• Investigation •

Seeing green in ophthalmology: carbon footprint of surgical waste in a Malaysian Tertiary Eye Centre

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Received: 2026-02-01 Accepted: 2026-08-03

Abstract

● **AIM:** To estimate the carbon footprint of ophthalmic surgical waste in a Malaysian tertiary hospital and to assess its implications for sustainable ophthalmology practice.

● **METHODS:** A prospective observational study was conducted in the Ophthalmology Department at University Malaya Medical Centre (UMMC) from 14 to 27 March 2025. All waste generated during ophthalmic surgeries was collected, weighed, and categorised as general waste, clinical waste, or sharps. Waste disposal pathways were recorded based on Malaysian hospital practices. Carbon emissions were calculated using emission factors from the Greenhouse Gas Protocol and Department for Environment, Food and Rural Affairs, UK (DEFRA), incorporating production and disposal emissions.

● **RESULTS:** A total of 88.2 kg of waste was generated by 46 ophthalmic surgeries during the study period, comprising 19.15 kg of general waste, 62.02 kg of clinical waste, and 7.03 kg of sharps. This corresponded to 353.99 kg of carbon dioxide equivalent (kgCO_2e), including 281.11 kgCO_2e from production emissions and 72.88 kgCO_2e from disposal emissions. Clinical waste was the main contributor (259.18 kgCO_2e; 73.2% of total emissions). The average carbon footprint per surgery was 10.41 kgCO_2e.Re.

● **CONCLUSION:** This study provides the first estimation of the carbon footprint of ophthalmic surgical waste in Malaysia. The findings highlight the significant contribution of ophthalmic consumables to healthcare emissions and underscore the need for sustainable practices, including recycling, reuse, and reduction of single-use items, to align ophthalmology with national and global carbon-neutral healthcare goals.

● **KEYWORDS:** ophthalmic surgery; carbon footprint; clinical waste; healthcare emissions
DOI:10.18240/ijo.2026.12.18

Citation: Mavani DR, Ho JY, Tajunisah. Seeing green in ophthalmology: carbon footprint of surgical waste in a Malaysian Tertiary Eye Centre. *Int J Ophthalmol* 2026;19(12):2463-2468

INTRODUCTION

Healthcare is a major contributor to global greenhouse gas (GHG) emissions, with supply chains responsible for up to 70% of the sector's total carbon footprint[1-2]. Surgical services are particularly resource-intensive due to their reliance on single-use consumables, sterile packaging, and energy-demanding processes. Ophthalmology represents one of the highest-volume surgical specialties worldwide, with cataract extraction being the most frequently performed operation. Therefore, ophthalmic surgery plays a significant role in healthcare waste generation and associated emissions[3-6].

In Malaysia, the environmental burden of healthcare is increasing. The Department of Statistics Malaysia reported that clinical waste rose from 33 757 metric tonnes in 2019 to 57 400 tonnes in 2021, largely driven by the COVID-19 pandemic, and although volumes decreased slightly in 2022, the overall trend remains upward[7-8]. Recognising this challenge, the Ministry of Health introduced the Carbon Neutral Healthcare Facilities Blueprint in 2023, with the goal of achieving carbon neutrality across all healthcare facilities by 2050[9]. The blueprint identifies four main focus areas to achieve Malaysia's long-term sustainability goals, namely global greenhouse gas emission reduction, safe environment, green building, and carbon neutral facility. A central pillar of this initiative is zero-waste management, which prioritises waste minimisation, recycling, and reuse to reduce emissions.

In the UK, one cataract operation was calculated to release approximately 181.8 kg of carbon dioxide equivalent (kgCO_2e) per case, mainly driven by consumables and operating

theatre energy use[6]. More recent observational data from England reported approximately 72.3 $kgCO_2e$ for a standard cataract pathway, with materials accounting for 42.9% of the footprint[10-11]. In contrast, high-volume eye care centres in low-resource settings such as the Aravind Eye Care System have reported as low as approximately 6 $kgCO_2e$ per case, attributed to conservative reuse strategies and lean packaging[12]. Factors that influence the carbon footprint of cataract surgery include procurement of materials, energy consumption, and travel emissions[13-14].

