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Comparative Performance Evaluation for Jebba, Kainji and Shiroro Hydro Power Schemes

Maruf A. Aminu[1*] and Garba U. Kangiwa[1]

[1]*Department of Electrical Engineering, Waziri Umaru Federal Polytechnic, Birnin Kebbi, Kebbi State, Nigeria.*

Authors' contributions

This work was carried out in collaboration between both authors. Author MAA designed the study, performed the statistical analysis and wrote the first draft of the manuscript. Author GUK managed the analyses of the study and reorganized the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

This paper evaluates performance indices based on industry-wide practice and suggests possible approach for improving the operational efficiencies of Jebba, Kainji and Shiroro hydro power generating stations. To actualize that, data including average daily gross operating head, daily flow rate and daily energy generated were obtained from Jebba, Kainji and Shiroro power stations and the National Control Center (N.C.C.) Osogbo. From the energy (MWh) generated the average daily power generated (MW) was computed. Consequently, the average operational efficiencies of Jebba, Kainji and Shiroro hydro schemes were evaluated and found to be 89.43%, 88.45% and 94.03% respectively. Similarly, performance indicators including deemed generation, auxiliary energy consumption, availability factor, capacity index, workforce deployment, forced outage factor and scheduled outage factor were evaluated and technical inferences made. The study was limited to the year 2010 due to non-availability of data for other years.

Keywords: Daily gross operating head; daily flow rate; auxiliary energy consumption; workforce deployment.

**Corresponding author: Email: maruf.aminu@gmail.com;*

1. INTRODUCTION

Efficiency is a measure of how much power a system (machine) delivers for a given input power. This means a more efficient machine delivers more power for a given input power when compared with an equivalent machine with less efficiency. Therefore, if a hydro scheme generates an average of 450 MW at 85.00% efficiency under certain operating conditions and the operating conditions are altered such that its efficiency now rises to 95.00%, then, for the same volume of water (stored potential energy) the hydro station will deliver 534.375 MW, representing an increase of 84.375 MW. If this hydro station were Jebba (or Kainji or Shiroro), the Nigerian power grid will have additional 84.375 MW, sufficient to meet the power need of the whole of Birnin Kebbi metropolis without load shedding [1]. Consequently, evaluation of the operational efficiencies and other industry-wide performance indicators of hydro power stations such as deemed generation, auxiliary energy consumption, availability factor, capacity index, workforce deployment, forced outage factor, and scheduled outage factor for Jebba, Kainji and Shiroro forms one of the first steps of an attempt to improve on their operational efficiencies. In addition, these performance indices form one of the critical factors valuable in costing the plants for prospective investors, especially in the current dispensation where attempts are being made by relevant stakeholders to liberalize the Nigerian power sector.

Table 1 provides a summary of the annual average generation for the three hydro stations in year 2010.

1.1 Background Concepts of Performance Indices for Hydro Schemes

Table 2 highlights the performance indices (or benchmarks) employed in the analyses of this article. These benchmarks are valuable as they mirror those used by hydroelectric utilities for performance analyses and are recognized as meaningful industry-wide hydro-power performance [2].

The operational efficiency η of a hydro scheme can be evaluated from hydrological data using eqn. 1.0 [3].

$$\eta = \frac{P}{gwQh} \tag{1.0}$$

Where,

P = power generated in watts.
g = acceleration due to gravity (9.81 ms^{-2}).
w = specific weight of water (1000 kgm^{-3}).
Q = flow rate in m^3s^{-1}.
h = gross operating head in metres.

The power losses which occur in each unit can be evaluated from the efficiency as given in eqn. 2.0 [3].

$$Power\ losses = Output\ \ power\, x \frac{(1-\eta)}{\eta} \tag{2.0}$$

1.2 Performance Indices of Jebba Hydro Scheme in Year 2010

The daily operational efficiency and power losses of Jebba power plant for year 2010 were evaluated using eqns. 1.0 and 2.0 respectively. The average efficiency was found to be 89.43%. The efficiency curve in terms of operational efficiency in per cent as a function of power generated was plotted as shown in Fig. 1(a). Fig. 1(b) shows the losses curve for the station. Table 3 gives a summary of relevant performance indices for the three stations in the year under study.

