Future Cities and Environment

TECHNICAL ARTICLE

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Comparison of Energy Production Between Fixed-Mount and Tracking Systems of Solar PV Systems in Jakarta, Indonesia

ELIESER TARIGAN

ABSTRACT

Most of the electrical energy demand is consumed by urban activities. One of the renewable sources that can be used by urban communities is solar energy through photovoltaic (PV) systems. The amount of energy produced by a PV system is directly affected by the level of irradiation received by PV modules. Conventional PV systems are commonly installed with a fixed-mount system where the angle of incidence of radiation on solar modules changes over time. Solar irradiation would be optimum received by solar modules if the angle of incidence is kept at zero degrees, i.e., radiation is perpendicular to the surface of the modules. This condition can be achieved by employing a solar tracker system for solar modules. This paper studies the comparison of the energy output of PV systems between fixed-mount and without solar tracking in the urban area of Jakarta, Indonesia. The studies are carried out using Photovoltaic Geographical Information System (PVGIS) online simulation tools. The objective of the study is to compare and figure out the specific energy output between the optimized fixed-mount installation (without a tracking system) with solar tracking. In general, the results showed that the specific energy output PV system of a fixed-mount PV system in Jakarta is about 1379 kWh/kWp per year, while for the system with a solar tracking system, the specific energy production is about 1672 kWh/kWp. The information found is expected to be a useful reference for the development and promotion of solar energy, particularly in Indonesia.

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INTRODUCTION

The fossil-based energy, which is the main source of energy world until today, has been known as one of the most impacts of GHG (greenhouse gas emissions) related to the global warming effect (Al-Ghussain, 2019). Meanwhile, fossil-based energy resources, i.e., oil, gas, and coal, are depleted and limited (Al-Ghussain, 2019; Hansen, Breyer, and Lund, 2019; REN21 Members, 2020). For the long run and energy sustainability, we need to find alternative energy sources that are clean and renewable. Electricity from solar energy using PV (photovoltaic) technology is considered one alternative option. Solar energy has a huge potential in the form of light or radiation. Technologically, it can be converted into electricity using solar cells or PV systems.

In Indonesia, solar electricity is expected to supply power of about 6.5 GW by 2025. This target is a part of 45 GW of total renewable energy power produced in the same year (Aprilia, 2017; Maulidia *et al*., 2019; Hidayatno *et al*., 2020). The target is officially stated in the General National Energy Plan (Rencana Umum Energy Nasional, RUEN) published through the Ministry of Energy and Mineral Resources (MEMR). It is also stated in the RUEN that the energy demand in Indonesia will be fulfilled with a renewable energy mix of 23% by 2025 (Tampubolon, 2020).

The amount of PV system energy output is affected mainly by two factors, i.e., internal and external factors. The internal factors include efficiency and material properties, while external factors are related to the operational conditions of the PV panels. For the external factors, one of the most important one is the amount of solar energy or irradiance received by PV panels. Theoretically, solar irradiance consists of three components: direct, diffuse, and reflected components. The sum of the three irradiation components is called global irradiation (Duffie and Beckman, 2013).

The amount of direct component irradiation that falls into a solar panel depends on the angle of incidence. As the Sun moves regularly and continuously, the angle of incidence for a fixed surface change over time throughout the day. Mathematically the angle of incidence is expressed as (Beckman and A., 2013):

$$\cos\theta = (\sin\delta\sin\phi\cos\beta - \sin\delta\cos\phi\sin\beta)\cos\gamma + (\cos\delta\cos\phi\cos\beta + \cos\delta\sin\phi\sin\beta\cos\gamma)\cos\omega + (\cos\delta\sin\beta\sin\gamma)\sin\omega \quad (1)$$

where θ = angle of incidence
δ = declination
ϕ = latitude
β = tilt
γ = azimuth angle
ω = hour angle

The amount of solar irradiation received by solar modules will be maximum when the modules are exposed and perpendicularly to the radiation. In terms of the angle of incidence, θ should be 0°. As the position of the sun changes over time, the angle of incidence would change as well. To keep the angle of incidence at 0°, a solar tracker system is required. The solar tracking system, however, would require additional types of equipment, which affects the cost of the PV system. It is important and interesting to figure out the comparison energy output of the PV system between conventionally fixed-mount (without solar tracking) and with a solar tracking system in a particular area.

