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The financial competitiveness of photovoltaic installations in water utilities: The case of the Tagus-Segura water transfer system

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ABSTRACT

The Tagus-Segura water transfer is a large infrastructure that allows the distribution of a large amount of water resources, which is associated with a significant energy cost. Therefore, energy improvements are a fundamental tool to reduce one of the main financial costs of the infrastructure, as well as the emission of greenhouse gases. For this reason, the feasibility of self-consumption through photovoltaic solar panels has been analysed, which requires a significant initial investment, but can be recovered over the lifetime of the panels due to the savings obtained yearly. The incorporation into the article of a sensitivity analysis of the price of energy and the amount of energy produced makes the analysis robust, as it can be seen that, although there is vulnerability with respect to variations in these variables, the risk of losses is low.

1. Introduction

Energy is one of the main inputs that human activities need in order to develop. This entails a significant environmental and financial cost that can compromise the sustainability of the activities carried out. This is the case of water services, where the energy cost of irrigation, water transfers, wastewater treatment and reuse or water desalination, among others, is one of the main financial costs (Langarita et al, 2016; Corominas, 2010; Melgarejo and Montano, 2011; Pardo et al., 2019b; Zarzo and Prats, 2018; Zarzo Martínez, 2020; Albadalejo-Ruiz and Trapote, 2013). Thus, reducing energy costs is one of the main priorities of water utilities (Pardo et al, 2020; Hernández-Sancho et al., 2011). This energy consumption is mainly met through non-renewable sources, with the associated pollution, which has promoted the development of energy efficiency techniques and alternative energy sources, such as photovoltaic (PV) solar panels (Yusta Loyo, 2016; IRENA, 2019; EPSAR, 2020). This would not only reduce the environmental impact of energy consumption, but the reduction in the price of energy for consumers would be associated with an increase in business competitiveness (González and Alonso, 2021; Moreno et al, 2014). This situation extends to households, where there is still potential for both energy savings and the development of self-consumption through solar PV panels (Rosenow et al, 2018; Hesselink and Chappin, 2019; Damette, Delacote and Del Lo, 2018; Zhang et al, 2017). The development of this potential would also provide a valuable economic boost after the economic problems caused by the COVID-19 crisis (UNEF, 2020b).

This partly explains why in recent years this alternative energy source has received substantial investment and has expanded significantly (Jäger-Waldau, 2019; IRENA, 2019; UNEF, 2020c). The continuous reduction of the financial cost that PV panels have enjoyed in recent years is one of the main factors explaining their recent evolution and their valuation for new projects (Mauritzen, 2017; UNEF, 2020c; Jäger-Waldau, 2019; Fraunhofer ISE, 2015). The presence of economies of scale, technological innovations and the possibility of installing batteries are other factors that justify the high potential of solar panels (Pillai, 2015; Mauritzen, 2017; Pardo et al, 2019; Harder and Gibson, 2011). Moreover, this cost reduction trend is expected to continue in the coming years (Reichelstein and Yorston, 2013).

However, despite these advantages, there are a number of disadvantages and factors that affect the viability of PV panels and which

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Abbreviations: PV, Photovoltaic; IRENA, The International Renewable Energy Agency; EPSAR, Spanish acronym for “Public Entity for Wastewater Treatment of the Valencian Community”; UNEF, Spanish acronym for “Spanish Photovoltaic Union”; JCU, Spanish acronym for “Vinalopó Alacantí Central Board of Users”; CHS, Spanish acronym for “Segura Hydrographic Confederation”; Hm^3, Cubic hectometres; SCRATS, Spanish acronym for “Central Irrigation Union of the Tagus-Segura Aqueduct”; MWh, Megawatt-hour; kW, Kilowatt; kWh, Kilowatt-hour; CO2, Carbon Dioxide; VAT, Value Added Tax; PMT, Payment; NPV, Net Present Value; CCE, Spanish acronym for “Central Commission for the Exploitation of the Tagus-Segura aqueduct.

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must be taken into account in any project. From a financial point of view, this type of projects involves short-term investment and losses, so they require a long-term perspective (Arazola-Martínez, 2019), especially considering that the useful life of the panels is between 25 and 30 years (Malandrino et al, 2017; Xu et al, 2018). During this period, it is essential to maximise the efficiency of the panels, for which it is necessary to assess the installation environment and design it appropriately (Hanes, Gopalakrishnan and Bakshi, 2018). In this regard, the renewal of solar panel modules, which have a shorter lifetime than the panels, affect operating and maintenance costs and whose renewal depends on several variables, should be optimised (Pardo et al, 2022). To the investment cost must be added the maintenance of the panels, although this is not very high and there are ways to do it automatically (Deb and Brahmbhatt, 2018). At the end of their useful life, and with the aim of using photovoltaic panels in an efficient and sustainable way in the context of circular economy, a large part of the materials that make up these panels can be reused (UNEF, 2020a; UNEF, 2020d).

The second factor, apart from financial, which is a major barrier to the development of solar PV panels is the bureaucracy related to these projects, as well as the lack of public support, both in regulatory and financial terms (Solarplaza, 2020). Therefore, a reduction of bureaucracy and an increase in public support for PV panels would combine with the constant reduction of panel costs to make this a great energy alternative for businesses and other large energy consumers (SolarPower, 2020). For this reason, the Spanish government published grants in 2021 to support this type of project and regions such as Valencia reduced in 2020 the necessary procedures to implement them (Ministry for Ecological Transition and the Demographic Challenge, June 29, 2021; Generalitat Valenciana, 2020). These punctual actions join a series of incentives that already existed to stimulate the installation of panels and that allow reducing the taxes to be paid or receiving financial support to cover part of the investment cost (Otovo, 2020; Hilcu, 2021).

