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NON-REVENUE WATER (NRW) FOR SUSTAINABLE UNIVERSITY CAMPUSES: A REVIEW

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ABSTRACT

Non-revenue water (NRW) is the difference between the supplied and the billed quantity due to apparent and real losses. A higher rate of NRW reflects higher revenue loss to the state. The NRW cannot be totally avoided, thus understanding, and managing its components is very vital. Of late, research on NRW particularly on University Campuses is still an emerging field. Hence, this paper delineates the overview of NRW, a sustainable University Campus, and the benefits of NRW in the University Campus' sustainability. To do so, an extensive literature review via three main databases (ie., Web of Science, Science Direct, and Scopus) was conducted. From the review, six (6) aspects of NRW (ie., NRW prediction or estimation, the water distribution network, digital tools, NRW management, driver of water losses, and cost-effectiveness of NRW) were discussed in the previous study. While, four (4) categories (i.e., water quality, customer complaints, water resources, and impact on service efficiency and financial management) are listed as benefits of NRW through the NRW reduction program in the sustainability of the University Campus. As a result, this paper is able to provide insight to University Stakeholders for the consideration of NRW in managing water management for sustainable campus development.

Keywords: *Non-revenue water, Sustainability, Literature Review, University Campus*

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INTRODUCTION

Water is the most crucial ingredient in supporting human life and their activities, construction ventures, food production, and health functionality as well as becoming a moderator in economic development worldwide. Various sources of water (i.e., rivers, lakes, springs, streams, reservoirs, and groundwater) provide water for public drinking supplies and private wells. Undeniably, having sufficient, clean, and safe water is essential to ensure the longevity of human life. Nevertheless, with an increasing urban population and expanding service areas, many developing countries are struggling to provide clean water to their consumers. Water management requires appropriate water governance such as water resources, water service, and water trade-offs to maintain the sustainability of water to the customer (Lai, 2016). Nevertheless, one of the major challenges faced by water management in these developing countries is related to managing the high rates of water loss or NRW that causes difficulty with consumer demands. Moreover, water loss in the water distribution system will impede water utilities in keeping water tariffs at a reasonable level (Frauendorfer & Liemberger, 2010; Lai, 2016).

NRW is defined as water that has been lost before reaching the customer due to various causes (i.e., apparent losses and real losses) (Frauendorfer & Liemberger, 2010; Lai, 2016). NRW is a good indicator of water management performance. As such, high rates of NRW indicate poor water management performance. According to Bhagat et al., (2019) cited from The World Bank, the annual volume of non-revenue water in most developing countries was estimated at 45 million cubic meters in the distribution networks. While, in low and middle-income countries, 60 million cubic meters of water were found to be lost every day due to water losses/leakage, and the total cost is estimated at 3 billion dollars per year due to water leakage. In addition, about 30 million cubic meters of water is delivered to the customers every day but has not been billed due to technical and non-technical problems. Thus, as the water losses can be halved, 90 million people could be salvaged.

In Malaysia, the problems related to NRW rates have been jeopardizing the sustainability of water management for many years. The Malaysian government (i.e., the 12th Malaysia Plan) has outlined the water sector as a significant contributor to national growth and wealth creation by becoming a regional water industry hub. It is aligned with the United Nations (UN) Sustainable Development Goals (SDG) 6: Clean Water and Sanitisation. The aim is to increase water efficiency across the sectors and ensure the sustainability of freshwater to address water scarcity and significantly reduce the number of people suffering from water scarcity. Consequently, University Campuses are not exceptional in promoting the sustainability of freshwater to its users. A better understanding of how water management, particularly related to NRW/ water losses is addressed in the campus sustainability is required. The university could serve as a model for the development of NRW management if they are provided with extensive seminars, training, and practice pertaining to sustainable water management. The sustainability campus initiatives are referred to as campus greening or campus sustainability programs to develop, plan, and manage efforts on the campus (McHugh, 2011). The green campus concept allows a university to lead the way in protecting the environmental culture and creating a new role by developing sustainable solutions to the world's environment, and economic as well as social requirements (Lopes & Vieira, 2021). These include the concentration of environmental sustainability such as water and energy conservation, green buildings, recycling, sustainable transportation, and greenhouse gas emission reduction. Thus, the paper attempts to conduct an extensive literature review of existing studies related to the overview of NRW, a sustainable campus, and the benefits of NRW in University Campus sustainability. Furthermore, the paper aims to provide an understanding and bridge the knowledge of NRW with campus sustainability as these topics are still emerging fields.

