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Waste flow analysis to improve waste management systems: Case studies in Diponegoro University

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Abstract

Implementation of solid waste management in educational institutions is one of the main challenges faced in achieving sustainable development. However, far too little attention has been paid to managing solid waste effectively in educational institutions. Thus, this research tries to map and characterize solid waste produced through waste flow analysis (WFA). A case study of waste flow mapping at Diponegoro University revealed that the waste management infrastructure in Diponegoro University has yet to achieve equilibrium, with around 50% of the waste ending up in landfills. Waste management has not been implemented effectively, leading to only half of the recyclable waste being processed monthly. The findings indicate that the Waste Flow Analysis (WFA) effectively assesses the existing waste management conditions at Diponegoro University. The findings of this study could serve as a reference for implementing comprehensive waste management in educational institutions.

Keywords: Waste Management; Material Flow Analysis; Waste Flow Analysis; Sustainability; Higher Education

1. Introduction

The growing population and urbanization directly affect the amount of generated waste, especially solid waste [1]. Projections indicate that by 2025, approximately 68% of the global population will reside in urban areas. Consequently, there are disparities in the development of infrastructure. One example is inadequate solid waste management [2]. Waste management in Indonesia is underfunded, with only $5-6 per capita per year, significantly below the international benchmarks of $15-20 per year [3]. Given the present condition, solid waste management infrastructure growth will be insufficient to match the waste generation rate [4].

Indonesia's Ministry of Environment and Forestry (KLHK) reported that the 290 cities/ regions in Indonesia generated 31,900,000 tons per year as of July 2024. The National Waste Management Information System (SIPSN) revealed that 63.3% of the total national waste accumulation is manageable, whereas the remaining 35.67% is unmanaged [5]. Waste management methods in Indonesian cities are still dominated by disposal, with 60% utilizing open dumping and 10% employing sanitary landfills [6]. If the waste management methods continue, waste management in many Indonesian cities may encounter serious issues due to the limited landfills. The waste management model has limitations, including restricted land disposal, disposal expenses, and environmental impact. In Indonesia, waste management is governed by Law No. 18 of 2008 [7], which transformed the paradigm from collect-haul-dispose to a treatment approach focused on waste reduction and management—the 3R Model (Reduce, Reuse, Recycle) solves waste issue [8].

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As the volume of waste increases, waste-related problems, such as human health and environmental risks, are increasing [9]. Waste management issues have emerged as a concern for multiple stakeholders in Indonesia, including academic institutions [10]. This is primarily due to insufficient environmental standards for managing waste in academic institutions [11]. As change agents in society, academic institutions must contribute to educating individuals on the impacts of waste dumping on the environment [12]. Waste management programs have also been key in achieving institutional sustainability [13].

Located in Semarang, Universitas Diponegoro (UNDIP) is Indonesia's leading green academic institution [14], [15]. UNDIP, with its thousands of students and staff, has a significant impact on the surrounding environment, particularly in waste management. UNDIP represents a typical higher education institution (HEI) in developing nations. UNDIP is the sole institution in Indonesia that owns an integrated solid waste processing facility (ISWPF) under the Occupational Safety and Health and Environmental Technical Implementation Unit. It is managed by the Dipo Waste Bank (DWB) Team [15]. Waste management in UNDIP uses environmentally friendly methods and techniques to avoid adverse effects on the health of Campus Residents and the environment, both for the current generation and future generations [16].

Waste within each department is classified into two categories: economically valuable and non-valuable. Economically valuable waste is sold to scrapyards in Semarang, generating monetary value, whereas the corresponding faculty department handles non-valuable waste. Waste collection in each department occurs daily and is transported to the ISWPF. At the collection point, waste was categorized based on its characteristics and composition, including organic, plastic, paper, metal, and other waste. The solid waste composition and the percentage are shown in Figure 1.

Furthermore, composting policies and regulations ensure that organic waste, such as leaves, is not discarded or sold but processed for reuse [16]. However, challenges remain in processing such waste, preventing the program from operating optimally. To implement effective waste management, it is essential to capture the waste flow and classify the waste generated within the faculty.