1.3 Performance Indices of Kainji Hydro Scheme in Year 2010

The daily operational efficiency and power losses of Kainji power plant for year 2010 were evaluated using eqns. 1.0 and 2.0 respectively. The average efficiency was found to be 88.45%. The efficiency curve in terms of operational efficiency in per cent as a function of power generated was plotted as shown in Fig. 2(a). Fig. 2(b) shows the losses curve for the station.

Table 1. Summary of MW capacities of hydro stations in Nigeria as operated in year 2010

	Jebba	Kainji	Shiroro
Annual average generation (MW)	307.40	263.62	277.43
Installed capacity (MW)	578.40	760.00	600.00
No. of units commissioned	6.00	8.00	4.00

Table 2. Performance indices for hydro scheme evaluation

S/no.	Benchmark	Definition of benchmark
1.	Operational Efficiency	This is the overall efficiency of the plant. It is given in per cent as: $\eta = penstock\ \ efficiency x turbine\ \ efficiency x alternator\ \ efficiency x 100$
2.	Deemed Generation	This is the energy which a hydro power generating station was capable of generating but could not generate due to reasons beyond the control of the generating station.
3.	Auxiliary Energy Consumption	This is, in relation to a period, the quantum of energy consumed by auxiliary equipment of the generating station and transformer losses within the generating station, and shall be expressed as a percentage of the sum of gross energy generated at the generator terminals of all the units of the generating station.
4.	Availability Factor	This benchmark illustrates the percentage of time, for a given period, the plant was available to generate power and shall be expressed in percentage of total hours in the given period.
5.	Daily Capacity Index (or Capacity Index)	This means the declared capacity expressed as a percentage of the maximum available capacity for the day and shall be calculated in accordance with the following formula: $Daily\ Capacity\ Index = \frac{Declared\ Capacity(MW)x100}{Maximum\ Available\ Capacity(MW)}$ % The term "Capacity Index" for any period shall be the average of the daily capacity indices calculated as above, for such period.
6.	Workforce deployment	This benchmark tracks the full-time equivalent (FTE) staffing levels. These staffing levels are further broken down by FTEs per generating unit and FTEs per megawatt.
7.	Forced Outage Factor	This benchmark illustrates the percentage of time a unit was out of service for unanticipated repairs, system collapse, etc.
8.	Scheduled Outage Factor	This benchmark illustrates the percentage of time the unit was scheduled for outage due to maintenance.