RESEARCH METHOD

The study has conducted an extensive literature view of the NRW. It covers resources from various sources (i.e., journal articles, conference proceedings) from leading databases (i.e., Scopus, Web of Science, and science direct). These journal articles and conference proceedings were drawn from the period 2017 to 2022 towards obtaining updated information regarding non-revenue water. Furthermore, both international and local publications particularly in Malaysia were also reviewed.

LITERATURE REVIEW

NRW Definition

Of late, NRW or water losses within the utility system has become a serious problem. NRW can cause inefficiency towards the financial ability of water utilities as well as threaten the sustainability of water supply systems (Yi et al., 2017). Table 1 presents the previous studies that have discussed the diverse definition of NRW which has led to many understandings of NRW definitions.

Table 1. NRW definition

Authors	Definition
The International Water Association (IWA) cited from BEWOP (2020)	Difference between the total daily flow of water that is distributed into the water distribution network and the total daily flow of water that is invoiced with the customer
Agbenyegah (2019)	Unbilled water that has been officially (authorized) extracted for internal use (firefighting, flushing filters, and sewers) or consumers privileged because of public interest (such as schools, military barracks, religious institutions – sometimes metered, sometimes not)
USEPA (2013) cited from Chabe (2018)	The summation of unbilled authorized consumption and water losses due to apparent and real losses.
USAID (2010) cited from Chabe (2018)	The total amount of water flowing into the water supply network from a water treatment plant, a borehole, or imported bulk water minus the total amount of water that consumers are authorized to use and are billed for.
Yi et al., (2017)	The difference between the supplied and billed quantity
AWWA (2016)	Those components of System Input volume are not billed and do not produce any revenue.
van den Berg (2014)	The difference between the volume of water from the water treatment plant to the water distribution system and the volume that is billed to customers.
Farley et al., (2008)	The total amount of water flowing into the water supply network from a water treatment plant (the 'System Input Volume') minus the total amount of water that industrial and domestic consumers are authorized to use (the 'Authorised Consumption')".
Lambert1 et al., (2000)	The difference between the system input volume and billed authorized consumption.

Adapted from Chabe (2018); Yi et al., (2017)

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According to Lai (2016) cited from Rudolf Frauendorfer Roland Liemberger (2010), the term 'unaccounted-for water' (UFW) is used for evaluating the water utility performance in managing water losses in the early 1990s. Due to the lack of standardization of the UFW definition, the water utility performance could not be compared. Later, in the early 2000s, the International Water Association (IWA) created a Water Loss Task Force to develop appropriate performance indicators related to water loss management. Since then, the term Non-revenue water (NRW) was introduced instead of 'unaccounted-for water' (UFW). Therefore, the most appropriate definition of NRW adopted in this study is "the summation of unbilled authorized consumption and water losses due to apparent and real losses" (USEPA, 2013).

Table 2. International Water Association (IWA) Standard International Water Balance and Terminology

Total System Input Volume	Authorized consumption	Bill authorized consumption	Billed metered consumption	Revenue water
			Billed unmetered consumption	
		Unbilled authorized consumption	Unbilled metered consumption	Non-revenue water (NRW)
			Unbilled unmetered consumption	
	Water losses	Apparent losses	Unauthorized consumption	
			Customer metering inaccuracies	
		Real Losses	Leakage in the distribution system	
			Leakage and overflow at utility storage tanks	
			Leakage on service connection up to point of customer metering	

Adopted from BEWOP (2020)

Table 2 presents the IWA water balance which summarizes the understanding of NRW (BEWOP, 2020). Total System Input Volume is defined as the annual input volume of water supplied to the distribution system from their sources. The apparent losses (i.e., commercial losses) result in water losses for utilities and are considered unauthorized consumption (i.e., from theft or illegal use), and all types of inaccuracies are associated with customer metering and production metering. While real losses (i.e., physical losses) encompass leakage from all components of the system and overflows at the utility's storage tanks. These occur as a result of lacking active leakage control, poor quality of underground assets, and poor operations maintenance.

