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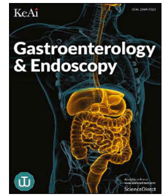

Green endoscopy: Sustainable practices and implementation strategies for environmentally responsible gastrointestinal care

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ABSTRACT

Healthcare contributes an estimated approximately 5% of global greenhouse gas emissions, with endoscopic procedures among significant contributors through high energy consumption, extensive single-use consumables, and substantial medical waste generation. Gastrointestinal endoscopy ranks among the highest waste-generating specialties within hospital settings, yet its environmental implications have received limited attention until recently. This narrative review aims to synthesise current evidence on sustainable green endoscopy practices, examine the environmental impact, evaluate existing sustainable interventions, and identify implementation barriers, offering evidence-based recommendations for environmental stewardship within endoscopic services. A comprehensive literature search was conducted across multiple databases including PubMed, Embase, Scopus, Web of Science, and Cochrane Library. Approximately 58 peer-reviewed articles, alongside relevant guidelines, position statements, and grey literature sources, were included. Narrative synthesis with thematic analysis was employed to accommodate the heterogeneity of included sources. Published estimates suggest endoscopic procedures generate approximately 2.5–10 kg CO_2 equivalent per colonoscopy, though these values vary considerably by healthcare setting, reprocessing model, and waste disposal pathway, and should be interpreted as approximate estimates rather than universal benchmarks. A substantial proportion of endoscopy-related waste is directed to incineration or landfill. Potential environmental impact reduction may be achievable through strategic implementation of reusable devices, comprehensive waste segregation protocols, energy-efficient technologies, and artificial intelligence integration, though the evidence base for many individual interventions remains preliminary. Key barriers include financial constraints, clinical safety concerns, regulatory uncertainty, and organisational resistance. Sustainable green endoscopy represents an achievable environmental imperative without compromising patient safety or clinical outcomes. Successful transition requires coordinated efforts across clinical, administrative, and policy levels, combining technological innovation with comprehensive change management strategies addressing organisational culture and professional behaviours. This review offers

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a framework integrating technological, behavioural, and policy interventions for sustainable endoscopy implementation, aiming to provide evidence-based pathways for healthcare systems at varying resource levels to advance environmental stewardship while maintaining clinical excellence.

1. Introduction

Gastrointestinal endoscopy is among the most widely performed and resource-intensive medical procedures globally. Healthcare activities contribute significantly to climate change, accounting for approximately 4.6% of global greenhouse gas emissions, with this figure rising to 5.2% when including indirect emissions from supply chains and patient travel.[1] Within healthcare, endoscopy combines uniquely high procedural volumes with substantial material consumption, energy utilization, and medical waste generation, making it a priority target for environmental stewardship.

Endoscopic procedures have experienced exponential growth over the past three decades, driven by advances in technology, expanding indications, and population screening programmes.[2,3] Recent data indicate that over 2.5 million gastrointestinal endoscopic procedures are performed each year in the UK, covering upper and lower gastrointestinal as well as hepatobiliary systems.[4,5] The most common procedures include oesophagogastroduodenoscopy (OGD), colonoscopy, flexible sigmoidoscopy, and endoscopic retrograde cholangiopancreatography (ERCP).[6] This volume represents not only a testament to the clinical value of endoscopy but also highlights the magnitude of its environmental footprint.

The environmental impact of endoscopy extends beyond the immediate procedural environment to encompass the entire healthcare ecosystem [7–9]. From device manufacturing and packaging through to waste disposal and treatment, each endoscopic procedure generates a complex web of environmental consequences.[7] Traditional metrics of endoscopic quality have focussed exclusively on clinical outcomes, patient safety, and procedural efficiency, with minimal consideration given to environmental sustainability or resource stewardship.[10,11]

Recent awareness of climate change and its health implications has catalysed a paradigm shift within healthcare, emphasising the concept of planetary health and the interconnection between environmental sustainability and human wellbeing. The concept of "green endoscopy" has emerged as a response to this challenge, encompassing practices designed to reduce environmental impact while maintaining or enhancing clinical outcomes.[12,13] This approach recognises that environmental degradation poses direct and indirect threats to human health, making sustainability not merely an ethical consideration but a clinical imperative.

Important recent contributions to surgical and endoscopic sustainability have been made by the joint Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) and European Association for Endoscopic Surgery (EAES) Task Force. Johnson et al.[14] issued a collaborative call to action for environmental sustainability in operating rooms, while Huo et al.[15] conducted a scoping review establishing standardised terminology, outcome measures, and scope for sustainability research in gastrointestinal surgical practice. These contributions have significantly advanced the field. However, they primarily address the operating theatre context and minimally invasive surgical endoscopy. The present review focuses specifically on gastrointestinal endoscopy in its full scope, including outpatient and day-unit endoscopy suites, reprocessing environments, procurement, patient engagement, and diverse resource settings, and provides an integrated framework spanning technological, behavioural, and policy domains. It thereby extends and complements the existing SAGES-EAES evidence base by addressing the distinct sustainability challenges of non-operative endoscopy services.

The rationale for this review stems from the urgent need to consolidate current knowledge and provide evidence-based recommendations for sustainable endoscopy practices. The primary aim of this narrative review is to synthesise current evidence on sustainable green endoscopy practices and identify strategies for environmental stewardship within endoscopic services. The specific objectives are: (1) to quantify the environmental impact of current endoscopy practices; (2) to evaluate existing sustainable practices and their effectiveness; (3) to identify barriers to implementation and propose solutions; (4) to examine patient perspectives and engagement in sustainable endoscopy; (5) to assess applicability across diverse healthcare settings including low- and middle-income countries (LMICs); and (6) to provide evidence-based recommendations for transitioning towards environmentally sustainable endoscopic care.

2. Methods

2.1. Literature search strategy

A structured literature search was conducted across multiple electronic databases to identify relevant studies, guidelines, and initiatives related to sustainable endoscopy practices. The search was completed on 28 April 2025. The search strategy encompassed both peer-reviewed academic literature and grey literature sources to ensure comprehensive coverage of this emerging field. Primary databases searched included PubMed/MEDLINE, Embase, Cochrane Library, Scopus, and Web of Science. The SAGES-EAES scoping review by Huo et al.[15] was additionally used to supplement terminology and outcome measure definitions used to refine search terms.

The search strategy employed a combination of controlled vocabulary terms (Medical Subject Headings [MeSH] terms where applicable) and free-text keywords. Key search terms included combinations of: "endoscopy" OR "gastrointestinal endoscopy" OR "colonoscopy" OR "gastroscopy" AND "sustainability" OR "environmental impact" OR "carbon footprint" OR "green healthcare" OR "waste reduction" OR "life cycle assessment" OR "eco-friendly" OR "climate change" AND "healthcare". Additional searches focused on specific interventions, including "reusable medical devices," "medical waste management," "energy conservation," "patient preferences," "patient engagement," and "sustainable procurement."

