Original research

Carbon footprinting and environmental impact of gastrointestinal endoscopy procedures at a tertiary care institution: a prospective multi-dimensional assessment

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ABSTRACT

Background Given the imperative to combat climate change, reducing the healthcare sector's implications on the environment is crucial.

Objective This study aims to offer a comprehensive assessment of the environmental impact of gastrointestinal endoscopy (GIE) procedures, specifically focusing on greenhouse gas (GHG) emissions and waste generation.

Design A prospective study was conducted at the Asian Institute of Gastroenterology (AIG Hospitals), Hyderabad, India, from 29 May to 10 June 2023, including all consecutive GIE procedures. Carbon emissions for various variables involved were calculated with specific emission factors using 'The GHG Protocol'.

Results Based on data from 3244 consecutive patients undergoing 3873 procedures, the study revealed a total carbon footprint of 148 947.32 kg CO_2e or 38.45 kg CO_2e per procedure. Excluding patient travel, the emissions were 6.50 kg CO_2e per procedure. The total waste generated was 1952.50 kg, averaging 0.504 kg per procedure, far less than 2–3 kg per procedure in the West. The waste disposal breakdown was 9.5% direct landfilling, 64.8% incineration, then landfilling and 25.7% recycling, which saved 380 kg CO_2e. India effectively recycles 25.7% of hospital-related waste, which undergoes landfilling in the West. The primary contributors to GHG emissions were patient travel (83.09%), electricity consumption (10.42%), medical gas transport and usage (3.63%) and water consumption (1.86%). Diagnostic procedures generate less waste and lower carbon footprint than therapeutic procedures.

Conclusion This study highlights the significant environmental footprint of GIE procedures, emphasising the importance of optimising practices to reduce patient travel and repeat procedures, alongside improving electricity and water management for sustainable healthcare.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ The healthcare sector plays a substantial role in greenhouse gas (GHG) production and contributes around 4.4% of the overall GHG emissions.

⇒ Gastrointestinal endoscopy (GIE) is the third largest source of hazardous waste within hospitals and is the second largest waste producer per clinical procedure, surpassed only by radiology.

WHAT THIS STUDY ADDS

⇒ Diagnostic procedures generate less waste and lower carbon footprint than therapeutic procedures.

⇒ Several critical differences in hospital waste management and GIE procedure carbon footprints emerge comparing India with the Western countries.

⇒ The waste disposal subdivisions were direct landfilling (9.5%), incineration, then landfilling (64.8%) and recycling (25.7%). This saved 9816 kg CO_2e per year, showing the positive impact of recycling.

INTRODUCTION

The greenhouse gases (GHGs) produced by human activity, most notably carbon dioxide (CO_2), are a major contributor to global climate change, a significant challenge in the 21st century. These emissions impact human health and necessitate immediate attention.[1,2] The healthcare sector plays a substantial role in GHG production and contributes around 4.4% of the overall GHG emissions.[3,4] Within hospitals, gastrointestinal endoscopy (GIE) is the third-largest source of hazardous waste, following only anaesthesia and paediatrics/intensive care, and is the second-largest waste producer per clinical procedure, surpassed only by radiology.[5]

Widely used in medical practice, GIE plays a vital role in diagnosing and treating

> **HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY**
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> ⇒ Sustainable transportation options, such as air biofuel, electric vehicles and telemedicine, can reduce patient-travel emissions.
> ⇒ Enhancing training at community healthcare facilities can improve care quality and diminish the need for specialised care referrals, addressing the high impact of patient travel.
> ⇒ Comparative studies should be designed to evaluate the carbon footprint of non-invasive versus invasive diagnostic procedures and the environmental impact of endoscopic therapeutic procedures compared to surgical procedures for similar clinical indications.
> ⇒ Detailed subgroup analyses should be conducted to assess the carbon footprint of various therapeutic endoscopic procedures.
> ⇒ Set up dedicated 'Sustainability' departments in major hospitals led by 'Eco-Visionaries' and 'Green Endoscopy Revolutionaries'.

gastrointestinal diseases. These procedures require significant resources, including energy, water and various consumables, and necessitate travel for both patients and staff.[6] The lifecycle of these consumables–from production and transport to usage–results in a substantial carbon footprint.[7] Many of these items are not recyclable, leading to increased hospital waste and GHG emissions. Moreover, there has been a surge in the adoption of disposable, single-use (SU) endoscopes,[8] mainly to enhance infection control measures but raising significant concerns over their economic, environmental and social impacts.[9] Given the ecological concerns of SU endoscopes, studies need to identify high-risk groups that require them, promoting judicious resource use, for example, immunocompromised patients and patients who have undergone previous endoscopic retrograde cholangiopancreatography (ERCP).

Countries around the world are targeting net-zero emissions by 2050 (USA and the European Union), 2060 (China) and 2070 (India).[10 11] Meanwhile, endoscopy societies worldwide are advocating for GIE to become a net-zero GHG emission practice by 2050.[12–14]

The *Green Endoscopy*[6 12 15] concept advocates environmentally responsible GIE practices, aiming to raise awareness, assess and reduce endoscopy's carbon emission impact. Given the limited research on the environmental impact of GIE, our study conducted a comprehensive, multi-factorial prospective analysis to thoroughly evaluate the carbon footprint from direct and indirect GHG emissions and waste generation in diagnostic and therapeutic GIE procedures. This analysis aimed to identify waste reduction, recycling and eco-friendly healthcare opportunities.