NRW Calculation

The NRW calculation is calculated based on the relation (1) below. This method is the expression of NRW as a percentage of the water entering the system (Popa-Albu et al., 2019).

$$\frac{Vws - Vwi}{Vws} x\ 100$$

Where:
Vws= Water volume supplied in the distribution network
Vwi= Water volume invoiced to all consumers

During the calculation of NRW, the delivery and billing periods are vital to coincide with one another to avoid inaccuracy of the data used. According to Popa-Albu et al., (2019), errors that occur within several meters at the source or from consumers will lead to the use of estimated values and may be prone to erroneous results. The above calculation is also used as an NRW performance indicator for the percentage of water produced and delivered in the distribution network which may have some limitations. As such, it does not indicate the real and apparent losses because it considers all the technical characteristics including bundle density and network pressure. The real and apparent losses can be determined after the NRW volume has been divided into both losses. Thus, this situation creates a useful indicator for the water operators to steadily monitor and report internally on changes in water loss over time. As a result, the performance indicator has been developed and can be linked to the network and the infrastructure performance criteria (i.e., need to rehabilitate) (Chabe, 2018; Popa-Albu et al., 2019).

Overview of NRW from the Previous Literature

Table 3 presents six (6) aspects of NRW (ie., NRW prediction or estimation, water distribution network, digital tools, NRW management, driver of water losses, and cost-effectiveness of NRW) were found in the

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literature. As such, Jang & Choi (2017) focused on estimating the NRW ratio by using Artificial Neural Networks (ANN). As a result, they found the accuracy of the NRW ratio calculated from the ANN model was higher compared to the multiple regression analysis. A similar study conducted by Elkharbotly et al., (2022) developed ANN models for the benefits of producing NRW estimations. Again, they proved that the ANN models provide an acceptable level of accuracy for NRW estimations. Thus, the study can contribute to the development of NRW reduction strategies concerning the cost reduction of water distribution. In a similar vein, Kızılöz & Şişman (2021) investigated the NRW ratio value prediction by using the Serial Triple Diagram Model (STDM) and later compared it with the Triple Diagram Model (TDM). In conclusion of the study, the STDM model showed better predictions of NRW ratio with less than 10% relative errors.

Table 3. Previous Studies Related to Non-revenue Water

Authors	Country	1	2	3	4	5	6
Elkharbotly et al., (2022)	Eygpt	x					
Kızılöz & Şişman (2021)	Turkey	x					
Shushu et al., (2021)	Tanzania		x				
Cassidy et al., (2021)	Portugal			x			
Jones et al., (2021)	Malaysia		x				
Ong et al., (2020)	Malaysia				x		
Lai et al., (2020)	Malaysia						x
Zaini & Rasam (2019)	Malaysia			x			
Ananda (2019)	Australia				x		
Popa-Albu et al., (2019)	Romania		x				
Güngör-Demirci et al., (2018)	California				x		
Perera et al., (2018)	India					x	
Jang & Choi (2017)	South Korea	x					
Lai et al., (2017)	Malaysia						x

Remarks: (1) NRW estimation; (2) Water distribution network; (3) Digital tools; (4) Driver water losses; (5) Cost-effectiveness of NRW; (6) NRW management

Apart from that, three researchers conducted a comprehensive study on the aspect of the water distribution network. As such, Shushu et al., (2021) conducted a study in a small area (part of the city water network) which is in Mwanza city of Tanzania for measuring and analyzing NRW techniques and management. They revealed that a comprehensive zone-by-zone assessment of the water distribution network is essential to improve NRW management, particularly in unplanned urban areas. Meanwhile, Popa-Albu et al., (2019) conducted a study related to methods and technologies used in addressing the issues of water loss in Timisoara, Romania. The technologies were used to detect the damages to the pipes of the distribution networks, continuous monitoring, and remote data transmission. The findings revealed that the water loss reduction is quantified by water savings through the reduction of pressure on existing networks. On the other hand, Jones et al., (2021) examined the various water pipe types that affect NRW loss in Malaysia and found that there is a significant correlation between mild steel and polyethylene pipes towards NRW loss. Furthermore, the study provides the best practices in the water industry to manage water losses and preserve water resources.

