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Assessment for the installation of a solar PV system in Pakistan for a sustainable environmental and economic development

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ABSTRACT

In this study, a photovoltaic system with RETScreen software is simulated to see its economic and environmental feasibility in the one of the remote locations in Pakistan. Our proposed photovoltaics power system is installed south Asia: particularly, Pakistan which receives a high amount of solar irradiance throughout the year. The proposed location has an electricity demand of 28.70 MWh/month, and our simulated PV system generates 31 MWh/month which is more than the amount of required electricity demand. The 25 years long life project will have energy payback time of 7.4 years and the net greenhouse gas (GHG) emission reduction will be 3,942 tCO_2 for the whole project life. These results summarize that installation of this solar power system is not only economically feasible, but also reduces the emission of greenhouse gases in that selected location.

1. Introduction

Over the past few decades, the environmental challenges have become severe. To address these challenges, the members of United Nations Climate Change (UNCC) unanimously reached an agreement in 2015 to increase the investments and actions needed for a low carbon future. After this agreement, many countries redesigned their policies for environmental challenges and realized the importance of the renewable energy sources.

Pakistan has also signed that agreement and trying to shift from hydrocarbon energy to renewable energy. Installation of renewable energy resources will be advantageous as they will address the global concerns of climate changes/global warming. Fig. 1 shows the annual CO_2 emission of Pakistan from the year 1970 to 2016 [1]. Pakistan has set the target of reducing greenhouse gases (GHG) emissions by 20% by 2030 from its projected emission levels [2].

This increasing emission of CO_2 is from the burning of fossil fuels to meet the energy needs of the country. The primary energy mix of Pakistan for the year 2017-18 is shown in Fig. 2. It can be clearly seen that the major constituents of energy mix of Pakistan are two hydrocarbon products i.e., oil followed by natural gas [3].

A huge amount of fossil fuels are burned to generate electricity in Pakistan. Fig. 3 shows the electricity generation mix of Pakistan in the previous years. It can be seen that the electricity generation largely depends on oil and natural gas. These conventional sources contribute nearly 61% of total electricity production [4]. However, there is a small contribution from non-conventional sources of energy as well.

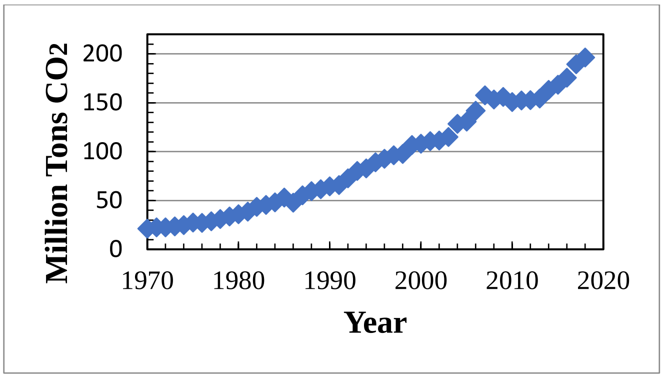

Fig. 1. GHG emission of Pakistan, reprinted with permission of Elsevier [1]

According to the World Bank report, the annual population growth of Pakistan is 2.056% in 2018 [5]. This rising population has increasing needs of energy. However, Pakistan did not increase its electricity generation capacity with time due to which it has seen the severe energy crises from the last couple of decades. Today, the total installed capacity of electricity production is of nearly 32,263MW, and maximum production capability during summer is 23,766 MW, whereas the demand of electricity during the peak season is more than 27,000 MW. Therefore, the country has an electricity deficit of 3,334 MW because of the gap between supply and demand [6].