METHODOLOGY

Study outcomes

The primary outcome was the overall carbon footprinting of the GIE procedures, conducted at the Asian Institute of Gastroenterology (AIG Hospitals), Hyderabad, India, by calculating the related GHG emissions and waste generated. The secondary outcome was the comparison between diagnostic and therapeutic procedure subgroups.

Study design

This prospective observational study was conducted from 29 May to 10 June 2023. *General Carbon*, a company specialising in this analysis, calculated the unit's carbon footprint.

Our centre is a premier tertiary care institution in India that specialises in various GIE procedures. The centre is equipped with a total of 15 procedure rooms: eight endoscopy rooms for diagnostic endoscopy, colonoscopy and enteroscopy, one room for therapeutic endoscopy and colonoscopy not requiring general anaesthesia (GA), two rooms for diagnostic endoscopic ultrasound (EUS), two rooms with high-end fluoroscopy for performing therapeutic ERCP and EUS, one room for extracorporeal shock wave lithotripsy (ESWL) and one dedicated *hybrid room* for performing third space therapeutic GIE procedures requiring GA. The therapeutic and hybrid rooms are equipped with anaesthesia and electrosurgical cautery machines. Our unit is outfitted with a total of 40 endoscopes: 15 upper GI endoscopes, 12 colonoscopes, one single balloon enteroscope, eight duodenoscopes and four EUS scopes, along with 10 endoscope re-processing automatic washing machines, all of which were included in the study analysis. Our centre has 92 staff members working in the endoscopy suites, including 16 endoscopists, 20 nurses, 20 technicians, 30 paramedical staff and six administrative staff. All consecutive patients undergoing diagnostic and therapeutic GIE procedures during the study period were included (online supplemental table 1). All devices and accessories used in the study are single-use devices (SUDs). No single-use (SU) endoscopes were used. Informed consent was obtained, as per hospital protocol, for each patient. The study team comprised two medical gastroenterologists, one senior anaesthetist, two experienced endoscopy nurses and one climate science consultant. The data collection process and study boundaries are illustrated in figure 1.

Patient and public involvement

This study does not involve human participants.

Ethics statement

The Institutional Review Board (Asian Healthcare Foundation, AIG Hospitals, Hyderabad, India) approved the study (IRB No: AHF/02-34/2023).