Cassidy et al., (2021) evaluated the impact of using cloud-based tools on the reduction of both real (real-time network monitoring) and apparent water losses (integrated customer meters management) with two water utilities. They concluded that the integration of smart water solutions with operation system management allows them to diagnose, prioritize areas and outline quick actions to improve water efficiency. Similarly, Zaini & Rasam (2019) proposed an alternative and effective solution for NRW issues in Malaysia by developing a mobile GIS application for managing water loss. A prototype of the water loss meter tracking mobile app received positive feedback from Water providers and could assist in increasing accuracy and efficiency in the management of water meters.

Ananda (2019) analyzed real water losses in drinking water networks in Australia by using a fixed effect panel regression model and later ascertained the main drivers of real water losses. The findings revealed that population growth together with water main breaks are the main drivers of water losses in Australia which could affect the utilities' net revenue per unit of water delivered, infrastructure leakage index, and operational costs. While, Ong et al., (2020) conducted a study to seek the public's Non-Revenue Water (NRW) reduction behavioral intention in Malaysia. The theoretical (i.e., Theory of Planned Behavior) study revealed the factors of perceived behavioral control, environmental knowledge, environmental concern, attitude, subjective norms, and gender to significantly influence the NRW reduction intention. Furthermore, the factors of education and ethnicity differences have significant influences on the expended TBP in

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the NRW reduction. Similarly, Güngör-Demirci et al., (2018) identified the determinants of NRW in California by using a fixed effect panel regression model. The results showed that technical, managerial, physical, and environmental factors are all known to influence the non-revenue water (NRW) volume. A positive relationship was found between the number of leakages and NRW; connection density, network length, and net operating revenue per cubic meter of water sold were found to be negatively correlated with NRW.

In addition, Perera et al., (2018) proposed a cost-effective management system for the NRW loss from water distribution in India. The developed cost-effective management model would be useful in long-term planning which delineates the water management strategies for preventing the different types of water losses. Lai et al., (2017) conducted a study on Public perceptions of NRW in Malaysia and concluded that NRW awareness among the public is still at the infancy stage, and community-led strategies are required to overcome the problems. Further, Lai et al., (2020) explored the challenges of the water sector reformation and the NRW reduction in Malaysia and later proposed the NRW management reform drivers. By utilizing a thinking system approach (i.e., causal loop diagrams (CLDs)), the key contextual elements of the NRW reduction system were identified and the relationships between these elements were mapped. As a result, the findings found that factors in terms of environmental (i.e., the availability of water resources), economic (i.e., water tariff), technical (i.e., water supply efficiency), corporate governance (e.g., capacity development), social (e.g., public concern and political influence), and institutional (e.g., regulatory framework) were among the factors that influenced the success of NRW management reforms in Malaysia. By contrast, it appears that there are inadequate studies that have been conducted to investigate the NRW for sustainability in University campuses. Hence, the following section discusses the sustainable definition, the sustainable university campus, and NRW's benefits in the context of a sustainable University Campus.

Sustainable Definition

The definition of sustainable was explained in many pieces of literature for more than 30 years. Nevertheless, the definitions of sustainability may differ depending on the researcher's perspective, formal or informal context, and the government or non-government organisations that they are referring to. The well-known definition of sustainable is from the Brundtland Report 1987 which defined sustainable development as "…development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Lopes & Vieira, 2021). Despite many researchers claiming that sustainability solely focuses on environmental issues, the definition has captured other related fundamental issues; social and economic sustainability. This statement is aligned with John (1998) who proposed a framework; Triple Bottom Line which highlighted this basic sustainability (i.e., social, environmental, and economic sustainability). He added that the Triple Bottom Line proposes that business sustainability depends on economic growth, social resources, and environmental impact. Figure 1 shows the Triple Bottom Line Framework of sustainability by John (1998).