Water services is a sector where the market situation of solar photovoltaic panels is very important, as there is a basic link between water and energy. Currently, the energy cost is not only important in the different water services, but in cases such as wastewater treatment and reuse and water desalination, the high energy cost is the main financial cost (Albadalejo-Ruiz et al., 2015; Albadalejo-Ruiz and Trapote, 2013; Villar, 2014). This cost is also very important with regard to pumping water for supply, long-distance water transfers or even water purification in greenhouses (Borg and Zitomer, 2008; Gil Tomás, 2018; Martí Vidal, 2018; Setiawan et al, 2014; JCU, 2020; Arazola-Martínez, 2019; Melgarejo and Montano, 2011). For this reason, agricultural companies in the areas irrigated by the largest water transfer in Spain, the Tagus-Segura water transfer, want to propose the installation of solar panels along 64 km of the water transfer canal, a project for which the Segura Hydrographic Confederation and irrigators in the area see several advantages, including financial savings and the possibility of reducing water evaporation along the route (Salas, 2022). This alternative was also studied for the Júcar-Vinalopó water transfer, finding that, after assessing the types of installations available, the level, modality and economic regime of energy self-consumption, the flow transferred, the price of energy, the cost of the panels and the characteristics of the locations of the panels, there were significant financial savings (Muñoz Riera, 2018). Where this alternative is being tried is in Navarre, whose government already has a positive feasibility analysis for supplying energy to public buildings in the region through a photovoltaic installation on a 9-kilometre stretch of the Navarre Canal (Diario de Navarra, 2022). In the case of water transfers, it should be borne in mind that they have more than one point where energy is consumed, so there are various factors to take into account in each case and the proposal must be adapted to each situation.

Installation over the water transfer canal is one of the alternatives, but it is also possible to locate the panels in a nearby body of water, which has a high potential. The Spanish territory has a heritage of reservoirs and hydroelectric plants that represents an opportunity for power generation using photovoltaic panels on reservoirs and ponds (Flores Montoya, 2022). In the case of not consuming all of the energy generated, it is possible to use the photovoltaic energy to pump the water turbined in the hydroelectric power plants back to its previous position, so that it can be turbined again when there is an energy need, thus using all the energy and minimising the risk of the photovoltaic project (Flores Montoya, 2022). This potential is not limited to Spain, since covering 10% of the surface area of the world's hydroelectric reservoirs would produce as electricity as that obtained from fossil fuels, although various advantages and disadvantages would have to be taken into account (Almeida et al, 2022).

Given the current situation of falling costs of solar panels and rising energy prices (from 41.1€/MWh of August 2020 to 162,4€/MWh of August 2022), projects such as that of agricultural companies in the irrigable areas of the Tagus-Segura water transfer, which could benefit significantly from economies of scale, are very interesting. Given the topicality of the issue in Spain and the world (Almeida et al, 2022), this article aims to analyse not only the financial viability of self-consumption projects using photovoltaic installations, but also their vulnerability to two basic financial risks: variations in the price of energy and in the amount of energy generated. This is possible thanks to the data on the energy cost of the Tagus-Segura water transfer, provided by the Central Commission for the Exploitation of the Tagus-Segura aqueduct (CEE), and the budgets designed by the company Enerficaz, which is dedicated to the preparation of this type of projects. In other words, the financial analysis takes into account the energy consumption and its price in 2020 of the infrastructure to be supplied, as well as all costs that would be incurred in a transition to PV self-consumption. In addition, to cover the limitation of having electricity prices from before the recent increases, the price risk analysis is performed with a wide price range. The use of two different types of projects that do not require land, such as the installation on the water transfer channel or on a pond, together with the risk sensitivity analysis, make this article a valuable example of the potential of photovoltaic installations to reduce both the energy expense of economic activities and the vulnerability to future increases in the price of electricity. These benefits bring a clear gain in competitiveness due to reduced costs, but also include a reduction in greenhouse gas emissions compared to traditional supply, which is useful in the pursuit of sustainability. This article fills a gap in the literature by highlighting the financial competitiveness of PV installations, as analyses tend to focus on technical aspects aimed at maximising the efficiency of projects and quantifying their environmental impact. Therefore, the present work is a good complement to the technical research that is currently under development, as well as justifying it, since the financial benefits of these projects are a great incentive for their development by the private sector, thus providing a destination for new research. In order to meet this objective, information about the study area, the data used and the methodology followed is given below. After this, the results and conclusions obtained are shown.

2. Study zone

The Tagus-Segura transfer is one of the largest hydraulic engineering works ever carried out in Spain. This infrastructure is in operation since 1979, providing valuable additional water resources to the Segura Hydrographic Demarcation, which suffers from a serious structural water shortage. The water received in the Segura basin can be used for both supply and irrigation and is of great importance, since, as well as representing an important additional resource, it can be used for irrigation on 147,255 ha of the 262,000 ha available for irrigation in the entire basin (CHS, 2021a). Since 1979, an annual average of 295hm^3 has been transferred, which is a significant part of the 1,662hm3 available in the demarcation (CHS, 2021b). Fig. 1 (SCRATS, 2022) shows the route taken by the water along the infrastructure and it is at the end of the route where the energy consumption analysed in this work occurs and for which the possibility of being satisfied by photovoltaic solar panels is

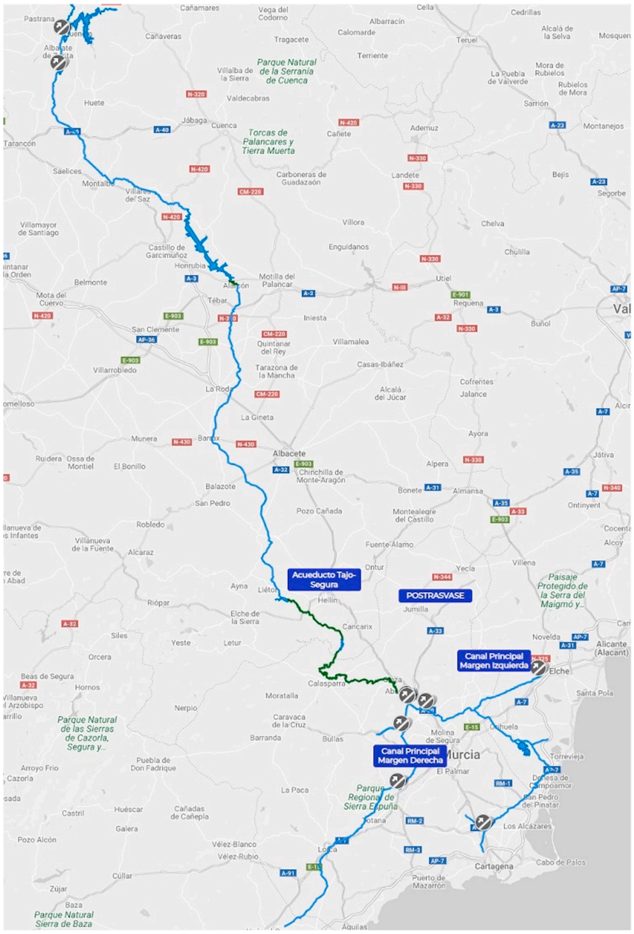

Fig. 1. Route of the Tagus-Segura water transfer. Source: SCRATS, 2022. Note: the grey circles show the transfer impulsions, which is where the energy consumption analysed in this article takes place. The southernmost point corresponds to Fuente Álamo, where the energy generated by the photovoltaic installations is intended to be supplied.

evaluated.

