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Research Article

Feasibility Study and Economic Analysis for Hydroelectric-PV Hybrid System Performed with PVsyst Software

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ABSTRACT

While energy demand is increasing day by day with the developing technology, the decrease in traditional energy sources and the negative effects of carbon emissions on the environment encourage countries to turn to sustainable and environmentally friendly renewable energy sources. Requirements such as the periodic change of renewable energy resources depending on weather conditions and the optimum use of existing resources have made it attractive to use different renewable energy resources together. In this paper, the feasibility study of a hybrid energy system for Akfen Renewable Energy's Gelinkaya Hydroelectric Power Plant (HPP) with an installed capacity of 6,866 MW, located in Aziziye district of Erzurum province. In the study, the economic analysis of the hybrid model resulting from the integration of Gelinkaya HPP with SPP (Solar Power Plant) using PVsyst software is discussed. The acceptance of Gelinkaya HPP by the Ministry of Energy was made on June 14, 2013 and the power plant started electricity generation activities. Since this date, the average annual electricity generation value of the power plant has been 10.062.411 MWh and the capacity factor has been realized as 16,73%. With the analysis of the HPP-SPP hybrid system, it was observed that the power plant was able to generate an average of 12.491 MWh more electricity per year by contributing to electricity generation, especially during irrigation periods, and the capacity factor increased to 37,50%.

1. Introduction

Hybrid power plants are plants that generate electricity using a combination of multiple energy sources (as primary and auxiliary sources) [1]. Such power plants provide diversity and efficiency in energy production by integrating renewable energy sources in addition to the primary energy source. The legislative amendment made in 2020 in our country has given a significant impetus to the development of hybrid power plants and paved the way for the conversion of existing electricity generation plants into hybrid power plants. This change aims to increase sustainability and energy supply security in power generation facilities by creating an incentive environment for investors. As of the end of 2023, there are 240 hybrid power plants in production and planning stages in our country, and all of these plants use solar as an auxiliary source [1].

Integrating hybrid power plants into existing power plants as an auxiliary source is relatively less costly than building a new power plant. Hybrid systems built on existing electrical infrastructure reduce operation and maintenance costs and contribute to energy diversity and increased energy efficiency. In order for a project to be considered as an investment instrument, it is important to conduct a detailed economic analysis and to provide a clear path for the investor in terms of viability. There are many software tools with different features available in the literature for the techno-economic evaluation of hybrid power plants. The most widely used ones are Solarius PV, SAM (solar advisor model), PVsyst, PVWatts, PVGIS (photovoltaic geographic information system), HOMER (Hybrid Optimization Model For Electric Renewable Resources), SolarGIS, PVSOL, RETScreen, BlueSol, HelioScope, PolySun, Solar Pro [2].

The studies on hybrid power plants in the literature are as follows:

Olkkonen and others, in this study, they discussed the sizing and planning of the hybrid-floating photovoltaic hybrid system. The techno-economic feasibility of the hybrid system is analysed under different types of [3].

Dursun and Saltuk studied two scenarios for the optimization of the installed capacity of the solar power plant in the hydro-solar hybrid modeling of an 18,777 MW hydroelectric power plant operating for electricity generation within the borders of Tokat and Resadiye district. In the first scenario, no reservoir area of the hydroelectric power plant was considered and the installed capacity of the solar power plant was calculated as 9,575 MW. In the second scenario, the reservoir area of the hydroelectric power plant was considered and the incoming water flows were adjusted according to the water flow value so that the electricity generation value of the solar power plant would be the highest and the installed power value of the solar power plant was calculated as 20,9 MW [4].

Balan et al. conducted a solar hybrid modeling study of a cascade hydroelectric power plant on the Tiete River in Brazil. They found that the hybrid model increased the production values and improved the reservoir operating conditions of the cascade hydroelectric power plant. They also concluded that the grid capacity limits the production value of the hybrid model [5].

In the Saltuk PhD thesis study, hydroelectric power plants made low production in the summer months due to rainfall, while solar energy power plants played a complementary role in terms of electricity production by making high production in the same summer months. Thus, hydroelectric-sun hybrid modeling has

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increased the production capacity of the hydroelectric power plant. It also concluded that the inefficient use of the transformer capacities divided into power plants as a result of changes in periodic production amounts of existing hydroelectric power plants will be prevented [6].