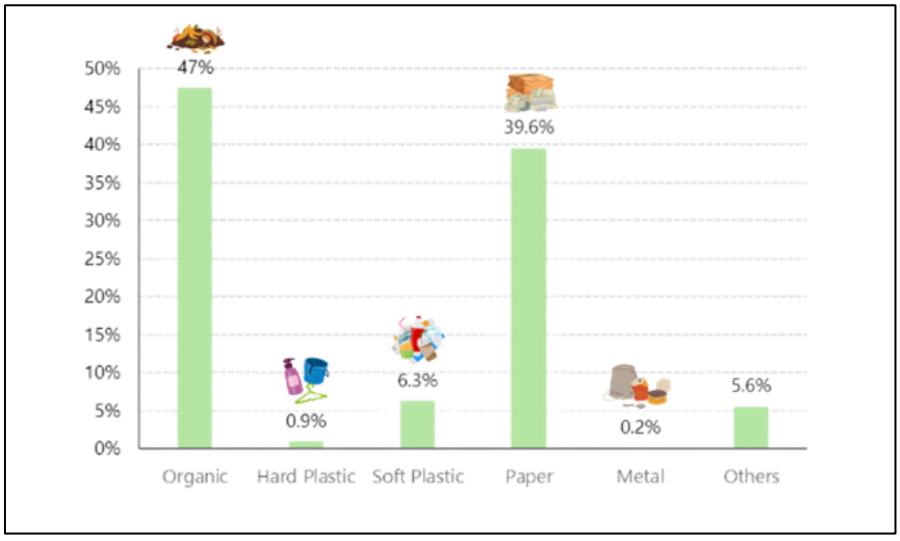

Figure 1 Solid Waste Composition in Diponegoro University

Analyzing waste generation and characterization is essential in determining waste treatment technology, capacity, and strategies. It is necessary to highlight waste generation from various sources, as the characteristics and composition of the waste vary according to their sources [10]. Nevertheless, information regarding solid waste generation and recovery rates is limited. A preliminary assessment of waste quantities, composition, recovery, and recycling rates is frequently unobtainable [17]. Through material flow analysis (MFA) methods, waste flows can be examined in detail, allowing for a more comprehensive evaluation of waste management practices [18].

MFA has become an extensively used method that offers a systematic perspective on interconnected processes and flows, facilitating strategic and priority-driven decision-making [19]. MFA analyses the flows of materials. However, there is no justification for limiting the extent of MFA within this definition. MFA is a comprehensive system methodology that examines various interfaces between flows and stocks [20]. The objective of MFA is to create a mass

balance for the system. The total of all inputs into the system must equal the total of all outputs plus changes in stock [19].

Several authors have studied waste management in HEIs for their research. Budihardjo et al. [14] explore the factors affecting sustainability in HEIs and develop strategies using strengths, weaknesses, opportunities, and threats (SWOT) analysis and quantitative strategic-planning matrix (QSPM) analysis. A case study conducted at Diponegoro University by Budihardjo et al. [15] shows that the combined influence of the student-gender ratio, student awareness level, administrative staff background, and green space constituted 67.7% of the waste generation at UNDIP. A study by Rugatiri et al. [9] evaluated the correlation between awareness and corresponding practices in solid waste management among university students. Rahmada et al. [10] captured the daily activities and waste in temporary disposal in HEIs through quantitative and qualitative description analysis. To date, The research has focused on factors affecting waste management practices in HEIs rather than waste flow within the campus environment.

Thus, this research aims to identify and assess waste flow patterns within the HEIs, which are an initial stage in formulating more effective and sustainable waste management strategies. This research investigates the current waste management practices at UNDIP and utilizes MFA to identify and evaluate waste flow. The hypothesis suggests that current waste management practices may demonstrate inefficiencies, especially in managing organic waste, and that MFA can provide significant insights into the dynamics of waste flow. This research seeks to improve waste management practices within the institution by systematically evaluating waste flows and identifying bottlenecks, which supports the HEIs' sustainability goals.