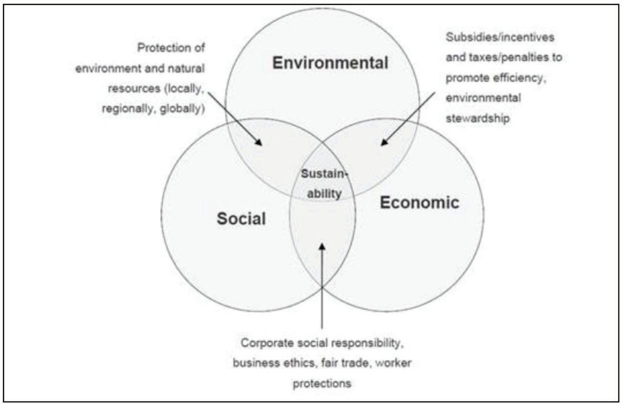

Figure 1. Triple Bottom Line Framework of sustainability by John (1998) adopted from (Ocampo, 2015)

Sustainable Campus

Recently, the sustainable campus issue has become a global concern (Azahar Abas et al., 2018). A university is an education center that plays a crucial role in educating prospective future leaders about the issue of sustainability on campus. A sustainable campus is an environmental-oriented campus that integrates environmental science into management, policies, and academic activities. It also represents the implementation and integration of environmental science into all managerial aspects and the best practices of sustainable development (Sugiarto et al., 2022). Many universities around the world are showing their support and commitment to implementing sustainable campus activities including water and energy efficiency, sustainable landscape, material conservation or wastage, sustainable buildings, and transportation (Nawi & Choy, 2020). The importance of sustainability among university campuses arose in the 1970s when academics realized that the environmental crisis influenced their social facilities and economic growth. Various conferences, declarations, and seminars were held to overcome environmental issues through the university organization, academic curriculum, and sustainable activities on the campuses. As a result, the first declaration (i.e., the Talloires Declaration) was created in 1990 in France and involved more than 300 university leaders from various university campuses who were committed to sustainability issues on university campuses. The purpose of this conference was to discuss the environmental issues between the industrialized and developing countries which were linked to economic growth, pollution issues (i.e., air, water, oceans), and the well-being of people around the world. In addition, the Talloires Declaration also aims to educate people in the university by increasing the awareness, knowledge, technologies, and tools to create an environmentally sustainable future. Thus, the teaching approaches, multidimensional subjects in the university curriculum, research, operations, and outreach at the university campuses are integrated with the environmental issues. Consequently, the delegates from the Talloires Declaration agreed to list a 10-point action plan to direct the sustainability roadmap on University campuses.

According to Azahar Abas et al., (2018), the integration of sustainable approaches on university campuses is one of the most significant initiatives to address ecological and social challenges in the future. In addition, the sustainable campus also needs to consider the three sustainable components (i.e., incorporates environmental impact, economic and social-cultural) (Nifa et al., 2016). Consequently, the various approaches (i.e., Water Management; Transportation System Management; Landscape and Biodiversity Management; Waste Management; Green Procurement; Energy Management; Education Management – Environment and Climate Change; and Change Management in Governance, Participation, and Communication) are among the main initiatives to minimize the sustainability issues (University of Malaya, 2020). Among others, water management initiative is highlighted in this study. In managing water on university campuses, the issue of wastewater or NRW/ water loss due to leakages is the biggest cause in the buildings (McHugh, 2011). According to Duke University (NC), to reduce the campus and facilities' water consumption, several incentives have been taken such as stopping the use of most automatic irrigation systems, using timers, reducing the watering of its fields from 36 minutes to 6 minutes, and installing drought-tolerant landscaping. Whereas, at University Malaya (UM) Malaysia, the implementation of water sensors, and water monitoring via Internet-of-Things (IoT) are targeted to reduce water consumption and improve water quality management on campuses (University of Malaya, 2020). Hence, a paradigm shift in university campuses is required, in order for sustainability awareness of NRW/ water losses to be promoted at various levels.

The Benefits of NRW on The University Campuses

The benefits of NRW through the implementation of the NRW reduction program have resulted in the sustainability of university campuses through four (4) categories (i.e., water quality, customer complaints, water resources, and impact on service efficiency and financial management) (Japan International cooperation agency (JICA), 2020)

Water quality

Leakage causes water loss from burst pipe networks or systems which means that cleaned water is lost and never reaches the users. By reducing the NRW rates, more treated water is able to reach the users (University campuses), more revenue in water, and the water production cost (i.e., energy, chemical, and operating cost) will be lower (Lai, 2016).

