Impact of a Portable Energy Efficiency Intelligence Power Socket (PEEiPS) for IoT Deployment

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Abstract
In the rapidly evolving domain of smart technology and Internet of Things (IoT) integration, the imperative for portable and energy-efficient solutions has become increasingly critical. The Portable Energy Efficiency Intelligence Power Socket (PEEiPS) represents a groundbreaking innovation in addressing the pervasive issue of energy wastage resulting from human forgetfulness in turning off electrical appliances. By integrating the ESP8266 microcontroller with IoT capabilities and solar energy, PEEiPS offers a robust solution to combat energy wastage caused by the common problem of leaving electrical appliances on unnecessarily. The automated switching feature, driven by the HC-SR04 ultrasonic sensor can be set to ensure devices are active only when needed, effectively addressing energy inefficiencies. PEEiPS's reliance on solar power enhances its sustainability, offering an environmentally friendly alternative to traditional energy management systems. The results demonstrate that PEEiPS can achieve significant energy savings, reducing total energy consumption from 12,000 kWh per year to 11,654 kWh per year. This represents a 3.63% saving for devices with a 600W usage and a substantial 36.3% saving for devices with a 6000W usage. The mobile application facilitates convenient remote control and monitoring, fostering user engagement and improving energy management practices. PEEiPS presents a promising avenue for enhancing energy efficiency and promoting sustainable energy practices, ultimately mitigating environmental impact and reducing electricity costs in residential and commercial settings. The implications of these findings are significant, suggesting that PEEiPS has the potential to revolutionise energy management practices in IoT deployments. Moving forward, further research and development efforts could focus on refining PEEiPS's functionalities, scalability, and interoperability to maximize its commercial potential and applicability across various industries. Additionally, initiatives to raise awareness and promote the adoption of PEEiPS could be instrumental in driving widespread adoption and realizing its full impact on energy conservation efforts globally.

Keyword: Energy Efficiency; Internet of Things; Portable Power Socket

1.0 Introduction
Energy efficiency is an increasingly important issue as global electricity demand continues to rise, leading to greater environmental impact and higher energy costs. One significant source of energy waste is the widespread habit of leaving electrical appliances switched on when not in use, often due to user forgetfulness. This issue is prevalent in both residential and commercial settings, resulting in unnecessary energy consumption and inflated electricity bills. Traditional power sockets provide no means to automatically control or

monitor the power usage of connected devices, which limits the ability to manage electricity consumption effectively. In response to this challenge, there is a growing need for smarter solutions that can intelligently manage power usage, thereby enhancing energy efficiency (Sharmila et. al., 2020).

Previous research and developments in the field of smart power sockets, object detection for energy management, and renewable energy integration highlight the potential of such technologies to significantly reduce energy waste. However, existing solutions often rely heavily on user intervention and require constant network connectivity, which can limit their overall effectiveness (Alattar & Azeez, 2021; Al-Hassan et. al., 2018). These limitations have driven the need for a more comprehensive and autonomous approach to energy management. In this context, the Portable Energy Efficiency Intelligence Power Socket (PEEiPS) was conceptualized as an innovative solution designed to optimize energy use through automation and sustainable technology.

PEEiPS incorporates several key features, including the ESP8266 microcontroller, which enables Wi-Fi connectivity and remote device control via a smartphone application (Udeani & Eze, 2020). This allows users to manage their electrical appliances conveniently from anywhere. To enhance automation, the device integrates an ultrasonic sensor that detects motion in the room and disconnects power when no activity is observed (Karanchery & Rakesh, 2020). This prevents unnecessary power usage by automatically turning off idle devices, thus improving energy savings. Additionally, PEEiPS includes a solar panel that charges an internal battery, enabling the system to operate even in the absence of a power grid connection. This feature not only supports off-grid usage but also aligns with sustainable energy practices.

The need for intelligent energy control has been well-documented in the literature. Sharmila et. al. (2020) highlighted the inefficiencies of traditional systems and advocated for the implementation of automated control solutions. Similarly, Karanchery and Rakesh (2020) as well as Udeani and Eze (2020) emphasized the benefits of combining motion sensors with Wi-Fi-enabled control mechanisms. Al-Hassan et. al. (2018), in a comparative analysis, demonstrated that smart sockets significantly outperform conventional power outlets in terms of efficiency, responsiveness, and adaptability. However, many of these systems still depend on a stable internet connection and require frequent manual configuration, which can reduce their practicality in dynamic environments.