2. Material and methods

2.1. Material Flow Analysis

This research uses Material Flow Analysis (MFA), a systematic method for assessing material flows within a specific system. The development of the MFA methodology began with the creation of hybrid models that integrate quantitative and qualitative data [21]. MFA is a method for quantifying the flows and stocks of materials within systems. MFA has been widely used in material systems to provide information about resource usage patterns and material losses [22]. MFA explains the system by collecting and describing the system's flow. MFA measures the flow of materials within a process so that it can be used to provide suggestions for improving the industrial system model. MFA encompasses the entire context of a product's lifecycle, starting from resource extraction, resource processing, product fabrication, utilization, reuse, recycling, and disposal. The process involves identifying and quantifying the primary material and energy flows. Understanding and measuring these flows is fundamental for implementing modifications to the current system. The modifications aim to minimize the system's environmental impact by enhancing its efficiency in resource utilization. The system's performance can be improved according to the MFA result, which identifies the waste lost within the system [23]. This research used the MFA methodology, which comprises the following steps [24]:

- Establishing the object and aims of the study
- Identifying relevant materials and system boundaries
- Defining the flow of materials
- Balancing the inputs, outputs, and stock through the processes
- Providing the interpretation of the results

2.2. Diponegoro University's Waste Flow

This research primarily centers on field observations and direct evaluations of waste management strategies at Universitas Diponegoro. It examines various elements, including waste collection methods, classifications, management protocols, and disposal techniques. In addition, supplementary information regarding waste management at Universitas Diponegoro was gathered through faculty and administrative staff interviews. The primary objective of this research is to describe the current waste management practices at Universitas Diponegoro, emphasize the associated challenges, and ultimately propose constructive recommendations for improving these practices. A diagram illustrating the waste flow within Diponegoro University is given in Figure 2, based on interview results:

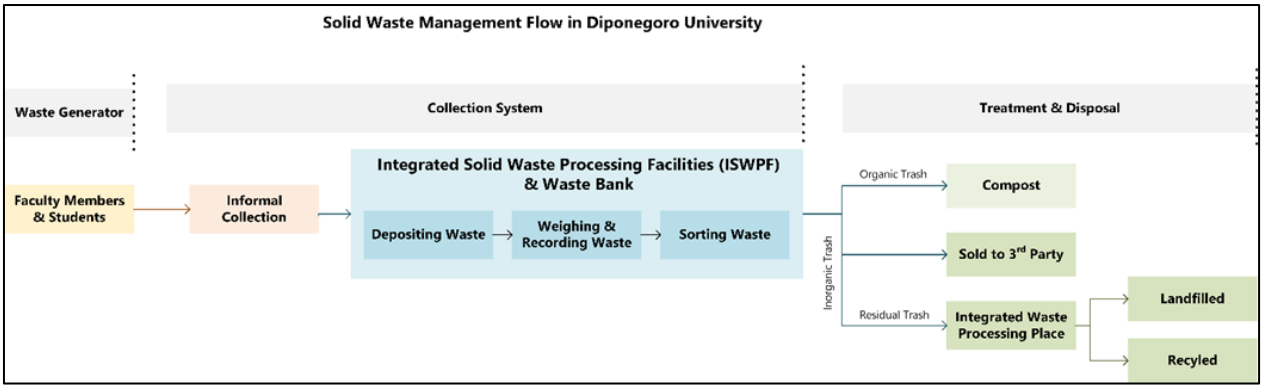

Figure 2 Solid Waste Management Flow in Diponegoro University

Through the evaluation of waste flow at UNDIP with MFA, it will be possible to determine the amount of the current waste flow, thereby assessing the effectiveness of the waste management practices that have been implemented. Every department must manage waste effectively before its disposal at the ISWPF, which aligns with the rector's regulation no. 5 of 2023 regarding waste management at Diponegoro University [16]. By minimizing the waste generated in each department, we can effectively reduce the amount of residual waste. Plastic bottles, cardboard, used papers, and metals can be sold to the junkyard for rupiah value. Then organic waste, particularly leaves, is collected in one location and recycled into compost. Therefore, residual waste that cannot be processed will be sent to ISWPF. At ISWPF, recyclable waste will be filtered, while non-recyclable waste will be disposed of in a landfill in Gunung Pati.