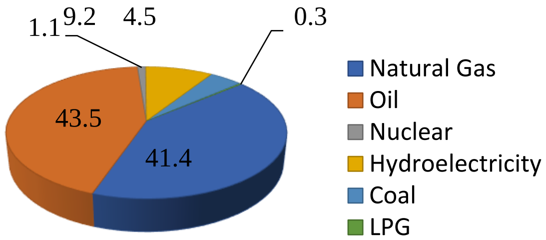

Fig. 2. Primary energy mix of Pakistan in year 2017-2021

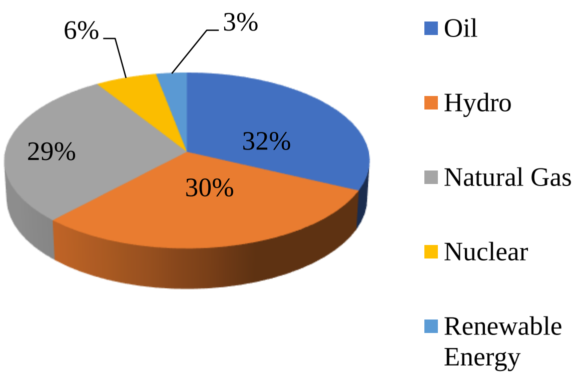

Fig. 3. Electricity generation mix of Pakistan

Fig. 4 illustrates that the residential consumption of electricity is even more than industrial consumption. According to a report of the World Bank, per capita consumption of electricity in the year 2014 is around 447.505 kWh, while it was at 93.55 kWh in the year 1973 [7]. However, the generation of electricity did not increase as the rise in the demand. As most of the energy is consumed in the residential sector, so, it complicates the load management of electricity during peak hours [8,9].

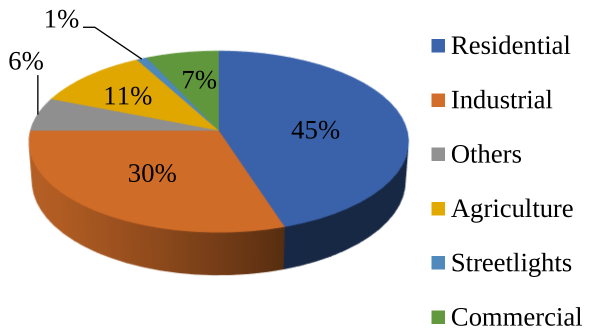

Fig. 4. Electricity consumption by sectors in Pakistan

In addition, a large proportion of the population of Pakistan lives in rural areas. Many rural areas do not have access to electricity, and those who have access suffer through a huge load shedding of electricity. It can be seen in Fig. 5 that among other Asian countries, Pakistan still lags behind in providing electricity to rural areas at the rate it has provided to the urban areas as the electrification rate in urban areas of Pakistan is 89.1% and it is 64.4% in rural areas [10]. It is noticeable that after Myanmar and Democratic People's Republic Korea (DPR), Pakistan has the least rural electrification rate among other compared countries. This difference of rate of electrification between rural and urban areas can be reduced by installing renewable energy resources. By implementing our proposed study, it would help the rural population to come into the mainstream and meet the electricity shortfall.

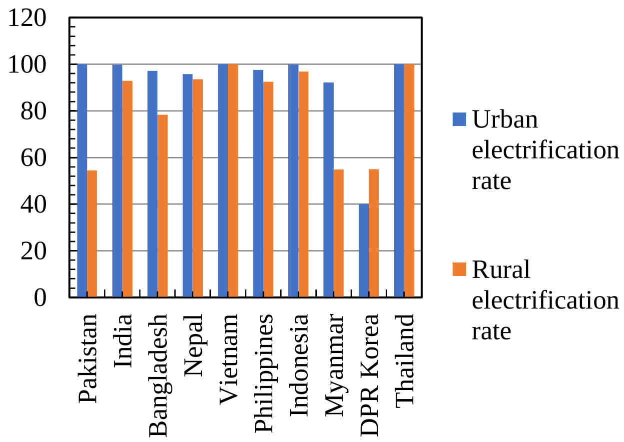

Fig. 5. Rate of electrification in Asian countries. World bank 2020, reprinted with permission of Elsevier [10]

Furthermore, as Pakistan is not a giant producer of oil and natural gas, so it imports these two products from countries like Saudi Arabia and Qatar to generate electricity, these costs billions of dollars. This cost, then burdens the economy of the country and increases the circular debt, which results in the impasse of payments, and consequently the economy of the country significantly suffers. According to Pakistan statistical Year book 2016 [11], the import cost of petroleum and related products reached all time higher which was around 6,675.01 million US$.