2.2. Information sources and selection criteria

Beyond traditional academic databases, the search strategy included grey literature sources relevant to healthcare sustainability policy and practice. These included reports from international organisations (World Health Organization, United Nations), national health services (NHS England, Australian Department of Health), professional medical societies (European Society of Gastrointestinal Endoscopy, American Gastroenterological Association), and healthcare sustainability initiatives (Health Care Without Harm, Global Green and Healthy Hospitals network).

Three distinct source categories were included in this review and are treated separately in the synthesis where relevant: (1) peer-reviewed research articles (randomised controlled trials, observational studies, case series, systematic reviews, and meta-analyses); (2) guidelines and position statements from professional societies and government bodies; and (3) grey literature, including industry reports, patient surveys, and implementation case studies. Language restrictions were not applied initially, though non-English sources were included only when translation resources were available or when English abstracts provided sufficient information for assessment. No specific date restrictions were

imposed, though particular attention was paid to publications from 2015 onwards.

Initial database searches yielded approximately 2847 records. After removing duplicates (n = 892), 1955 records underwent title and abstract screening. Following full-text review of 312 potentially relevant articles, approximately 58 sources met inclusion criteria for narrative synthesis. Additional grey literature sources (n = 14) were identified through manual searching and professional society websites.

2.3. Data extraction and synthesis

Information extraction followed a structured approach designed to capture key elements relevant to sustainable endoscopy practice. Extracted data included: study characteristics (design, setting, population, geographic location, healthcare system context), environmental outcomes (carbon footprint, waste generation, energy consumption), clinical outcomes (safety, efficacy, patient satisfaction), economic outcomes (costs, cost-effectiveness, return on investment), patient perspectives and preferences, implementation factors (barriers, facilitators, success factors), contextual factors (resource availability, infrastructure, regulatory environment), and policy implications.

Given the heterogeneity of study designs, outcome measures, and healthcare settings represented in the literature, a narrative synthesis approach was employed rather than quantitative meta-analysis. Thematic analysis was conducted to identify common themes, patterns, and relationships across different types of evidence. Two authors independently coded a subset of studies to ensure consistency, with discrepancies resolved through discussion.

Quality appraisal tools were applied to contextualise the strength of evidence from included studies, using the Newcastle-Ottawa Scale for observational studies, AMSTAR-2 for systematic reviews, and customised criteria for guidelines and policy documents. Formal quality scoring was not used to exclude studies from the narrative synthesis; rather, quality assessments were used to contextualise findings and flag where evidence was derived from lower-quality sources. As this is a narrative review rather than a systematic review, we did not follow PRISMA guidelines or produce a PRISMA flow diagram. This methodological choice is further discussed in the limitations section.

3. Environmental impact of endoscopy

3.1. Carbon footprint assessment

The carbon footprint of endoscopic procedures encompasses direct emissions from energy consumption, equipment sterilisation, and facility operations, alongside indirect emissions from device manufacturing, transportation, and waste disposal.[16] Comprehensive lifecycle assessments have revealed that a single colonoscopy procedure generates between 2.5 and 10 kg of CO_2 equivalent emissions, with the wide range reflecting variation in healthcare setting, local electricity mix, reprocessing model, staffing patterns, and waste disposal pathway.[17] Values should therefore be interpreted as approximate procedure-level estimates rather than universal benchmarks. Caution is warranted when applying these figures across different healthcare contexts.

Direct energy consumption represents the largest component of endoscopy-related carbon emissions, accounting for approximately 60–70% of the total footprint.[18] This includes electricity consumption for endoscope illumination, image processing systems, electrosurgical units, and facility infrastructure such as heating, ventilation, and air conditioning (HVAC) systems. Endoscope reprocessing contributes substantially to energy consumption, with automated reprocessors requiring significant electrical and thermal energy for cleaning, disinfection, and drying cycles.[19]

The use of anaesthetic gases, particularly nitrous oxide and volatile anaesthetics, contributes additional greenhouse gas emissions in procedures requiring sedation. Nitrous oxide has a global warming potential approximately 265 times greater than CO_2, making even small quantities environmentally significant.[20] The environmental impact is further compounded by the energy-intensive manufacturing processes required for single-use endoscopic accessories and consumables. As illustrated in Fig. 1, direct energy consumption represents the largest contributor to the carbon footprint of endoscopy, with additional emissions arising from anaesthetic gases, device manufacturing, and waste disposal.

3.2. Medical waste generation

Endoscopic procedures generate substantial quantities of medical waste across multiple categories, as detailed in Table 1. The volume and complexity of this waste stream have increased significantly with the adoption of single-use devices and enhanced infection prevention protocols. Current estimates suggest that an average endoscopy unit generates between 2 and 5 kg of waste per procedure, with approximately 64% of this waste going to landfill, 28% classified as biohazardous waste, and 9% being recyclable.[21] These proportions are context-dependent and may differ substantially across healthcare systems, regulatory frameworks, and waste management infrastructure.

The segregation and disposal of medical waste require energy-intensive processes, including high-temperature incineration and specialised transportation systems.[27] Incineration of medical waste generates not only CO_2 emissions but also potentially harmful byproducts, including dioxins, furans, and heavy metals, which can persist in the environment and pose long-term health risks.[28]

3.3. Water consumption and contamination

Endoscope reprocessing represents one of the most water-intensive activities within healthcare, with each cleaning cycle requiring 55–113 L of water per endoscope.[26] Large-volume endoscopy units may consume thousands of litres of water daily for instrument reprocessing, facility cleaning, and patient care activities. The environmental impact extends beyond consumption to include the contamination of wastewater with disinfectants, detergents, and biological materials. Chemical disinfectants used in endoscope reprocessing, including glutaraldehyde, hydrogen peroxide, and peracetic acid, can persist in wastewater and pose risks to aquatic ecosystems.[29] The treatment of contaminated wastewater requires additional energy and resources, contributing further to the environmental footprint of endoscopic services.

4. Sustainable practices in endoscopy

4.1. Reusable versus single-use devices

The debate surrounding reusable versus single-use endoscopic devices represents one of the most contentious areas in sustainable endoscopy.[30] Single-use devices have gained popularity due to perceived infection control advantages, elimination of reprocessing costs, and consistent performance characteristics.[31] However, lifecycle assessments consistently demonstrate that reusable devices, when appropriately maintained and utilised, have significantly lower environmental footprints than their single-use counterparts.[32]

Reusable endoscopes require substantial upfront investment and ongoing maintenance costs but distribute their environmental impact across hundreds or thousands of procedures. The manufacturing of a single reusable endoscope typically generates between 500 and 800 kg of CO_2 equivalent emissions. However, when the environmental impact is distributed across the device's operational lifetime, the per-procedure carbon footprint is significantly reduced to approximately 2–5 kg CO_2. This amortisation of emissions makes reusable endoscopes more environmentally sustainable compared to their single-use counterparts in many settings.[33]

