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Green endoscopy, one step towards a sustainable future: a review of the literature.

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Abstract:
Rapid climate change or climate crisis is one of the most serious emergencies of the twenty-first century, accounting for highly impactful and irreversible changes worldwide. Climate crisis can also affect the epidemiology and disease burden of gastrointestinal (GI) diseases as they hold a connection with environmental factors and nutrition.
GI endoscopy is a highly intensive procedure with a significant contribution to greenhouse gas (GHG) emissions. Moreover, endoscopy is the third highest generator of waste in healthcare facilities with significant contributions to carbon footprint. Main sources of direct carbon emission in endoscopy are the use of high-powered consumption devices (e.g. computers, anesthesia machines, wash machines for reprocessing, scope processors and lighting), and waste production derived mainly from the use of disposable devices. Indirect sources of emissions are those derived from the heating and cooling of facilities, processing of histological samples, transportation of patients and materials etc.
Consequently, sustainable endoscopy and climate change have been the focus of discussions between endoscopy providers and professional societies with the aim of taking action to reduce environmental impact. The term „green endoscopy" refers to the practice of gastroenterology that aims to raise awareness, assess, and reduce endoscopy´s environmental impact.
Nevertheless, while awareness has been growing, guidance on practical interventions to reduce carbon footprint of GI endoscopy are lacking. This review aims to summarize current data regarding the impact of endoscopy on GHG emissions and possible strategies to mitigate this phenomenon. Further, we aim to promote the evolution of a more sustainable „green endoscopy".

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INTRODUCTION

Rapid climate change is a serious emergency of the twenty first century. This climate crisis has created highly dangerous and irreversible changes with serious consequences around the world, from human health to economic and geopolitical effects.

According to the Global Climate Report of the National Centers for Environmental Information, the global surface temperature in September 2022 tied for the fifth highest position since the record began in 1880 [1].

Because of its impact on energy retention in the atmosphere, greenhouse gases (GHG) represent a critical link between human activities and rising temperatures. For instance, deforestation and the use of fossil fuels contribute significantly to GHG production and accumulation, leading to global warming and extreme weather events.

The term ‘carbon footprint’ is defined by the Carbon Trust as “the total set of GHG caused directly and indirectly by an individual, event, organization or product.” GHG refers to any gas which accumulates in the atmosphere and absorbs and re-emits heat, thereby carrying the potential for global warming. Carbon dioxide (CO_2) accounts for 85% of all GHG, while other "CO_2 equivalent gases" include Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulfur hexafluoride (SF_6), Nitrogen trifluoride (NF_3), etc.

Consequently, in the United Kingdom (UK) the National Health Service (NHS) has committed to a net-zero carbon footprint for directly controlled emissions by 2040 and net zero for those within its supply chain (indirectly) by 2045 [2]. Current global targets to face the climate crisis include reaching net-zero carbon emissions by 2050 and keeping rising global temperature below 1.5 ˚C [3].

Rising temperatures can have a direct impact on health, causing a significant increase in disease, morbidity and mortality, and potentially leading hospitals and health services to collapse.

Climate crisis may also affect the epidemiology and burden of gastrointestinal (GI) diseases since they have a close connection with environmental factors and nutrition. For instance, environmental changes may affect the quality and contamination of land and agricultural products thereby increasing the spread of infectious diseases in both developing and industrialized countries. The corollary of consuming poor-quality food has far reaching consequences which includes altering the epidemiology of GI cancers, increasing the level of stress of the general population, and possibly increasing the prevalence of gut-brain interaction disorders (DGBI) [4-7].

In a call to action to raise awareness about environmental issues and the need to keep the Earth's temperature stable, 197 countries signed the famous Glasgow Climate Pact in 2021COP 26. More recently, in November 2022 at Sharm el Scheikat WHO Health pavilion, at the United Nations Climate Change Conference COP 27, countries promised to reduce CO_2 emissions and decarbonization [8].

The aim of this narrative review is to summarize current data regarding the impact of endoscopy on GHG emissions and possible strategies to mitigate this phenomenon.

The primary sources MEDLINE, Scopus, and the Cochrane Library were searched for studies assessing GHG emission in endoscopy facilities, through December 2023.

THE ENVIRONMENTAL IMPACT OF GI ENDOSCOPY

Table 1 summarizes the results of current studies estimating carbon footprint in GI endoscopy. One procedure generates 1.5-2 Kg of plastic waste but only 0.3 Kg is recyclable. A recent estimate showed that the energy consumption over an average of 40 procedures per day was estimated at 31,416 kWh per year, accounting for carbon emissions of 22.1 tCO2 per year (Figure 1) [09-10].