Customer complaints

Inconsistency of water availability affects the university campus users' relations with water utilities which in the end leads them to refusal of payment. The water losses or NRW will cause high tariffs for their water supply on the university campus and causes a sense of unfairness in paying unnecessary rates due to apparent and real losses. Therefore, by implementing the NRW reduction program, University campus users can enjoy reasonable tariffs, and efficient water services if the water is sufficient in the system.

Water resources

Poor management of water resources contributes to water loss. As such, there is also the lack of maintenance of the supply network that resulted from pipe burst leakages, the lack of University campus meters, and the user's bill that can not be billed based on actual consumption. The NRW reduction programs facilitate and control water losses by lowering the water pressure using a pressure reduction valve on the University campus and preventing overflows. Consequently, the water resources of the University campus can be controlled and treated.

Service efficiency and financial management

The implementation of NRW reduction programs uses high technologies which encourage water management services to become more efficient. As such is the application of the Geographic Information System (GIS) that develops an accurate distribution network record, incoming or outgoing District Water Meters (DMA), university campus meters, service connections, valves, etc. Furthermore, the NRW reduction program encourages the improvement of asset management planning. The integration of data from GIS and Building Information Modeling (BIM) is needed to build up a database of leakage findings, repair details, and locations. As a result, the data is able to be used for asset management planning as well as to identify the service line replacement during water management maintenance projects.

The NRW reduction programs are most beneficial as they create business opportunities (i.e., service providers; planners; maintenance services, etc) and lead to positive economic growth. NRW reduction involves protecting massive quantitive renewable resources and enables water bill savings. The effect of NRW reduction is to minimize running costs due to the reduction of electricity, solvent consumption, and low water loss charges. Consequently, it will improve the productivity, and the water providers' integrity in managing NRW reduction (Musa & Selamani, 2021).

CONCLUSIONS AND RECOMMENDATIONS

NRW is an important topic and yet somewhat an overlooked issue in the sustainability of University Campuses. Nevertheless, to date, numerous university campuses are making excessive efforts (i.e., research programs, and university campus activities) to manage their NRW within the University Campus by contributing to enhancing the reduction of water consumption and improving water quality management. This study effort is a literature exploration of NRW in the sustainability of university campuses and much more remains to be studied and understood on how University Campuses manage their NRW issues. From the literature, six (6) aspects of NRW (ie., NRW prediction or estimation, water distribution network, digital tools, NRW management, driver water losses, and cost-effectiveness of NRW) were discussed in the previous study. It has been found that the three (3) main aspects are dominant in the previous literature (i.e., NRW prediction or estimation, water distribution network, and driver water losses). Furthermore, most of the researchers are from developing countries, and Malaysian researchers have contributed to five publications since 2017. This implies that the NRW rates in developing countries are higher compared to developed countries and thus will allow them to lose their water performance and become unable to meet the sustainable development objectives.

Furthermore, from the review, four (4) main benefits of NRW (i.e., water quality, customer complaints, water resources, and impact on service efficiency and financial management) through the NRW reduction program in the sustainability of University Campuses are revealed. These benefits can also affect the University campus' cost, time, quality, and safety due to the:

- Less energy is used due to less drinking water required to be pumped out of the utility network system.
- Less sewage water needs to be treated or pumped due to less leakage from drinking water systems into sewage pipelines.
- Less water abstraction and the stress on the environment due to less NRW.
- Less risk of contaminated drinking water due to fewer leakages in the pipelines.

Hence, further research should focus on how and why NRW reduction plans and decisions are made in University campus operations and how this differs from other university campuses. In addition, the potential for cost savings of sustainability and NRW reduction practices in University Campuses could assist the University Campus leaders or administrators in effectively planning and implementing NRW reduction programs on their campus. Moreover, the social and behavior of university campus users towards the NRW reduction program also needs to be explored further. Hence, university campuses around the world and particularly in Malaysia should have further insights on how to effectively manage NRW reductions in conjunction with environmental, social, and economic aspects of sustainability.

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CONFLICT OF INTEREST

The author declares that she has no conflicts of interest.

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