Mehadi et al. conducted a comprehensive analysis by simulating the installation of a 50 MW floating photovoltaic system in the reservoir area of Kaptai Dam in Bangladesh. With the hybrid system, it was observed that there was a 10% increase in the generation value of the existing hydroelectric power plant. They also determined that electricity generation will be realized more efficiently with different operating models in different seasons with hybrid modeling. With this model, they determined that the hybrid structure performed much better than the hybrid systems in China (Longyangxia hybrid power plant) and Portugal (Alto Rabagão hybrid power plant) with a capacity factor of 33.64% and full load generation of approximately 2.944 hours [7].

Agyekum et al. conducted a research on a hybrid model of Hydropower/Battery (1st scenario) and PV/Hydroelectricity/Battery (2nd scenario) for the irrigation of 100 hectares of land and electrification of the area in a rural settlement in northern Ghana. According to the data obtained from the results of the research; 1.095.679 kWh of electricity will be generated annually in scenario 1, while 2.005.544 kWh of electricity will be generated annually in scenario 2. In terms of operating cost, while the cost of scenario 1 is $18,318, this value is $22,606 for scenario 2 [8].

Cazzaniga et al. investigated the integration of a floating photovoltaic system with a hydroelectric power plant for the top 20 largest hydroelectric power plants in the world. It was observed that the amount of hydroelectric power generation increased by 65% when a photovoltaic system was installed in 10% of the hydroelectric power plant basin [9].

Pianco et al. simulated a floating photovoltaic system covering 2,8% of the reservoir area of a hydroelectric power plant in Santa Branca, Brazil. In the study, 20 years of data of the hydroelectric power plant were analyzed and it was aimed to optimize the production values of the hydroelectric power plant by ensuring that the photovoltaic system is in production during daytime hours. While the hydroelectric power plant produced 4 TWh of electricity, this value increased by 50% to 6 TWh with the hybrid structure [10].

In their research, Anandhi et al. summarized the critical role and benefits of solar-hydroelectric hybrid systems in electricity generation. Hybrid systems provide a reliable energy source by effectively balancing energy production and consumption. They reduce dependence on traditional grids and minimize environmental impacts. Innovations in storage and control systems are critical to address the inherent imbalances of renewable energy sources. These developments increase the efficiency of the systems and optimize their performance. Economic analyses show that while hybrid systems may initially appear costly, they become more cost-effective over time, with significant reductions in investment and operating costs [11].

In their research, Campos et al. note that reservoirs of hydroelectric power plants play an important role in arid regions where water is very precious. In these regions, a balance needs to be struck between the use of water for different purposes, such as power generation, agriculture and drinking water. However, water demand for hydropower generation during severe droughts can reduce water levels in the reservoir to critical levels and increase the risk of water scarcity. As a solution to this problem, the integration of solar energy systems, especially floating photovoltaic [1] systems, is being considered. This approach has aimed to diversify energy production and reduce dependence on hydropower plants [12].

In their research, Niaki and Davoodi investigated the technical and economic parameters of a hybrid hydroelectric power plant floating photovoltaic system in “Sardasht” region in West Azerbaijan province using sensitivity analysis and obtained optimum designs in various scenarios in terms of different load values, dam reservoir water levels and equipment costs [13].

In their research, Clot and Tina examined the integration of floating photovoltaic systems with hydroelectric power plants and determined that this hybrid structure has several advantages. The floating photovoltaic system power potential of the top 20 large hydroelectric power plants in the world was analyzed and it was shown that if 10% of the hydroelectric power plant basin surfaces are installed with photovoltaic systems, the energy production of the hydroelectric power plant increases by 75% [14].

In their study, Velloso et al. aim to evaluate the impact of photovoltaic system on the production value of the Sobradinho Hydroelectric Power Plant operating in the Sao Francisco River, which is the most important water source in the semi-arid region of Brazil. It has been reported that the photovoltaic system contributes to water savings and contributes to the prevention of greenhouse gas emissions by thermal power plants during prolonged periods of intense drought [15].

In his research, Dominique analyzed the photovoltaic-hydro hybrid modeling of Mukungwa Hydroelectric Power Plant in the northern province of Rwanda using HOMER and PVsyst software. With this modeling, it was predicted that the production value, which decreases in summer periods, would be increased with the photovoltaic system [16].