However, the environmental advantage of reusable devices is

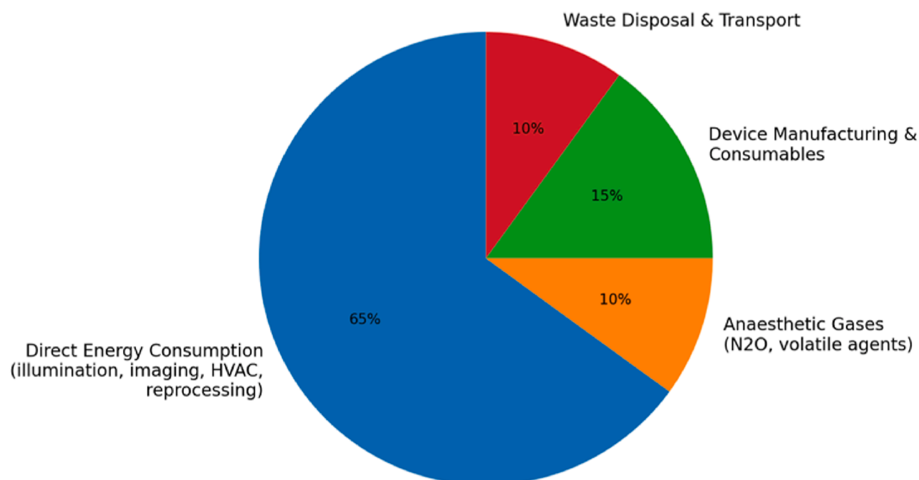

Fig. 1. Estimated contributions to the carbon footprint of a single endoscopic procedure. Direct energy consumption (illumination, imaging systems, HVAC, and endoscope reprocessing) accounts for the majority of emissions, followed by device manufacturing and consumables, anaesthetic gases, and waste disposal/transport. Percentages are approximate values based on published lifecycle assessment data [17–20]. (Author-derived conceptual figure; values are approximations synthesised from published lifecycle assessment literature and are not drawn to scale. Individual proportions will vary by setting).

context-dependent and should not be treated as universal. The net benefit depends critically on the efficiency of reprocessing cycles, local electricity mix, transport logistics for devices and consumables, device lifespan under local conditions, and institutional capacity to maintain validated reprocessing protocols. In settings with unreliable energy supply, limited reprocessing infrastructure, or inadequate quality assurance, the environmental case for reusable devices may be less clear-cut. Endoscopy units should therefore evaluate reusable device programmes against their own operational context rather than applying generalised claims.

The safety profile of reusable devices depends critically on adherence to validated reprocessing protocols and regular quality assurance testing.[34,35] Advanced reprocessing technologies, including hydrogen peroxide gas plasma sterilisation and automated cleaning systems with real-time monitoring, have significantly enhanced the safety and reliability of reusable device decontamination.[36,37] As shown in Fig. 2, reusable endoscopes offer a markedly reduced per-procedure carbon footprint compared to single-use devices, reinforcing their environmental advantage when supported by effective reprocessing protocols.

4.2. Water and energy conservation strategies

Energy and water conservation represent fundamental components of sustainable endoscopy practice, offering both environmental benefits and operational cost savings. Table 2 compares conventional and sustainable practices across key operational areas, highlighting potential improvements and their associated benefits.

It is important to note that evidence underpinning specific energy and water conservation strategies varies considerably. Some interventions, such as LED lighting and low-flow reprocessors, are supported by quantitative studies with measured outcomes. Others, such as smart HVAC scheduling and batch-case processing, are largely informed by modelling studies, single-site quality improvement reports, or extrapolations from non-endoscopy settings. The percentage estimates below should therefore be interpreted as indicative rather than definitive, and units should conduct local audits before attributing specific savings to individual interventions.

Energy conservation strategies focus on optimising the efficiency of endoscopy suite operations while maintaining clinical functionality. LED illumination systems offer substantial energy savings compared to

Table 1
Categories and environmental impact of endoscopy-related waste.

Waste Category	Examples	Vol./ Procedure (kg)	Disposal Method	Environmental Impact	Infection Risk Status	Packaging Contribution	Disposal Pathway Demands
Single-use devices[21]	Biopsy forceps, snares, injection needles	0.3–0.8	Incineration	High CO_2 emissions, toxic residues	Yes, clinical/ infectious waste	No	High, specialised incineration required
Personal protective equipment[22]	Gloves, gowns, masks, caps	0.2–0.4	Incineration/ Landfill	Microplastic pollution	Yes (if contaminated)	No	Moderate, potential for recycling if uncontaminated
Packaging materials[7]	Device packaging, sterile wraps	0.5–1.2	Landfill/ Recycling	Resource depletion, landfill burden	No, general waste	Yes, significant packaging component	Moderate, recyclable if segregated correctly
Cleaning agents[23]	Disinfectants, detergents	0.1–0.3	Chemical treatment	Water contamination risk	No, chemical waste	No	High, requires specialist effluent treatment
Sharps waste[24]	Used needles, scalpels	0.05–0.1	High-temperature incineration	Heavy metal emissions	Yes, high-risk infectious/sharps	No	High, mandatory specialist disposal pathway
Pharmaceutical waste[25]	Unused medications, contrast agents	0.05–0.2	Specialised incineration	Persistent organic pollutants	No, pharmaceutical/ cytotoxic waste	No	High, must not enter general or clinical waste streams
Water waste[26]	Reprocessing effluent, disinfectant-contaminated water	55–113 L/ endoscope cycle	Effluent treatment	Aquatic ecosystem contamination	No, wastewater	No	High, requires effluent monitoring and treatment

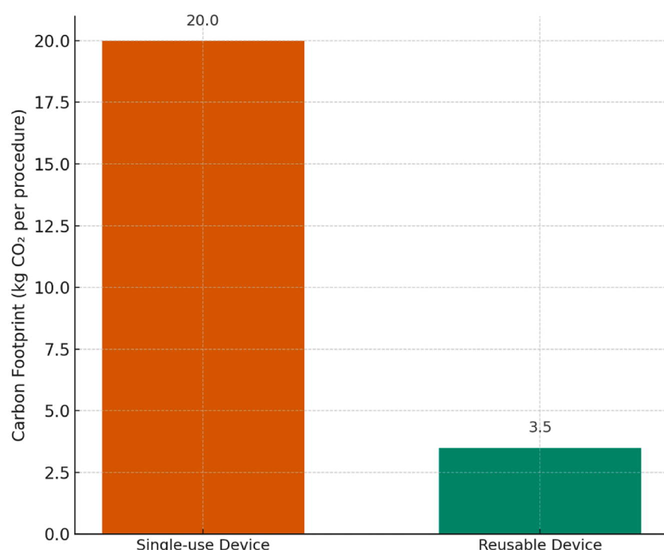

Fig. 2. Comparative carbon footprint of single-use versus reusable endoscopic devices. While single-use devices generate substantially higher emissions per procedure (~20 kg CO_2), reusable devices distribute their manufacturing impact across hundreds of uses, resulting in a much lower footprint (~2–5 kg CO_2 per procedure).[30,32,33] (Author-derived conceptual figure; values are representative approximations. Actual figures vary by device type, reprocessing system, and healthcare setting).

traditional xenon light sources, reducing energy consumption by up to 80% while providing superior light quality and consistency.[43] Smart environmental controls, including occupancy sensors and programmable thermostats, can significantly reduce HVAC energy consumption during off-peak hours.[44] Water conservation initiatives centre on endoscope reprocessing optimisation and facility management improvements. Low-flow reprocessing systems can reduce water consumption by 40–60% through improved spray patterns and water recycling technologies.[45,46]

4.3. Comprehensive waste management programmes

Effective waste management in endoscopy requires a systematic approach encompassing waste minimisation, segregation, treatment, and disposal.[47] The development of comprehensive waste management programmes begins with detailed waste audits to establish baseline generation rates and identify opportunities for reduction.[48] These audits should examine all waste streams, from single-use devices to packaging materials and administrative waste.