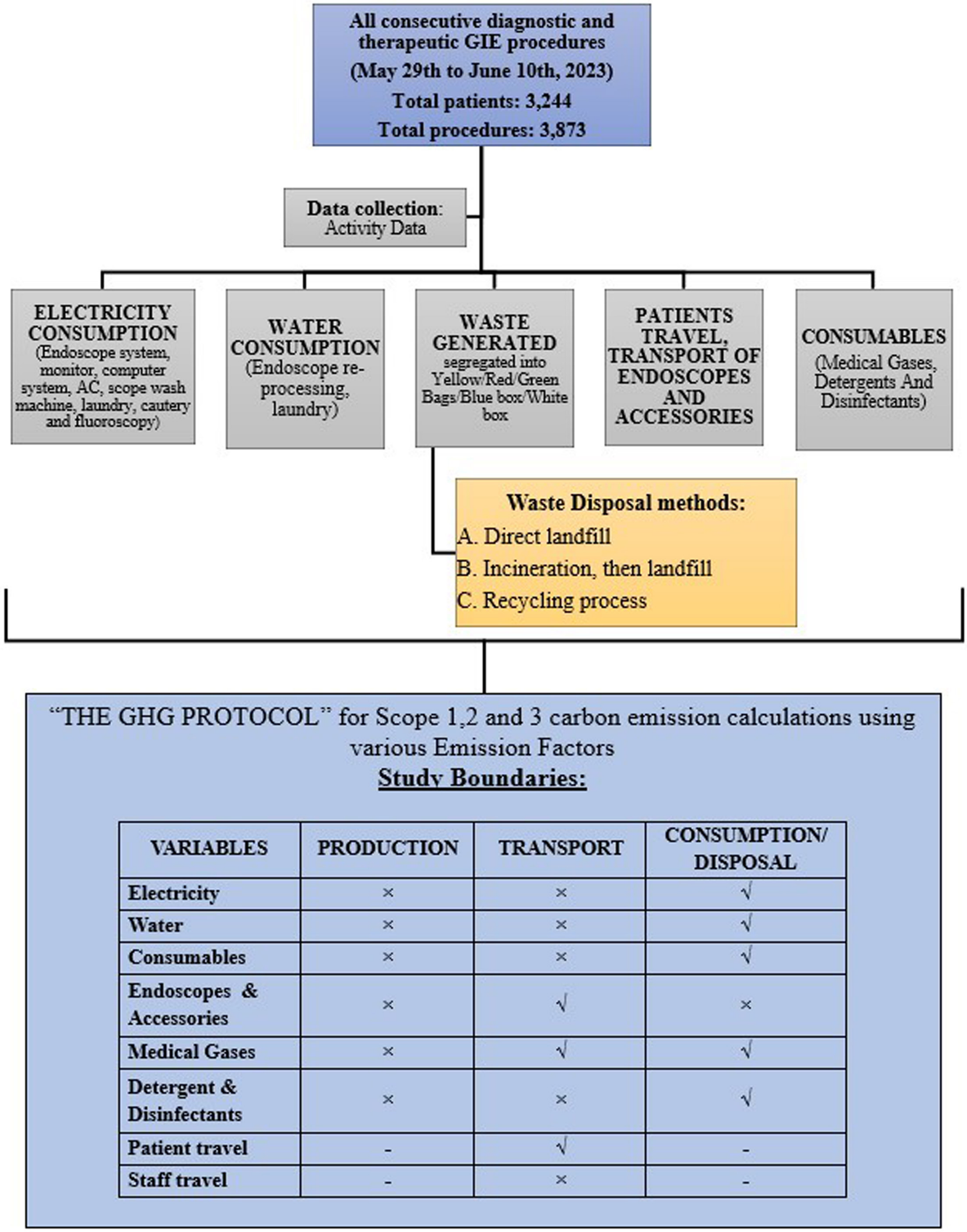
Definitions

Carbon footprint[6] is defined as the total set of GHG emissions caused directly and indirectly by an individual, event, organisation or product and is expressed as carbon dioxide equivalent (CO_2e). GHG emissions are classified into three scopes[16]: *Scope 1*, *Scope 2* and *Scope 3*, based on the type of energy consumption. *Diagnostic endoscopy* was defined as performing endoscopy, colonoscopy, enteroscopy or EUS, either with or without the collection of biopsy samples, depending on the clinical indication and the findings during the procedure.

Data collection and data analysis

The following **variables** were considered: electricity and water consumption, waste generated, patient travel, transport of medical gases, endoscopes, accessories and usage of medical gases, detergents and disinfectants. **Activity data (AD)** was collected for each variable, and the **GHG emissions** were calculated for each data category.

The *'GHG protocol'* was the methodological guideline used for data analysis.[17] This protocol provided a robust framework for calculating and reporting GHG emissions. While the GHG



VARIABLES	PRODUCTION	TRANSPORT	CONSUMPTION/ DISPOSAL
Electricity	×	×	√
Water	×	×	√
Consumables	×	×	√
Endoscopes & Accessories	×	√	×
Medical Gases	×	√	√
Detergent & Disinfectants	×	×	√
Patient travel	-	√	-
Staff travel	-	×	-

Figure 1 Schematic diagram showing the data collection process and greenhouse gas emission calculations. GIE, gastrointestinal endoscopy; GHG, greenhouse gas; AC, air conditioner.

protocol recommends a comprehensive assessment of all emissions, some exceptions in our study will be discussed subsequently (figure 1). Carbon footprinting was done using *emission factors (EF*), which quantified emissions released per activity unit and were sourced from pre-specified data (online supplemental table 2). These EFs, combined with the AD, were used to calculate the GHG emissions for each activity. By applying the respective EFs to the cumulative AD, we determined the total GHG emissions associated with GIE for diagnostic and therapeutic procedures.

The data was collected and analysed as follows:

1. *Electricity consumption*: electricity details (used for endoscopy processor units, monitors, computer systems, air conditioners, lights, endoscope re-processing washing machines,

Table 1 Electricity consumption, water consumption and waste generated overall and per procedure, comparing diagnostic and therapeutic procedures

Parameter	Diagnostic procedures (n=3503)	Therapeutic procedures (n=370)	All GIE procedures (n=3873)
Electricity consumption	13 166 kWh overall, 3.75 kWh per procedure	5994.4 kWh overall, 16.20 kWh per procedure	19 160.4 kWh overall, 4.94 kWh per procedure
Water consumption	204 000 litres overall, 58.23 litres per procedure	58 800 litres overall, 158.91 litres per procedure	262 800 litres overall, 67.85 litres per procedure
Waste generated			
Yellow bag (incineration, then landfill)	539.92 kg	73.23 kg	613.15 kg (31.42%)
Red bag (incineration, then landfill)	476.65 kg	174.95 kg	651.60 kg (33.38%)
Green bag (recycling)	244.80 kg	181.78 kg	426.58 kg (21.84%)
Blue box (direct landfill)	141.56 kg	22.22 kg	163.78 kg (8.38%)
White box (direct landfill)	19.30 kg	2.90 kg	22.2 kg (1.13%)
Miscellaneous waste (recycling)	69.10 kg	6.08 kg	75.18 kg (3.85%)
	1491.33 kg overall, 0.425 kg per procedure	461.16 kg overall, 1.24 kg per procedure	1952.50 kg overall, 0.504 kg per procedure

GIE, gastrointestinal endoscopy.

fluoroscopy machines, ESWL machines, laundry machines for washing gowns and bedsheets) were retrieved from the hospital's Engineering and Maintenance departments. The power consumption of machines in our study was calculated using approximate hours of use per day, multiplied by the power requirements as specified by the manufacturers in kilo Watts per hour (kWh); for example, per each endoscope processor unit, it is 1.6 kilo Watts per hour (kWh), and for each endoscope re-processing automatic washing machine, it is 4.5 kWh (online supplemental table 3). Emissions were calculated by multiplying the power consumption per instrument by the duration of usage, the number of instruments employed and the EF for electricity consumption (0.81 t CO_2e) (online supplemental table 3).