The potential of solar energy is different for the different sites around the earth's surface. It is necessary to identify and assess the solar irradiation potential at a particular place before building the real installation. Simulation is commonly done for assessment studies. There were a lot of solar assessment studies and simulations in many different places found in the literature (Marcel S. & Tomáš C., 2012; Singh and Banerjee, 2015; Merrouni *et al*., 2016; Shukla, Sudhakar and Baredar, 2016; Dondariya *et al*., 2018; Anang *et al*., 2021). However, fewer studies had been reported on the Indonesian case, especially in urban areas (Tarigan, Djuwari, and Kartikasari, 2015; Tarigan, 2018).

The Jakarta Capital City Government is pushing for the use of renewable energy to reduce GHG emissions by 30% by 2030. This can be done by building solar power plants. In 2030, Jakarta is estimated to produce 116,910,000 tonnes of CO_2. The Jakarta Capital City Government, in accordance with The Paris Agreement, is aiming to reduce this enormous emission by 30%. This amount of CO_2 would be equivalent to 43,663,400 MWh in 2030. The government is accelerating green transformation in the city to achieve this goal. One is the acceleration of the implementation of the Regional Climate-Resilient Low Carbon Development Plan.

This work simulates PV systems with and without solar tracking in Jakarta, the largest and most populated city in Indonesia. The simulation studies the comparison of energy output between two systems. The works are conducted using Photovoltaic Geographical Information System (PVGIS) simulation tools(re.jrc.ec.europa.eu, 2022). The aim of the study is to figure out the specific energy output of fixed-mounted and solar-tracking PV Systems in Jakarta. The difference in specific energy between the two systems is compared. The results of the study are expected to be a useful reference for the development, application, and promotion of solar PV systems in Indonesia.

METHODS

The energy output of PV systems in this work was obtained from simulation works. The simulations were conducted using Photovoltaic Geographical Information System (PVGIS) simulation tools (re.jrc.ec.europa.eu, 2022). The software is free online, and it can be used as a tool to estimate the solar electricity production of a photovoltaic (PV) system. It gives the annual output power of solar photovoltaic panels. As a photovoltaic Geographical Information System, it proposes a google maps application that makes it easy to use. The simulated area in this work was Jakarta, Indonesia. The detail of the geographical data of the location is presented in Table 1.

The PV system simulated is 1000 Wp capacity, with an on-grid connection system. This is to obtain the specific energy output of a simulated PV system. The other input parameters for simulations are shown in Table 1. Two different main mountings of PV systems installation were simulated, i.e., (1) fixed-mount or without a tracking system and, (2) a solar tracking system with a two-axis tracking system. The first installation is fixed–mounted with the optimum tilt of 12° from the horizontal, with a panel azimuth of 0° or facing North. The two different mounting systems are schematically shown in Figure 1.

The PV system-specific energy output is the amount of electricity output in comparison with the input solar irradiation under standard test operating conditions. The value is determined by comparing the energy output *Eout*, (in kWh) with the maximum power capacity, *Pmax* (kWp), under standard test conditions. Hence, the unit of the specific energy output is kWh/kWp. It can be mathematically defined as:

$$Specific\ Energy\ Output = \frac{Eout,AC}{Pmax,STC} \quad (2)$$

The photovoltaic simulation model can be arranged into three steps as Figure 2. These are for the photovoltaic system of the plant dataset. The first is the calculation of the output power of the solar panels using the PVGIS sunlight-to-power algorithms. The second step is to calculate the electricity generated by each photovoltaic panel, taking into account the date of (de)commissioning. The resulting time series for the ensemble is then converted into local time and spatially aggregated and stored in CSV format (Lehneis *et al*., 2022).

PARAMETERS	INPUT
Location [Lat/Lon]	–6.162,106.744
Horizon	Calculated
Database used	PVGIS-SARAH
PV technology	Crystalline silicon
PV installed	1 kWp
System loss	14%
Time zone	UTC+07
Terrain Elevation	3 m
Inverter type	String inverter

Table 1 Input parameters for simulation.