In the UK the healthcare system is responsible for 6.3% of UK's total carbon emissions and 5% of total air pollution [11-12].

Of note, this estimate excludes the energy consumption necessary for heating and cooling which adds to the overall carbon footprint.

Concerning waste production, endoscopy is the third highest generator of waste in healthcare facilities, contributing to GHG emissions worldwide.

Each endoscopy bed-day is thought to generate approximately 3 kg of waste, and the specialty is responsible for 13,500 tons of plastic waste in the United States each year, making it the hospital's third-highest waste generator [13]. Most supplies used during endoscopic examinations are often disposable and made of plastic, resulting in approximately 2 kg of waste per procedure [10].

A recent study estimated the environmental impact of a digestive endoscopy unit by measuring the mass and volume of waste in suites, pre-procedure, and post-procedure areas [14]. The total waste generated during a 5-day routine in a high-volume endoscopic center was 546 kg, which included direct landfill, biohazard, and recycled waste. During the same period, 73 kg of total waste was generated in a low-volume center. Using the number of endoscopic procedures performed in the United States each year (18 million), the authors calculated a disposable waste production of 836,000 cubic meters per year, which is equivalent to covering approximately 117 soccer fields to a height of 1 meter with waste. Another analysis estimated CO2 emissions of more than 3 million gallons of gasoline consumed or more than 39 million pounds of coal burnt [10].

Sequestering the CO_2 produced by endoscopy procedures would take 112,009 acres of forests for 1 year [9-10]. Thus, to decarbonize health care, endoscopy represents a high-yield mitigation opportunity [14].

Although this is a fairly recent topic and many studies are emerging, there is still not enough data to quantify the problem globally.

A 2022 systematic review summarized the available literature and found only 9 full full-length articles. This indicates an urgent need for collecting systematic data on GI endoscopy emissions worldwide [15].

SOURCES OF CARBON EMISSION IN ENDOSCOPY

GHG emissions can have different sources within endoscopy.

A retrospective study conducted in 2021 in an ambulatory GI center in France performing 8524 procedures on 6070 patients showed that the main GHG emission was from travel by patients and staff to and from the center (45%), followed by medical and non-medical equipment (32%), energy consumption (12%), consumables (7%), waste (3%), freight (0.4%), and medical gases (0.005%) [16].

To approach emissions in an organized manner, the carbon dioxide producing processes can be divided into three scopes based on the GHG Protocol [17].

Scope 1 includes “direct emissions” from sources that are owned or controlled by the healthcare facility. Scope 2 includes all the emissions released into the atmosphere from the energy used in the healthcare facility but produced by a different organization. Scope 3 includes all other indirect emissions that occur across the value chain and are outside of the healthcare facility’s direct control.

Scope 1 emissions

They include “direct emissions”, for instance the burning of fuel or natural gas used for heating, or release of anesthetic gases within a hospital. In this regard, a recent study analyzing yearly emissions of a middle-sized GI endoscopy unit in Germany (8000 procedures per year) showed a total yearly production of 62.72 tons of carbon dioxide equivalents, of these, more than a half (35.91 tons) from scope 1 and related to the consumption of natural gas used for heating [18].

Scope 2 emissions

Decontamination and reprocessing of endoscopic equipment

Equipment reprocessing is a critical step for reusable endoscopes where effective cleaning and sterilization is required to prevent transmissible infection. The process is complex and resource consuming, involves multiple cycles requiring large volumes of tap or filtered or deionized water (80-100L per wash), electricity, heat, disinfectants and detergents. Reprocessing may be broken down to include: precleaning, cleaning, disinfection, rinsing, drying, and cleaning of reusable components. Each endoscopy wash machine incurs approximately 24.67 kWh/d equating to 0.017 tCO2e/d [10,14,19-23].

The adoption of double basin washing machines uses less energy when cleaning 2 scopes (simultaneously) compared with single basin wash machines (600 W for 2 scopes cleaned vs 400 W for one scope cleaned, respectively) [9].

The consequences from improperly performed reprocessing of endoscopes can place patients at risk for acquiring infections. Additionally, exposure to biohazardous and toxic conditions in the reprocessing room can be harmful. The centralization process is driven with the primary goals of increasing reprocessing oversight and efficiency, increasing productivity through the deployment of a dedicated reprocessing team, promoting standardization of products utilized in reprocessing, reduction in the requirements for capital reprocessing equipment, and reducing reprocessing variability [23].

