlines the key regulatory aspects that must be taken into account during the design and operation of a PV installation with a capacity of less than 100 kW.

2.1 National Regulations

At the national level, Spain has a comprehensive legal framework governing the generation, distribution, and consumption of renewable energy, including solar PV installations. Key regulations applicable to small-scale PV installations include:

Photovoltaic installations must comply with the electrical safety standards established in the Low Voltage Electrotechnical Regulations (REBT) (Royal Decree 842/2002 of August 2, 2002), and specifically its Technical Guide for the application of ITC–BT–40: Low Voltage Generating Installations.

Royal Decree 244/2019, which establishes the regulatory framework for self-consumption of renewable energy and simplifies the administrative process for small-scale PV installations (BOE, 2019). For systems with an installed capacity of less than 100 kW, this regulation allows for a streamlined registration process and exempts the installation from certain taxes and charges. This Royal Decree regulates the conditions for the installation and connection to the grid of self-consumption electrical energy systems, including photovoltaic systems. It sets the administrative, technical, and economic requirements that these installations must meet, with the aim of ensuring proper functioning and safety within the framework of energy self-consumption. It is important to ensure compliance with this regulation to guarantee the legality and proper functioning of photovoltaic installations.

In addition, compliance with the UNE 206010:2019 standard "Solar Photovoltaic Energy. Installations for electricity production with grid connection. Design and commissioning requirements" is necessary. This standard establishes the technical requirements for the design, installation, and commissioning of photovoltaic installations connected to the electricity grid in Spain. It includes aspects such as location, sizing, electrical protections, monitoring systems, and other necessary requirements to ensure the safety, efficiency, and quality of photovoltaic installations. Compliance with this standard is essential to ensure that the installation meets the technical standards established in the industry and guarantees its proper functioning.

2.2 Regional Regulations in Valencia

In addition to national regulations, small-scale PV installations in the Valencia region must also comply with regional regulations, such as:

The Valencian Energy Agency (AVEN) provides financial incentives and support for the installation of renewable energy systems, including small-scale PV installations. These incentives may include grants, tax deductions, or low-interest loans, and can help offset the initial investment costs of the project (Provincial Council of Valencia, 2020).

Local urban planning and building regulations may also apply to small-scale PV installations, depending on the location and specific characteristics of the project. It is essential to consult with the local authorities in Titaguas to determine any applicable requirements or restrictions, such as building permits or zoning regulations.

2.3 Compliance and Certification

To ensure the safety and reliability of the PV-powered water pumping system, it is crucial to comply with the relevant technical standards and certification requirements, such as IEC 61730-1:2023 and IEC 61215-1:2021, which are international standards for the safety and performance of solar PV modules.

There are many other standards and guidelines, though they are not as relevant, that also contribute to ensuring the overall safety and performance of the system.

In conclusion, understanding and adhering to the relevant regulations and standards at the national, regional, and local levels is crucial for the successful implementation of a small-scale PV installation in Titaguas.

3. Existing Wells and Pumping System.

Before discussing the integration of the photovoltaic (PV) system, it is essential to understand the existing wells and pumping system's characteristics. This section will provide an overview of the current setup, including the installed pumps and their operational parameters.

3.1 Pumping System Description

The municipal water supply wells (two in the same location) are currently equipped with the following submersible pumps:

- Aturia XN-10-6 M10-M125 submersible electric pump with a power rating of 96 kW and operating voltage of 380/660 V. The pump is installed at a depth of approximately 144 meters.
- Grundfos SP-10-12 M8-870 submersible electric pump with a power rating of 92 kW and operating voltage of 380/660 V. The pump is installed at a depth of approximately 144 meters.

Both pumps are never operated simultaneously, and as observed, their maximum power demand is 96 kW. The existing pumping system is designed to pump water against a storage reservoir.

3.2 Operational Characteristics

As the pumps operate independently and not at the same time, the total power demand of the system is limited to the maximum power of the individual pumps (96 kW). The system is designed to pump water from the well to a storage reservoir, providing a continuous supply of water to the community. The existing well and pumping system's operational characteristics will serve as a basis for designing the PV system to improve the energy efficiency of the water supply and reduce the reliance on grid electricity.