The "Eyefficiency" audit tool has been used across nine global cataract centres to quantify variability in costs, waste generation, and carbon emissions, with per-case global greenhouse gas emissions ranging from 41–130 $kgCO_2e$[15-16]. To date, no published data exist on the carbon emissions associated with ophthalmic surgical waste in Malaysia. This study aims to fill that gap by auditing waste and estimating the related carbon footprint in a tertiary Malaysian eye centre. By providing the first local estimate of emissions from ophthalmic theatres, we hope to highlight opportunities for more sustainable surgical practice and support the integration of ophthalmology into Malaysia's Carbon Neutral Healthcare Facilities Blueprint target of carbon-neutral healthcare facilities by 2050.

MATERIALS AND METHODS

Ethical Appraval This study was conducted as a service evaluation of operating theatre waste and did not involve patient contact, any patient intervention or identifiable patient data. According to institutional guidelines, formal ethical approval was not required.

Study Design and Setting This was a prospective observational study conducted in the Department of Ophthalmology, University Malaya Medical Centre (UMMC), Kuala Lumpur, Malaysia, between 14 and 27 March 2025. UMMC is the country's largest teaching hospital and a major tertiary referral centre with a high surgical volume, including cataract, glaucoma, vitreoretinal, and corneal procedures. Ophthalmic surgeries were performed in mainly Day Case operating theatres. The surgeries consisted of cataract surgeries, combined cataract and trabeculectomy procedures and oculoplastic surgery cases. Surgeries took place on weekdays only; no procedures were performed on weekends or public holidays during the study period.

Waste Collection and Categorization All waste generated during ophthalmic surgeries in the study period was collected daily. Processing or disposal methods for each type of waste were identified based on Malaysian hospital practices, in accordance with Management of Clinical Wastes in Malaysia.

Segregation followed standard Malaysian hospital protocols into three waste streams: General waste-non-hazardous items primarily consisting of packaging materials such as glove wrappers, intraocular lens boxes, phacoemulsification tubing wrappers, cardboard boxes, and mixed paper and plastics. Clinical waste—potentially infectious materials including surgical drapes, gauze, cotton buds, cannulas, gloves, and residual suturing materials with packaging. Sharps–syringes with attached needles, suture needles, and glass drug vials or ampoules.

Waste Disposal Pathways General waste and clinical waste bins were emptied at the end of each day. For sharps, the bin weight was recorded before the start of the surgical list and again at the end of the day to calculate the net daily weight. Disposal methods were documented based on Malaysian hospital practices and confirmed with the hospital's waste management department. All waste was treated according to standard practices: general waste was disposed of *via* landfill, and clinical waste and sharps were incinerated in accordance with national guidelines (Management of Clinical Wastes in Malaysia). No recycling infrastructure was available in the ophthalmology theatres during the study period.

Carbon Footprint Estimation Carbon emissions were estimated using emission factors published by the UK Department for Environment, Food and Rural Affairs UK Department for Environment (DEFRA) within the Greenhouse Gas Protocol accounting framework. The analysis focused exclusively on Scope 3 emissions arising from the production and disposal of surgical consumables. Scope 1 emissions (*e.g.*, anaesthetic gases) and Scope 2 emissions (electricity consumption) were excluded.

Both production emissions from the manufacture of surgical consumables and disposal emissions from waste management processes were included in the calculations. The majority of theatre waste consists predominantly of plastics and disposable textiles, including items such as single-use sterile phacoemulsification packaging, tubing, basins, jugs, surgical blue wrap, and latex.