Waste segregation protocols form the cornerstone of effective medical waste management, enabling appropriate treatment pathways and material recovery opportunities.[49] Clear visual guides and regular staff training ensure consistent segregation practices, reducing contamination rates and enabling maximum recycling potential.[50,51]

Mis-segregation is a significant and underrecognised problem in endoscopy units. Common examples include: disposal of non-contaminated single-use packaging, such as outer wrapping for biopsy forceps, into clinical waste bags instead of general or recycling streams; placement of uncontaminated paper or cardboard into regulated medical waste; and mixing of sharps with soft clinical waste. Each of these errors escalates disposal costs substantially, clinical incineration typically costs 10–15 times more per kilogram than general waste disposal, and generates avoidable carbon emissions. Staff education specifically targeting segregation errors, supported by clear colour-coded waste guides and regular audit feedback, is an evidence-based strategy for reducing mis-segregation rates.

Non-contaminated packaging materials, including cardboard and plastics, can often be diverted from the regulated medical waste stream to standard recycling channels, resulting in significant cost savings and environmental benefits. Partnership with specialised medical waste recycling companies has proven effective in several healthcare systems, particularly in Europe where regulatory frameworks support medical device recycling.[52–54]

4.4. Sustainable procurement and supply chain management

Green procurement represents a strategic approach to sustainability that extends environmental considerations throughout the supply chain. Sustainable procurement in endoscopy requires integrating environmental criteria such as supplier eco-performance, product lifecycle impacts, and packaging sustainability alongside traditional cost, quality, and service considerations.[55,56] Environmental certifications, including ISO 14001 and ENERGY STAR ratings, provide objective measures of supplier environmental performance.[57] Life cycle assessments (LCAs) of medical devices enable informed decision-making by quantifying the environmental impact of products from raw material extraction through disposal.[58,59] Packaging optimisation represents a significant opportunity, as packaging can account for 20–30% of total endoscopy-related waste.[60]

4.5. Patient perspectives and engagement in sustainable endoscopy

Patient engagement represents a critical yet often overlooked dimension of sustainable endoscopy implementation. Understanding patient attitudes and willingness to participate in environmentally responsible care is essential for maintaining patient-centred principles while advancing sustainability initiatives.

Current evidence reveals a paradox: while many patients support environmental sustainability in healthcare generally, they demonstrate strong preferences for single-use medical devices when given a choice. A prospective survey of 147 patients undergoing endoscopy in India found that 86.4% preferred single-use biopsy forceps over reusable

Table 2
Comparison of conventional and sustainable endoscopy practices.

Practice Area	Conventional Approach	Sustainable Alternative	Environmental Benefit	Evidence Level	Implementation Challenges
Endoscope reprocessing[26]	Standard flow rate systems	Low-flow reprocessors with recycling	40–60% water reduction	Interventional studies	Equipment upgrade costs
Lighting systems[38]	Halogen/xenon illumination	LED light sources	70–80% energy reduction	Comparative technical data	Initial investment, training
HVAC systems[39]	Constant volume ventilation	Variable air volume with sensors	30–50% energy reduction	Modelling and audit data	System retrofitting required
Case scheduling[40]	Individual case setup	Batch processing approach	25–35% setup time reduction	Single-site QI reports	Workflow reorganisation
Documentation[41]	Paper-based records	Electronic documentation	90% paper waste reduction	Observational data	IT infrastructure, staff training
Instrument storage[42]	Open shelving systems	Closed storage with monitoring	Reduced reprocessing frequency	Expert guidance/limited primary data	Storage system investment

instruments.[61] When informed that single-use devices cost approximately £11 more per procedure, 89.1% still preferred single-use forceps, demonstrating that cost considerations had minimal impact on device preference. Only 10.9% of patients preferred reusable devices, citing environmental concerns as their primary motivation.[61] Patient concerns centred primarily on infection control and the perceived superiority of "new" versus "reused" instruments.

It is important to acknowledge that the evidence base underpinning patient engagement strategies in sustainable endoscopy remains limited and should be interpreted with caution. The majority of studies are small, single-centre, and conducted in limited geographic and demographic contexts, most notably, the largest preference study was conducted in a single Indian tertiary centre. Evidence from European, North American, and LMIC settings outside India is sparse. The observed preference for single-use devices may not be generalisable across cultures, age groups, or health literacy levels. Practitioners should therefore avoid drawing broad conclusions from existing data and recognise the need for larger, culturally diverse, prospective studies before implementing patient engagement strategies at scale.

Educational interventions can partially mitigate resistance to sustainable practices. Studies demonstrate that when patients receive detailed information about environmental impacts of healthcare and the safety of reprocessing protocols, acceptance of certain sustainable modifications increases.[62] Emerging frameworks for shared decision-making are beginning to incorporate environmental considerations alongside clinical data.[63] Critical ethical considerations must guide patient engagement: environmental sustainability must never compromise patient safety or optimal care. Patients should not feel pressured regarding environmental impacts of necessary medical care.

5. Behavioural and organisational change

5.1. Leadership commitment and governance

Within endoscopy specifically, successful implementation of sustainable practices requires strong leadership commitment and integration of environmental considerations into organisational governance structures.[64,65] Endoscopy unit managers, clinical leads, and departmental directors are pivotal in this regard, as decisions about procurement, scheduling, staffing, reprocessing, and waste contracts are made at unit or departmental level. Healthcare leaders must champion sustainability initiatives by establishing clear environmental policies, allocating necessary resources, and demonstrating personal commitment to environmental stewardship. This leadership commitment should be formalised through the incorporation of sustainability metrics into organisational key performance indicators and strategic planning processes.