As stated in the literature, the trend towards renewable energy resources has increased due to the limited availability of traditional energy resources, their day by day decline and their negative environmental impacts. In addition to the advantages of renewable energy sources such as being sustainable and environmentally friendly, periodic fluctuations in their supply due to seasonal effects can be considered as a disadvantage. In order to prevent this negative situation, hybrid systems, which are formed by using multiple energy sources together, come to the fore. Hybrid systems provide electricity supply security as a result of the integrated operation of more than one renewable energy source in order to provide optimum benefit from renewable energy sources.

2. Hybrit Systems

Hybrid power generation systems are the combination of two or more different power sources to generate electricity [17]. In the same way, a facility that performs production activities is integrated with the addit in the same way, it is a facility that performs electricity generation activities in an integrated manner with an additional energy source in order to increase efficiency and security of supply ional energy source in order to increase the efficiency and supply safety [18]. Hybrid systems are available in many different combinations of different renewable energy sources such as hydro-solar, wind-solar, hydro-solar-wind. With the Regulation on the Amendment of the Electricity Market License Regulation published in the Official Gazette dated March 8, 2020, the establishment of electricity generation facilities based on more than one source in our country has been paved [19]. With the amendment of the regulation, the installation of hybrid power plants in our country has accelerated, paving the way for the optimum utilization of existing renewable energy resources. There are many software tools for modeling hybrid power plants.

3. Material and Method

Gelinkaya HPP (Hydro Power Plant) is a facility operating for electricity generation within the borders of Aziziye district of

Erzurum province of Akfen Renewable Energy company. Gelinkaya HEPP is a canal-type facility and started its electricity generation activities on June 13, 2013 after its provisional acceptance by the Ministry of Energy and Natural Resources. The characteristics of the facility are shown in table 1.

Table 1. Features of Gelinkaya HPP Facility

Project Name	**Gelinkaya HPP**
City	Erzurum
District	Aziziye
Facility Type	Renewable, Headrace Type
Number of Unite	2 pieces
Unit Installed Power	2x(3,538)MWm/ 2x(3,433)MWe
Total Installed Power	7,076 MWm/ 6,866MWe
Source	Hydro
Annual Electrical Energy Production	25.800.000 kWh
Network Connection Point and Voltage	MV busbar of 154/31.5 kV Aşkale switchgear to be installed over dispatching center

Gelinkaya HEPP operates as a joint facility with the Daphan Irrigation Union for agricultural irrigation purposes under the 8th Regional Directorate of DSİ. The project is located downstream of Kuzgun Dam on Serçeme Stream. The water taken by Seksenveren Regulator is transported to the agricultural irrigation area through the transmission line. Gelinkaya HEPP facility receives water by turning the water from the canal at km 13 of the transmission line. Since Gelinkaya HEPP is a joint facility for agricultural purposes, it cannot generate electricity or partially generates electricity during the irrigation periods of June, July, August and September. The production values realized by Gelinkaya HEPP facility from June 2013 until today are shown in Figure 2. It is observed that the production values of the facility over the years are not stable depending on the water regime.

Fig.1. Gelinkaya HPP

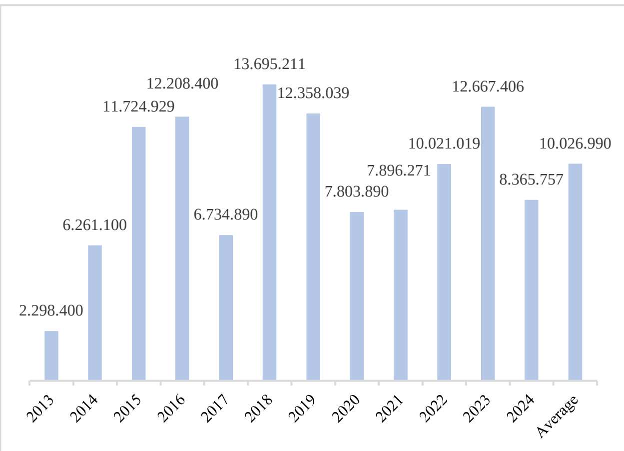

Fig.2. June 2013 – October 2024 Annual Production (kWh)

When the monthly average production values of the plant shown in Figure 1 are analyzed, it is seen that the highest production is realized in May and the lowest production is realized in July. With the hybrid modeling, it is aimed to increase the electricity generation capacity of the plant, especially in June, July, August and September, which are the irrigation periods.