One of the pumps is an old one and is going to be replaced. Currently, the system pumps water at night when energy is cheaper.

Figure 1. Pumping installation at the starting point of the project.

4. Photovoltaic System Design

The feasibility of self-consumption can be explored by considering the following options:

1) Shifting nighttime consumption to daytime, increasing the use of peak hours, which are much more expensive than off-peak hours. Additionally, to try to cover most of the demand during these hours, the generation installation's power should be higher than the 96 kW required by the pump. The advantage of this option is that the self-consumed kWh is fully saved (energy cost plus energy tolls), while the disadvantage is that non-self-consumed energy is more expensive, and the installation must be adapted to the pump's power rather than its consumption. Otherwise, the demand would never be met. This requires an energetically oversized installation that needs space, which is currently unavailable.
2) Injecting the energy generated during the day into the grid to compensate for it at night. This modality, allowed under RD 244/2019 for self-consumption and called self-consumption with compensation, enables the design of an energy consumption installation to be much more efficient. The disadvantage of this option is that only the cost of energy is recovered, not the tolls (although these tolls consumed during off-peak periods are minimal).

The decision is made to transfer consumption to peak periods and not to design a self-consumption installation with compensation (Option 1).

The photovoltaic modules used in our case are the UL-540 | 545 | 550 M-144HV model from Ulica Solar. This high-efficiency monocrystalline silicon solar panel model features half-cut cell technology, which divides the solar cells into two halves, thereby improving the panels' effectiveness and performance. Additionally, aluminum structures are chosen to support the modules. Monocrystalline silicon modules are made from a single silicon crystal, making them more efficient in converting sunlight into electricity but also more expensive to produce.

As we mentioned in the introduction, our goal is to design a photovoltaic installation that allows us to pump water extracted from wells to the reserve tanks. For this purpose, we will use the SIA-8-77/14 submersible pump with an M8"55kW motor. The SIA-8-77/14 pump with an

M8"55kW motor is a submersible pumping system manufactured by Aiguapres, a company specializing in pumping and water treatment solutions. One of the main features of the SIA-8-77/14 pump is its 55 kW motor, which provides sufficient power to handle large volumes of water in industrial or municipal applications.

The pump is constructed with high-quality materials to ensure its durability and resistance to corrosion, making it suitable for use with drinking water, irrigation water, industrial process water, and other types of water with varying quality and solid content levels. This pump also has an efficient hydraulic design that allows for high performance in terms of flow rate and lifting height, making it suitable for high-flow and high-pressure applications. Additionally, it features an "open channel" impeller system, allowing it to handle water with moderately sized suspended solids without clogging.

In the case of our photovoltaic installation, the inverter used is a POWER ELECTRONICS SD7SP0150 5. This inverter, manufactured by the Spanish company Power Electronics, is used in renewable energy generation applications, such as photovoltaic solar power systems and energy storage systems.

The project for a photovoltaic installation to supply a submersible pump as part of the drinking water supply system for the municipality of Titaguas must consider several aspects:

- Installation of photovoltaic modules.
- Installation of the inverter.
- Installation of the pump.

The inclination of the photovoltaic module, meaning the angle of inclination with respect to the horizontal surface on which it is installed, is a crucial factor that affects the performance and efficiency of a photovoltaic system.

When solar panels are tilted at the correct angle, they can capture the largest amount of solar radiation for the longest possible time during the day. This results in higher energy production and better overall performance of the photovoltaic system.

The optimal tilt angle of solar panels varies depending on the geographic location. According to IDAE's Technical Specifications, the optimal angle to maximize photovoltaic production in an installation with annual consumption is obtained by subtracting 10 degrees from the location's latitude. In the case of our installation in Titaguas (Valencia), the optimal inclination of the solar panels would be 30 degrees.

Another key factor that influences the performance and efficiency of photovoltaic modules is their orientation. The optimal orientation of photovoltaic modules primarily depends on the geographical location of the project. In the case of Spain, and specifically in Valencia, it is located at approximately 39 degrees north latitude, which means it is in the northern hemisphere of the equator. In this region, the ideal orientation of solar panels is southward to maximize exposure to solar radiation during the day.