Further insights by Bedi et. al. (2018) underscore the advantages of smart sockets equipped with scheduling functions, allowing users to set specific times for appliances to switch on or off automatically. This functionality contributes to energy conservation by ensuring that devices operate only when needed. Nevertheless, these systems still require active user participation and a reliable network to maintain performance. Leow (2023) also noted that future smart socket systems should integrate sustainability, user-friendliness, and autonomous features to support large-scale IoT deployment. PEEiPS is developed in response to these findings by minimizing user dependence, reducing network reliance, and incorporating renewable energy for uninterrupted operation.

The objective of this project is to develop a reliable and scalable solution that addresses energy waste from unattended electrical appliances. By combining remote control, motion-based automation, and solar-powered operation, PEEiPS presents a practical and sustainable alternative to conventional smart sockets. Its portability and low energy requirements make it suitable for various applications, including homes, small offices, learning institutions, and off-grid locations. The implementation of PEEiPS not only enhances individual energy management but also supports broader efforts to reduce carbon footprints and promote responsible energy consumption.

This paper details the design, integration, and testing of PEEiPS in a real-world setting. It aims to demonstrate how the proposed system can contribute to reducing unnecessary power usage and improving the energy efficiency of IoT systems. By evaluating its technical features, performance, and user convenience, this study contributes to ongoing research into smart energy solutions and provides insights into the development of future energy-efficient technologies. This project not only enhances energy efficiency but also promotes sustainable energy practices, offering a comprehensive approach to modern energy management challenges.

2.0 Methodology

This section details the methodology used for the design and implementation of the PEEiPS using the waterfall model. The waterfall model is a linear and sequential approach often used in software development and engineering projects (Royce, 2021). It involves distinct phases, each of which must be completed before moving on to the next phase as present in Figure 1.

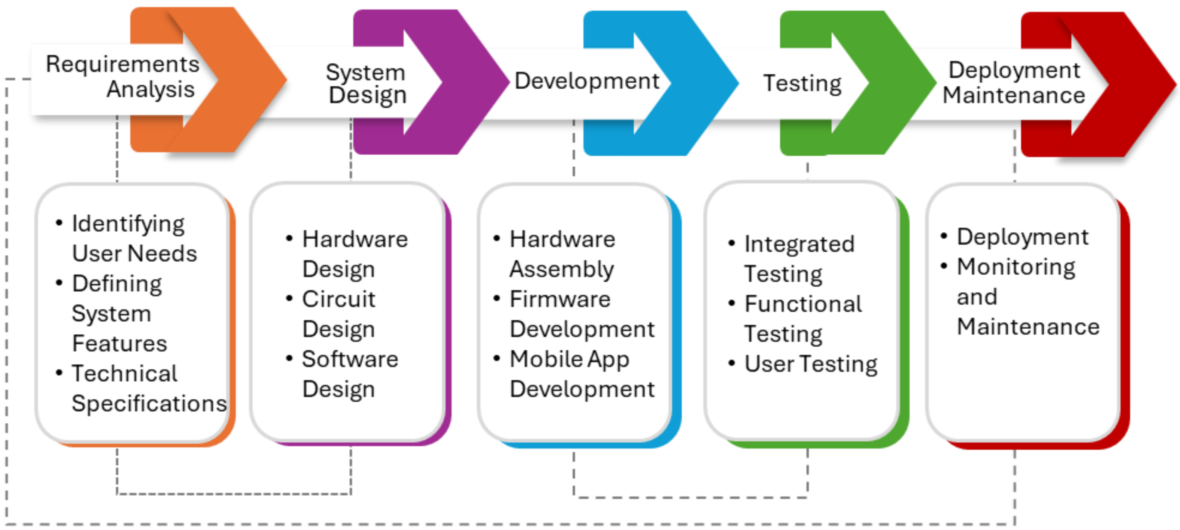

Figure 1: Methodology

2.1 Requirements Analysis

The first phase involved a comprehensive requirements analysis to understand the specific needs and functionalities required for PEEiPS. This phase identified the essential features such as remote control via a smartphone, automated switching using motion detection and the use of solar power for operation. Detailed user stories were developed to capture these requirements, ensuring that all aspects of user needs were considered.