RESULTS AND DISCUSSIONS

POTENTIAL SOLAR ENERGY

The information on the availability and the potential of solar energy is required to assess PV potential at the particular site. The information includes solar irradiation, sun path, components of radiation, day length, and

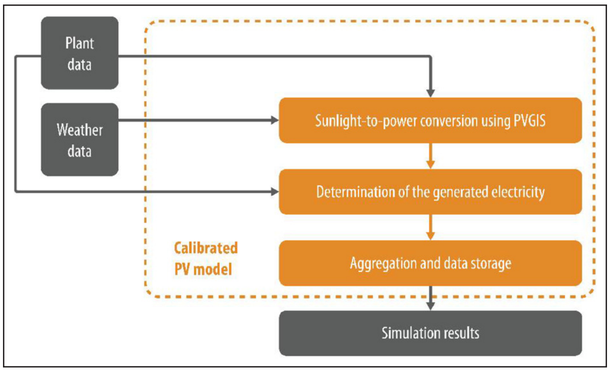

Figure 2 The photovoltaic simulation model (Lehneis *et al*., 2022).

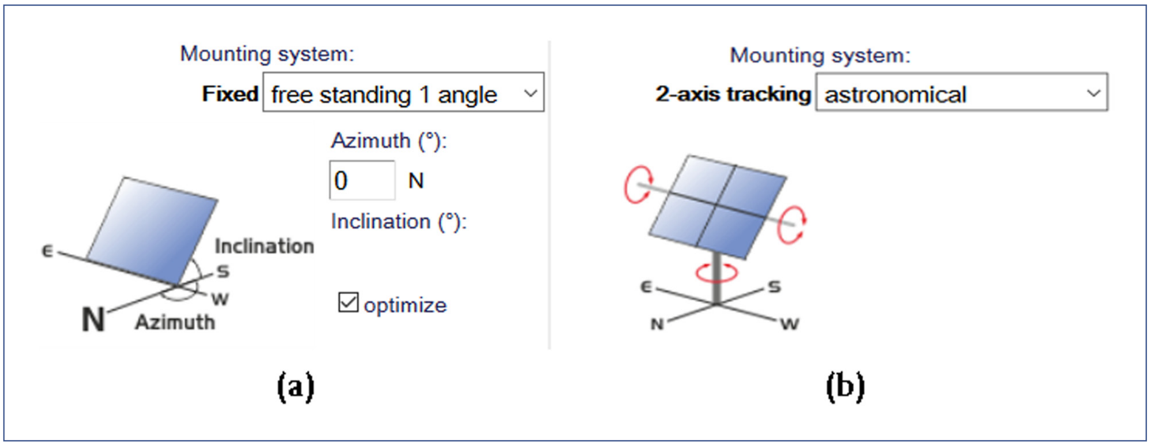

Figure 1 Schematic diagram of PV mounting: **(a)** fixed-mount; **(b)** 2-axis tracking.

temperature. Sun path diagrams can provide information about how the sun will impact a site and building throughout the year. It is very useful in determining the period of the year and hours of the day when shading will take place at a particular location. The annual Sun path in Jakarta is shown in Figure 3. The Sun path diagram also shows the corresponding solar elevation, civil time, and solar time, as well as the active area with solar and civil time, terrain horizon, and module horizon over a year. The higher terrain horizon of an object will make a shorter period of the Sun above the horizon than the astronomical day length. The variation of day length and solar zenith angle in Jakarta are shown in Figure 4.

The estimated solar irradiation in Jakarta from 2005 to 2020 is shown in Figure 5. From this figure, it can be seen that the solar irradiation in Jakarta varies between 110.99 kWh/month.m^2 to 110.99 kWh/month. m^2. Maximum irradiation occurs from July to December, while minimum radiation occurs from December to March. The average monthly irradiation is about 140.0 kWh/month.m^2 means that the average daily solar irradiation in Jakarta is around 4.7 kWh/m^2. With this number, the annual potential solar energy in Jakarta is found to be 1,716 kWh/m^2. This number is quite close to other areas in Indonesia that have been previously reported (Asian Development Bank (ADB), 2016; IESR, 2018).

Global irradiation consists mainly of direct and diffuse components. For some areas with higher surface reflectance, such as snow, ice, and water, the reflected irradiance component might be significant. In Jakarta, the component of diffuse varies from 21% to 55% of the global radiation. On average diffuse radiation is about 0.45% of the global radiation. This number is relatively high in comparison to some areas with clear skies. The diffuse and global irradiation ratio in Jakarta from 2005 to 2020 is shown in Figure 6. (The figure in this section were generated directly from the simulation software). The daily ambient temperature in Jakarta is found from $23^{o}C$ to $31^{o}C$.