2. *Water consumption:* details of the water consumed for endoscope reprocessing washing machines and laundry were retrieved from the hospital's Engineering and Maintenance departments. For example, each cycle washes two endoscopes using 75 litres of RO water. Emissions were estimated by multiplying the machines used and the water required for every two endoscope washes based on the daily procedures performed with the EF for water consumption (10.6 kg CO_2e/KL) (online supplemental table 4).
3. *Waste generated*: the hospital's waste management policy, a crucial aspect of our research, mandated the segregation of waste into colour-coded categories[18 19] – yellow and red plastic bags for biohazard waste, green plastic bags for general waste, blue plastic boxes for glass waste and white plastic boxes for sharps. Additionally, miscellaneous waste included consumables such as plastic biopsy containers and case paper sheets used for pre-anaesthesia fitness. The waste generated was further sub-categorised based on three disposal methods: direct landfilling; incineration, then landfilling; or recycling. Although the waste in yellow and red bags undergoes incineration first then landfilling, there is a difference in the incineration process due to the nature of their waste. The incineration process for yellow bag waste is more rigorous. It involves higher temperatures and stricter controls to ensure the destruction of infectious materials, while red bag waste undergoes pretreatment and is incinerated at lower temperatures. Plastic waste recycling in India[20] involves a sequential process comprising the collection of plastic waste, its sorting based on type and quality, shredding into smaller pieces, cleaning to remove impurities, melting at controlled temperatures, converting the molten material into uniform pellets and finally reusing these pellets to manufacture new products.
Two experienced nurses were responsible for monitoring and recording the consumables and instruments used for each diagnostic and therapeutic procedure for data collection of the waste generated. The waste generated in both the pre- and post-procedure areas, as well as in the endoscopy room, was considered. The weight of each instrument used and discarded for various procedures throughout the day was determined using a paediatric weighing machine (SAMSO FLEX; Docbel Scales, Uttarakhand, India). The scale was calibrated, with its stated accuracy being 2 grams. This was multiplied by the approximate number of materials used during the day based on the procedures to get the exact weight in kilogram units (kg) of things discarded in each colour-coded box or bag. At the end of each working day, it was consistently verified that the waste sorting was adequately accomplished.
The carbon footprint was calculated in the following way: we took the weight of each instrument and multiplied it by the numbers used during the study period to derive the total weight of individual instruments. This weight was multiplied by the EFs. Our study's EFs for waste disposal are DESNZ factors: the Department of Energy Security and Net Zero factors, sourced from the UK. These EFs (online supplemental table 2) were based on the known constituent materials of the instruments,[7] as determined from previous studies and available material information. To decide the EFs, we have considered the primary materials in the instrument, eg, forceps and snares are made of plastic and steel, and hemoclips are made of steel. We have presented some examples of calculations in online supplemental table 5.
4. *Patient travel*: the patient's addresses were extracted from the hospital's electronic medical record system (Health Plug MD, IQVIA, Hyderabad) to assess the travel component. This assessment and calculations were based on a previous survey conducted by the AIG Hospital management in September and October 2018. The survey was conducted to understand the socioeconomic and socio-demographic patterns of patients visiting the hospital when the new hospital branch started in June 2018. The responses of this survey with the response rate (84.74%) are mentioned in online supplemental table 6. We used data from our previous survey for travel emission calculations because the socioeconomic and com-

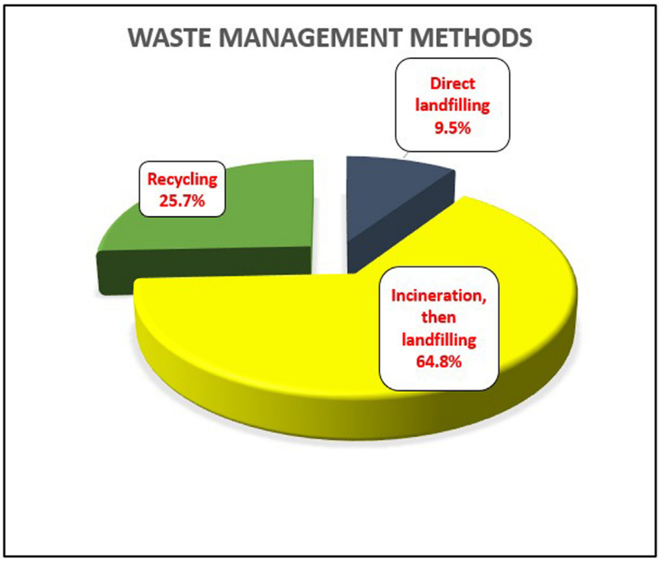


Figure 2 Distribution of waste management pattern based on the type of disposal: direct landfilling, incineration, then landfilling and recycling.

muting patterns closely match our current study population. It provided insights into the standard modes of transportation patients use, allowing us to make reasonable assumptions about their travel emissions. Based on the above data, we then considered the following travel patterns: patients within the same state (Telangana) travelled by bus (100%), patients from different states travelled either by train (80%) or by flight (20%) and patients from outside India travelled by flight (100%). The nearest mappable major city was identified from each address, and the distance from Hyderabad was calculated. After obtaining the distances, the average distance was taken for all three modalities: bus, train and flight. The number of patients travelling by each respective mode was multiplied by the average kilometres travelled to obtain the passenger kilometres (pax/km). This value was then multiplied by the EFs for that mode of transport, as mentioned in online supplemental table 2, to calculate the overall emissions related to travel (online supplemental table 7).