Governance structures should include dedicated sustainability committees with representation from clinical, administrative, and support services.[66] The establishment of environmental performance metrics, including energy consumption, waste generation, and water usage, enables data-driven improvement initiatives and accountability measures.[67] Executive-level sponsorship is essential for overcoming institutional resistance and securing necessary resources for sustainability initiatives.[68,69]

5.2. Staff engagement and education

Healthcare professionals represent the primary drivers of sustainable practice implementation, making staff engagement and education critical success factors.[70] In endoscopy, this includes endoscopists, nursing and technical staff, reprocessing technicians, and support workers, each of whom interacts with the waste, energy, and procurement streams that drive environmental impact. Engagement programmes should be tailored to each professional group rather than relying on generic healthcare sustainability messaging. These programmes must address the environmental impact of healthcare activities, the rationale for sustainable practices, and specific actions that individuals can take to reduce environmental impact.

The designation of "Green Champions" within endoscopy units has proven effective in driving cultural change and supporting practice implementation.[71] These individuals receive additional training in sustainability principles and serve as local experts and advocates for environmental initiatives. Green Champions facilitate peer education, monitor compliance with sustainable practices, and provide feedback to leadership regarding implementation challenges and opportunities.[72] Gamification strategies, including sustainability competitions and recognition programmes, can enhance staff engagement.[73–75] Survey evidence from the SAGES-EAES task force indicates that while the majority of clinicians are motivated to improve sustainability, fewer than 10% can accurately estimate the carbon footprint of surgical activities,[76] highlighting a substantial knowledge gap that education programmes should specifically target.

5.3. Quality improvement and audit processes

The integration of sustainability metrics into routine quality improvement processes ensures systematic monitoring and continuous improvement of environmental performance.[77,78] Sustainability audits should examine all aspects of endoscopy operations, from energy and water consumption to waste generation and procurement practices.[79] Quality improvement methodologies, including Plan-Do-Study-Act cycles and Lean principles, can be applied to sustainability initiatives to drive systematic improvement, as waste reduction in both the environmental and Lean senses often reveals simultaneous improvements in efficiency, cost, and environmental impact.[80,81]

A practical implementation sequence for endoscopy units can be summarised in five steps. First, a baseline environmental audit should be conducted to establish current waste volumes, energy consumption, water usage, and procurement patterns. Second, a green team should be established with representation from clinical staff, nurses, reprocessing technicians, and management, ensuring that sustainability ownership is distributed across the unit. Third, a time-limited pilot intervention should target the highest-impact area identified in the audit, most commonly waste segregation or lighting energy use. Fourth, a KPI dashboard should be developed to track progress across core metrics including waste per procedure, energy per session, water per reprocessing cycle, and segregation accuracy. Fifth, a formal re-audit at six to twelve months should evaluate progress, identify unresolved gaps, and inform the next cycle of improvement. This iterative sequence transforms sustainability from a rhetorical commitment into a measurable operational programme.

6. Technological innovations

6.1. Artificial intelligence and digital technologies

Artificial intelligence (AI) and digital technologies offer potential opportunities to optimise endoscopic practice efficiency and reduce environmental impact.[82–84] Claims in this domain must, however, be grounded in concrete sustainability endpoints rather than generalised transformation narratives. In endoscopy, specific pathways through which AI may contribute to environmental benefit include the following. First, AI-assisted diagnostic systems may reduce the need for repeat or inconclusive examinations by improving first-pass diagnostic accuracy, thereby decreasing the total procedural volume and associated resource consumption. Computer-aided detection systems for polyp identification have demonstrated improved diagnostic accuracy and reduced procedure times.[85] Second, AI-driven scheduling and resource allocation tools may reduce equipment idle time and energy waste by predicting optimal session durations, staffing requirements, and maintenance windows. Third, AI-assisted real-time polyp characterisation may support more

selective biopsy practice, reducing unnecessary consumable use. Fourth, digital reporting and documentation systems eliminate paper consumption and, where supported by renewable-energy data centres, reduce IT infrastructure-related emissions.[86,87] Broader claims, for example, that AI will comprehensively transform healthcare sustainability, remain speculative and require prospective evaluation in endoscopy-specific contexts before being treated as evidence-based.

6.2. Advanced reprocessing technologies

Innovation in endoscope reprocessing technologies offers significant potential for environmental impact reduction. Low-temperature plasma sterilisation systems utilise hydrogen peroxide vapour and radiofrequency energy to achieve sterilisation without the high temperatures required by traditional steam autoclaving, resulting in reduced energy consumption and shorter cycle times.[36,88] Safety and clinical validation must remain the primary consideration in the adoption of any reprocessing technology. No environmental benefit justifies a reduction in infection control standards, and new reprocessing systems should only be adopted where they have been validated against the full spectrum of endoscopy-associated pathogens and meet relevant regulatory standards.

Ultraviolet-C (UV-C) disinfection systems provide rapid, chemical-free surface disinfection for endoscope storage and transportation containers.[89] Automated reprocessing systems with real-time monitoring capabilities ensure consistent reprocessing quality while optimising resource utilization.[90,91] These systems incorporate sensors to monitor cleaning solution concentration, temperature, and contact time, enabling precise control of reprocessing parameters and reducing waste from solution changes and equipment failures.

6.3. Sustainable medical device innovation

The development of environmentally sustainable medical devices represents a critical frontier in green endoscopy implementation. Biodegradable endoscopic accessories, including biopsy forceps and injection needles manufactured from plant-based polymers, offer potential alternatives to traditional single-use devices.[92] However, it is important to distinguish between technologies that are commercially available and quality-assured and those that remain at prototype or pilot stage and have not yet been validated in routine clinical use. Biodegradable accessories and modular device designs currently fall largely in the latter category, and healthcare organisations should exercise caution before incorporating these into procurement planning. Premature adoption of unvalidated technologies risks both clinical harm and reputational damage to the sustainability agenda.

Design for sustainability principles are being integrated into medical device development, focusing on material selection, manufacturing processes, packaging optimisation, and end-of-life management. Modular device designs enable component replacement rather than complete device disposal, extending operational lifetime and reducing waste generation.[93,94] 3D printing technologies enable on-demand production of certain endoscopic accessories, reducing inventory requirements and packaging waste.[95,96] These innovations remain predominantly research- or prototype-stage and should be monitored through the literature rather than applied in clinical practice without independent validation.

7. Regulatory and policy framework

7.1. International and national initiatives

The regulatory landscape surrounding sustainable healthcare is evolving rapidly. The World Health Organization's "Healthy hospitals, healthy planet, healthy people" initiative provides a comprehensive framework for healthcare sustainability, including specific guidance for medical specialties such as endoscopy.[97] The European Union's Green Deal and associated circular economy action plan include specific provisions for healthcare waste reduction and sustainable medical device design.[98,99] The Medical Device Regulation (MDR) now includes environmental considerations in device approval processes.[100] The NHS Net Zero strategy commits to achieving net-zero emissions by 2040, with intermediate targets and specific guidance for clinical services including endoscopy.[101,102] The SAGES-EAES Call to Action by Johnson et al.[14] and the associated scoping review by Huo et al.[15] represent important international milestones in establishing structured sustainability frameworks for gastrointestinal practice, complementing national regulatory developments.