Nonetheless, field data indicates several problems. Waste is not effectively recycled due to insufficient facilities and human resources. Furthermore, inorganic waste accumulates to thousands of tons of residual waste requiring disposal each month. According to the records of the ISWPF, from July to December 2023, Diponegoro University disposed of 176 containers of waste, each measuring 6 m^3, to the Gunung Pati landfill, spending a total cost of Rp. 60,198,000.00. According to the mass balance principle, all inputs to a process equal the mass of all outputs from that process plus any storage. This research is limited to the processes related to receiving recyclable waste, conducting recycling operations within the ISWPF, and evaluating the outcomes produced from these recycling activities. The following section explains the calculation procedure for recyclable waste entering ISWPF:

2.2.1. Waste Quantification Based on Container Capacity

The following is the quantification of waste based on the truck container's capacity:

- Upon entering the ISWPF, the workers will count the containers in the waste transportation truck.
- The standard volume of each container is 6 m^3 or 6000 liters.
- The workers will calculate the total volume of waste transported by the truck by multiplying the number of containers by the standard volume, assuming the container was filled.
- The waste volume will be converted from cubic meters (m^3) to kilograms (kg) using a predetermined conversion factor, 1 m^3=200 kg. This conversion factor may be adjusted based on the type of waste and its average density. If one truck container arrives per day, and 6 m^3 are converted with a conversion factor of 1 m^3 = 200 kg, the total weight of waste amounts to 6 x 200 kg = 1200 kg per day.
- The workers will record and report the calculated weight of waste in kilograms in the database.

2.2.2. Waste Quantification Based on Trashbag Volume

Waste can be quantified through truck containers and by counting the number of large trash bags transported. The following is the quantification of waste based on the trashbag volume:

- Upon entering the ISWPF, the workers will count the large trash bags in the garbage truck.
- The standard volume for large trash bags is 0.73 m^3.
- The workers will calculate the total volume of waste transported by the truck by multiplying the number of large trash bags by the standard volume of each trash bag. For instance, if a truck contains 10 large trash bags, each with a volume of 0.73 m^3, the total volume of waste is calculated as 10 x 0.73 m^3 = 7.3 m^3.

- The workers will convert the waste volume from cubic meters to kilograms using a predetermined conversion factor, 1 m^3=200 kg. This conversion factor may be adjusted based on the type of waste and its average density. Converting 7.3 m^3 using the conversion factor will result in a total waste weight of 7.3 m^3 x 200 kg = 1460 kg.
- The waste weight in kilograms will be recorded and reported in the database.

3. Results and discussion

ISWPF collects waste from every department or faculty in UNDIP. Table 1 shows the monthly data on waste generated at UNDIP. The sources of non-household waste generated at UNDIP are office waste and leaf/ twig waste. The ISWPF carries out waste sorting activities for certain types of waste, such as duplexes, Cardboard, Plastic bottles, and Plastic bags. ISWPF also carries out waste management activities such as plastic reduction and composting.

Table 1 Amount of Solid Waste at Diponegoro University

Month	Number of Days per Month	Total Waste Accumulation (kg)		Total Amount of Segregated Waste (kg)	Total Amount of Managed Waste (kg)	Total Amount of Waste Transported to Landfill (kg)
		Organic Waste	Inorganic Waste			
January	21	18,459	8465	580	18,460	7,885
February	20	14,660	7745	706	15,220	7,109
March	21	17,497	11,285	640	17,497	11,145
April	14	10,555	5380	0	10,555	5,380
May	21	20,445	12,964	0	20,445	12,964
June	17	16,105	14,105	1,077	16,105	13,028
July	20	18,815	12,670	1,097	18,815	11,573
August	22	11,405	19,265	5,131.6	11,405	14,133.4
September	19	13,310	16,485	721	13,310	15,764
October	22	8,685	43,735	715	8,685	43,020
November	22	5,630	20,485	250	5,630	20,235
December	19	9015	15835	130	9,015	15,705

UNDIP transports the recyclable waste to the ISWPF, where the waste will be weighed, and the weight will be recorded in the database. The collected waste will undergo manual sorting prior to being transported and sold. Figure 3 shows the waste management activities at UNDIP.

UNDIP, as a leading green academic institution, has established waste management facilities, including waste bins, a transfer depo, waste trucks, and an Integrated Solid Waste Processing Facility (ISWPF). Waste from personal or office activities is thrown in bins, including waste segregation bins. However, despite the availability of waste segregation bins, waste is still often mixed. The cleaning service collects and transfers waste from the bins to the Transfer Depo. The transfer department does not include any treatment facilities, so the mixed waste is transported by truck to the ISWPF. In the ISWPF, the waste is segregated. Organic waste is treated through composting. The inorganic waste with economic value and the recyclable plastic waste are sold, and the waste without economic value and unrecyclable waste are transported to landfills.