Production emissions (manufacture of consumables) were estimated using average plastic emission factors, reflecting the predominance of plastic-based disposable materials in ophthalmic surgery: 3179 $kgCO_2e$/tonne for general and clinical waste; 3281 $kgCO_2e$/tonne for sharps. Disposal emissions factors were applied according to Malaysian waste management practices. According to DEFRA, disposal emissions were based on waste management method: 0.2 $kgCO_2e$/kg for landfilled general waste; 1.0 $kgCO_2e$/kg for incinerated clinical waste and sharps. Carbon emissions per waste stream were calculated using the formula: emissions ($kgCO_2e$)=weight of waste (kg)×emission factor ($kgCO_2e$/kg). For example, 10 kg of clinical waste incinerated would contribute 10 $kgCO_2e$, 15 kg of general waste landfilled would contribute 3 $kgCO_2e$,

Table 1 Production and disposal emission factors for ophthalmic surgical waste streams according to DEFRA

Waste type	Production emission factor ($kgCO_2e$/tonne)	Disposal emission factor ($kgCO_2e$/kg)	Disposal method
General waste	3179	0.2	Landfill
Clinical waste	3179	1	Incineration
Sharps	3281	1	Incineration

DEFRA: UK Department for Environment, Food and Rural Affairs; kgCO2e: Kilograms of carbon dioxide equivalent.

Table 2 Waste generated during ophthalmic surgeries at University Malaya Medical Centre over the study period

Date	General waste (kg)	Clinical waste (kg)	Sharps (kg)	Total (kg)
14/03/25	2.32	6.24	0.85	9.41
17/03/25	3.48	10.16	1.12	14.76
19/03/25	2.24	5.56	0.68	8.48
20/03/25	3.94	15.98	1.16	21.08
21/03/25	1.82	5.20	0.85	7.87
24/03/25	1.41	5.32	0.77	7.50
26/03/25	1.56	4.50	0.78	6.84
27/03/25	2.38	9.06	0.82	12.26
Total	19.15	62.02	7.03	88.20

No surgeries were conducted on 15, 16, 18, 22, and 23 March due to weekends and a public holiday.

Table 3 Total carbon emissions from ophthalmic surgical waste over the study period

Waste type	Weight (kg)	Production emissions ($kgCO_2e$)	Disposal emissions ($kgCO_2e$)	Total emissions ($kgCO_2e$)	Total emissions (%)	Average of emissions per case ($kgCO_2e$)
General waste	19.15	60.88	3.83	64.71	18.3	1.90
Clinical waste	62.02	197.16	62.02	259.18	73.2	7.62
Sharps	7.03	23.07	7.03	30.10	8.5	0.88
Total	88.20	281.11	72.88	353.99	100	10.41

$kgCO_2e$: Kilograms of carbon dioxide equivalent.

and 5 kg of sharps incinerated would contribute 5 $kgCO_2e$, yielding a total carbon footprint of 18 $kgCO_2e$ for this sample.

This approach provides an estimate of both production and disposal-related carbon emissions associated with ophthalmic surgical waste at UMMC across the study period (Table 1).

RESULTS

Waste Generation Over the two-week study period, a total of 46 ophthalmic surgeries were performed which consisted of 33 cataract surgeries, 2 combined cataract and trabeculectomy procedures, 10 oculoplastic surgeries, and 1 complex intraocular lens explantation. These ophthalmic surgeries generated a total of 88.2 kg of waste, comprising 19.15 kg (21.7%) general waste, 62.02 kg (70.3%) clinical waste, and 7.03 kg (8.0%) sharps (Table 2). Daily waste generation varied depending on the number and type of surgical procedures performed (range: 6.84–21.08 kg/d). Clinical waste consistently accounted for the largest proportion of daily output.

Carbon Emissions The total carbon footprint of surgical waste during the study period was 353.99 $kgCO_2e$ (Table 3). Of this, 281.11 $kgCO_2e$ (79.4%) arose from production emissions associated with the manufacture of surgical consumables, while 72.88 $kgCO_2e$ (20.6%) derived from disposal emissions. The average emission per case was 10.41 $kgCO_2e$. Clinical waste was the largest contributor, responsible for 259.18 $kgCO_2e$ (73.2%) of total emissions.