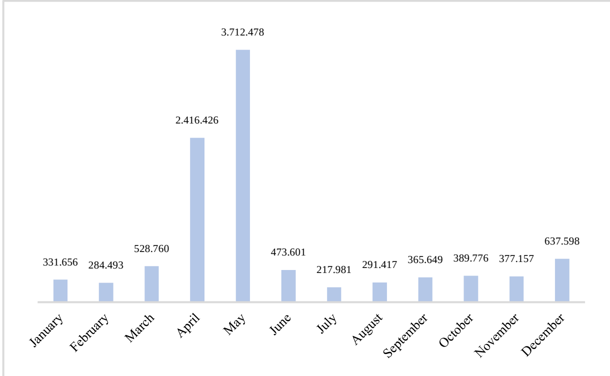

Fig.3. Monthly Average Hydroelectric Production (kWh)

Hybrid modeling of the Gelinkaya HEPP plant was performed using PVsyst Version 7.4.6 software. Simulation output summary information is given in Table 2. PVsyst software was chosen among simulation programs because it offers more detailed and analytical results to analyze the performance of photovoltaic systems and evaluate the different losses in the system [20].

Table 2. Simulation Output

Project and System Summary			
Geographical Site		**Latitude**	**40.01 °N**
Gelinkaya		Longitude	40.91 °E
Turkey		Altitude	1795 m
		Time zone	UTC+3
Weather data			
Gelinkaya			
Meteonorm 8.1 (2005-2013), Sat=100% - Synthetic			
Grid-Connected System	**Near Shadings**		**User's needs**
Simulation for year no 1	Linear shadings : Fast (table)		Unlimited load (grid)
PV Field Orientation	**Inverters**		
Fixed plane		Nb. of units	20 units
Tilt/Azimuth 26.4 / 17.4 °		Pnom total	6000 kWac
		Grid power limit	6870 kWac
		Grid lim. Pnom ratio	0.999
System information			
PV Array			
Nb. of modules	12480 units		
Pnom total	6864 kWp		
Produced Energy 12490.44 MWh/year			
Specific production 1820 kWh/kWp/year			
Perf. Ratio PR 87,38 %			

4. Results and Discussion

Simulation output PV array characteristics are shown in Table 4. In the simulation because it is also used in other facilities of the company Seraphim SRP-550-BMA-Bifacial model PV module and Huawei Technologies SUN2000-330KTL-H1 model inverter were preferred. The hybrid system consists of a total of 12.480 modules and the installed power of the system is 6,864 MWp under nominal conditions (STC: lrradiance 1.000 W/m² modul temperature 25°C AM=1.5).

Table 3. PV Characteristics

PV Array Characteristics			
PV module		**Inverter**	
Manufacturer	Seraphim	**Manufacturer**	Huawei Technologies
Model	SRP-550-BMA-Bifacial	**Model**	SUN2000-330KTL-H1
(Original PVsyst database)		**(Original PVsyst database)**	
Unit Nom. Power	550 Wp	**Unit Nom. Power**	300 kWac
Number of PV modules	12480 units	**Number of inverters**	20 units
Nominal (STC)	6864 kWp	**Total power**	6000 kWac
Modules	480 string x 26 In series	**Operating voltage**	550-1500 V
At operating cond. (50°C)		**Max. power (=>30°C)**	330 kWac
Pmpp	6293 kWp	**Pnom ratio (DC:AC)**	1.14
U mpp	980 V	**Power sharing within this inverter**	
I mpp	6425 A		
Total PV power		**Total inverter power**	
Nominal (STC)	6864 kWp	**Total power**	6000 kWac
Total	12480 modules	**Max. power**	6600 kWac
Module area	32338 m²	**Number of inverters**	20 units
		Pnom ratio	1.14

According to the simulation results, generation values by month are shown in Table 5. According to the results, the annual generation value is 12.490 MWh, while the highest value in terms of performance ratio is February and the lowest is December.