3. Materials and methodology

3.1. Materials

The data used in this work come from two sources, depending on whether it is the energy consumption of the Tagus-Segura aqueduct or data on the possibility of installing solar panels in order to satisfy part of the energy consumption of the infrastructure.

3.1.1. Data on the energy consumption of the Tagus-Segura aqueduct

On the one hand, the data on the energy cost of the Tagus-Segura Transfer come from the Central Commission for the Exploitation of the Tagus-Segura Transfer, as this is one of the variable costs that affect the transfer tariffs and which, therefore, must be studied for the adequate financing of the infrastructure. The available data allow us to analyse the situation in some detail, as they show a clear distinction between the amount paid for the power term and the amount paid for the consumption term. It should be noted that data from 3 locations is available, Palmar, Crevillente and Fuente Álamo, the first of which is the largest because it includes 4 different metering points, while the other two locations are individual metering points. Specifically, the place chosen to propose the projects is Fuente Álamo, as there is a high level of consumption and the presence of space in which to locate the proposed installations at a single measurement point. Regarding the power term, the contracted quantity (kW) and the unit price (€/kW) are available, so that it is possible to know the total cost of the power term. As for the variable term, the consumption (kWh) and its price (€/kWh) are included, so it is also known the total cost involved. It should be added that, in both cases, the data are distributed by periods of consumption, which is essential for an accurate analysis, as the price of energy varies according to the period in which it is consumed. In addition, consumption also varies between these consumption periods and months, which is closely related to the energy production of the panels. However, the facilities proposed in this article only cover a small part of the energy consumption of the infrastructure in the Fuente Álamo area, so the temporal aspect of energy generation and consumption is not included in the analysis.

3.1.2. Data about the floating installation of photovoltaic solar panels

The first project analysed in this article consists of a floating photovoltaic installation on a pond near Fuente Álamo. The system used is ISIFLOATING 4.0, a modular and flexible system of floating photovoltaic elements that create a structured grid of floating units. The main components of the ISIFLOATING 4.0 floating system are a main float, a secondary float, the connection (with nuts and screws) of both floats, the photovoltaic panels, the clips to fix the photovoltaic modules to the floats, the electrical conduits, the inverters and the maintenance corridors. The complete technical details of the floating system are available in Fig. A1. This alternative is interesting because it has certain advantages over traditional ground mounted systems. The advantages consist in a reduction of CO2 emissions, the release of land for other productive uses, an increase in energy production of 10–15% due to water cooling, a reduction of evaporation of water from the reservoir as the installation functions as a roof, low cost of ownership and lower transport, installation and maintenance costs. The floating photovoltaic installation is proposed for Fuente Álamo, Murcia, on a reservoir dedicated to crop irrigation. The exact location is Latitude: 37.734134°; Longitude: 1.029523°. The installation would occupy 4,732 m^2 of the 54,654 m^2 available on the pond, which is just under 9% of the total surface. ENERFICAZ S.L. proposes, based on the analysis of real consumption, an installation of 809kWp. For this purpose, Longi photovoltaic modules, model LR5-72HPH-545 M and SMA inverters, model Sunny Highpower SHP150-20-PEAK3, have been chosen. The installation will have 1485 modules and 5 inverters, distributed as follows: 55 parallel strings of 27 modules per inverter. The modules can be positioned on a raft using floating technology, allowing them to be positioned completely south-facing, with azimuth 0°. For the same reason, the floats on which the modules are placed have a standard inclination of 5° with respect to the horizontal, which means that the modules will have an inclination of 5°.

For the electricity production of this alternative, the PVGis programme has been used with data from the PVGIS-SARAH2 satellite database. This programme takes into account the location, installed peak power and losses and the inclination and azimuth of the installation, so the data it provides are highly reliable. The estimated annual production is 1,318 MWh/year, although there is a possibility that the panels may lose power generation capacity over their lifetime. However, the manufacturer guarantees an average production of 90% of this energy each year over the 25-year lifetime of the solar panels. The analysis is carried out on the basis of the full generation, but also includes the possibility of losing some production.

The total cost of this project amounts to €882,234.25 excluding VAT, to which some additional costs should be added. These costs are the cost of financing, as it is likely that an investment of this size would not be possible without financing, and the cost of operation and maintenance. The first is calculated based on an interest rate of 2.31%, which is the rate applicable to a loan granted to a non-financial institution in July (the most recent consolidated rate available at the time of calculation), for a loan of between 1 and 5 years for an amount of between 250,000 and 1 million euros. Specifically, in this article is considered that the loan is repaid by monthly payments over a period of 5 years. The second one, on the other hand, involves an additional yearly cost of approximately 1% of the cost of the project without taxes and interests. It should be noted that all figures are shown excluding VAT for simplicity, as it does not affect the calculations as it is 21% in all cases.

3.1.3. Data about the photovoltaic solar panels installation on the canal

The second proposal analysed in this article, and also developed by ENERFICAZ S.L., is to install the system on a structure located on the Tagus-Segura water transfer canal. The characteristics of the photovoltaic panels are the same as in the floating installation, but in this case, it is proposed to install 490 modules of 540 W, with a total installed power of 264.6kWp. This installation would occupy 100 m long by 13 m wide, occupying a total of approximately 1,300 m^2. The annual production generated would be 383.3MWh, again guaranteeing 90% of this, at a price of 530,808€, VAT not included, which is distributed between 379,126€ for the structure, 98,762€ for the equipment and 52,920€ for the electrical assembly. To these costs it would be added an annual maintenance cost of 1% of the total budget and the interest resulting from obtaining a loan under the same conditions as in the other case, i.e., an interest rate of 2.31% to be paid over a period of 5 years.