5. *Transport of endoscopes and accessories:* the transportation emissions from manufacturing sites worldwide to Hyderabad, India, were calculated based on the weights of the endoscopes and accessories with their packaging as provided by the manufacturers in Japan (for endoscopes) and the USA and Europe (for accessories). The air travel distance from Tokyo to New Delhi, and then to Hyderabad, was noted for endoscope transport. Similarly, the sea-travel distance from manufacturing sites in the USA and Europe to Mumbai was reported, followed by air travel from Mumbai to Hyderabad (online supplemental table 2). The emissions for transporting endoscopes and accessories were calculated using the EFs for freight transport by air and sea, as shown in online supplemental table 8.
6. *Transport and usage of medical gases (CO_2 and O_2):* we obtained details of transporting medical gases from the manufacturing sites to our unit in tanker trucks by road to the hospital. Also, details of their daily usage through central supply to the entire endoscopy division, including the pre- and post-endoscopy area, were retrieved from the hospital's Engineering and Maintenance departments. The carbon emissions due to carbon dioxide gas usage (4000 kg CO_2e, as per the EF of 1 kg CO_2e / kg CO_2) (Scope 1 emissions). Additionally, based on the EF of freight transport by road, the emissions for transport of medical gases were calculated as shown in online supplemental table 9 (Scope 3 emissions).
7. The quantity of *detergents and disinfectants* used for endoscope washing and laundry of bedsheets and gowns was noted daily. The emissions were calculated based on the amount used and applying the EFs, as shown in online supplemental table 10.

Statistical analysis

Data collection and analysis were conducted using Microsoft Excel (Microsoft Excel for Microsoft 365, Version 16.0, Microsoft Corporation, Redmond, WA, 2024) in line with standard scientific practices. All authors had access to the data and approved the final manuscript. A descriptive analysis was conducted to summarise the basic features of the data in the study.

RESULTS

Study sample

We examined data from 3873 procedures performed on 3244 consecutive patients during the study period. These encompassed the full spectrum of GIE procedures, as detailed in online supplemental table 1. Of these procedures, 3503 were diagnostic, and 370 were therapeutic. Most procedures were performed under conscious sedation using propofol, with only n=18 (0.46%) patients being given GA.

Electricity consumption, water consumption and waste-generated analysis

The electricity (4.94 kWh/procedure) and water (67.85 litres/procedure) consumption during the study period are depicted in table 1. The total waste generated was 1952.50 kg, averaging 0.504 kg per procedure. Annually, the estimated total waste (considering 310 working days per year) is 50 439.60 kg, which, if spread in a 0.5-metre layer, could cover a 20 000 m^2 cricket stadium. Diagnostic procedures produced 1491.33 kg of overall waste (0.425 kg per procedure) and therapeutic procedures produced 461.16 kg of overall waste (1.24 kg per procedure). Although there was a clear numerical difference, this did not reach a statistical difference. The waste disposal subdivision, according to methods of disposal (figure 2), was direct landfilling (9.5%), incineration, then landfilling (64.8%) and recycling (25.7%).

Carbon footprinting calculations

The total carbon footprint generated during the study period was 148 947.32 kg CO_2e, averaging 38.45 kg CO_2e per procedure. Therapeutic procedures had higher per-procedure carbon emissions than diagnostic procedures (table 2).

Scope 1 (direct) emissions were 4000 kg CO_2e, while Scope 2 (indirect) emissions totalled 15 519.92 kg CO_2e, and Scope 3 (indirect) emissions amounted to 129 428.08 kg CO_2e, as shown in table 2. The contributors to GHG emissions in descending order were patient travel (83.09%), electricity consumption (10.42%), medical gas transport and usage (3.63%) and water consumption (1.86%), followed by detergent and disinfectant usage (0.52%), endoscopes and accessories transport (0.41%) and waste generated emissions (0.025%).