General waste contributed 64.71 $kgCO_2e$ (18.3%), despite accounting for over one-fifth of total waste mass. Sharps accounted for 30.10 $kgCO_2e$ (8.5%) of total emissions.

Distribution by Category Tables 2 and 3 illustrate the proportional contribution of each waste stream by weight and by emissions, respectively. While general waste comprised 21.7% of the waste mass, it generated only 18.3% of the carbon footprint due to landfill disposal having lower emission factors. In contrast, clinical waste represented 70.3% of total waste mass but accounted for more than 73% of total emissions because incineration is carbon-intensive.

Sharps contributed only 8.0% of total waste by weight but were responsible for 8.5% of emissions, also reflecting the impact of incineration. Importantly, no recycling practices were identified for general waste, despite the majority consisting of paper and plastic packaging that could potentially be diverted from landfill.

DISCUSSION

This study provides the first quantitative assessment of the carbon footprint associated specifically with ophthalmic surgical waste in a Malaysian tertiary centre. The findings

specifically reflect waste-related carbon emission from surgical consumables and disposal pathway rather than a complete life-cycle carbon footprint of ophthalmic surgery. Our findings demonstrate that ophthalmic surgery generates a substantial volume of waste, with a total carbon footprint of 353.99 $kgCO_2e$ over a two-week period and an average of 10.4 $kgCO_2e$ per case. This study highlights the substantial carbon footprint of ophthalmic surgery at UMMC, primarily driven by single-use consumables and the absence of recycling. Clinical waste accounted for the largest share of emissions, reflecting ophthalmology's heavy reliance on disposable surgical materials such as intraocular lens packaging, ophthalmic viscosurgical device containers, and sterile draping[4,17-20].

Our findings are consistent with reports from the UK, where cataract surgery generates significant waste and carbon emissions, particularly through packaging and disposable surgical sets[6,17-18,21-22]. In contrast, systems such as the Aravind Eye Care model have demonstrated the feasibility of safe and efficient high-volume cataract surgery with markedly lower carbon intensity, reporting emissions of only about 6 $kgCO_2e$ per case[12]. These comparisons suggest that Malaysian ophthalmology could adopt similar sustainability strategies without compromising patient safety.

Additionally, glaucoma surgery audits have shown similar patterns: Aravind generated 0.5±0.2 kg of waste per trabeculectomy compared with 1.4±0.4 kg at a US hospital[13,23-25], reinforcing that low-waste pathways are achievable in resource-limited settings.

The absence of recycling infrastructure in the ophthalmology theatres at UMMC represents a key area for improvement. A large proportion of general waste in this study consisted of potentially recyclable materials, including plastic packaging and paper products, yet all were directed to landfill. In contrast, healthcare systems such as the UK National Health Service have implemented multi-stream waste segregation systems that enable recycling of non-contaminated materials[11,26-27].

Improving recycling practices in ophthalmology theatres requires coordinated efforts beyond individual departments. Collaboration with hospital waste management units, environmental sustainability offices, and university engineering or environmental science departments could facilitate the development of effective recycling practices. For example, partnerships between various departments could enable segregation and reprocessing of clean plastic packaging, auditing the amount of waste products, and pilot testing of waste models. Educational initiatives targeting theatre staff are also essential to improve compliance with waste segregation protocols. Such interdisciplinary approaches have the potential to significantly reduce landfill burden and associated emissions in Malaysian healthcare settings.

The majority of emissions were related to the production of consumables rather than disposal, emphasizing the need for broader systemic changes. Manufacturers and policymakers must prioritise sustainable product design, reduce unnecessary packaging, and encourage reuse where feasible. Ophthalmology societies could also play a role by setting sustainability standards for surgical practice[16,28-31]. Lessons can be drawn from high-volume, resource-efficient models such as the Aravind Eye Care System, which has demonstrated that safe reuse of selected surgical materials and minimization of packaging can dramatically reduce both waste generation and carbon emissions without compromising patient outcomes. While direct replication may not be feasible due to regulatory differences, these models highlight the potential for innovation in sustainable ophthalmic practice.