2.2 System Design

In the system design phase, the architecture and design of both hardware and software components were developed. Table 1 present the hardware requirement of this project. The hardware design involved selecting the ESP8266 microcontroller for its efficient Wi-Fi capabilities, the relay module for controlling the power supply to electrical appliances, the ultrasonic sensor for detecting human presence and automating switching, and a solar panel with a battery system for sustainable energy operation.

Table 1: Hardware requirement of this project

No.	Hardware	Description	Quantity
1	NodeMCU	Controller with onboard ESP8266 Wi-Fi Chip	1
2	Relay Board	5V 10A 2 Channel Relay Module	1
3	Plug	13A Plug	1
4	HC-SR04 Ultrasonic Sensor	to detect the presence of objects or people near the power socket.	1
5	Solar Panel	20V, 30W Solar Panel	1

Detailed circuit diagrams were created to ensure accurate connections and efficient power management. The software design encompassed the development of firmware for the ESP8266 using the Arduino IDE, with a focus on enabling Wi-Fi communication, processing sensor data, controlling the relay, and managing power from the solar panel. Additionally, the design of a mobile application using React Native was planned to provide users with remote control capabilities, scheduling, real-time monitoring, and notifications. The PEEiPS system architecture are illustrated in Figure 2. This comprehensive design ensured that all components would work together harmoniously to create an efficient, user-friendly, and energy-saving power socket system.

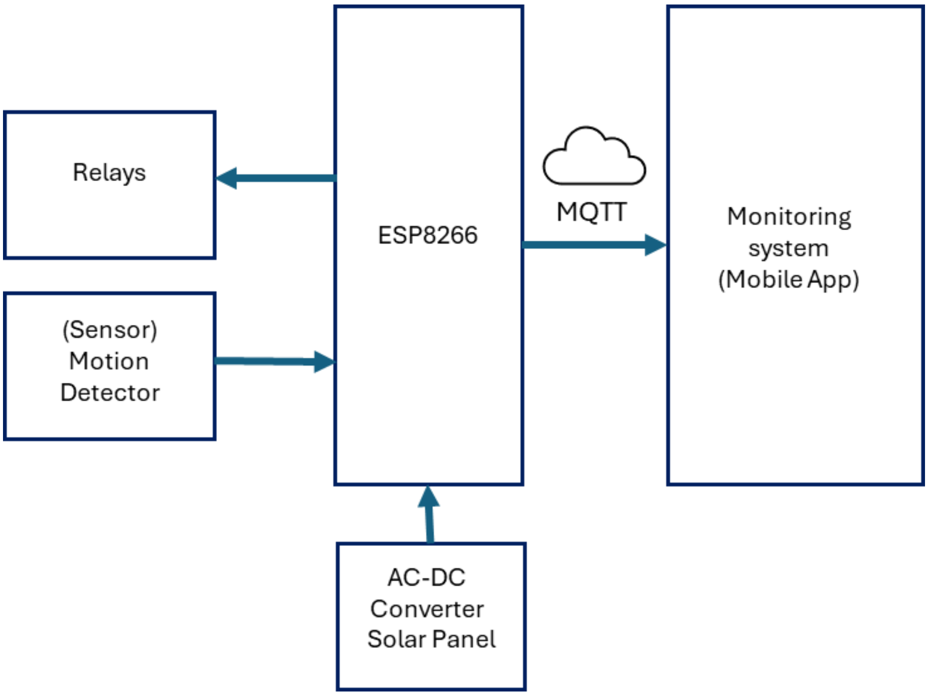

Figure 2: PEEIPS system architecture

2.3 Implementation

The implementation phase focused on the actual development and assembly of both the hardware and software components. Figure 3 shown the hardware assembly which is physically connecting the ESP8266 microcontroller, relay module, ultrasonic sensor, and solar panel based on the circuit designs. Moreover, Figure 4 presents the firmware and mobile application development that uses the Arduino IDE to develop and upload firmware to the ESP8266, incorporating functionality for Wi-Fi communication, sensor data reading, relay control, and efficient power management. Meanwhile, the developing mobile application using blynk, implementing features like remote control, scheduling, real-time monitoring, and notifications.