7.2. Professional society guidelines and standards

Medical professional societies are increasingly recognising their responsibility to provide guidance on sustainable practice implementation.[103] The European Society of Gastrointestinal Endoscopy (ESGE) has published position statements on sustainable endoscopy practices, providing evidence-based recommendations for environmental stewardship.[104] A US Multi GI Society Task Force has jointly released a strategic plan for environmentally sustainable GI practice across seven major domains.[105] Accreditation bodies are incorporating sustainability criteria into endoscopy unit assessment frameworks, creating additional drivers for sustainable practice implementation.[106]

7.3. Procurement policy reforms and green purchasing frameworks

Procurement policy represents a powerful lever for driving sustainability in endoscopy through market-shaping mechanisms and supplier engagement.[107] In endoscopy-specific procurement, environmental criteria should be incorporated into tender specifications for endoscopes and reprocessors, single-use accessories (biopsy forceps, snares, haemostasis devices), cleaning agents and disinfectants, personal protective equipment, and waste management contracts. Service contracts with endoscopy equipment suppliers could include sustainability milestones, annual carbon reporting requirements, and recyclability commitments, creating ongoing accountability without displacing clinical or infection control considerations.

Healthcare organisations must navigate the interface between environmental procurement criteria and infection control obligations carefully. The adoption of reusable devices does not reduce the obligation to achieve validated decontamination outcomes; any preference for reusable endoscopes in a procurement framework must be contingent on evidence that reprocessing protocols meet the applicable standard. Similarly, preferences for reduced packaging must not compromise sterility assurance. Green procurement frameworks should be co-developed with infection prevention and control teams to ensure that environmental gains are not achieved at the expense of patient safety, and that sustainability claims are only applied where infection control integrity is independently verified.

Progressive healthcare systems are implementing green procurement frameworks that integrate environmental criteria into purchasing decisions.[107] Environmental certifications including ISO 14001 provide objective measures of supplier environmental performance.[57] Supplier sustainability scorecards evaluate vendor environmental performance across carbon footprint reporting, lifecycle assessments, packaging sustainability, take-back programmes, and supply chain transparency.[108,109] Value-based procurement frameworks consider total cost of ownership rather than initial purchase price alone, incorporating operational costs, disposal costs, and externality costs.[110] Extended producer responsibility (EPR) schemes are shifting end-of-life management costs to manufacturers, with pilot programmes demonstrating material recovery rates exceeding 60%.[93]

8. Barriers to implementation

The successful implementation of sustainable endoscopy practices faces multifaceted challenges that span financial, clinical, regulatory, organisational, and technical domains.[111–113] Table 3 synthesises the primary barriers identified across these categories alongside evidence-based solutions and critical success factors.

8.1. Financial and economic considerations

Financial constraints represent one of the most significant barriers to sustainable endoscopy implementation, particularly in resource-limited healthcare systems.[105] The upfront capital investment required for sustainable technologies can be substantial and may not be readily available within existing budgets.[106] Economic assessments should encompass total cost of ownership rather than acquisition price alone. Total cost of ownership incorporates operational costs (energy, reprocessing consumables, maintenance), disposal and waste management costs, and environmental externality costs where applicable. Total cost of ownership analyses frequently reveal that sustainable alternatives, such as low-flow reprocessors or LED lighting, deliver net financial savings over their operational lifetime despite higher upfront costs, making the economic and environmental case mutually reinforcing rather than in tension.

The business case for sustainability initiatives often relies on long-term operational savings that may not align with short-term budget cycles and performance metrics.[119] Cost-benefit analyses for sustainable endoscopy initiatives must consider both direct and indirect costs and benefits, including regulatory compliance costs, risk mitigation benefits, and reputational advantages.[120] Many healthcare organisations lack the financial expertise and analytical tools necessary to conduct comprehensive economic assessments of sustainability investments.[121] Reimbursement structures that fail to incorporate environmental performance indicators can act as significant barriers to the adoption of sustainable practices.[122] Emerging value-based payment models have been shown to better align financial incentives with quality and resource stewardship.[123]

8.2. Clinical and safety concerns

Patient safety concerns represent legitimate barriers to sustainable endoscopy implementation, particularly regarding the use of reusable devices and modified clinical protocols.[124,125] Healthcare professionals may perceive sustainability initiatives as potentially compromising patient care or increasing clinical risk, creating resistance to change even when evidence supports safety equivalence. The conservative culture of healthcare, appropriately focused on risk minimisation, can impede adoption of innovative practices without extensive safety validation.[126] The perceived complexity of sustainable practices, including modified waste segregation protocols and equipment maintenance requirements, may discourage adoption among busy clinical staff.[127] Inconsistent guidance from professional societies and regulatory bodies regarding sustainable practices creates uncertainty among practitioners and institutions.[128]

8.3. Organisational and cultural factors

Organisational culture represents a fundamental barrier to sustainable endoscopy implementation, particularly in institutions where environmental considerations have not traditionally been prioritized.[129] The lack of leadership commitment and visible championing of sustainability initiatives can undermine staff engagement and implementation success.[130] Competing organisational priorities, including quality improvement, cost reduction, and regulatory compliance, may overshadow sustainability initiatives.[131] Resistance to change among healthcare professionals, particularly senior clinicians with established practice patterns, can significantly impede sustainability implementation.[132] Survey data from the SAGES-EAES task force confirm that while the majority of clinicians are willing to adopt sustainable practices, a significant minority express concerns about adverse consequences, and a critical knowledge gap exists regarding the environmental impact of specific procedures and consumables.[76] Targeted education addressing these knowledge gaps, rather than generic environmental messaging, is most likely to be effective in converting positive attitudes into sustained behavioural change.

8.4. Context-specific challenges in low- and middle-income countries

The implementation of sustainable endoscopy in low- and middle-income countries (LMICs) faces distinct challenges that differ substantially from high-resource settings.[133] The LMIC context is not uniform, and it is important to avoid treating all LMICs as a single category. Significant heterogeneity exists across lower-middle income, upper-middle income, and low-income settings, as well as across regions, health system structures, and levels of endoscopy service development. Recommendations must therefore be tiered: upper-middle income settings with established endoscopy infrastructure may be able to implement digital reprocessing monitoring, batch scheduling, and green procurement frameworks; lower-middle income settings may prioritise waste segregation, consumable reduction, and staff education; and the lowest-income settings with limited basic endoscopy provision should focus on pragmatic, low-cost interventions directly aligned with patient safety and service quality before addressing broader sustainability targets.

Infrastructure limitations represent fundamental barriers. Unreliable electricity supply, water scarcity, and inadequate waste management systems significantly constrain feasibility of interventions proven effective in high-resource settings.[134] Studies across sub-Saharan Africa reveal only 28–34% of health facilities have reliable electricity, and hospital access to dependable running water ranges from 22 to 46%.[135] Approximately 80% of healthcare facilities in low-income countries lack adequate medical waste treatment capacity.[136] Financial constraints are

Table 3
Implementation barriers and potential solutions.