As in the previous case, this alternative avoids the use of land, leaving it free for other productive uses. In addition, a large installation would reduce the temperature of the water, so that the panels are more efficient than those located on the ground and the evaporation of the water from the water transfer along its course is reduced, thus increasing the value of the infrastructure. The final advantage of this alternative is the reduction of algae proliferation in the canal, which can cause clogging and toxicity.

3.2. Methodology

The methodology followed to carry out the proposed feasibility analysis is simple, as it consists of making relatively simple calculations based on the available data. Firstly, the data on the energy cost of the Tagus-Segura aqueduct is presented in three different figures to show the most important aspects about it. The Appendix contains three tables about the exact details of this cost, where it is observable the cost of the contracted power term, the cost derived from consumption and the summary, which also includes other costs and taxes to be covered. These data provide the energy cost that is satisfied through self-consumption, so it is one of the axes of the analysis. The use of figures makes it possible to present the most important aspects without having to examine the tables in depth.

Regarding the installation of solar panels, all the data shown in the tables of the document come from the data included in the projects proposal or in the data on the energy cost of the Tagus-Segura water transfer, except for the interest, which has been calculated on the basis of the official interest rate in Spain in July for non-financial entities for credits of between 1 and 5 years for an amount between 250,000€ and one million euros. In this article it is assumed that users of the electricity produced by photovoltaic panels cannot afford the necessary investment without taking out a loan. This entails the payment of certain interest, which can be calculated from using the Microsoft Excel function PMT (Payment). Specifically, it is considered the repayment of the loan at a fixed interest rate of 2.31% through monthly payments over a period of 5 years. The other calculations performed consist mainly of obtaining the annual and total maintenance cost by applying 1% to the project budget and estimating the annual savings as the difference between the cost of self-consumption (the total cost of the project is distributed equally along the 25 years of the project) and the price of supply through purchase (considering that the price is constant), from which the annual maintenance cost is also subtracted. In other words, the annual savings express the difference between the cost of electricity from the grid and that obtained through the PV installation. It should be remembered that all calculations are made without including VAT, which is 21% for all the amounts in the article, so that the final result would not vary if VAT were included. In addition, the payback period of the investment is estimated by dividing the investment made, including interest, by the annual savings. The last variable calculated is the Net Present Value (NPV), which corresponds to the present value of the net cash flows arising from an investment. This requires the use of a discount rate, which in this case is the interest rate (2.31%) as it is a financial analysis. Again, this calculation can be done from Microsoft Excel with the NPV function, which only requires the investment to be made, the cash flows, the discount rate and the lifetime of the project. Finally, the calculations are made considering that 100% production is obtained from the solar panels over the 25 years, although it should be noted that the structure of the panel installation on the water transfer canal has a lifetime of more than 25 years. In this case its useful life is included as 50 years, so it would have a second use in 25 years. This is relevant, as at the end of the project's lifetime the cost of a new installation would be lower and the structure is a positive cash-flow in the NPV calculation.

4. Results

4.1. Energy cost of the Tagus-Segura aqueduct

The first step to determine the feasibility of the photovoltaic solar panel project in the Tagus-Segura water transfer infrastructure is to analyse its energy cost. Firstly, Fig. 2, based on Table A1. data, shows the contracted power (kW) and its price, which the users of the water of the aqueduct must satisfy through the tariffs. With regard to the contracted power, all consumption periods show the same value except the last one. This is due to the fact that the price of both the power term and the consumption term is lower in this period, in an attempt to concentrate energy consumption at this time in order to minimise costs. The difference in price according to periods is very high, since, to illustrate the situation with data from Palmar, in period 1 the cost per kW is 18.92€ and it decreases to 3.16€ in period 6. This large difference means that a contracted power of 9,000 kW in consumption period 1 means a total cost of 170,245.78€ while a contracted power of 29,000 kW in consumption period 6 means a cost of 91,665.72€. This situation also applies to the Crevillente and Fuente Álamo metering points, which shows the importance of the consumption periods.

However, the main source of the financial cost related to energy comes from the consumption itself, since the cost of the power term amounts to 653,062.99€ when that of the consumption term amounts to 11,361,100.37€. In this case, Fig. 3, based on Table A2. data, shows the price in euros per kWh and the quantity consumed. Starting with the unit price, the situation is similar to the previous one, as the price of energy in consumption period 1 is significantly higher than in consumption period 6. In the case of energy consumption, the difference is smaller than in the case of the power term, but it is still a relevant difference that conditions the costs of the infrastructure and the tariffs to be paid by users of the transferred water. Consequently, this energy cost is relevant when explaining the costs of the productive activities that use these waters. Moreover, as part of the transferred water is used for urban supply, this energy cost can affect the price of water paid by households and municipalities. Therefore, minimising the energy cost derived from the operation of this infrastructure would have positive effects on the economic activity of the receiving basin and on the well-being of households, apart from the environmental benefits. As can be seen from Fig. 3 and Table A2., there is a high concentration of energy consumption in consumption period 6 in order to minimise the cost of energy consumption. However, there is still consumption outside this period that could be satisfied by using the energy generated by the solar panels, thus reducing as much as possible the consumption in the peak periods.

In short, the importance of the consumption term cost, as Fig. 4 shows, and the quantity consumed justifies the search for alternative energy supplies. In addition to the contracted power and the energy consumed, other costs must be added, which are shown in Table A3. Specifically, these are rental costs, special taxes and Value Added Tax.