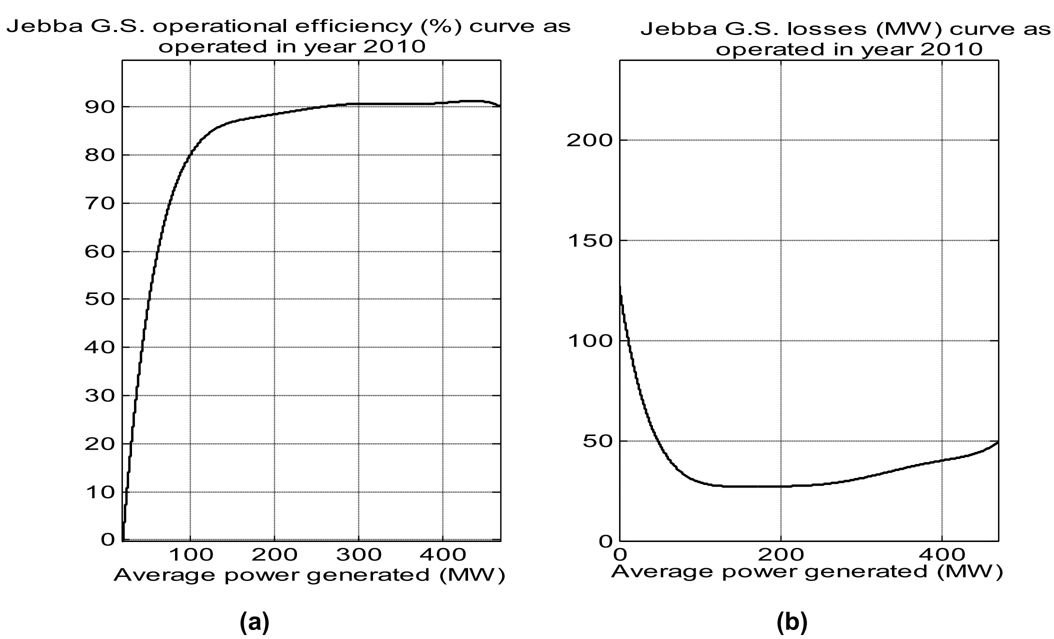
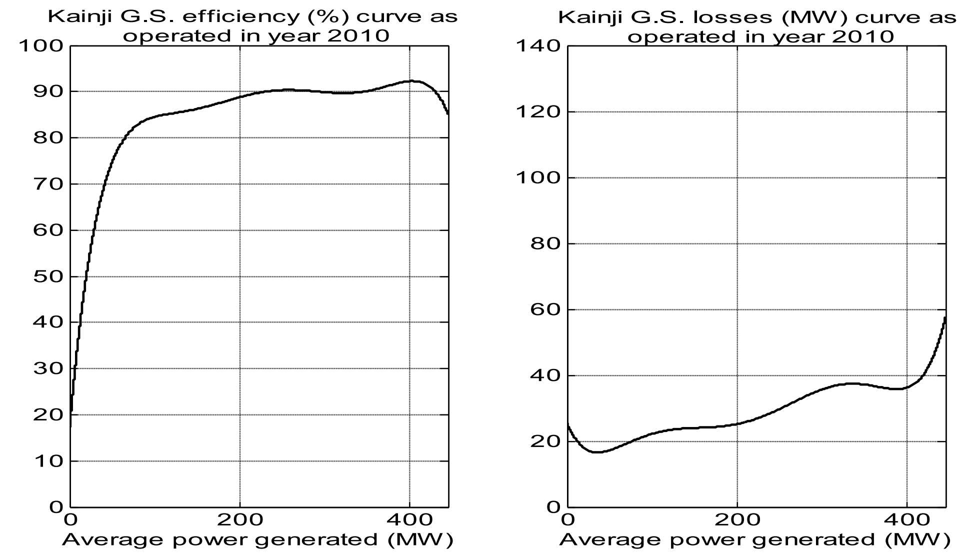


Fig. 1. Efficiency (%) and losses (MW) curves of Jebba hydro scheme for year 2010
Source: Data from National Control Centre, Osogbo

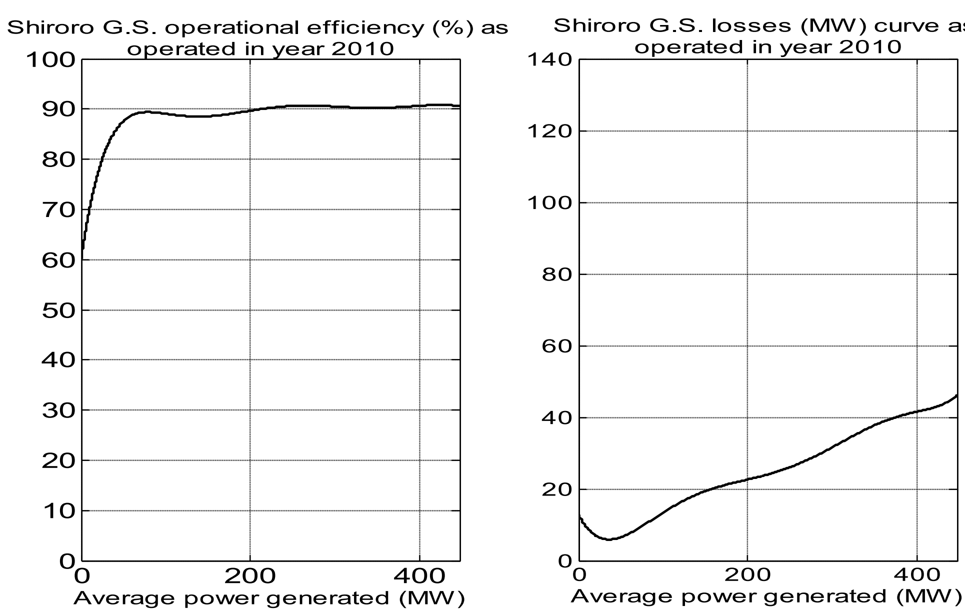


(a) (b)

Fig. 2. Efficiency (%) and losses (MW) curves of Kainji hydro scheme for year 2010
Source: Data from National Control Centre, Osogbo

1.4 Performance Indices of Shiroro Hydro Scheme in Year 2010

The daily operational efficiency and power losses of Shiroro power plant for year 2010 were evaluated using eqns. 1.0 and 2.0 respectively. The average efficiency was found to be 94.03%. The efficiency curve in terms of operational efficiency in per cent as a function of power generated was plotted as shown in Fig. 3(a). Fig. 3(b) shows the losses curve for the station.