Barrier Category	Specific Challenges	Potential Solutions	Success Factors	Key Caveats
Financial[114,115]	High upfront costs, uncertain ROI, misaligned budget cycles	Phased implementation, grants, partnerships	Strong business case, executive support	Total cost of ownership analysis; long-term savings often exceed initial costs
Clinical/Safety[116]	Infection control concerns, workflow disruption	Evidence-based protocols, pilot programmes	Robust safety data, clinical champions	Sustainability must never compromise infection control standards
Regulatory[112]	Inconsistent guidance, liability concerns	Professional society engagement, advocacy	Clear standards, regulatory alignment	Co-design of frameworks with infection prevention teams
Organisational[117]	Cultural resistance, competing priorities	Leadership commitment, staff engagement	Change management, communication	Endoscopy-specific rather than generic sustainability messaging
Technical[118]	Equipment limitations, infrastructure gaps	Staged upgrades, technical partnerships	Vendor collaboration, training programmes	Infrastructure investment itself has an environmental footprint

substantially more severe in LMICs, with per-capita health expenditure averaging $110 annually compared to $5000+ in high-income countries.[137]

It is also important to acknowledge that some sustainability interventions require significant infrastructure investment, such as automated reprocessing systems, solar power installations, or digital reporting platforms, that may themselves carry substantial environmental and financial costs during procurement, manufacture, and installation. In resource-constrained settings, the net sustainability gain from such investments must be carefully evaluated over the full device lifecycle. A reprocessing system that requires grid electricity, specialist maintenance, and imported consumables may not deliver a net environmental benefit in a setting with unreliable power and limited technical capacity, even if it does so in a high-income context. Sustainability interventions should therefore be assessed for contextual fit, not simply adopted because they are classified as "green" in higher-resource environments.

However, LMICs possess unique opportunities. Lower baseline infrastructure enables leapfrogging to sustainable technologies without legacy constraints. Digital platforms may be adopted more readily without entrenched paper systems.[138] Resource scarcity has driven innovation in low-cost, low-energy devices aligning with sustainability objectives.[139] Context-appropriate LMIC strategies must prioritise interventions that require minimal capital investment, align with existing safety protocols, utilise locally available resources, address both environmental and health outcomes, and incorporate capacity building.

9. Recommendations and future directions

9.1. Strategic Implementation Framework

Fig. 3 presents an integrated implementation framework for sustainable endoscopy, illustrating the interconnected elements necessary for successful transition to environmentally responsible practice. The framework is structured around five core pillars: (1) Foundational Assessment; (2) Multi-Level Interventions; (3) Enabling Infrastructure; (4) Continuous Monitoring; and (5) Adaptation and Scaling.

(The recommendations arising from this review are organised into three levels of implementation priority, reflecting different resource requirements, time horizons, and organisational readiness:

Level 1: Immediate, low-cost actions (implementable within 0–6 months with minimal capital): Waste segregation improvement through staff education and clear visual guides; LED lighting replacement where existing infrastructure permits; paper reduction and electronic documentation adoption; batch case scheduling to reduce room idle time; and baseline environmental audit to establish performance metrics. These actions require minimal capital investment, generate early evidence of progress, and build staff engagement and credibility for subsequent interventions.

Level 2: Medium-term service redesign (implementable within 6–24 months with moderate investment): Procurement policy revision to incorporate environmental criteria into tender documents and supplier scorecards; strategic reusable device programmes where reprocessing infrastructure is validated and reliable; green team establishment with

Fig. 3. Strategic Implementation Framework for Sustainable Endoscopy. The framework comprises five interconnected core pillars: (1) Foundational Assessment, establishing baseline environmental performance metrics; (2) Multi-Level Interventions, encompassing technological, procedural, and behavioural changes; (3) Enabling Infrastructure, including leadership, governance, policy, and financial mechanisms; (4) Continuous Monitoring, using real-time tracking with standardised metrics and feedback; and (5) Adaptation and Scaling, supporting iterative refinement and expansion across services and settings.

representation across clinical and support functions; development and regular review of a KPI dashboard; and partnership with specialist medical waste recycling providers. These actions require moderate planning and investment but deliver sustained environmental and financial returns.

Level 3: Long-term research and policy actions (requiring multi-year commitment and stakeholder collaboration): Development and adoption of standardised environmental metrics for endoscopy, facilitated by professional societies such as ESGE and BSG; participation in national and international sustainability networks and benchmarking databases; research and advocacy for regulatory reform supporting green procurement in endoscopy; and controlled trials of emerging technologies including biodegradable accessories and closed-loop reprocessing systems. These actions require sustained institutional and policy-level commitment but are essential for advancing the evidence base and driving systemic change.

To support monitoring at all three levels, the following core key performance indicators (KPIs) are recommended for sustainable endoscopy programmes: (1) waste segregation accuracy, proportion of non-contaminated waste correctly diverted from regulated medical waste streams; (2) total waste per procedure (kg), subdivided by waste category; (3) regulated medical waste per procedure (kg); (4) energy consumption per procedure session (kWh); (5) water consumption per endoscope reprocessing cycle (litres); (6) reusable-to-single-use device ratio for key accessories (biopsy forceps, haemostasis devices); (7) procedure room idle energy time (minutes per session); and (8) carbon dioxide equivalent per procedure (kg CO_2e), where lifecycle data are available. Units should select three to five of these KPIs based on local data availability, beginning with those where baseline measurement is immediately feasible, and expand the set as capacity develops.

Table 4 provides a summary of key recommendations for sustainable endoscopy implementation, organised by domain across waste management, energy and water, procurement, technology, governance, staff engagement, patient engagement, and policy, with corresponding supporting strategies, expected outcomes, and priority levels to guide healthcare teams at varying resource levels.

9.2. Research and innovation priorities

Future research priorities should address critical knowledge gaps in sustainable endoscopy implementation and effectiveness. Comparative effectiveness research is needed to evaluate the clinical and environmental outcomes of sustainable practices. Given the current absence of standardised environmental metrics for endoscopy, a priority for professional societies should be the development and validation of agreed definitions for key outcomes, waste per procedure, energy per session, water per reprocessing cycle, and CO_2e per procedure, without which meaningful benchmarking and evidence synthesis are not possible. Particular research needs include: (1) patient preference studies across diverse populations and cultural contexts; (2) implementation science research identifying effective change management strategies in varied healthcare settings; (3) economic evaluations incorporating environmental externalities and long-term health impacts; (4) comparative effectiveness studies of sustainable alternatives in LMIC contexts; and (5) longitudinal assessments of sustainability programme durability and staff engagement.

9.3. Policy and advocacy recommendations

Policy advocacy represents a critical component of scaling sustainable endoscopy practices. Healthcare organisations and professional societies should actively engage with policymakers to promote supportive regulatory frameworks and financial incentives for sustainability implementation. This advocacy should focus on the development of endoscopy-specific environmental performance standards, reimbursement mechanisms that incentivise sustainability, and research funding for sustainable healthcare innovation. The SAGES-EAES framework[140,141] provides a useful model for multi-society collaboration, and similar structures should be developed specifically for non-operative gastrointestinal endoscopy at national and international levels.