Thus, our motivation to do this study is to contribute in the economic progress of the country by providing a carbon-free source of electricity to the residential consumers, particularly those living in rural areas, of Pakistan. The current installed capacity of renewable energy is much lower than the projected theoretical potential by many studies in Pakistan [12]–[14]. To address these issues of shifting electricity generation from oil and natural gas, difference in supply and demand of electricity, and to reduce the CO_2 emission, it is inevitable to install the renewable energy resources in Pakistan.

2. Solar Energy Potential

A survey conducted by the National Renewable Energy Laboratory (NREL), USA indicated that Pakistan has a potential of 2.9 million MW of solar energy [15]. Fig. 6 shows the annual solar radiation in Pakistan. It can be seen that most parts of the country have immense sunshine where the solar radiation ranges between 4.5 to 5 kWh/m²/day.

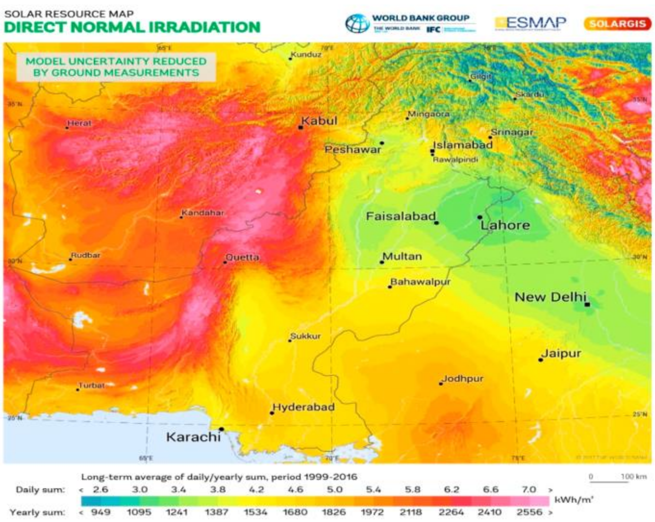

Fig. 6. Annual solar radiation map of Pakistan, reprinted with permission of Elsevier [16, 17]

The data of monthly variation in the solar irradiance on our site are presented in Fig. 7. The data taken from National Aeronautics and Space Administration (NASA), United States shows that the overall annual solar irradiance is 4.93 kWh/m²/day in which the solar irradiance increases gradually from the month of April to August. The data also indicate that the month of June receives the highest solar irradiance and the months of January and December have the lowest solar irradiance. Thus, the abundance of the sunshine available in the project site indicates the feasibility of installation of the project.

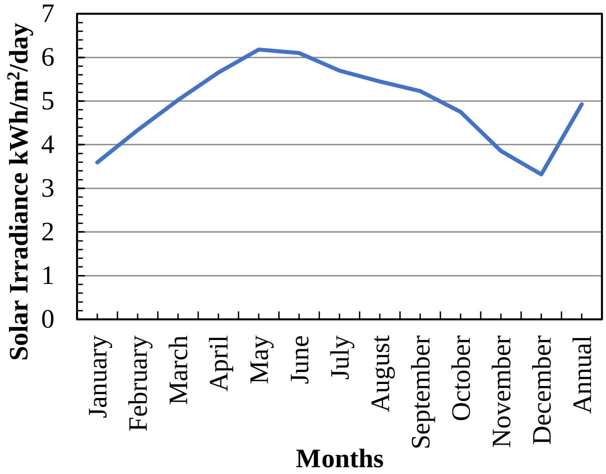

Fig. 7. Monthly solar irradiance

3. Methodology and Results

There are wide ranges of software programs and energy models which are available to analyze and optimize technical, economic and environmental impacts of renewable energy systems [18–21]. These freely available tools can be applied in various applications. One of the available tools is RETScreen which allows calculating the economic feasibility of a renewable energy project as well as gives details about site selection and GHG emissions. This simulation tool also states the estimated life cycle of the project and maintenance cost.

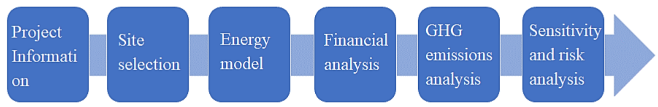

Fig. 8: Flow Chart of RETScreen model

The RETScreen simulation tool is designed by the government of Canada to facilitate and promote renewable energy resources. This software predicts the life cycle of the project by analyzing different input parameters. It also calculates the total cost of a project depending upon which equipment is used in the project. In addition to that, it suggests the maintenance and the operational cost along with sensitivity and risk analysis. Fig. 8 represents the schematic process flow of analysis done by the RETScreen simulation tool.