Table 4. Main Results

	T_Amb	**EArray**	**E_Grid**	**PR**
	°C	**MWh**	**MWh**	**ratio**
January	-10,74	764	739	0,849
February	-8,70	840	813	0,915
March	-1,11	1.160	1.123	0,908
April	5,51	1.254	1.215	0,899
May	10,42	1.297	1.255	0,888
June	15,03	1.385	1.344	0,889
July	19,83	1.310	1.269	0,864
August	20,42	1.297	1.257	0,853
September	14,38	1.204	1.167	0,860
October	7,98	985	954	0,869
November	0,.05	734	709	0,847
December	-7,34	669	646	0,816
Year	5,56	12.898	12.490	0,874

While the annual production value, which is expected to be realized by 90% compared to the simulation output given in Figure 4, is 11.788 MWh, the production value of 50% is 12.490 MWh.

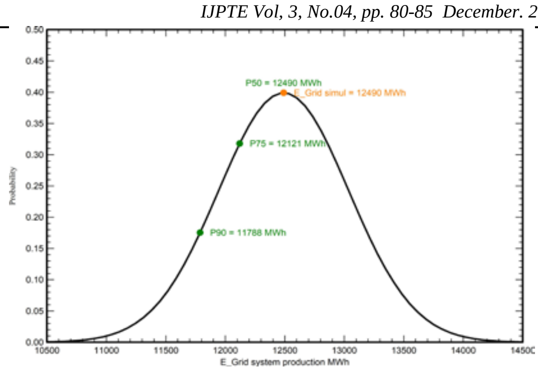

Fig.4. P50 – P90 Evaluation

The loss diagram for the modeling is shown in Figure 2. The main losses that negatively affect the annual electricity generation value are light induced distortion, mismatch loss and inverter loss.

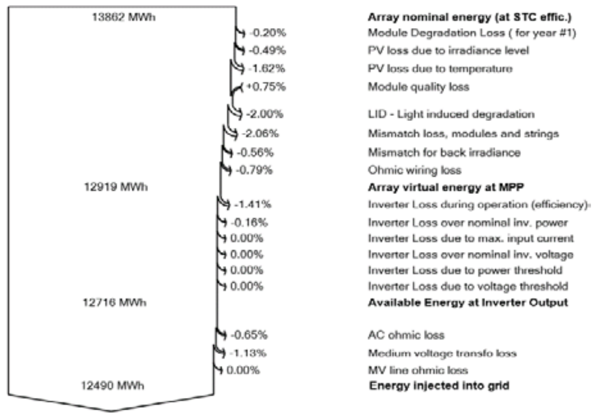

Fig.5. Loss Diagram

According to Table 5, the wear status of the system was examined and 14,57% performance loss occurred at the end of 25 years.

Table 5. Wear Ratio

	EUseful	**PR (Performans Ratio)**	**PR (Performans Ratio) loss**
Years	**MWh**	**%**	**%**
1	12.490	87,38	-0,23
2	12.432	86,97	-0,70
3	12.373	86,56	-1,17
4	12.314	86,15	-1,64
5	12.256	85,74	-2,11
6	12.197	85,33	-2,58
7	12.108	84,71	-3,29
8	12.019	84,08	-4,00
9	11.931	83,46	-4,70
10	11.842	82,84	-5,41
11	11.753	82,22	-6,12
12	11.690	81,78	-6,62
13	11.627	81,34	-7,13
14	11.564	80,90	-7,63
15	11.501	80,46	-8,14
16	11.438	80,02	-8,64
17	11.381	79,62	-9,10
18	11.323	79,21	-9,56
19	11.266	78,81	-10,01
20	11.209	78,41	-10,47
21	11.151	78.01	-10,93
22	11.037	77,21	-11,84
23	10.923	76,42	-12,75
24	10.810	75,62	-13,66
25	10.696	74,82	-14,57

5. Conclusions

Due to the limited structure of traditional energy sources and their negative effects such as carbon emissions, the tendency towards renewable energy sources has increased in recent years. In order to obtain optimum benefit from renewable energy sources, the idea of periodically changing renewable energy sources and hybrid systems has emerged. In this study, the hybrid model of Gelinkaya HEPP plant operating as a joint facility with Daphan Irrigation Association in Aziziye district of Erzurum province for the purpose of electricity production was created with PVsyst software and the model was analyzed economically. As seen in Figure 6, while the annual average production value of Gelinkaya HEPP plant was 10.062.411 kWh, it was seen that this value increased to 22.553.411 kWh with the hybrid system. In addition, as seen in Figure 7, the capacity factor value of 16,73% exceeded the country average and increased to 37,50%.