Figure 3: Hardware development activities

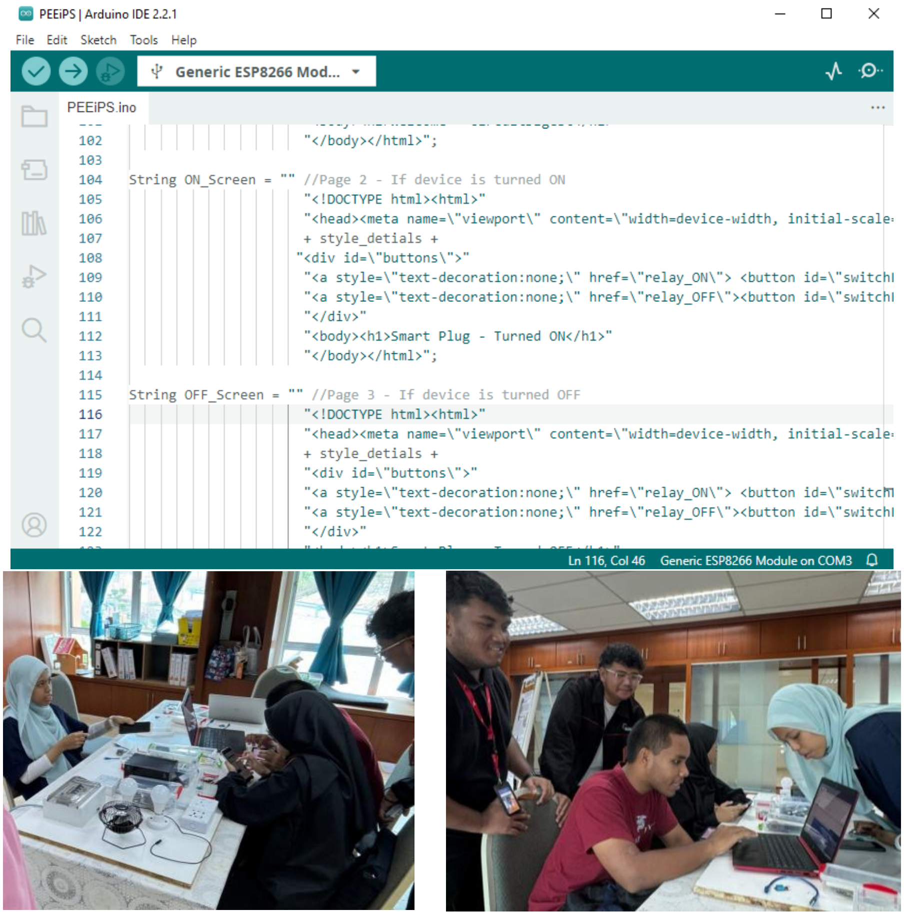

Figure 4: Firmware and mobile application development activities

2.4 Verification and Testing

Verification and testing were essential to ensure that the PEEiPS system met all specified requirements and functioned as intended. The process began with unit testing, where each individual component including the ESP8266 microcontroller, ultrasonic sensor, relay module, and solar panel was tested independently to confirm correct functionality. This was followed by integration testing, in which hardware and software components were combined to evaluate the system's overall operation and ensure seamless communication between modules.

Functional testing was then conducted to verify that key features, such as motion detection via the ultrasonic sensor, automated relay control, and solar-powered operation, worked reliably under various conditions. Lastly, user testing involved deploying the PEEiPS prototype in real-world environments such as homes and small offices to observe performance, gather user feedback, and identify potential usability issues for further refinement

Figure 5: PEEiPS Prototypes

2.5 Deployment and Maintenance

The final phase of the project involved the deployment of PEEiPS prototypes in selected households and workplace environments to evaluate real-world performance. During the deployment stage, the devices were physically installed, connected to electrical appliances, and configured to ensure full operational readiness. This included verifying network connectivity, calibrating the ultrasonic sensor for motion detection, and ensuring the solar panel could power the system effectively.

Following deployment, a monitoring and maintenance process was implemented to evaluate long-term functionality. The system's performance was continuously monitored to track energy consumption patterns, detect anomalies, and validate power-saving outcomes. Firmware and mobile application updates were also conducted to incorporate user feedback and improve user interaction.