3.1 Description of Site

Our targeted site is the Kott Haibat village which is located few kilometers away from the district Dera Ghazi Khan of Pakistan. The geographical and climate data for the site is summarized in Table 1 and 2, respectively.

Table 1

Geographical description of the site

	Unit	Climate data location	Project location
Latitude	ºN	30.1	30.1
Longitude	ºE	70.6	70.6
Elevation	m	493	493
Heating design temperature	ºC	4.9	-
Cooling design temperature	ºC	37.3	-
Earth temperature amplitude	ºC	25.8	-

As mentioned in Table 2, our site receives a good amount of solar irradiance throughout the year. The annual solar irradiance at our site is 4.93kWh/m^2 on a horizontal surface. The overall annual humidity and atmospheric pressure are 37.9% and 93.9kPa, respectively. The temperature of the air remains 22.5ºC at our selected location.

3.2 Estimation of Load and Design of PV System

In any grid connected solar power system, it is very important to accurately calculate the estimated load and design the system for that purpose. Table 3 shows the estimated load of the site.

Table 2

Annual solar irradiance data of the site

Month	Relative humidity (%)	Air Tempe. (ºC)	Daily solar radiation – horizontal(kWh/m2/d)	Atmospheric pressure (kPa)	Heating degree-days (ºC-d)	Cooling degree-days (ºC-d)
January	42.8	10.3	3.59	94.6	239	9
February	37.0	13.0	4.33	94.4	140	84
March	29.7	19.0	5.02	94.1	0	279
April	27.5	24.8	5.65	93.8	0	445
May	26.4	29.6	6.18	93.4	0	606
June	34.6	32.2	6.10	93.0	0	667
July	55.4	30.5	5.70	93.0	0	636
August	64.1	28.5	5.45	93.3	0	575
September	46.7	27.6	5.23	93.7	0	527
October	27.2	23.3	4.75	94.2	0	414
November	27.0	17.8	3.86	94.5	7	233
December	35.4	12.6	3.32	94.7	167	81
Annual	37.9	22.5	4.93	93.9	553	4555

For the above calculated power requirements, it is important to design a feasible solar system that can provide power to consumers without any interruptions. The solar power system consists of solar PV modules, connecting wires, batteries (in some cases), charge controllers and inverters to convert a DC power supply to AC power. One of the major steps in setting up this solar power system is to do sizing of the solar PV system. In general, the solar panel sizing is calculated by the following steps:

- Daily kWh / Peak sun hours = kWh needed from solar panel array
- Multiply the kWh by 1000 to get total watts needed from panels
- Divide the watts required by the selected panel size (in our case it's 225W).
- It will result in number of solar panels required for our energy demand in our location.

Table 4

Technical Parameters of the PV system.

PV System	Unit	Specification
Installed capacity	kW	
Type of module	-	mono-Si
Model	-	Centrosolar
Efficiency	%	14.8
Temperature coefficient	%/ºC	0.40
Solar collector area	m^2	1520
Control method	-	Maximum Power Point Tracking (MPPT)
Loses	%	10
Inverter		
Efficiency	%	96.0
Capacity	kW	230

To install this system, it is also extremely critical to accurately calculate the difference between supply and demand of electricity. The schematic design for this study is shown in Fig. 9. The next step is the design of a solar PV system and determination of the size of the inverters according to the estimated load. For a grid-connected PV system Ataie et al. [22] calculated the energy output of the installed PV system as follows.

$$P = Y_{array} \times f x \frac{G_T}{G_{STC}} \{1 + \alpha_p (T_c - T_{STC})\} \quad (1)$$

In the Eq. 1, Y_{array}represents the PV array rated capacity in kW, f is derating factor (%) that corresponds to all the negative factors which affect the PV module performance, the G_T is the incident solar radiation at test conditions (kW/m^2) whereas G_{STC} is the incident solar radiation at standard conditions (1 kW/m^2), α_p shows temperature coefficient (%/^{o}C), T_C is the cell temperature at test conditions (^{o}C) and T_{STC} is the cell temperature at standard conditions (^{o}C). Now, if we do not consider the effect of temperature on PV modules and assuming that they will be stable at a certain temperature then the Eq. 1 becomes as.