Southward orientation allows solar panels to capture the largest amount of direct solar radiation throughout the day, resulting in higher energy production. However, other orientations can also be considered depending on the project objectives and space availability. For example, if a perfect southward orientation is not available, southeast or southwest orientations can be considered, which will still allow for significant energy production, albeit slightly lower than the ideal southward orientation.

In a photovoltaic installation like the one described in the article, the separation of photovoltaic modules should also be taken into account. The separation between photovoltaic modules refers to the distance left between them once they are installed on a structure. One of the main reasons to consider proper separation between photovoltaic modules is to avoid shading. The shade generated by one module over another can decrease the energy production of the system, as it reduces the amount of solar radiation reaching the shaded modules. Therefore, it is essential to ensure that there are no shadows from other modules, structures, or nearby elements that could affect the energy generation of the system.

The installation is capable of generating 100% of the energy consumed every month, except for July and August. The excess production is 13%, which indicates that the installation is well-adjusted.

In the months of July and August, when the energy demand may be higher due to increased water usage, the photovoltaic system may not be able to fully meet the energy demand. However, the 13% excess production in other months can help compensate for this shortfall. Additionally, the energy compensation mechanism provided by RD 244/2019 allows for the excess energy generated during other periods to be compensated by drawing energy from the grid when needed.

This well-adjusted installation ensures a more sustainable and cost-effective energy supply for the well pump throughout the year. By generating the majority of the energy consumed on-site through solar power, the system reduces the dependency on grid electricity and contributes to a greener energy mix for the municipality of Titaguas.

Only in the months of July and August does the production not cover the demand. It can be observed that the production closely matches the demand with an annual surplus of 13,580 kWh, which is 13% of the production. This surplus is considered optimal, and the panels have a production loss of 15% in 25 years. Therefore, this is an installation that is well-adjusted to the demand.

The well-adjusted installation ensures that the majority of the energy demand is met through solar power throughout the year, with the exception of the peak demand months of July and August. The 13% annual surplus helps to offset any potential shortfalls in production during these months, and the energy compensation mechanism provided by RD 244/2019 allows for the excess energy generated during other periods to be compensated by drawing energy from the grid when needed.

Moreover, the 15% production loss over 25 years is typical for solar panels, and it is still a viable and sustainable solution for the well pump's energy needs. Overall, the installation contributes to a greener energy mix and cost savings for the municipality of Titaguas.

The self-consumption option (Option 2) requires a smaller solar field but necessitates:

- Expensive high-voltage protections.
- Administrative procedures for grid connection, which are not without difficulty and require approval from the distribution company.
- Negotiating the price of energy fed into the grid with the utility company. Furthermore, the price of energy will vary over time and is expected to decrease in the future.
- Self-consumption is heavily regulated, and long-term results depend on the stability of the legislation affecting it.

The direct solar pumping option requires a larger solar field and replacing one of the existing pumps:

- The installation is easier to legalize and commission than the self-consumption with excess option.

- It does not depend on self-consumption legislation, which is subject to tariffs and changes in recent years and potentially in the future.
- The energy not consumed from the grid has a full price, including the cost of energy, energy tariffs, electric tax, and Value Added Tax (VAT).
- It allows for contracting the appropriate power levels according to the electricity tariff periods.
- The savings obtained are 454% higher than in the case of self-consumption.

Thus, the option chosen for the project is direct solar pumping. This choice takes into account the long-term stability, ease of implementation, and higher savings compared to the self-consumption option. By opting for direct solar pumping, the project can achieve greater energy independence, financial savings, and environmental benefits for the municipality of Titaguas.

The inverter for this project will be specially designed for direct solar pumping applications, featuring a variable input power to ensure it extracts the maximum power from the photovoltaic generator throughout each day. The inverter will be a hybrid, meaning it will have grid connectivity, although this does not imply any interaction between the photovoltaic installation and the grid, resulting in self-consumption. The grid supply is intended as a backup to guarantee the water supply to the municipality if needed and will typically be disconnected.

This hybrid approach provides a reliable and efficient solution for the water pumping system, ensuring that the municipality of Titaguas receives a consistent water supply while maximizing the use of clean, renewable solar energy. By implementing this direct solar pumping system with a hybrid inverter, the project can achieve greater energy independence, financial savings, and environmental benefits for the community.