To visualize the system's live operation, Table 6 presents the deployment setup and application interface. As shown, the lamp is controlled via the Blynk app, with "Button Settings" enabling manual ON/OFF control and "SuperChart Settings" displaying real-time power usage data. The solar panel supplies power to the ESP8266-based PEEiPS, and all sensor data is captured and visualized on the mobile dashboard, making the system both interactive and responsive. This configuration demonstrates the practicality of PEEiPS in a real-world setting and its ability to operate reliably with minimal manual intervention.

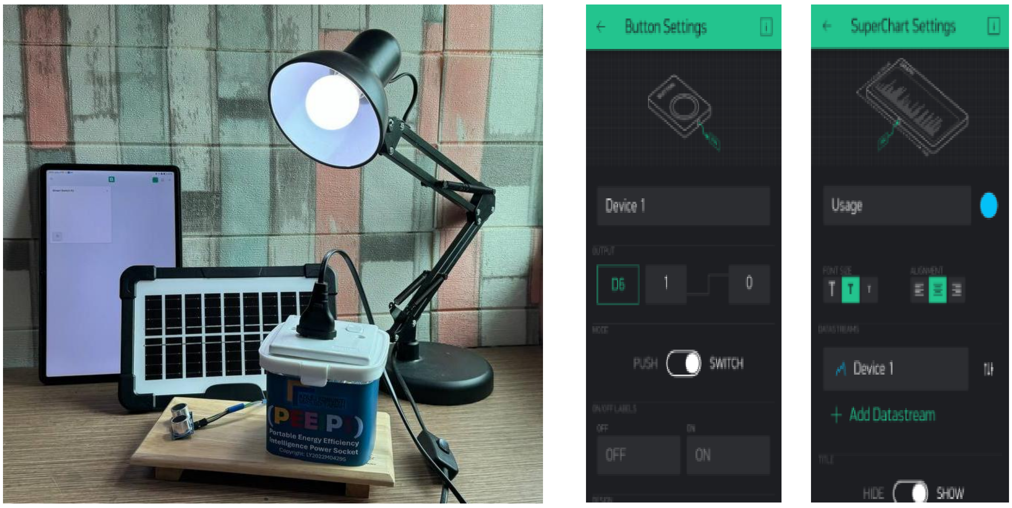

Figure 6: Deployment and monitoring activities

3.0 Result and Discussion

The PEEiPS was successfully developed and implemented, achieving the project's objectives of reducing energy wastage and enhancing sustainability through the integration of IoT technology and solar energy. In phase development and implementation**,** the PEEIPS system, built around the ESP8266 microcontroller, was assembled with a relay module, ultrasonic sensor, and a solar panel. The microcontroller's firmware was programmed to manage Wi-Fi communication, sensor data processing, and relay control, while the mobile application was developed to provide remote control, scheduling, real-time monitoring, and notifications. While in the functionality and testing phase, the PEEiPS prototypes were deployed in various households and workplaces for testing.

The system effectively reduced unnecessary energy consumption by automatically turning off lights when no motion was detected. The solar panel successfully powered the ESP8266, ensuring the system's sustainability without additional grid electricity. For the discussion focuses on comparing the estimated electrical usage of ten lamps with and without the PEEiPS. The analysis considers a common scenario where users forget to turn off their lights six times a month. and how PEEIPS can effectively mitigate this issue, particularly in households with monthly electricity consumption exceeding 1000 kWh. The additional feature of PEEIPS using solar energy to power the ESP8266 microcontroller ensures that no additional grid energy is consumed for its operation. Without PEEiPS, each instance of leaving the lamps on unnecessarily leads to substantial energy wastage. Assuming each lamp has a power rating of 60 watts and is left on for an average of 8 hours each time this happens, the total unnecessary energy consumption for five lamps can be calculated as follows:

$$\textit{Energy per instance} = 60 \textit{ watts} \times 10 \textit{ lamps} \times 8 \textit{ hours} = 4.8 \textit{ kWh} \quad (1)$$

For six instances per month:

$$\textit{Total energy wasted per month} = 4.8 \textit{ kWh} \times 6 = 28.8 \textit{ kWh} \quad (2)$$

Over a year, this amounts to:

$$Total\ energy\ wasted\ per\ year = 28.8\ kWh \times 12 = 345.6\ kWh \quad (3)$$