PV SYSTEM-SPECIFIC ENERGY OUTPUT

The monthly specific energy output of the PV system with optimized-fixed mounted varies from 95.83 kWh/kWp to 137.53 kWh/kWp. The highest electricity energy is generated during the month of September, and the lowest is during February. The monthly specific energy output over a year is shown in Figure 7. In total, the annual specific energy output is found to be about 1,379.05 kWh/kWp.

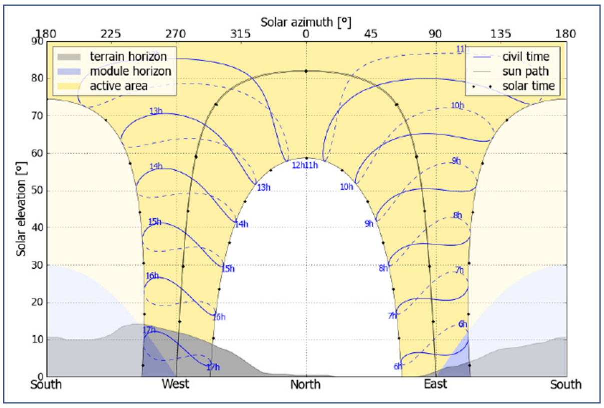

Figure 3 Sun path in Jakarta.

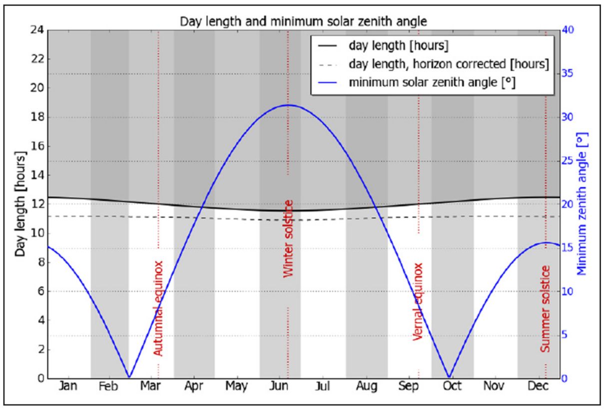

Figure 4 Day length and minimum solar zenith angle.

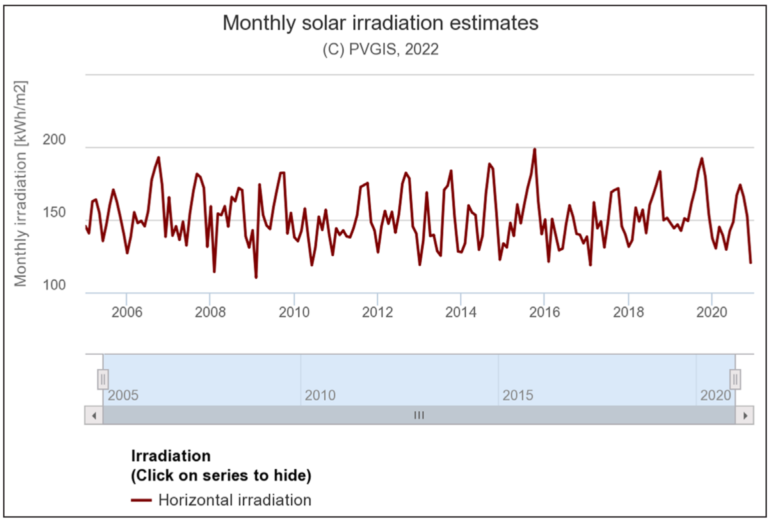

Figure 5 Monthly solar irradiation in Jakarta.

Figure 8 shows simulation-specific energy output results of the PV system with solar tracking each for the vertical axis, inclined axis, and two-axis, respectively. It is obviously seen that of the three systems, the two-axis system generates the highest energy; however, the difference is relatively small. For all systems, the highest energy is generated in August, and the lowest is in February. For a two-axis system, the monthly specific energy output varies from 110.9 kWh/kWp to 171.4 kWh/kWp, with an annual specific energy output of 1,672.0 kWh/kWp.