Protections and safety.

The protections will be located according to the provisions of the "Low Voltage Electrotechnical Regulations" and Royal Decree 1663/2000. Additionally, the schemes proposed in the Resolution of May 31, 2001, with the protections proposed in the R.D., will be taken into account.

The following will be installed:

- DC fuses: These will protect each of the branches, from the terminals of the panels of each branch to a junction box or electrical panel.
- DC surge arresters: These will protect the branches against atmospheric overvoltage. Implemented in the SOLAR KIT by POWER ELECTRONICS.
- Automatic circuit breakers: IMPLEMENTED IN THE SOLAR INVERTER.

The thermal-magnetic protections used will comply with the UNE-EN 60898 standard. The differential protections will comply with the UNE-EN 61008 standard. Protection against indirect contacts in the DC part will be achieved by installing components with insulation class II.

The inclusion of automatic circuit breakers and compliance with the relevant standards for thermal-magnetic and differential protections ensures that the solar pumping system is safeguarded against electrical faults and potential hazards. By implementing these protections and adhering to the specified insulation requirements, the project can maintain a high level of safety and reliability throughout its operation, further contributing to the secure and efficient water supply system in Titaguas. These safety measures ensure that the solar pumping system operates efficiently and securely while minimizing the risk of electrical faults or damage due to atmospheric conditions.

A programmable logic controller (PLC) with internet access is installed, which will be programmed with management software that allows monitoring and management of the well from a computer or mobile device.

The use of a PLC with internet connectivity provides numerous benefits for managing and maintaining the solar pumping system. By allowing remote access to the system, operators can monitor performance, troubleshoot any issues, and optimize system settings from a distance. This not only improves the overall efficiency of the system but also reduces maintenance costs and downtime. Additionally, having real-time data available on a computer or mobile device enhances decision-making capabilities and ensures that the well operates effectively and safely.

5. Performance Evaluation

The solar field consists of 192 photovoltaic modules with a nominal peak power of 500 Wp, resulting in a total of 96,00 kWp. They will be arranged in 12 strings with 16 panels in series per string to comply with the maximum and minimum voltage limitations of the inverter.

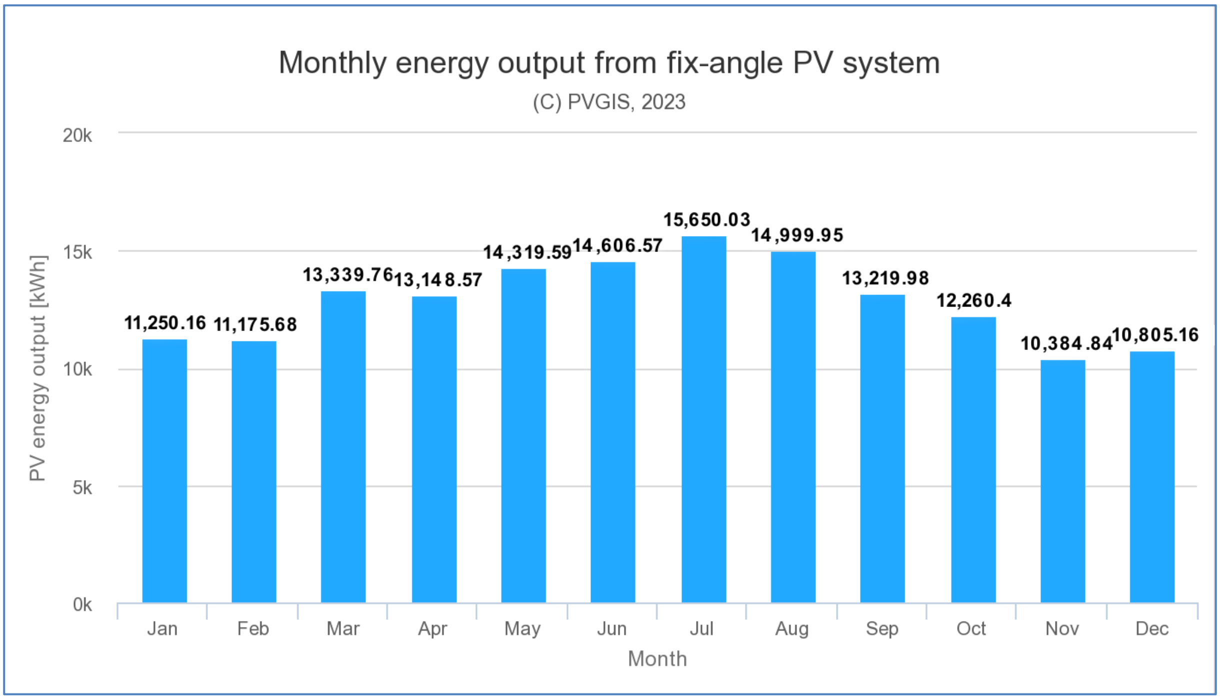
The tilt angle of the panels also affects the annual energy production. Calculations have been made at 20º, 30º, and 35º, with the optimal tilt angle being 30º (optimal = the angle that best satisfies the monthly water demand).