The limitations of this study include its short two-week duration and the inability to stratify waste by procedure type. Longer audits and procedure-specific analyses would allow for more accurate estimation of annual ophthalmic emissions. The study included a heterogeneous mix of ophthalmic procedures which require different consumables and waste profile. Therefore, the findings represent overall environmental burden of ophthalmic surgery at institutional level rather than procedure specific. Besides that, waste was collected at the operating theatre level and was not stratified according to surgical complexity or additional operative steps such as anterior vitrectomy or secondary intraocular lens fixation which may increase the use of disposable consumables and overall waste generation. Additionally, this study was designed specifically to evaluate waste-related Scope 3 waste related emission. Other contributors to overall environmental footprint of ophthalmic surgery including patient and staff transportation, hospital infrastructure, energy consumption, operating microscope, phacoemulsification equipment, sterilization processes, and anesthetic gases were beyond scope of the present study. Besides that, pharmaceuticals waste was not evaluated and may have contributed to additional carbon emissions. Future studies including comprehensive life-cycle assessment methodology incorporating Scope 1, Scope 2, and Scope 3 would provide a more comprehensive evaluation of the environmental impact of ophthalmic surgery.

In summary, ophthalmology contributes substantially to healthcare emissions in Malaysia. Targeted interventions at both institutional and policy levels are essential if ophthalmic practice is to align with Malaysia's 2050 carbon-neutral healthcare target.

In conclusion, this study demonstrates that ophthalmic surgeries at a major Malaysian tertiary hospital generate a substantial volume of surgical waste with a correspondingly

high carbon footprint. Clinical waste not only constituted the majority of surgical by-products but also accounted for the greatest proportion of emissions, highlighting the environmental burden of incineration. Importantly, production of disposable consumables contributed nearly three-quarters of total emissions, underscoring the hidden but significant upstream impact of current surgical practices.

On average, each surgery generated 10.4 $kgCO_2e$, a figure substantially lower than reports from the UK, where emissions per cataract operation range from 72 to 182 $kgCO_2e$, but still higher than the 6 $kgCO_2e$ per case reported from Aravind Eye Care in India[12]. This comparison suggests that while Malaysia's footprint per case is not as carbon-intensive as some high-income settings, there remains considerable scope to improve efficiency and move closer to best-practice low-carbon models.

These findings highlight a pressing need for sustainable solutions within Malaysian surgical services. Practical interventions include segregation of recyclable materials, optimisation of instrument re-use where safe, and national policies that incentivise low-carbon procurement. International collaboration and benchmarking against models from the UK[10-11] and Aravind Eye Care[12-13] may guide the development of greener ophthalmic surgery pathways.

Ultimately, reducing the environmental footprint of ophthalmic care is not only compatible with maintaining surgical excellence but is also aligned with the broader responsibility of healthcare to safeguard planetary health.

ACKNOWLEDGEMENTS

Authors' Contributions: Tajunisah: Conceptualization, methodology, supervision, and survey design. Ho JY: Data curation, investigation, formal analysis, and preparation of the initial manuscript draft. Mavani DR: Writing–review and editing, manuscript revision, and finalization of the manuscript. Ho JY and Mavani DR contributed equally to this work and share first authorship. All authors contributed to the interpretation of the findings, critically reviewed the manuscript, and approved the final version of the manuscript.

Data Availability Statement: The data generated and analysed during this study are available from the corresponding author on reasonable request. Requests for access to the data will be considered subject to appropriate ethical, institutional, and confidentiality requirements.

AI-Generated Content Disclosure: AI-language model ChatGPT (Open AI) was used to assist with improving the clarity and readability of the manuscript. All content was reviewed and edited by the authors, who bear full responsibility for its accuracy and interpretation.

Conflicts of Interest: Mavani DR, None; **Ho JY,** None; **Tajunisah,** None.

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