A comparison of energy output between fixed-mounted and tracking (two-axis) PV systems over a year is shown in Figure 7 and Figure 8. It is shown that solar tracking PV system generates higher energy than fixed-mounted ones throughout the year.

The difference in specific energy output between fixed-mounted and tracking PV systems over a year ranges from 15%–29%, with an average of 21%, whereas the system with solar tracking always produces higher energy. Figure 9 presents the comparison of energy output in

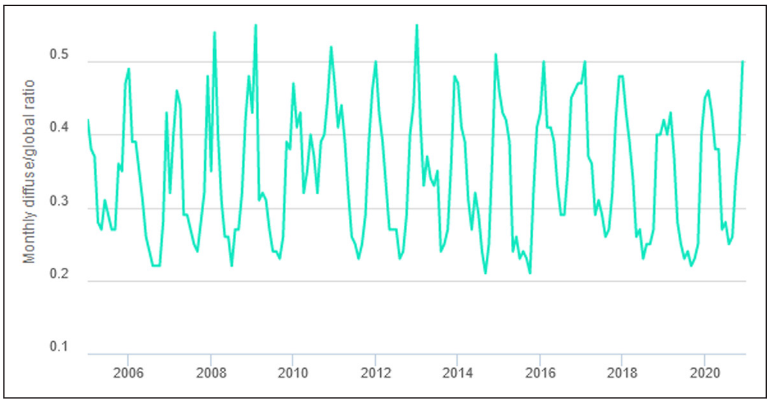

Figure 6 Diffuse and global irradiation ratio in Jakarta.

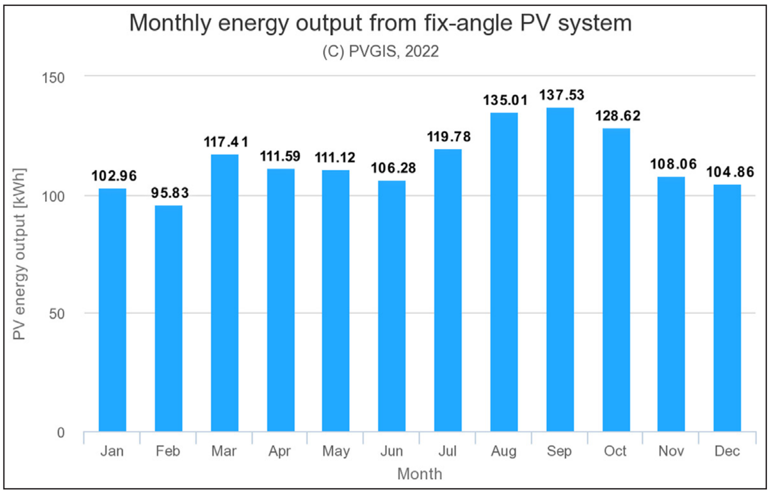

Figure 7 The monthly specific energy output of the PV system with optimized-fixed mounted.

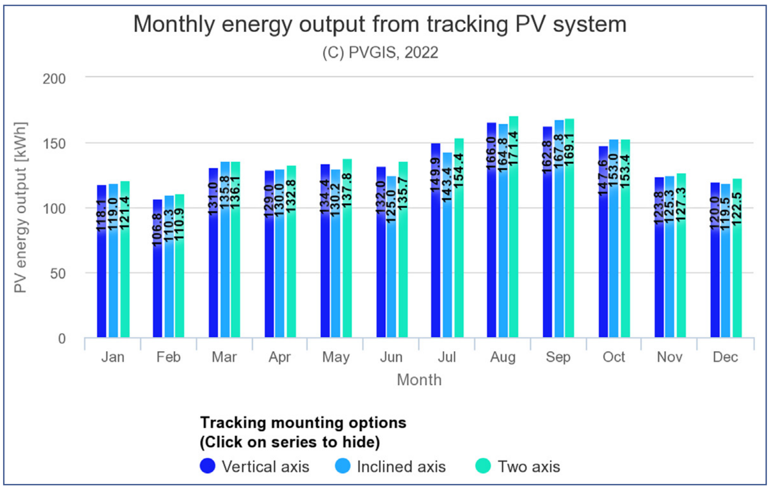

Figure 8 The monthly specific energy output of the PV system with a solar tracking system.