- High power consumption devices

Endoscopy facilities are characterized by their high energy consumption. The main sources of energy consumption within endoscopy units are, in descending order: 1) computers, 2) anesthesia machines, 3) washing machines, 4) scope processors and 5) lighting [9].

Computers consume a large amount of energy. However, they enable data digitization and avoid secondary emissions resulting from paper consumption. However, their consumption must be limited, especially when not in use.

The reprocessing of reusable endoscopes is a resource-intensive process that requires large amounts of water (30 gallons per cycle), disinfectants, detergents, as well as electricity (24.67 kWh per day) [10].

Similarly, lights can be optimized by replacing halogen lights with LEDs and optimizing their use (for example, using soft lights during endoscopic tasks, and ensuring they are switched off when not in use).

In addition to reducing energy consumption, it is essential to guarantee a green energy supply from renewable sources.

Of note, the above-mentioned analysis of a middle-sized GI endoscopy unit in Germany showed 0% scope 2 emissions. In fact, despite the yearly electrical energy attributable to the unit being 46622 kWh, 100% of electrical energy used came from regenerative sources (solar, water or wind energy) [18].

Scope 3 emissions

These include all other indirect emissions that occur across the value chain and are outside of the healthcare facility direct control. Among these:

<u>Single-use devices</u>

The use of disposable materials in endoscopy mainly refers to two areas: single-use ancillary devices and single-use endoscopes.

Endoscopy requires a significant number of single-use ancillary devices. Most of them are disposable, and made of plastic, accounting for approximately 1.5-2 kg of waste per procedure [10,14,22]. Moreover, digestive endoscopy and its accessories produce varying amounts of highly polluting elements (e.g. nickel, titanium and synthetic polymers) [19-20].

A recent study analyzed material composition of disposable forceps, snares, and clips showed that composition from different manufacturers varied widely, from common materials (polyethylene, polypropylene and acrylonitrile) to low global warming potential waste materials (stainless steel). Significant differences were found for the forceps (0.31-0.47 kg of CO2 equivalent (CO2-eq)) and hemostatic clips (0.41-0.57 kg CO2-eq) between the manufacturers [24].

As a result, the use of disposable ancillary devices must be optimized to reduce GHG emissions. Moreover, proper knowledge of carbon footprint is crucial to selecting the most sustainable product since large variations between brands are present.

<u>Single use endoscopes</u>

Concerning single-use endoscopes, recent research has been focused on duodenoscope-associated infections. In fact, the use of these endoscopes poses a significant reprocessing challenge for a variety of reasons, and a recent meta-analysis of over 13,100 samples revealed a 15% contamination rate of reprocessed patient-ready duodenoscopes [21-22]. However, the clinical impact of contaminated endoscopes is debatable.

Single-use endoscopes have been developed as a solution to decreasing endoscopy—related infections. In addition, the concept of single-use endoscopes has expanded from duodenoscopes to gastroscopes and colonoscopes.

Nevertheless, the sustainability of these endoscopes is still debated, since recyclable metal represents only a smaller part of the endoscope and, therefore, the main part of the device is disposed of in the same way as other waste [25].

Concerning reprocessing-related emissions, recent data showed that using single-use endoscopes, with an assumed infection rate of 0.02%, would produce 20 to 47 times the CO_2 emissions of reusable duodenoscopes without accounting for packaging or transporting of disposed duodenoscopes [26].

Moreover, a recently published paper has quantified the implications of a single-use endoscope and showed that it would result in 40% increase in total waste after accounting for the lack of waste from reprocessing [14].

If all endoscopic retrograde cholangiopancreatographies (ERCP) and colonoscopies were performed with disposable rather than reusable devices, the net waste mass generated per endoscopic procedure would increase by 25%, even if waste mass generated from reprocessing would decrease [14].

A recent RCT showed that in patients with bacterial infections (with positive rectal swab), the rate of post-ERCP infections was 0% after testing for the pathogens isolated from the rectal swab prior to the procedure [27].

In the United States, approximately 500,000 ERCPs are performed annually [28]. The rate of serious infections occurring is about 0.007% (36 cases per 500,000 procedures) likely due to ineffective cleaning based on 2018 data. The use of disposable endcaps would be able to reduce this number by half, to a theoretical rate of 0.0046% (23 cases per 500,000 procedures). With a contaminations rate of 1/1600 ERCPs and a transmission range from 1/1,800,000 to 1/276,000 ERCPs, the risk of a patient becoming infected by a contaminated endoscope seems to be exceptionally low, at too high a cost for the current and future generations (ICER 500,000 USD) [26].