Excluding patient travel, the emissions from all endoscopic procedures during the study period amounted to 25 176.76 kg

Table 2 Greenhouse gas emission calculations (kg CO_2e) as per Scope 1, Scope 2 and Scope 3, comparing diagnostic and therapeutic procedures

Parameters		Diagnostic procedures (n=3503) (kg CO_2e)	Therapeutic procedures (n=370) (kg CO_2e)	Total GHG emissions (n=3873) (kgCO_2e)
Medical gas usage (CO_2)	Overall			4000
	Per procedure			1.03
Total **Scope 1** emissions				4000 (2.68%)
Electricity consumption	Overall	10 664.46	4855.46	15 519.92
	Per procedure	3.04	13.12	4.00
Total **Scope 2** emissions				15 519.92 (10.42%)
Water consumption	Overall	2162.4	623.28	2785.68 (1.86%)
	Per procedure	0.61	1.68	0.71
Patient travel	Overall			123 770.56 (83.09%)
	Per procedure			31.95
Scope transport	Overall			605.04 (0.40%)
	Per procedure			0.15
Accessories transport	Overall			21.31 (0.014%)
	Per procedure			0.005
Waste generated	Overall	29.60	9.11	38.71 (0.025%)
	Per procedure	0.008	0.02	0.009
▶ Yellow bag		10.74	1.45	12.19
▶ Red bag		9.52	3.48	13.00
▶ Green bag		4.67	3.54	8.22
▶ Blue box		3.01	0.47	3.48
▶ White box		0.17	0.02	0.19
▶ Misc. waste		1.47	0.12	1.59
Transport of medical gases (CO_2 and O_2)	Overall			1428.90 (0.95%)
	Per procedure			0.36
Usage of detergents and disinfectants	Overall			777.2 (0.52%)
	Per procedure			0.20
Total **Scope 3** emissions				129 427.4 (86.9%)
Total emissions	Overall			148 947.32
	Per procedure			38.45

CO_2e, averaging 6.50 kg CO_2e per procedure. Extrapolating this data to a year (310 working days), the estimated annual GHG emissions from GIE procedures would be 650 400 kg CO_2e. These yearly carbon emissions of 650 400 kg CO_2e are akin to the GHG emissions[21] from 145 gasoline-powered passenger vehicles driven for 1 year or 1 667 520 miles driven by an average gasoline-powered passenger vehicle. To illustrate further, covering 1 667 520 miles is about making seven round trips to the Moon, circling the globe approximately 67 times, travelling the length of the Great Wall of China around 126 times or journeying the length of the Amazon River about 383 times.

So, suppose this data was flipped around and viewed from a patient perspective. In that case, 6.5 kg CO_2e (generated by a single GIE procedure) is 0.26% of an individual's yearly ***carbon 'budget'*** (according to global averages, an individual's carbon budget to limit global warming[22] to 1.5°C is roughly 2000 to 3000 kg CO_2e per year). Assuming a total lifetime carbon budget of 2500 kg CO_2e per year, with an average life span of 80 years and a patient undergoing five such GIE procedures, these procedures will account for 0.01625% of an individual's lifetime carbon budget. If an average car in India emits about 0.12 kg CO_2e per kilometre, a 55 km round trip commute emits approximately 6.5 kg CO_2e daily, the emissions from a single GIE procedure. The average CO_2 emissions per household in India due to electricity use is approximately 1000 kg CO_2e annually, which is roughly equal to performing 154 GIE procedures. This approach contextualises carbon emissions from a patient's perspective by comparing them to everyday activities, helping patients and healthcare providers understand their environmental impact and the importance of sustainable practices.

Review of the recycling process

The recycling figure in our study was arrived at through a detailed review of the recycling process and its impact on carbon emissions. In our study, 25.7% of waste undergoes recycling. Assuming this waste had undergone landfilling disposal as in the West, we avoided 380 kg CO_2e emissions (approximately 9816 kg CO_2e per year), underscoring the positive impact of recycling. A simple example can explain this. Considering the empty glove boxes (online supplemental table 5), the total calculated emissions are 0.6 kg CO_2e (with EF of 21.281 kg CO_2e/tonne). If this same content goes to the landfill directly, the EF will be 1164.39 kg CO_2e/tonne, making the emissions 33.53 kg CO_2e. Similarly, if applicable EFs are used for other components; the total emissions avoided by not doing landfill for the recyclable materials is 380 kg CO_2e per 2 weeks. This equates to approximately 9816 kg CO_2e per year. Recycling[21] in this context is as effective as generating 9816.6 kWh of solar energy, removing 2.1 cars from Indian roads and absorbing the annual CO_2 emissions of 467 trees, emphasising its environmental benefits amidst India's deforestation issues.

Table 3 Comparison of greenhouse gas emissions and waste generated between previously published studies from the West and the present study from India

Parameters	Namburar[24] *et al* (USA)	Lacroute[16] *et al* (France)	Desai[25] *et al* (USA)	Present study (India)
Procedures included (study duration)	278 (5 days)	8524 (1 year)	450 (1 month)	3873 (2 weeks)
Water consumption (per procedure)			13.85 gallons (52.42 litres)	17.92 gallons (67.85 litres)
Waste generated (overall)	619 kg		1398 kg	1952.50 kg
Waste generated (per procedure)	2.2 kg		3.03 kg	0.504 kg
Landfill waste disposal	1.34 kg per procedure (direct landfill: 63%)		2.19 kg per procedure (direct landfill: 61%)	0.04 kg per procedure (direct landfill - 9.5%), 0.34 kg per procedure (Incineration, then landfill: 64.8%)
Recyclable waste	56 kg (9%)		282 kg (20%)	501.76 kg (25.7%)
Electricity consumption-related emissions (per procedure)		3.39 kg CO_2e	19.80 kg CO_2e	4.00 kg CO_2e
Patient and staff travel-related emissions		45%	–	83.09% (staff travel excluded)
Carbon emissions (overall)		2 42 081 kg CO_2e	6754 kg CO_2e	148,947.32 kg CO_2e
Carbon emissions (per procedure)		28.4 kg CO_2e	15.01 kg CO_2e	38.45 kg CO_2e
Carbon emission (per procedure, excluding patient and staff travel)		12.78 kg CO_2e	15.01 kg CO_2e	**6.50 kg CO_2e**