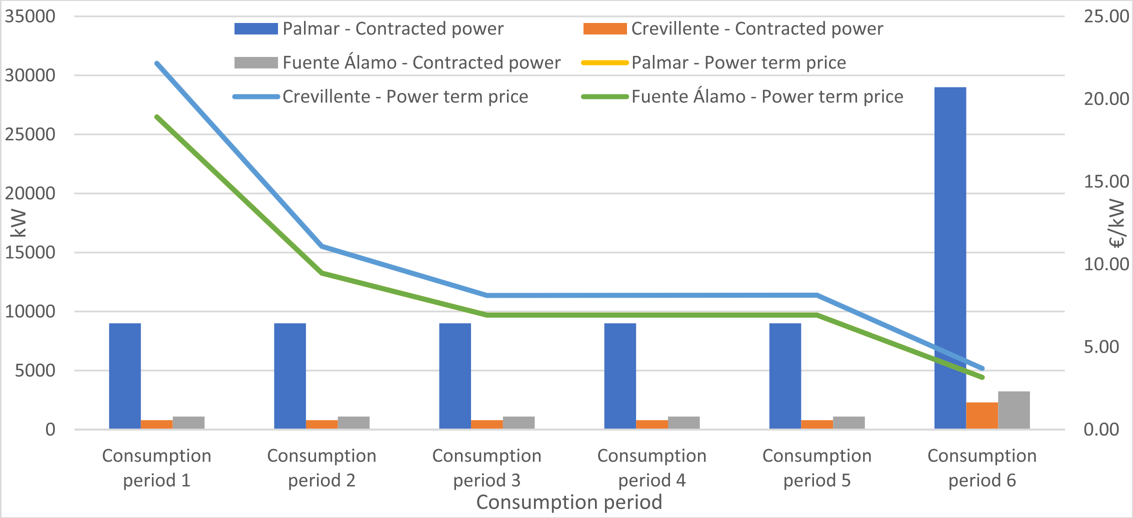

Fig. 2. Contracted power (kW) and unit price (€/kW) per period of consumption of the Tagus-Segura aqueduct. Source: Own elaboration with CCE (2021) data.

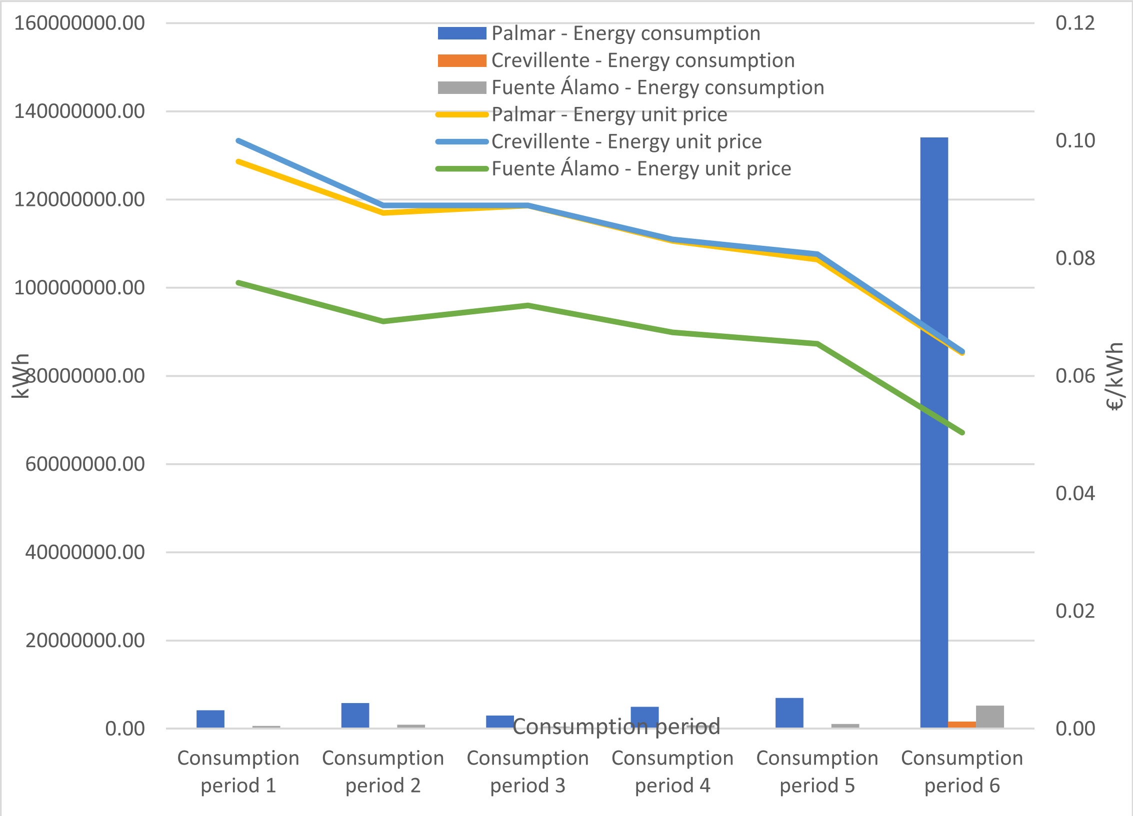

Fig. 3. Energy consumed (kWh) and unit price (€/kWh) per period of consumption of the Tagus-Segura aqueduct. Source: Own elaboration with CCE (2021) data.

The first two items represent a lower cost, but the Value Added Tax represents a significant cost that could also be reduced by using photovoltaic solar panels. In total terms, the energy cost of the Tagus-Segura water transfer was estimated at 15,285,430.3€ in 2020. These figures, taking into account the expectation of pumping 334hm^3 between transferred and own water that year, means a cost per cubic metre of almost €0.05. Due to the recent increases in the price of energy, the cost derived from the variable term will be higher, which represents an opportunity for photovoltaic projects as the analysed in this article, saving part of the financial cost and the pollution derived from traditional energy consumption. However, the updated version of this data is not yet available.