$$P = Y_{array} \times f \text{ x } \frac{G_T}{G_{STC}} \quad (2)$$

Mono-crystalline silicone solar panels are widely used and available in the market at a very reasonable cost. Also, their installation in a power generating system is relatively easier than other renewable energy sources. Therefore, we are using these solar panels for our system. Hence, by putting the solar module parameters, described in Table 4, in the Eq. 2 we can get the expected power output from the system. Based on the calculations made, almost 220 kW is required to meet our power demands. A study reveals that modules mounted at an angle of 30^o have optimal height at which modules give the maximum output. Moreover, an optimum design of inverter is also necessary for designing a PV system. The parameters for inverter are also described in Table 4. Since the system will be generating output of 220 kW, so a slightly higher rated inverter will best match with the design.

4. Discussion

The total power consumption in our selected location is estimated to be 956.88 kWh/day. In this total demand, a major consumption of 930.6 kWh/day is from the domestic residents of that locality. Therefore, a system to meet the required energy needs has been designed and analyzed by RETScreen for its economic feasibility. M. Mujahid Rafique et al. [23] reported that the slope angle of 30^o yields higher energy output. So, with a fixed solar tracking mode, solar slope angle is kept at 30^o which corresponds to the latitude of our selected site. The energy will be exported to the grid at the rate of 160 $/MWh or 0.16 $/KWh.

Table 5

GHG reduction parameters

Parameter	Unit	Value
GHG emission factor	MWh/tCO_2	0.425
Net GHG reduction	tCO_2/year	158
Net GHG reduction for 25 yrs	tCO_2	3,942

Our monthly energy demand is 28.70 MWh/month, and the designed photovoltaic system is giving the output of 31MWh/month on average. This shows that the designed power system based on photovoltaics is feasible to be installed. Apart from that, the photovoltaics-based power systems are attractive for being environment friendly. Therefore, CO_2 emission analysis in this study also indicates the feasibility of this study, and the net annual GHG emission reduction by the installation of this is in Table 5.

Moreover, the financial prospects are vital in these types of projects. It is necessary to measure all the expected cost and profit for investment and budgeting. The financial parameters on the basis of which the feasibility is determined are summarized in Table 6. The project life for this system is 25 years and all other parameters are put keeping the fluctuations in rates with every passing year. The fuel escalation cost and inflation rate is kept at 4% increase per annum. Moreover, the government of Pakistan is giving a subsidy for the installation of renewable energy resources and gives interest free loans, so, it is due to this reason that debt interest is assumed to be zero in this study.

Table 6

Financial parameters

Parameter	Unit	Value
Fuel cost escalation rate	%	4
Inflation rate	%	4
Discount rate	%	4
Project life	Year	25
Debt ratio	%	70
Debt interest rate	$ (%)	4
Debt term	Year	20
Debt payments	$/year	22,339

The economic analysis is also shown in the Table 7. It shows that, after spending the initial cost it yields the net annual savings of 59,405 US$. The net present value of the asset rises to 701,114 US$ over the period of 25 years. Fig.10 shows the cash flow graph of the investment. It can be seen that the energy payback time is 7.4 years, after which the investment starts generating the income.

Table 7

Economic analysis

Parameter	Unit	Value
Internal rate of return (IRR) – equity	%	14.8
IRR – assets	%	2.9
Simple payback	year	14.5
Equity payback	year	7.4
Net present value (NPV)	$	701,114
Energy production cost	$/MWh	102.20
GHG reduction cost	$/t$CO_2$	178

5. Recommendations for Future Energy Policy of Pakistan

Pakistan made renewable energy policy in the year 2006 to invest and expand the use of non-conventional resources to harness energy. However, this renewable energy policy could not be executed properly to lead Pakistan to achieve its targets due to various factors. Therefore, we are recommending some steps that can help Pakistan to meet its energy needs and sustainable development. The policy recommendations are given below.