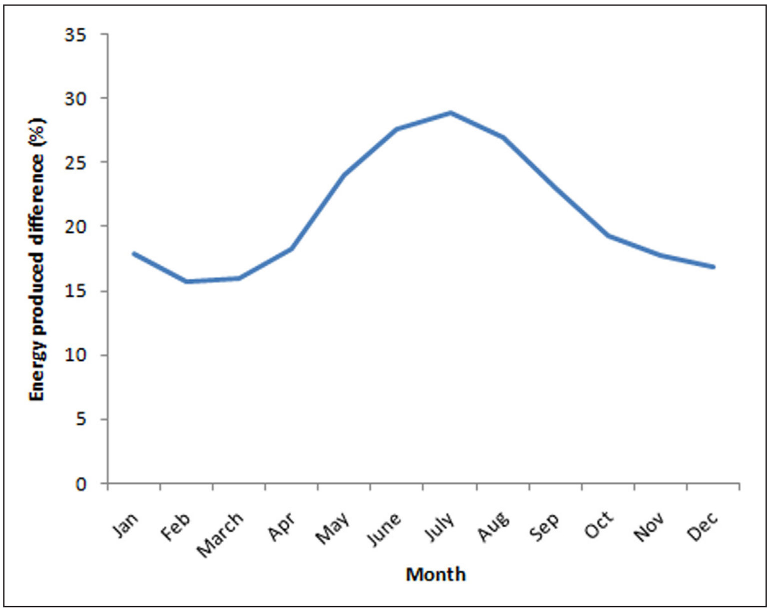

Figure 9 The difference in energy in percentage.

MOUNTING	ANNUAL ENERGY [kWh/m²]	RELATIVE TO FIXED-OPTIMIZED [%]
Fixed-horizontal	1340.0	97
Fixed-optimized	1379.1	100
Vertical axis	1621.4	117
Inclined axis	1615.1	117
Two axis	1672.0	121

Table 2 Annual energy production by the different mounting of PV systems.

terms of monthly percentage. The total annual specific energy output for five different conditions of installation is presented in Table 2. It is obviously seen that applying a solar tracking system for PV systems in the Jakarta area will generate electricity about 21% higher than with the conventional fixed-mounted system.

SOLAR TRACKING CONSIDERATIONS

Solar tracker's advantages:

- Because they are able to track the sun's movements, tracking systems can produce more energy than the fixed-mounted solar system.
- There are many trackers from different manufacturers available
- The use of solar trackers would be advantageous in areas where Time-of-Use electricity rates are high. The users do not need to pay more for grid energy during peak hours.

Solar trackers limitations

- The cost of a photovoltaic installation can be greatly increased by using solar trackers. A typical 4-kilowatt ground-mounted solar system costs about $13,000. Tracking equipment costs anywhere from $500 per panel up to more than $1,000 per panel (Solarreviews.com, 2022).
- Because solar trackers are composed of moving parts, they are more susceptible to breaking. This means higher maintenance costs.
- Tracker installation may require extra planning and preparation, including digging additional trenches for wiring and additional grading.

Solar trackers, particularly for residential solar systems might not be worth the extra investment in almost all cases. Solar trackers aren't used widely in the residential solar industry. When there is not enough space to install solar trackers, they can be very useful. Installing a solar tracker system might generate more power in a smaller area than installing additional solar panels. Solar trackers can also be useful for large-scale commercial or utility installations.

CONCLUSIONS

Simulations study and comparison of PV system energy output between fixed-mount and solar tracking system PV systems in Jakarta, Indonesia, have been conducted. The results of the study showed that the difference in specific energy output between the two systems ranges from 15%–29%, where the PV system with solar tracking always generates more energy than the fixed mount over the year. Annual specific energy with fixed mount installation is about 1379 kWh/kWp, while the system with a two-axis tracking system is about 1672 kWh/kWp. That means energy output by using solar tracking for PV systems in Jakarta would produce energy about 21% higher than with the conventional fixed-mount system. Solar trackers, particularly for residential solar systems might not be worth the extra investment in almost all cases. When there is not enough space to install solar trackers, they can be very useful.

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COMPETING INTERESTS

The author has no competing interests to declare.

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