International collaboration and knowledge sharing can accelerate global progress towards sustainable endoscopy practices. Educational policy changes are needed to integrate sustainability competencies into medical and nursing education curricula.

Table 4
Summary of key recommendations for sustainable endoscopy implementation.

Domain	Key Recommendations	Supporting Strategies	Expected Outcomes	Levels
Waste Management	• Implement comprehensive segregation protocols (with regular mis-segregation audit) • Audit waste streams quarterly • Establish recycling partnerships	Staff training, visual guides, dashboards	40–60% reduction in regulated waste; 20–30% cost savings	Level 1
Energy & Water	• Upgrade to LED illumination • Install smart HVAC controls • Adopt low-flow reprocessors	Occupancy sensors, real-time monitoring, automated shutdown protocols	60–80% lighting energy reduction; 40–60% water conservation	Level 1–2
Procurement	• Develop green purchasing criteria for endoscopy tenders • Implement supplier scorecards • Use total cost of ownership analysis	Lifecycle cost analysis, vendor requirements, EPR	15–25% reduction in supply chain emissions	Level 2
Technology	• Deploy AI for scheduling and selective biopsy use • Implement digital documentation • Monitor prototype device developments	Cloud systems, predictive analytics, remote consultation	Reduced repeat procedures; decreased consumable use	Level 2–3
Governance	• Establish endoscopy-level green team • Integrate KPIs into departmental governance • Secure executive sponsorship	Dedicated sustainability role, board reporting, resource allocation	Embedded sustainability culture; accountability	Level 1–2
Staff Engagement	• Appoint Green Champions • Provide endoscopy-specific sustainability training • Track KPI progress with staff	Peer education, gamification, regular feedback	Sustained behaviour change; frontline innovation	Level 1
Patient Engagement	• Provide balanced sustainability information • Incorporate virtual alternatives where safe • Acknowledge limited evidence base	Patient information materials, shared decision-making, telemedicine	Enhanced satisfaction; reduced travel emissions	Level 2
Policy & Advocacy	• Engage professional societies on standardised metrics • Support regulatory reform on green procurement • Share implementation evidence	Multi-stakeholder collaboration, evidence dissemination	Favourable regulatory environment; accelerated adoption	Level 3

10. Limitations of the review

A critical limitation of this review is that, as a narrative synthesis rather than a systematic review with standardised evidence appraisal, it cannot support comparative effectiveness conclusions for the interventions discussed. Without standardised outcome reporting, controlled study designs, and multi-site data, it is not possible to determine with confidence which interventions produce the greatest environmental benefit, under what conditions they are most effective, or what magnitude of impact is reliably achievable. Readers should not interpret the percentage estimates and environmental benchmarks presented throughout this review as definitive targets, but rather as indicative values requiring local validation.

The absence of standardised, endoscopy-specific environmental metrics represents a particularly significant structural limitation of the entire field, and not merely of this review. Without agreed definitions for key outcomes, waste per procedure, energy per session, water per reprocessing cycle, CO_2e per procedure, it is not possible to benchmark meaningfully across units, compare studies, or aggregate data in future systematic reviews. This gap is highlighted here as a priority issue for the research community and professional societies, rather than deferred solely to a limitations discussion.

As a narrative rather than systematic review, this work did not follow PRISMA guidelines or produce a PRISMA flow diagram. This methodological approach was deliberately chosen to enable comprehensive coverage of this multifaceted topic, including diverse evidence types that would be difficult to capture within a traditional systematic review framework. However, this approach introduces potential for selection bias and limits reproducibility compared to systematic reviews.

The rapid pace of innovation in sustainable healthcare technologies means that some emerging solutions may not be fully represented in the available literature. The heterogeneity of healthcare systems, regulatory frameworks, and resource availability across different countries limits the generalisability of specific recommendations. The literature remains heavily skewed toward high-income country perspectives, limiting the depth of evidence-based guidance for LMIC implementation. The review's LMIC analysis is constrained by this skew, and the tiered recommendations offered in Section 8.4 should be regarded as a framework for contextual adaptation rather than a definitive evidence-based guide.

Patient perspective literature remains limited, with most studies conducted in European settings. Research specifically examining patient attitudes in LMICs is particularly sparse. Publication bias may favour studies reporting positive outcomes from sustainability interventions, potentially overestimating effectiveness and underestimating challenges. The commercial interests of medical device manufacturers and technology companies may influence the availability and interpretation of evidence regarding sustainable products.

11. Conclusion

Sustainable green endoscopy represents both an environmental imperative and a clinical opportunity to align healthcare delivery with planetary health principles. The evidence synthesised in this review suggests that meaningful environmental improvements may be achievable through systematic implementation of sustainable practices without compromising patient safety or clinical outcomes, though the evidence base for many specific interventions remains preliminary and context-dependent. The integration of waste reduction strategies, energy conservation measures, sustainable procurement practices, and innovative technologies offers a comprehensive pathway to environmental stewardship within endoscopic services.

The successful transition to sustainable endoscopy requires coordinated action across multiple levels, from individual practitioner behaviour change to systemic policy reform. Healthcare leaders must champion sustainability initiatives through visible commitment, resource allocation, and integration of environmental considerations into organisational governance structures. Clinical professionals require education, training, and support to implement sustainable practices effectively, while maintaining their primary focus on patient care and safety.

Technological innovation continues to expand the possibilities for sustainable endoscopy, with artificial intelligence, advanced materials, and novel reprocessing technologies offering promising solutions to environmental challenges. However, technology alone cannot drive the cultural and behavioural changes necessary for widespread sustainability adoption. Comprehensive change management strategies that address organisational culture, professional attitudes, and patient expectations are essential for sustainable transformation.

The regulatory and policy environment is evolving to support sustainable healthcare implementation. Professional societies and accreditation bodies have important roles in establishing evidence-based guidance and creating accountability for environmental performance. The development of standardised metrics and reporting frameworks would support consistent assessment and benchmarking of sustainability initiatives. The SAGES-EAES call to action and associated scoping review represent significant international milestones, and similar multi-society structures should be developed specifically for non-operative gastrointestinal endoscopy.[140,141]

Patient engagement represents an essential yet underutilised component of sustainable endoscopy. The implementation of sustainable endoscopy must be contextualised within the diverse realities of global healthcare systems, with LMIC strategies adapted to local infrastructure, resources, and priorities. Future success will depend on continued research, innovation, and knowledge sharing across healthcare systems globally.

For endoscopy units seeking an immediate starting point, the most practical first step is a structured waste audit of the unit, followed by implementation of a targeted waste segregation improvement programme. This intervention is low-cost, rapidly actionable, and measurable; it builds the organisational foundation for broader sustainability engagement; and it delivers both environmental and financial returns that can be used to build the business case for subsequent investment. The time for action is now, and the pathway forward should begin with what is immediately achievable.

CRediT authorship contribution statement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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