PVGis is an excellent tool for obtaining solar resource data, including radiation and temperature values, for specific locations. Developed by the European Commission's Joint Research Centre, PVGis provides an online platform that allows users to estimate the performance of grid-connected and stand-alone photovoltaic systems across Europe, Africa, and parts of Asia (see Table 1).

Table 1. Radiation and temperatures in Titaguas for a 30º tilt angle and 0º azimuth

30º	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEPT		OCT		NOV		DEC	
TIME	RAD	TEMP	RAD	TEMP	RAD	TEMP	RAD	TEMP	RAD	TEMP	RAD	TEMP	RAD	TEMP	RAD	TEMP	RAD	TEMP	RAD	TEMP	RAD	TEMP	RAD	TEMP
0	0,00	3,49	0,00	4,31	0,00	6,62	0,00	9,37	0,00	12,87	0,00	17,03	0,00	20,14	0,00	19,68	0,00	16,39	0,00	12,89	0,00	7,40	0,00	4,39
1	0,00	3,35	0,00	3,96	0,00	6,04	0,00	8,90	0,00	12,23	0,00	16,28	0,00	19,61	0,00	19,35	0,00	16,17	0,00	12,71	0,00	7,35	0,00	4,11
2	0,00	3,10	0,00	3,69	0,00	5,67	0,00	8,49	0,00	11,77	0,00	15,80	0,00	19,14	0,00	18,91	0,00	15,73	0,00	12,31	0,00	7,09	0,00	3,87
3	0,00	2,85	0,00	3,41	0,00	5,30	0,00	8,07	0,00	11,30	0,00	15,33	0,00	18,67	0,00	18,47	0,00	15,28	0,00	11,90	0,00	6,83	0,00	3,63
4	0,00	2,60	0,00	3,14	0,00	4,93	0,00	7,66	0,00	10,84	0,00	14,85	0,00	18,20	0,00	18,03	0,00	14,84	0,00	11,50	0,00	6,57	0,00	3,39
5	0,00	2,49	0,00	2,96	0,00	4,68	0,00	7,54	0,00	11,08	0,00	15,20	0,00	18,37	0,00	17,96	0,00	14,58	0,00	11,30	0,00	6,41	0,00	3,29
6	0,00	2,38	0,00	2,78	0,00	4,42	0,00	7,42	8,80	11,32	21,97	15,54	8,75	18,55	0,00	17,88	0,00	14,31	0,00	11,10	0,00	6,24	0,00	3,19
7	0,00	2,27	0,00	2,60	0,22	4,17	43,57	7,30	93,59	11,57	103,04	15,89	83,03	18,73	54,12	17,81	20,47	14,05	0,00	10,90	0,00	6,07	0,00	3,09
8	0,00	3,13	12,75	3,72	117,61	5,93	216,44	9,33	266,19	13,62	282,82	17,88	263,12	20,85	228,16	19,90	201,59	16,06	144,15	12,59	40,31	7,21	0,00	3,99
9	171,79	3,99	228,22	4,83	320,28	7,70	411,76	11,36	461,92	15,67	477,07	19,87	469,46	22,98	435,99	22,00	412,28	18,07	340,23	14,27	263,32	8,35	198,95	4,89
10	380,61	4,84	414,03	5,94	509,82	9,46	576,30	13,38	633,27	17,72	657,90	21,87	666,64	25,10	635,44	24,10	593,99	20,08	515,69	15,96	421,27	9,49	394,59	5,79
11	518,46	6,45	552,53	7,28	655,05	10,66	705,12	14,33	758,14	18,64	791,47	22,87	825,42	26,29	799,97	25,38	739,25	21,14	653,60	17,08	556,43	10,74	540,83	7,33