- As depicted by the simulation that the installation of PV system results in the generation of clean and affordable energy, therefore, the government of Pakistan should also invest more in this sector.
- Establishment of well-equipped research and development centers in Pakistan to enrich the knowledge in understanding every aspect related to PV power system technology.
- This year government exempted taxes for solar module manufacturers for next 5 years. However, this exemption should be extended to project life of a PV power system to attract more investments. Tax exemption should also be given to the industries making other products being used in the solar energy technology such as inverters etc.
- Encourage people to install the solar panels domestically to meet their energy needs at domestic level.
- Those who are generating a certain amount of electricity through renewable energy should be given some credits for helping to reduce carbon emission.

By implementing above suggested policies, Pakistan can also meet its needs of energy and list itself among developed countries.

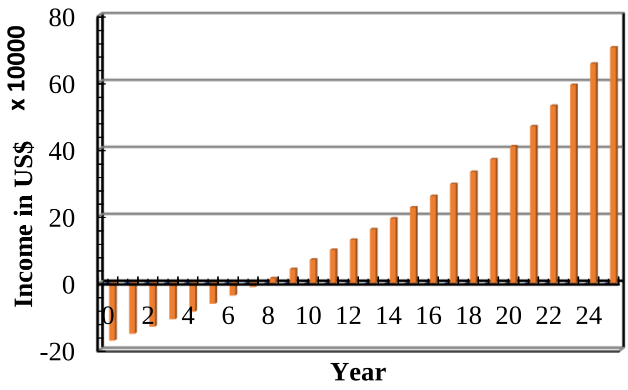

Fig. 10. Cash flow during project lifetime

6. Conclusion

Our study showed that the PV power systems are economically, technically and environmentally suitable to be installed in Pakistan. In this work, RETScreen model is used to analyze the feasibility of a PV power system in a remote location of Pakistan which receives high amount of solar irradiance throughout the year. The monthly electricity demand in the location is about 28.70 MWh/month and our designed model generates the electricity of 31 MWh/month on average. It shows that the designed model will be sufficient to provide the required electricity to that location and sends the extra electricity to the grid. Furthermore, the economic analysis also indicated that after 7.4 years of installation the power system will begin to generate income until its project life of 25 years. In addition to that, we also did the CO_2 emission analysis. The analysis showed that during the whole project life 3,942 tCO_2 of GHG emission will be reduced. Furthermore, by installation of this PV power system a huge burden on economy of Pakistan will also be reduced which comes from importing oil and natural gas to generate electricity.

Table 3

Estimated load of the site

Unit	Appliances	Load per appliances (W)	No. of appliances	Summer operating time Hrs/day	Wh/day	Winter operating time Hrs/day	Wh/day	Total load per day (Kwh/day)
Residential Homes	Electric bulbs	15	2	5	150	4	120	48.6
	Ceiling fans	40	2	15	1200	0	0	216
	Televisions	100	1	5	500	5	500	180
	Fridge (165 ltr.)	100	1	18	1800	1	100	342
	Water pump	100	1	2	200	2	200	72
	Misc.	200	1	1	200	1	200	72
	Total							930.6
Healthcare Centre	Electric bulbs	15	8	8	960	8	960	1.92
	Ceiling fans	40	5	8	1600	0	0	1.6
	Water Pump	100	1	2	200	1	100	0.3
	Computer	150	2	8	2400	8	2400	4.8
	Freezer	200	1	8	1600	0	0	1.6
	Misc.	100	1	1	100	1	100	0.2
	Total							10.42
Mosque	Electric bulbs	15	10	8	1200	8	1200	2.4
	Ceiling fans	40	8	8	2560	0	0	2.56
	Water pump	100	1	1	100	1	100	0.2
	Misc.	100	1	1	100	1	100	0.2
	Total							5.36
School	Electric Bulbs	15	10	8	1200	8	1200	2.4
	Ceiling fans	40	10	8	3200	0	0	3.2
	Water pump	100	1	2	200	1	100	0.3
	Freezer	200	1	8	1600	0	0	1.6
	Computers	150	1	8	1200	8	1200	2.4
	Misc.	100	1	3	300	3	300	0.6
	Total							10.5
Commercial	Electric bulbs	15	10	8	1200	8	1200	
	Ceiling fans	40	10	8	3200	0	0	
	Freezer	200	4	10	8000	4		
	Misc.	300	4	8	9600	8		
	Gross total							956.88

7. Acknowledgement

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8. Declaration of 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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