(a) (b)

Fig. 3. Efficiency (%) and losses (MW) curves of Shiroro hydro scheme for year 2010
Source: Data from National Control Centre, Osogbo [3]

Table 3. Summary of computed performance indices of Jebba, Kainji and Shiroro G.S. for year 2010

S/no.	Performance index	Power stations		
		Jebba	Kainji	Shiroro
1.	Operational Efficiency (%)	89.43	88.45	94.03
2.	Deemed Generation in MW(annual average)	270.60	496.38	322.57
3.	Auxiliary Energy Consumption (%)	0.16	-	0.61
4.	Per cent availability (%)	53.18	34.69	46.24
5.	Annual capacity index (%)	79.00	78.30	76.00
6.	Workforce deployment (FTEs per generating unit)	72.67	50.63	112.5
7.	Workforce deployment (FTEs per megawatt)	1.42	1.54	1.62
8.	Forced Outage Factor (%)	0.04	14.30	31.91
9.	Scheduled Outage Factor (%)	0.34	1.92	13.24

2. METHODS OF IMPROVING HYDRO POWER STATION OPERATIONAL EFFICIENCY

In order to maintain optimum efficiency continuously, plant performance characteristics must be monitored and stored, at least occasionally and at best continuously. This performance information includes water levels, power generation and inlet/outlet canal characteristics all as a function of the discharge from individual turbines. Having this data available in a database enables an accurate model of the system to be kept current. From this model operational decisions can be made for the best performance under constantly changing conditions of load, head, unit availability, and other important constraints. Some of the popular schemes of improving on the overall efficiency of hydro schemes include the Gibson method, Current meters, Allen Salt velocity, Dye – dilution, Winter – Kennedy taps and the high accuracy multipath chordal acoustic flowmeters [4].