12	630,30	8,05	642,01	8,63	754,98	11,87	780,30	15,27	813,76	19,55	878,47	23,87	937,12	27,47	902,20	26,67	821,41	22,20	722,41	18,20	632,28	11,99	622,24	8,88
13	673,46	9,65	674,31	9,97	752,77	13,07	779,08	16,22	811,65	20,47	896,59	24,86	969,27	28,65	939,20	27,96	821,62	23,27	721,05	19,32	645,67	13,24	640,33	10,43
14	629,26	9,92	644,51	10,27	729,40	13,36	722,40	16,45	757,42	20,71	843,29	25,22	925,20	29,15	900,76	28,36	766,06	23,56	664,75	19,52	581,09	13,36	600,64	10,59
15	535,64	10,19	570,36	10,58	641,07	13,66	629,73	16,69	665,29	20,96	760,77	25,57	810,59	29,65	792,71	28,77	656,51	23,86	573,17	19,73	462,74	13,48	486,35	10,74
16	399,47	10,45	443,72	10,88	506,18	13,95	506,71	16,92	532,99	21,21	599,71	25,92	661,54	30,16	636,86	29,17	488,87	24,16	417,90	19,94	331,19	13,60	348,04	10,90
17	219,28	9,01	283,70	9,65	329,20	12,80	341,72	15,95	370,70	20,26	409,60	25,00	469,78	29,01	443,57	27,91	318,97	22,94	223,13	18,52	138,85	12,33	134,97	9,49
18	0,27	7,57	73,06	8,41	141,56	11,65	170,63	14,98	200,15	19,32	232,85	24,08	265,91	27,85	226,40	26,66	133,03	21,72	26,99	17,10	0,00	11,05	0,00	8,09
19	0,00	6,12	0,00	7,17	0,88	10,50	24,10	14,01	51,81	18,38	75,60	23,16	82,44	26,70	49,37	25,40	2,80	20,50	0,00	15,68	0,00	9,78	0,00	6,68
20	0,00	5,40	0,00	6,41	0,00	9,50	0,00	12,75	0,68	16,89	12,62	21,46	10,54	24,85	0,17	23,78	0,00	19,36	0,00	14,95	0,00	9,16	0,00	6,09
21	0,00	4,68	0,00	5,65	0,00	8,50	0,00	11,49	0,00	15,41	0,00	19,77	0,00	22,99	0,00	22,17	0,00	18,21	0,00	14,22	0,00	8,53	0,00	5,49
22	0,00	3,96	0,00	4,89	0,00	7,50	0,00	10,23	0,00	13,93	0,00	18,07	0,00	21,13	0,00	20,55	0,00	17,06	0,00	13,49	0,00	7,90	0,00	4,90
23	0,00	3,72	0,00	4,60	0,00	7,06	0,00	9,80	0,00	13,40	0,00	17,55	0,00	20,64	0,00	20,12	0,00	16,72	0,00	13,19	0,00	7,65	0,00	4,64

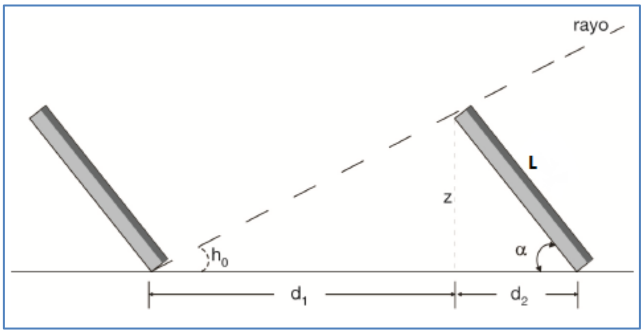
Figure 2. Monthly Energy Output. Retrieved from PVGIS



By designing the solar field and pump according to these conditions, the system can achieve optimal performance and efficiency in meeting the water needs of Titaguas (See Figure 2). The choice of the optimal tilt angle, panel orientation, and system configuration contribute to the overall effectiveness of the solar pumping system, ensuring that it can satisfy the local water demand on a monthly basis.