DISCUSSION

This is the first study to comprehensively estimate the carbon footprint of an Asian tertiary care GI endoscopy unit. It encompasses various sources of GHG emission and differentiates between diagnostic and therapeutic GIE procedures. The study reveals that the average carbon footprint is 38.45 kg CO_2e per procedure, with patient travel being the largest contributor, accounting for 83.09% of emissions. Furthermore, it underscores the environmental benefits of recycling, with 25.7% of waste being recyclable, reducing 380 kg CO_2e emission in 2 weeks. Although the data covers a short study period, it represents the unit's endoscopic procedures throughout the year, as we consistently experience a similar workload year-round.

In our study, electricity consumption (15 519.92 kg CO_2e; 10.42%) is a significant contributor, indicating the need for sustainable renewable energy sources. Water consumption, at approximately 2785.68 kg CO_2e (1.86%), presents a viable opportunity for optimisation to reduce environmental impact. Transport of endoscopes and accessories (605.04 kg CO_2e; 0.40%), medical gas transport and usage (5428.90 kg CO_2e; 3.63%) and detergent and disinfectans usage (777.2 kg CO_2e; 0.52%) also contribute to GHG emissions.

In comparing our study's findings with those from Western countries, several key differences in carbon footprinting emerge (table 3):

1. As previously shown in studies from the West,[15 23] each GIE procedure generates 1.5 kg of plastic waste, which is not recycled and thus contributes to landfill. Subsequent studies from the USA,[24 25] France[16] and Germany[26] expanded the research on GIE procedures, reporting an average waste of 2–3 kg. In India, waste per procedure is significantly lower at 0.504 kg, 4–5 times less than in the West, mainly due to the more prevalent use of reusable materials like doctor's gowns and patient bedsheets. Excluding patient travel, carbon emissions in India are lower due to reduced waste generation and more effective resource use, including *conscious sedation* for anaesthesia, which involves fewer disposables and less energy consumption.
2. In Western countries, primarily, the waste goes directly to landfills (62%),[23] while in India, direct landfilling accounts for only 9.5%, with the majority undergoing incineration and then landfilling (65%). India effectively recycles 25.7% of recyclable waste, often landfilled in the West. India is increasingly adopting innovative technologies to transform waste into energy,[27 28] enhancing nationwide waste management and recycling efficiency. Some salient differences exist between the carbon emissions of ***incineration*** and ***landfilling*** processes. Incineration has some *advantages* over direct landfilling: (a) landfilling[29] produces more methane, while incineration produces more CO_2. Given methane's higher global warming potential (28–36 times the potential of CO_2 over 100 years), this can be a significant factor. (b) Incineration reduces the volume of waste (up to 80–90%) that needs to be landfilled, which can indirectly reduce methane emissions from landfills in the long term. The *disadvantage* of incineration is the generation of toxic emissions like dioxins and other harmful substances if not efficiently managed. In our study, carbon emissions of yellow and red bags undergoing incineration, then landfilling are 25.30 kg CO_2e. If the same materials underwent only landfilling, then using the applicable EFs, the total emissions would have been 82.97 kg CO_2e (eg, the EF for cotton gauze piece undergoing incineration is 21.281, and if it undergoes landfilling, then it is 496.683). As a result, the emissions from only landfilling of the same waste would be more than three times higher than from waste disposed of using incineration, followed by landfilling (online supplemental table 11).
3. Patient travel contributes disproportionately to GHG emissions in India (123 770.56 kg CO_2e; 83.09%), differing from Western studies. This is primarily due to the tertiary nature of our healthcare facility and the necessity of patient travel for specialised care, especially when the required facilities are unavailable at their local centres. To mitigate this, sustainable transportation options like air biofuel[30] and electric vehicles[31] are essential. Telemedicine[32] also significantly reduces emissions, with potential savings of 0.70 to 372 kg CO_2e per appointment, primarily by decreasing travel. Future research is needed to assess these impacts. Enhancing the training of the physicians at community healthcare facilities can improve care quality and diminish the need for specialised care referrals, addressing the high impact of patient travel. Unlike the study by Lacroute *et al*,[16] which calculated staff travel

emissions too, we did not include these in our calculations. In our case, most of our staff reside in hospital-provided residential facilities near the hospital. Their commuting distance is minimal and would likely have an insignificant impact on the overall carbon footprint. We acknowledge that these travel patterns are not directly generalisable to most European countries and the USA, where healthcare facilities may be more evenly distributed and accessible, reducing the need for long-distance travel. We recommend that if more robust patient-related travel data from different regions of the world becomes available, conducting a ***sensitivity analysis*** in the future would be valuable. This analysis could illustrate the impact and percentage of travel-related emissions within the total emissions related to endoscopy, providing a comparative perspective across various global regions.