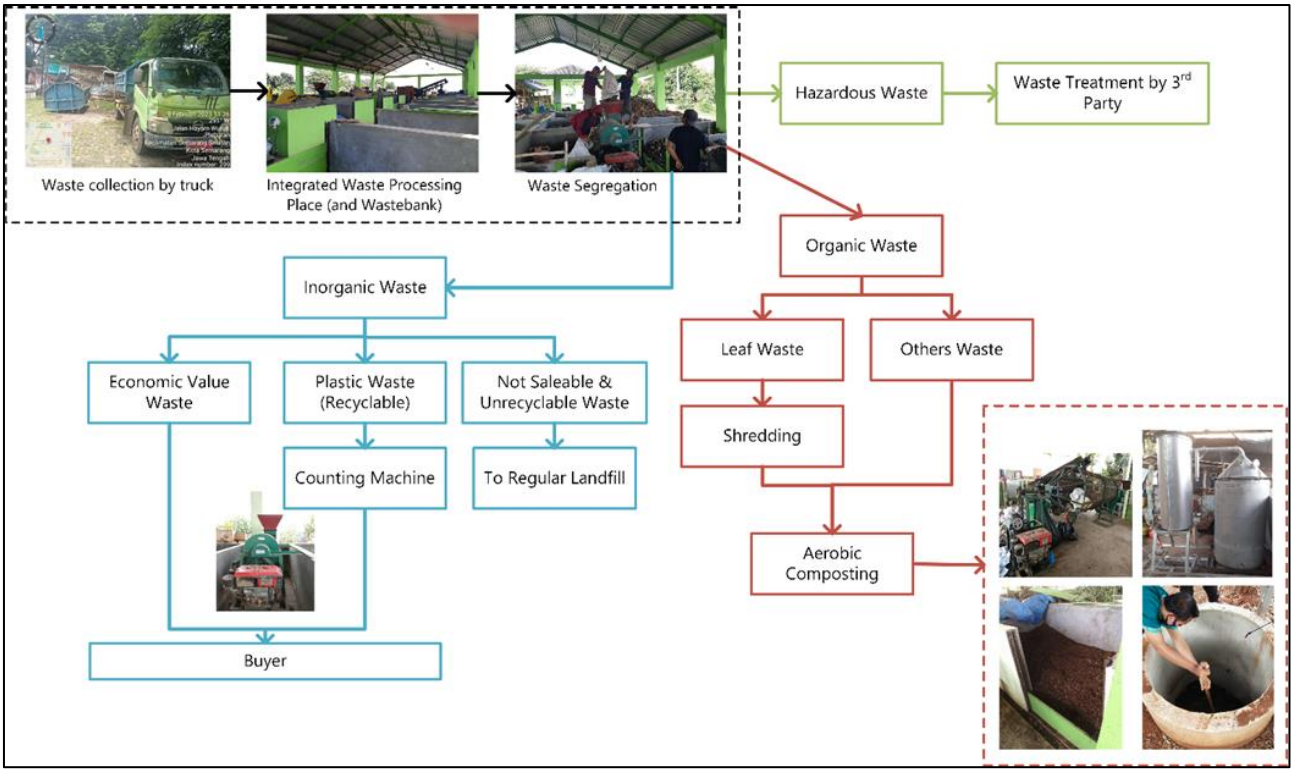

Figure 3 Waste Management in UNDIP

Optimizing processes at the ISWPF is essential to improve waste management. As shown in Figure 4, the treatment for solid waste consists of two main processes: composting and sorting. The primary focus of the ISWPF remains on segregating and composting waste, as most waste sent to Gunung Pati Landfill consists of inorganic waste.