For the Titaguas photovoltaic installation, the distance between collectors is calculated by considering the length of the panel, its inclination, and the latitude of the location.

Figure 3. Collectors in-between distance calculation diagram.



$$h_0 = (90^0 - latitude\ of\ the\ place) - 23.5^0 \quad (1)$$

$$d = L(\sin\alpha \,/\, \tan h_0 + \cos\alpha) \quad (2)$$

So, the optimal separation between collectors for the Titaguas photovoltaic installation is approximately 4,15 meters (Figures 3 & 4).

Figure 4. PV installation already finished. Source: own elaboration.

6. Economic Analysis.

The total execution budget for the Titaguas installation is 159,948.31 euros (including VAT). This amount covers the costs of drafting the execution project, the Health and Safety Report, and the Work Management and Health and Safety Coordination.

6.1. Initial Investment and Annual Savings

Initially, the annual energy cost for the traditional pumping installation was €23,408.63 (including VAT). After the installation of the photovoltaic modules, this cost is reduced to €3,027.20 annually (including VAT), resulting in substantial annual savings of €20,381.43 (including VAT).

6.2. Payback Period

Considering the initial investment and the annual savings, the simple payback period for the photovoltaic installation is calculated as follows:

$$Simple\ Return\ on\ Investment\ (ROI) = \frac{Total\ investmet}{Anual\ savings} = \frac{159{,}948.31}{20{,}381.43} = \ 7.8\ years \quad (3)$$

This means that the investment will be recouped in approximately 7.8 years. After this period, the system will provide significant financial benefits, contributing to considerable cost savings over its lifespan, which is typically around 25 years or more depending on maintenance and the quality of the components used

6.3. Long-term Financial and Environmental Benefits

Beyond the financial savings, the implementation of a solar-powered pumping system offers substantial environmental benefits. By reducing the reliance on conventional electricity, the system decreases greenhouse gas emissions, aligning with global sustainability goals and helping the municipality of Titaguas to meet its environmental objectives.

6.4. Detailed Cost Breakdown

The detailed cost breakdown of the project is as follows:

-	Civil Works:	€24,165.88
-	Support Structures and Photovoltaic Modules:	€35,040.00
-	Cabling and Direct Current Protections:	€4,096.21
-	Solar Inverter and Low Voltage Installation:	€16,101.36
-	Pumping System:	€22,229.61
-	Pumping Management System:	€2,120.04
-	Health and Safety:	€630.86
-	Waste Management:	€283.64
	Total amount	€104,667.60

Adding general expenses (13%) and industrial profit (6%) to the material execution budget gives a total project base budget (excluding VAT) of €124,554.45. With a VAT of 21%, the total project budget amounts to €150,710.88. Including additional costs for project drafting and Health and Safety coordination, the final investment required is €159,948.31 (including VAT).

7. Conclusions

The use of photovoltaic installations today represents a promising and sustainable opportunity for renewable energy generation. These installations use sunlight to generate clean, renewable electricity, reducing dependence on fossil fuels and contributing to climate change mitigation.

Technological advances in the design and production of solar panels have made photovoltaic installations more accessible and efficient than ever, leading to a significant increase in their adoption worldwide. Furthermore, the cost of solar energy has decreased considerably in recent years, making it an increasingly economical and competitive option compared to traditional energy sources.

Implementing a photovoltaic installation for water pumping in the town of Titaguas is not only an environmentally friendly option but also a sound economic decision.

In conclusion, the proposed solar pumping system for Titaguas represents a valuable investment, with a reasonable payback period and long-term financial and environmental benefits. It's important to ensure proper maintenance and monitoring of the installation to maximize its performance and extend its useful life.

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