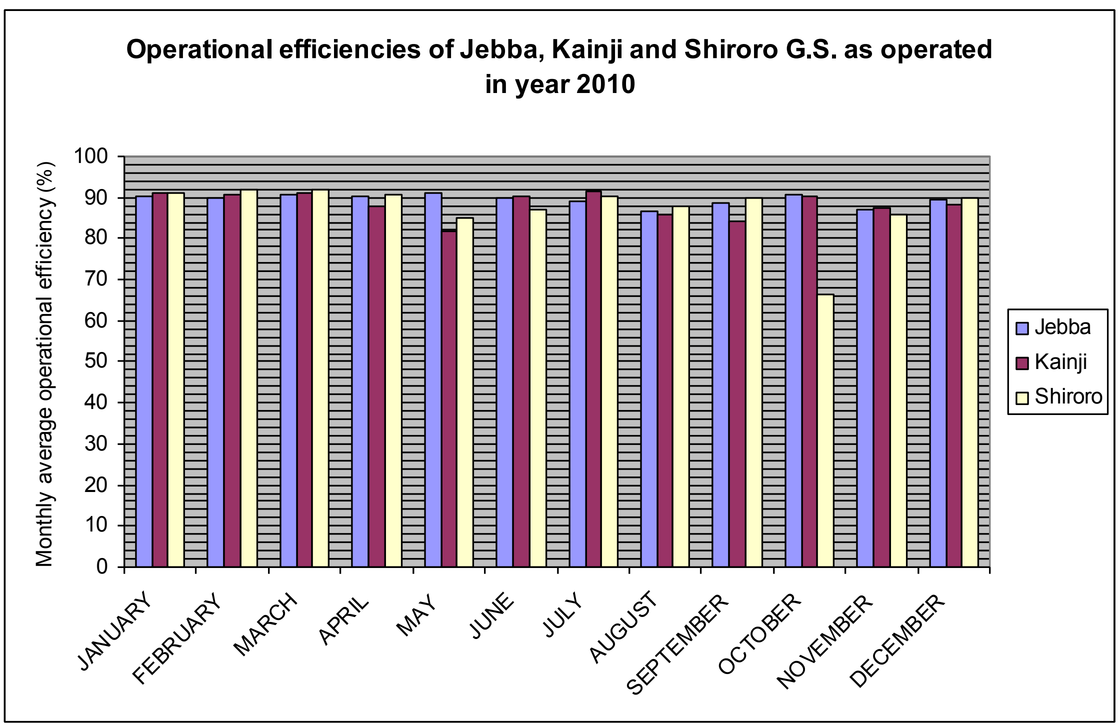


Fig. 4. Operational efficiencies of Jebba, Kainji and Shiroro G.S. as operated in year 2010

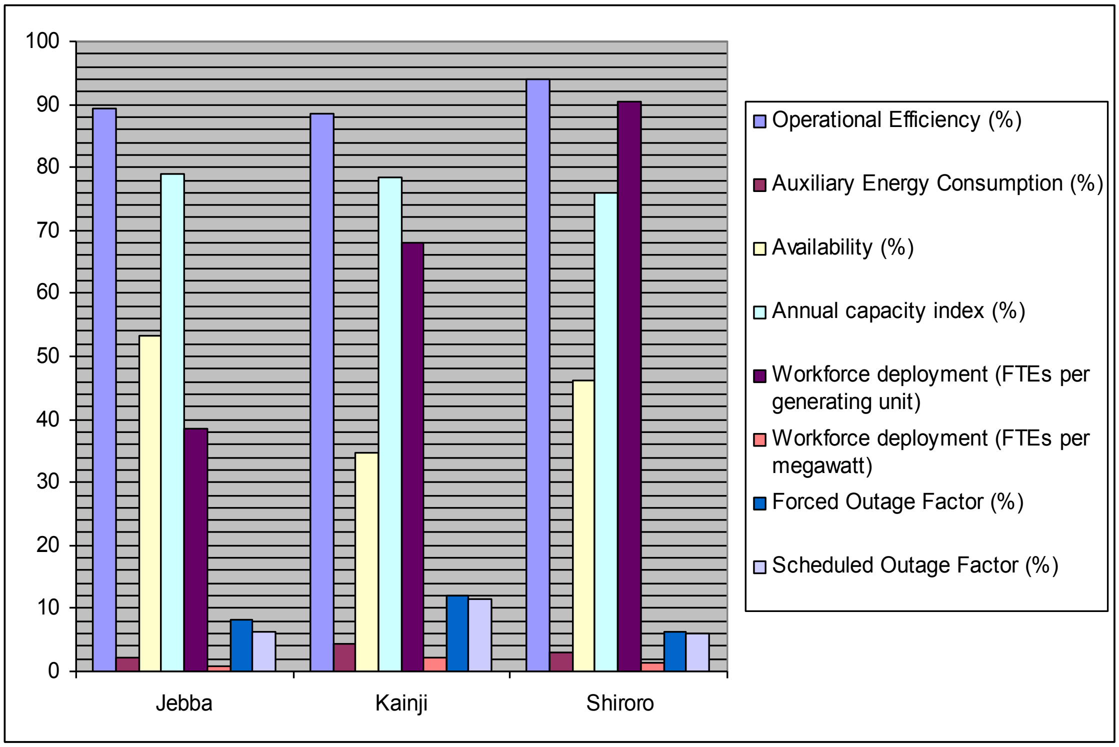


Fig. 5. Performance indices of Jebba, Kainji and Shiroro hydro schemes as operated in year 2010