4.2. Financial viability of photovoltaic panels in the Tagus-Segura aqueduct

4.2.1. Financial viability of a floating photovoltaic installation to supply the Tagus-Segura aqueduct

In order to reduce the energy bill of the Tagus-Segura aqueduct, one of the main alternatives consists of self-consumption through photovoltaic solar panels. To determine the feasibility of this possibility, the costs of the floating installation on a nearby pond are calculated, as well

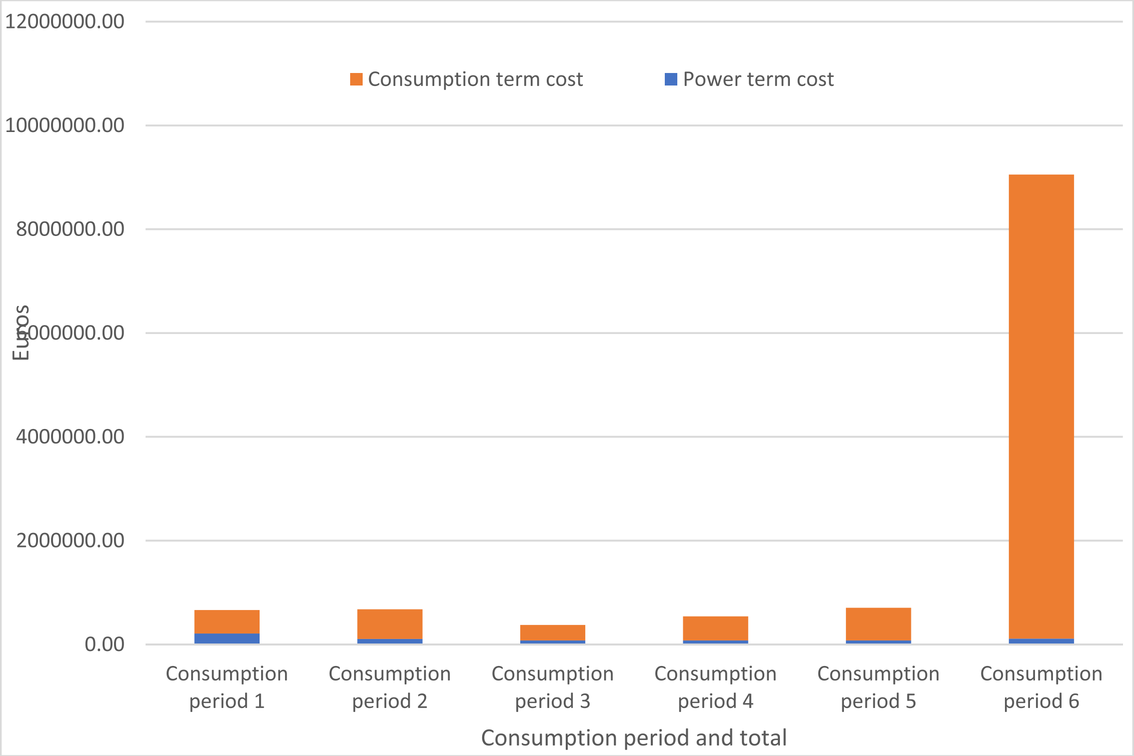

Fig. 4. Consumption term cost and power term cost (€) per period of consumption of the Tagus-Segura aqueduct. Source: Own elaboration with CCE (2021) data.

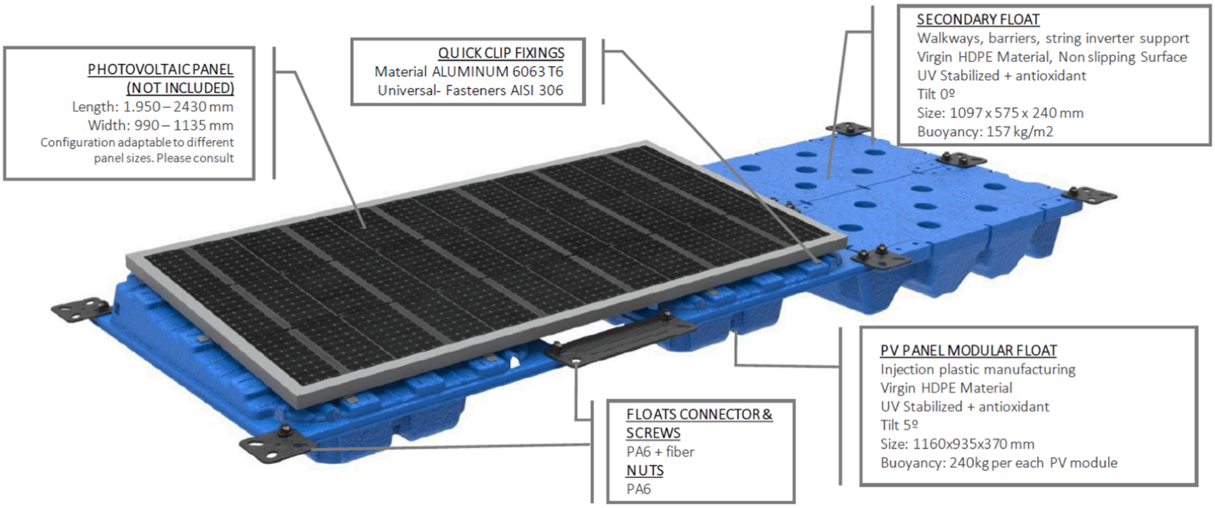

Fig. A1. Technical details about the floating photovoltaic installation. Source: ISIFLOATING webpage. Note: as this is a floatation system, the solar panels are shown in the picture as not included, but they are included in our study case.

as those of the installation on the infrastructure of the aqueduct, and a comparison between them and the 25-year costs of the Tagus-Segura aqueduct, based on 2020 prices, is made. It should be noted that the consumption of the infrastructure and the price paid for the energy are considered as constant over the 25 years. To cover this limitation, a sensitivity analysis with different price levels is included below.

Table 1 shows the values for the Tagus-Segura water transfer and the floating installation. Regardless of the price of energy, the initial investment amounts to €882,234.25, to which must be added €101,898.06 in interest to be paid over 5 years, as it is likely that it will be necessary apply for financing to cover the initial costs. To this cost must be added maintenance, which amounts to €8,822.34 per year and which, in the calculations, is deducted year by year from the potential savings derived from self-consumption. The budget and maintenance include everything necessary to keep the installation in operation during the 25-year lifetime of the solar panels, so there are no additional costs during this period. Thus, the total cost of the installation amounts to 1,204,690.87€ with a production of 32,950,000kWh, which leaves a unit cost of approximately 0.037€/kWh. This production value represents around 14.44% of the energy consumed at the Fuente Álamo metering point, the cost of which on the market amounts to 1,923,311€ over 25 years considering that the original prices do not vary over time, thus obtaining an annual saving of 68,110.08€. Based on this saving, the investment made is recovered in the fifteenth year after the investment, when the installation still has 10 more years of lifetime. Therefore, this alternative has proven to be viable even with prices prior to the price increases of

Table 1

Key variables of PV installations analysed in this article. Source: Own elaboration.