As seen in our study, the difference in carbon footprints between *diagnostic and therapeutic procedures* is a key factor in guiding resource allocation and identifying emission reduction opportunities to mitigate their environmental impact. Therapeutic procedures consume more *electricity* due to their longer duration; use of cautery, anaesthesia and fluoroscopy machines; and extended scope re-processing time. The waste from therapeutic procedures, over double that of diagnostic procedures, is mainly due to using SUDs and consumables. The reprocessing of endoscopes typically involves a similar quantity of *water* for both diagnostic and therapeutic procedures. However, the difference in water usage in our study is mainly because, for diagnostic procedures, two scopes are usually washed per cycle, which is not always the same for therapeutic procedures, resulting in higher water usage per scope wash. Additionally, therapeutic procedures may involve multiple scopes, further contributing to variations in water usage. Notably, the reverse osmosis water used for scope re-processing, despite having a high wastage rate, is repurposed in the hospital for gardening and sanitation, demonstrating effective water management.

In our study, emissions from medical-grade gases, particularly CO_2 used in procedures like endoscopy (5428.90 kg CO_2e; 3.63%), are negligible when compared with broader industrial sources, confirming a minimal impact on global GHG levels. Medical-grade CO_2 is often a byproduct of other industrial processes; it is captured and repurposed, which can be viewed as a form of recycling. While any release of CO_2 into the atmosphere could technically contribute to GHG concentrations, the scale of CO_2 usage in medicine is very small when compared with overall emissions from sources like fossil fuel combustion, deforestation and large-scale industrial activities. Therefore, the impact of CO_2 used in medical procedures on global climate change is negligible.

Waste disposal emissions represent only a small fraction (38.71 kg CO_2e; 0.025%) of the overall carbon footprint, reflecting effective waste management. Although emissions from hospital waste disposal represent a relatively small fraction of the overall carbon footprint, the substantial energy consumption and space required for waste management highlight a complex area for research and policy development. It is imperative to focus on reducing waste generation and exploring eco-friendly disposal options, including comprehensive recycling programmes.

While endoscopy is a valuable diagnostic tool, studies indicate some endoscopy procedures may be unnecessary or avoidable.[33] The debate continues over the necessity of endoscopies[34] and colonoscopies,[35] especially screening programmes. *Non-endoscopic alternatives* should be considered as part of a comprehensive approach to reducing the carbon footprint. These include advanced imaging techniques[36–38] (eg, MRI, CT scans, fibroscan) or biochemical markers,[39 40] which may provide effective alternatives to endoscopy. Artificial intelligence[41] can help avoid unnecessary histopathology examinations, such as those for colon polyps. Although emissions per case are small, their cumulative impact is considerable, highlighting the importance of making pathology labs more eco-friendly.[42]

There is an urgent need for dedicated *'Sustainability' departments* in major hospitals led by *'Eco-Visionaries'* and *'Green Endoscopy Revolutionaries'*. These are collective terms for healthcare professionals, endoscopists, stakeholders, societies and legislators who tackle pressing eco-environmental issues and study the impact of human activities on our planet.

Our research calls for prioritising *high-impact* strategies like minimising patient transportation, optimising medical device logistics and reducing water and electricity usage while also adopting *lower-impact* yet cumulatively significant measures like transitioning to digital patient information through QR codes and replacing physical booklets with metal biliary or oesophageal stents to lessen material use substantially.

Nonetheless, some *limitations* of our study must be addressed, which are as follows. *First*, this is a single-centre study, which may not reflect the varied GHG emissions and waste disposal patterns across different centres in India. *Second*, the analysis includes transport emissions for endoscopes and accessories, but the complete life cycle assessment (cradle to grave) was not performed. *Third*, an *uncertainty analysis* of AD and EFs could not be done as incorporating it would require a more extensive dataset and additional resources to quantify the variability and confidence intervals around our estimates accurately. *Fourth*, due to the lack of precise timing for each procedure, we could not calculate the mean and SD or perform accurate significance tests, which prevented us from establishing statistical significance between diagnostic and therapeutic procedures. *Fifth*, our study did not account for the complexity, duration or variations in therapeutic techniques, limiting the ability to conduct a detailed subgroup analysis. Most procedures were ERCPs, which are more energy-intensive than simpler procedures like polypectomies. This variability in environmental impact means the findings should be interpreted cautiously. The absence of a subgroup analysis may affect the accuracy of comparing carbon footprints between diagnostic and therapeutic procedures, and the results may not be fully generalisable. Future research should gather more detailed data to support subgroup analysis and address this limitation. *Lastly*, the GHG emissions from the outpatient department were not included, which would provide a more comprehensive understanding of the gastroenterology department's carbon footprint.

In **summary**, our study highlights the significant environmental impact of endoscopic procedures and advocates for a comprehensive sustainability approach, from product lifecycle analysis to the adoption of eco-friendly practices and guidelines. The positive impact of recycling hospital waste in India, demonstrated by substantial CO_2 emission reduction, aligns with the country's broader environmental and sustainable developmental goals.

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