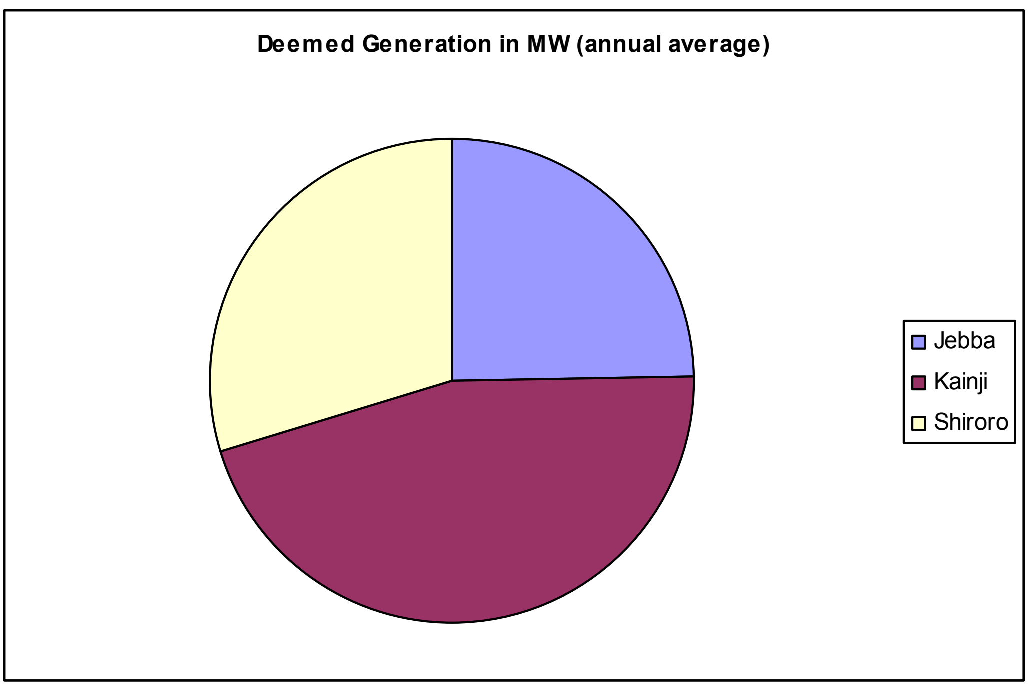


Fig. 6. Deemed generation in MW as operated in year 2010

3. CONCLUSION

Fig. 4 presents average monthly efficiencies of the three stations in year 2010. All stations recorded efficiencies between 80% to 90%, except in the month of October where Shiroro G.S recorded lower efficiency. From Fig. 5 it could be observed that amongst the three hydro generating stations in Nigeria, Jebba generating station had the highest availability of 53.18%. Shiroro had availability of 46.24%, while Kainji had the lowest availability of 34.69%. Observe that the capacity index of Jebba was the highest (79.00%) while Shiroro had the lowest capacity index (76.00%). In Fig. 6 observe that the average annual deemed generation (synonymous with deficit or shortfall in generation) of Kainji is highest. Kainji generating station had a deemed generation of 496.38MW. This is considered very high, for a station whose installed capacity is 760 MW [6]. The deemed generation of Jebba was 270.60 MW while that of Shiroro was 322.57 MW, both of which indicate poor generation for stations with installed capacities of 578 MW [7] and 600 MW [8] respectively. Observe that the “Workforce deployment” (FTEs per generating unit) of Jebba was 72.67, while that of Shiroro was 112.5 (more than double that of Kainji). This indicates poor staff deployment in Shiroro, literally speaking; it could be fair to conclude that Shiroro is comparatively overstaffed. This is corroborated by the “Workforce deployment” (FTEs per megawatt) of Shiroro which had the highest value of 1.62. The Forced outage factor of Kainji was evaluated at 14.30. This is considered higher than acceptable. The very high outage factors of Shiroro are notably due to the fact that unit 411G2 was forced out of service throughout year 2010. On a good note, the operational efficiencies of Jebba, Kainji and Shiroro were valued at 89.43%, 88.45% and 94.03% respectively. Consequently, the operational efficiencies of these hydro power stations are, by industry standards, considered to be fairly moderate, leaving measurable allowance for improvement.

4. RECOMMENDATIONS

Consequent upon evaluation of the performance indices of these hydro generating stations in this paper, the following are strongly recommended:

(i) Incorporation of the acoustic flowmeter which is a microprocessor-based control system designed for improving the efficiency of hydro schemes with additional capabilities such as self-check, providing for internal diagnostics to ensure rapid repair in the event of failure. In some cases, these meters are built with redundant features to further increase reliability and consequently availability.

(ii) Scheduling the units at the hydro stations using economic load dispatch optimization. This ensures that the units generate maximum power using minimum inputs with least adverse impact on the environment [9] and minimize the cost of generating energy per KWh.

DISCLAIMER

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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