Variable	Floating PV installation	Installation on the canal
Budget for the installation (€)	882,234.25	530,808
Interest on financing (€)	101,898.06	61,308.32
Total maintenance (€)	220,558.56	132,702.00
Maintenance per year (€)	8,822.34	5,308.08
Energy produced (kWh)	32,950,000	9,582,500
Part of the consumption that satisfies (%)	14.44%	4.20%
Total price of the satisfying consumption (€)	1,923,310.66	559,336.10
Annual savings (€)	68,110.08	17,065.36
Year in which the investment is amortised	14.45	34.70
Unit price of self-consumption energy (€/kWh)	0.037	0.076
Energy price traditional supply (€/kWh)	0.058	0.058

Table A1

Costs per power term of the Tagus-Segura aqueduct. .

Power Term Data	Palmar	Crevillente	Fuente Álamo	Total
Contracted power (kW)				
Period of consumption 1	9,000	800	1,100	
Period of consumption 2	9,000	800	1,100	
Period of consumption 3	9,000	800	1,100	
Period of consumption 4	9,000	800	1,100	
Period of consumption 5	9,000	800	1,100	
Period of consumption 6	29,000	2300	3,230	
Price Power term (€/kW)				
Period of consumption 1	18.92	22.16	18.92	
Period of consumption 2	9.47	11.09	9.47	
Period of consumption 3	6.93	8.12	6.93	
Period of consumption 4	6.93	8.13	6.93	
Period of consumption 5	6.93	8.14	6.93	
Period of consumption 6	3.16	3.70	3.16	
Total Power Term Cost (€)				
Period of consumption 1	170,245.78	17,726.68	20,807.82	208,780.28
Period of consumption 2	85,196.57	8,871.01	10,412.91	104,480.50
Period of consumption 3	62,349.75	6,492.04	7,620.53	76,462.31
Period of consumption 4	62,349.75	6,500.04	7,620.53	76,470.31
Period of consumption 5	62,349.75	6,508.04	7,620.53	76,478.31
Period of consumption 6	91,665.72	8,515.89	10,209.67	110,391.28
Total Power Term Cost (€)	534,157.33	54,613.68	64,291.97	653,062.99

Source: CCE, 2021

the last two years.

4.2.2. Financial viability of the photovoltaic panels on the Tagus-Segura water transfer canal

The other alternative for self-consumption of energy through photovoltaic solar panels is to install the panels on a structure located above the water transfer channel. This option also has the advantage of not requiring land, however, the cost of the structure is a large part of the total budget, which significantly increases the average cost of the energy produced, making it less competitive than the floating installation.

Table 1 shows the same results seen for the floating installation, but in this case for the on-channel installation. As can be seen, the budget is lower, but the energy produced is even lower, so the average cost goes up. The average cost after 25 years of the project goes from almost 4 euro cents for the floating installation to around 8 euro cents for this second alternative. Bearing in mind that the average price of energy in 2020 was almost 6 cents, the cost increase between projects means that the alternative of setting the PV installation over the water transfer canal is not financially viable without including the potential environmental benefits. Of course, in the case of a larger installation, taking advantage of economies of scale would reduce the average cost of energy, which together with energy price increases could make this alternative a viable option. It should also be remembered that the space for floating installations is limited, as it is necessary to have nearby bodies of water in which the installation can be placed and, in addition, there is a limit to the occupiable space, so that both alternatives are compatible and combining them could generate great benefits, although the higher average cost of this second option requires a higher energy price. This justifies the preparation of a sensitivity analysis of both proposals to determine the risk of the projects in relation to the price of energy and the amount of energy generated.

4.3. Sensitivity analysis of self-consumption projects using photovoltaic solar panels

The last part of the article consists in a sensitivity analysis to determine the vulnerability of both projects to variations in the amount of energy generated and the price of energy. The three variables used for this purpose are the annual financial savings, the payback period of the investment and the Net Present Value of the project (NPV). Therefore, different results are obtained for these variables depending on a series of values for the amount of energy generated and the price of energy.

The results, available in Tables 1, 2 and 3 of the supplementary material, show, as is logical, that the higher the energy generated and the higher the energy price, the higher the annual savings and the financial NPV and the shorter the time needed to amortise the investment. The objective of this analysis is to identify the sensitivity of the two projects to the price of energy and the amount of energy generated, to which the floating installation has shown relatively little sensitivity, while the installation on the canal is more vulnerable due to its higher average costs.

As for the floating installation, the reduction in the price of energy or the amount of energy produced would have to be very significant to seriously compromise the viability of the project. Considering that the price of energy consumed by the transfer was almost 0.06€ per kilowatt-hour in 2020 and since then it has increased significantly, it is unlikely that this price will fall to levels that are problematic for the project, which has a unit cost of 0.04€ per kilowatt-hour. If the amount of energy generated were also to be reduced, this could already be a significant problem. However, this is unlikely, as the manufacturer of the panels guarantees an average production of 90% of the project amount over the 25-year lifetime of the installation. In other words, the two variables to which the project is particularly sensitive in financial terms do not pose a sufficiently high risk to compromise the project to the point of generating losses. The most likely scenario is that the energy produced

Table A2
Costs per term of consumption of the Tagus-Segura aqueduct. .