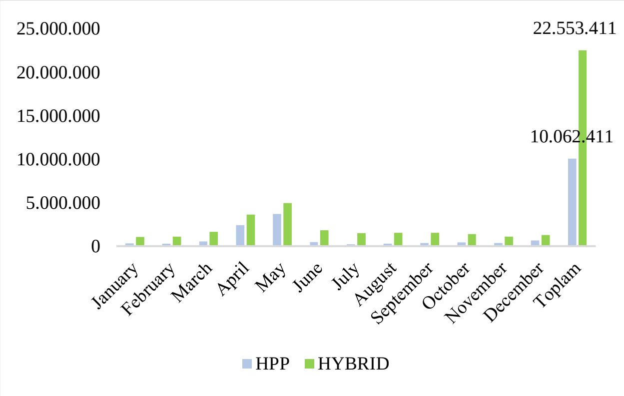

Fig.6. Comparison of Production (P50 - kWh)

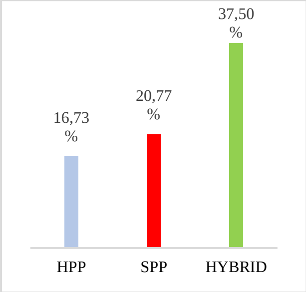

Fig.7. Capacity Factor (P50 - %)

According to the market research, the cost of hybrid power plant installation is $600.000 / MWh. The main items that make up this cost include PV module, inverter, transformer, distribution building, cable and labor. Since the hybrid system is integrated into the existing power plant structure, there are no major costs such as ENH and land acquisition. Since the operation of the hybrid power plant is carried out from a single point and maintenance and repair activities are carried out by Gelinkaya HPP personnel, there is no need to employ additional personnel. In terms of operating costs, only equipment maintenance and repair costs can be considered and this amount is $27.440 per year ($4000 x installed capacity). The revenue and expenditure values of the Solar Power Plant integrated into the existing plant for 25 years are given in Table 6. The electricity generated by Gelinkaya HEPP is traded in the day-ahead market and sold at the market clearing price (PTF). In 2024, the average market clearing price is $67,80 / MWh. Therefore, the value of 1 MWh of electricity generated by the SPP plant is calculated at $67,80. In line with this information, it is seen that the SPP plant covers its investment cost in 6 years and generates profit.

Table 6. Income Statement

Years	Production Value	Hybrid Production	Income	Cost	Gain
	MWh	MWh	USD	USD	USD
1	12.490	22.516	$846.822	$3.299.018	
2	12.432	22.458	$842.890	$2.483.568	
3	12.373	22.399	$838.889	$1.672.119	
4	12.314	22.340	$834.889	$864.670	
5	12.256	22.282	$830.957	$61.153	
6	12.197	22.223	$826.957		$738.364
7	12.108	22.134	$820.922		$1.531.846
8	12.019	22.045	$814.888		$2.319.294
9	11.931	21.957	$808.922		$3.100.776
10	11.842	21.868	$802.888		$3.876.224
11	11.753	21.779	$796.853		$4.645.637
12	11.690	21.716	$792.582		$5.410.779
13	11.627	21.653	$788.311		$6.171.650
14	11.564	21.590	$784.039		$6.928.249
15	11.501	21.527	$779.768		$7.680.577
16	11.438	21.464	$775.496		$8.428.633
17	11.381	21.407	$771.632		$9.172.825
18	11.323	21.349	$767.699		$9.913.084
19	11.266	21.292	$763.835		$10.649.479
20	11.209	21.235	$759.970		$11.382.009
21	11.151	21.177	$756.038		$12.110.607
22	11.037	21.063	$748.309		$12.831.476
23	10.923	20.949	$740.579		$13.544.615
24	10.810	20.836	$732.918		$14.250.093
25	10.696	20.722	$725.189		$14.947.842

Declaration of conflicting interests

The authors declare no competing interests.

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