With PEEiPS, the system's automated switching feature, controlled by the ultrasonic sensor, ensures that lights are turned off when there is no presence of objects or people near the power socket. This effectively eliminates the problem of forgetting to turn off the lamps. As a result, the estimated unnecessary energy consumption can be significantly reduced, leading to substantial energy savings. In addition to energy savings, PEEIPS contributes to a reduction in electricity costs. Assuming an average electricity rate of RM 0.571 per kWh (, the annual cost savings can be calculated as follows:

$$Annual\ cost\ savings = 345.6\ kWh\ \ x\ RM\ 0.571 = RM\ 197.34 \quad (4)$$

The estimated savings of PEEiPs implementation are shown in Table 2.

Table 2: The estimation saving of PEEiPS implementation

Comparison	Total Energy Usage/year (1000kWh per month)	% saving for 600W usage	% saving for 6000W usage
PEEiPS	11, 654 kWh	3.63%	36.3%
Without PEEiPS	12,000 kWh		

Moreover, the ESP8266 microcontroller in PEEiPS operates on solar energy, ensuring that its functionality does not require additional grid electricity. This utilization of renewable energy enhances the system's sustainability and further contributes to energy conservation efforts. In households with high electricity consumption exceeding 1000 kWh per month, the impact of these savings becomes even more significant. The ability to cut down on unnecessary energy usage helps in managing and reducing overall electricity bills, contributing to more efficient energy use.

By leveraging solar power, PEEiPS not only addresses the issue of forgotten lamps but also operates in an environmentally friendly manner. This feature eliminates the need for external power sources for the microcontroller, making the entire system self-sustaining and reducing the overall carbon footprint. Overall, the comparative analysis underscores the significant impact that PEEiPS can have on energy efficiency. PEEiPS effectively reduces unnecessary energy consumption, leading to both economic and environmental benefits. The successful implementation of PEEIPS demonstrates its capability to tackle common energy wastage issues, highlighting its potential for broader adoption in various residential and commercial environments.

4.0 Conclusion

The PEEiPS project successfully demonstrated its potential to significantly reduce energy wastage and promote sustainable energy practices in residential and commercial settings. By integrating the ESP8266 microcontroller with IoT capabilities and solar energy, PEEiPS offers a robust solution to the common problem of forgetting to turn off electrical appliances. The automated switching feature, enabled by the ultrasonic sensor, ensures that devices like fans and lights are only on when necessary, effectively addressing the issue of energy wastage. The use of solar power to operate the microcontroller enhances the system's sustainability, making it an environmentally friendly alternative to traditional energy management solutions.

The testing and deployment of PEEiPS showed considerable energy savings and cost reductions. In scenarios where users typically forget to turn off their appliances multiple times a month, PEEiPS eliminated this unnecessary consumption, resulting in significant annual energy and cost savings. Additionally, the user-friendly mobile application provided convenient remote control and monitoring capabilities, further improving user engagement and energy management. However, there are still avenues for future work and improvement. One direction could involve refining the intelligence algorithms to further optimize energy usage based on real-time data and user behaviour patterns. Additionally, exploring advanced sensing technologies and integration with other IoT devices could expand the functionalities and applications of PEEIPS.

Moving forward, future efforts to commercialize PEEiPS could focus on market validation, product refinement, and scalability. This includes conducting market research to identify industry needs, enhancing PEEiPS's design and features to meet commercial standards, and developing scalable production processes for cost-effective manufacturing. Overall, PEEiPS stands out as an innovative, practical solution for improving energy efficiency. Its successful implementation underscores the importance of combining renewable energy and smart technology to address today's energy challenges. The project contributes not only to individual energy and cost savings but also to broader environmental sustainability. PEEiPS shows strong potential for wider adoption and continued advancement in energy-efficient technologies.

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Author Contributions

M.R. Mohd Roni: Conceptualisation, Methodology, Software Development, Data Collection, Writing – Original Draft; **H.H. Hanafee:** System Design, Implementation, Testing, Validation, Writing – Supporting Draft; **N. Hayati Mohd Yusoff:** Supervision, Project Administration, Validation, Writing – Review & Editing.

Conflicts of Interest

The manuscript has not been published elsewhere and is not under consideration by other journals. All authors have approved the review, agree with its Submission and declare no conflict of interest in the manuscript.

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