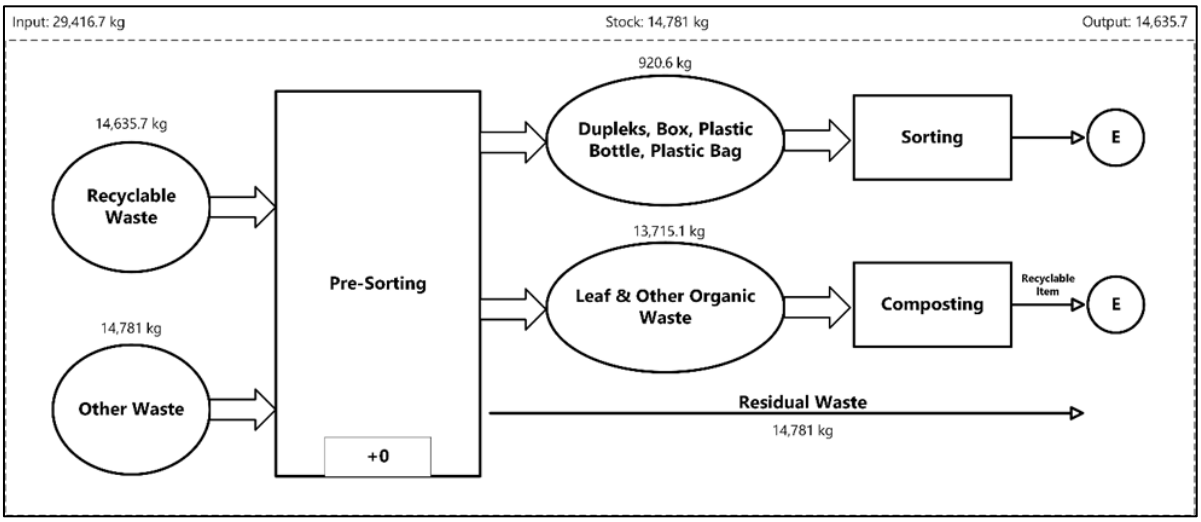

Figure 4 Waste Flow in ISWPF of UNDIP (number in kg/ month)

The majority of waste received at ISWPF should consist of recyclable materials that can be recycled from the waste generated by each department. In practice, a significant amount of recyclable waste is compromised and must be directed to ISWPF due to insufficient resources for waste processing within each department. The waste sorting process at ISWPF involves sorting duplex waste, cardboard, plastic bottles, and plastic bags for inorganic waste. For organic waste, composting is done to produce compost or similar products. The next step is to clean the plastic from contaminants by washing and drying it. ISWPF sorts waste daily; four to five workers are responsible. Although ISWPF is supposed to receive only sorted recyclable waste from each department, residues are still found. Sorting activities, such as sorting plastic that can no longer be processed, still leave residues disposed of in landfills. On average, per

month, the ISWPF receives an average of 29,416.7 kg of recyclable waste for sorting. However, on average, ISWPF can only process 14,635,7 kg of waste. Hence, the overall process, the ISWPF generates an average of 14,781 kg of residual waste per month to be disposed of at the Gunung Pati landfill.

An integrated waste management system requires the cooperation of all stakeholders. Implementing integrated solid waste management is challenging and requires a collective effort from all university stakeholders. A shift in perspective is necessary to view waste as a resource rather than solely garbage. A framework the United Nations provides, illustrated in Figure 5, can guide shifting paradigms [10]. One of the challenges is the lack of adequate waste management laws, which impacts the inefficiency of waste management in Indonesia. Existing legal regulations do not regulate the waste management system effectively. The most recent regulation, Indonesian Law No. 18 Tahun 2008, has not been implemented well due to low waste management services.

adapted from Rahmada et al. (2019)

Figure 5 United Nation's Shifting Paradigm

4. Conclusion

The current waste management system at ISWPF encounters challenges. A significant problem is that a substantial quantity of recyclable waste arrives in a damaged state and cannot be processed. Despite the efforts of the Dipo Waste Bank Team at ISWPF, a substantial quantity of waste continues to be deposited in landfills. On average, half of the recyclable waste is processed monthly, indicating a significant deficiency in the university's waste management practices. The university needs to improve the preliminary waste sorting in each department, increase the waste processing capacity at the ISWPF, and guarantee adequate resources for the Dipo Waste Bank Team. Enhanced collaboration between departments and the Dipo Waste Bank Team is crucial for minimizing waste and improving recycling.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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