Energy Consumption Term Data	Palmar	Crevillente	Fuente Álamo	Total
Energy Consumption Term Price (€/kWh)				
Period of consumption 1	0.10	0.10	0.08	
Period of consumption 2	0.09	0.09	0.07	
Period of consumption 3	0.09	0.09	0.07	
Period of consumption 4	0.08	0.08	0.07	
Period of consumption 5	0.08	0.08	0.07	
Period of consumption 6	0.06	0.06	0.05	
Energy Consumption (kWh)				
Period of consumption 1	4,180,357.00	0.00	648,241.00	4,828,598.00
Period of consumption 2	5,820,239.00	0.00	902,535.00	6,722,774.00
Period of consumption 3	2,984,049.00	0.00	462,732.00	3,446,781.00
Period of consumption 4	4,973,415.00	0.00	771,219.00	5,744,634.00
Period of consumption 5	6,989,664.00	0.00	1,083,876.00	8,073,540.00
Period of consumption 6	134,106,874.00	1,681,660.00	5,260,966.00	141,049,500.00
Total (kWh)	159,054,598.00	1,681,660.00	9,129,569.00	169,865,827.00
Total Cost of Energy Consumption Term (€)				
Period of consumption 1	403,241.42	0.00	49,167.78	452,409.20
Period of consumption 2	510,597.93	0.00	62,518.60	573,116.53
Period of consumption 3	265,508.74	0.00	33,313.46	298,822.21
Period of consumption 4	412,619.38	0.00	51,983.25	464,602.62
Period of consumption 5	557,691.31	0.00	70,962.45	628,653.76
Period of consumption 6	8,570,636.21	107,907.08	264,952.77	8,943,496.06
Total Cost of Energy Consumption Term (€)	10,720,294.98	107,907.08	532,898.31	11,361,100.37

Source: CCE, 2021

Table A3
Total energy cost of the Tagus-Segura aqueduct. .

Total energy cost of the Tagus-Segura aqueduct	Palmar	Crevillente	Fuente Álamo	Total
Total power term cost (€)	534,157.33	54,613.68	64,291.97	653,062.99
Total Cost of Energy Consumption Term (€)	10,720,294.98	107,907.08	532,898.31	11,361,100.37
Rent and Special Taxes	577,517.97	9,077.19	31,828.53	618,423.69
Subtotal	11,831,970.3	171,598	629,018.81	12,632,587
Value Added Tax (VAT)	2,484,713.76	36,035.57	132,093.95	2,652,843.28
Total (€)	14,316,684	207,633.5	761,112.76	15,285,430.3

Source: CCE, 2021

will be around the 90% guaranteed by the manufacturer and that the price of energy will remain higher than in 2020, which in any case represents an annual saving, thus allowing the investment to be amortised over a maximum period of 12–13 years and obtaining a positive financial NPV.

Unfortunately, space for floating installations is limited, so it is also important to consider the other alternative that does not require land, which involves building a structure over the water transfer channel. This possibility, however, is associated with a higher risk due to the higher average cost of power generation. Thus, Tables 4, 5 and 6 of the supplementary material show that the potential savings and NPV are lower and the payback time longer. In case of building a larger installation, the average costs could be reduced, but in any case, the cost of the structure makes this alternative a more expensive option than the floating installation. This means that, in a similar energy price situation, the floating installation offers better results. The average cost of this alternative does not reach 0.08€ per kWh when the 2020 price was almost 6€ per kWh. Taking into account the increase in the price of energy in the last two years, it would currently be an alternative that, at the very least, would not produce losses, since with an energy price of 0.10€ per kWh and generating the minimum guaranteed energy, 90%, the NPV of the project is positive. This, of course, requires knowing the price paid in practice, but considering that the general energy price has risen from 41.1€/MWh to 162.4€/MWh in two years it does not seem complicated that this alternative currently presents financial benefits and allows a reduction in the cost of the water transferred.

5. Conclusions

This article has analysed the financial viability of two photovoltaic solar panel installations to supply energy to a large infrastructure, the Tagus-Segura water transfer system. This is very useful in a context of high energy prices and significant greenhouse gas emissions due to the use of fossil fuels. To this end, and after a bibliographic study on the current situation of photovoltaic solar panels, the energy data of the water transfer and the budgets prepared by the company Enerficaz were analysed. The analysis has been possible thanks to the use of budgets designed specifically for the Tagus-Segura water transfer and to their comparison with the data used by the Central Commission for the Exploitation of the Tagus-Segura water transfer.

The first step has been to analyse the energy cost of the infrastructure to which supply alternatives are being sought, which was over 15 million euros per year before the recent energy price increases. The unit price varies depending on the period of consumption, which explains the distribution of energy used. The average energy cost amounted to almost 6 cents per kWh before the energy price increases, so now it will be higher and it stands as a high cost for its users, who are mainly irrigators and local users.

After analysing the energy cost of the Tagus-Segura water transfer, the self-consumption projects using photovoltaic solar panels installed, firstly, on a floating platform on a pond near the Fuente Álamo measuring point and, secondly, on the water transfer canal itself were presented. Both projects involve a significant investment, but it is possible to recover it over the 25-year life of the panels in the case of the floating installation thanks to the low unit cost of the energy produced by this installation, which is around 4 euro cents per kWh. In the other case, with 2020 prices it is not a viable alternative due to the relatively high cost (8 euro cent), so it would be necessary to know the prices currently paid for the electricity.

The sensitivity analysis has allowed us to determine the vulnerability of the projects to changes in the price of energy and in the amount of energy produced. For the floating installation, the results have been positive, as it is highly unlikely that the critical variables will decrease so much as to cause the project to generate losses, as the manufacturer guarantees 90% of the production for 25 years and there are no indications that the price of energy will drop at a lower level than in 2020. As for the second proposal, the situation is more complicated due to its higher cost. This alternative is more vulnerable, but it has potential depending on energy price increases. In addition to this, there is the possibility of a larger installation with lower cost. The current situation for floating PV installations is therefore promising, as there is available space, potential financial benefits and relatively low risk.

This study case is useful not only as an example of the potential of solar photovoltaic installations, but it also allowed us to compare two different ways of carrying out them and to see how little risk they present. However, there is a limit to the floating projects, as the surface area is limited. With regard to the other alternative, the water transfer infrastructure has a large area available for the installation of panels, but the design of the project must be precise considering that the size of the installation is related with the average cost of the energy. In any case, the viability of self-consumption and the potential of photovoltaic installations have been demonstrated, especially in the current context of high energy prices. With a view to the practical implementation of a project of these characteristics, it would also be necessary to include the environmental benefits (water evaporation and reduction of greenhouse gas emissions) and negative impacts (on the water body). Focusing on the financial aspect is the main limitation of this article, illustrating the relative ease of making return on investment.

CRediT authorship contribution statement

Marcos García-López: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Visualization, Funding acquisition. **Borja Montano:** Conceptualization, Formal analysis, Investigation, Writing – review & editing, Supervision, Funding acquisition. **Joaquín Melgarejo:** Conceptualization, Investigation, Writing – review & editing, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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