Despite their theoretical advantage, the role of single-use endoscopes in terms of clinically relevant infections is still debatable.

Clarification is needed to determine which instruments should be considered for single-use only (duodenoscopes only or also gastroscopes and colonoscopes). Furthermore, the type of patients should also be clarified (e.g. ICU, frail or immune compromised).

Moreover, there is a lack of RCTs comparing single-use devices to reusable ones in terms of infection risk due to sample size constraints. Many studies evaluate only colonization, even though colonization does not necessarily equate to clinically relevant infection.

A recent international group of experts identified a series of best practice recommendations for single use endoscopes and accessories using a modified Delphi process. They concluded that further research is needed for expanding possible indications of single-use scopes. Additionally, it was recommended that single use endoscopes should be distributed with an effective recycling mechanism in place, considering patient characteristics and setting (frail, immunocompromised, treatment in an ICU setting, ongoing sepsis or infection from multidrug-resistant organisms).

Overall, the safety, environmental impact, sustainability and acceptability of single use endoscopes should be explored prior to their adoption [23].

Personal protective equipment

Personal protective equipment (PPE) (e.g. facemasks, gowns, aprons, gloves) are often used during endoscopy. The need for PPE grew during the COVID-19 pandemic and increased the production of waste (about 8,060,000 Kg per year in Italy), with significant environmental consequences [29-32].

Histological examinations

Endoscopy often requires additional diagnostic examinations such as histology.

Processing of biopsy samples taken during endoscopy is responsible for high GHG emissions. Above all, this concerns all the steps necessary for the processing of biological samples including the production and travel of chemical reagents, the production of waste, and electricity consumption.

Applied to more than 20 million biopsies performed in the US annually, emissions from biopsy processing are equivalent to yearly GHG emissions from 1,200 passenger cars [33].

Transportation

These include packaging and transportation of supplies used in endoscopy significantly impacts GHG emission, and accounts for a significant rate of plastic waste. As a result, about one million metric tons of clean plastic is generated by healthcare systems each year, with only a minimal amount of this plastic waste being recovered [31].

Emissions resulting from transportation also include the journey of patients to hospitals, especially referral centers, which are usually further away. To this end, travel generates considerable GHG emissions. Added to this are the costs of transporting materials required by endoscopy units. This cost can be higher depending on the distance between the producer and consumer [9].

STRATEGIES TO IMPROVE THE SUSTAINABILITY OF ENDOSCOPY

Gastroenterologists and endoscopists should reconsider daily activities and pay more attention to sustainability. The term "green endoscopy" refers to the practice of GI that aims to raise awareness, assess, and reduce the environmental impact of endoscopy.

In this regard, measures may be applied to mitigate carbon footprint and favour the evolution of a more sustainable "green endoscopy".

According to the World Health Organization (WHO), the general strategies for reducing GHG emissions can be summed up in ‘3 Rs’: ‘Reduce, Reuse, Recycle’ [9,13]. Other important Rs are Review, Research and Re-invent, Recover, and Repair [34].

All these principles can be applied in endoscopy with a multi-level approach, from individuals to institutions (Figure 2).

Inappropriate diagnostic and follow-up examinations

Data shows that the rate of inappropriate examinations reach up to 52% of upper GI endoscopies and 23% to 52% of colonoscopies [35]. A recent study estimates that the carbon cost of inappropriate EGD and colonoscopy in Italy was 4133 CO2 metric tons/year, ranging from 3527 to 4749, and equivalent to 1,760,446 L of gasoline consumed. When translating this data to other European countries, the estimated carbon footprint of inappropriate digestive endoscopy in Europe is estimated to be 30,804 metric tons [36].

Therefore, this represents a relevant issue in endoscopy units. A first step in reducing the number of inappropriate diagnostic examinations is to rationalize the number of procedures requested for young patients without risk factors or alarm symptoms.

Another point is reducing inappropriate endoscopic follow-up. The most frequent cases are follow-up of chronic distal atrophic gastritis without dysplasia and no additional risk factors, peptic duodenal disease, or low-risk polyps removed at colonoscopy. In these cases, it is important to avoid unnecessary testing and ultimately reduce GHG emissions [37].

In this regard, international guidelines for improving endoscopic appropriateness should guide clinical practice on indications for surveillance and diagnostic endoscopy (Table 2) [34,38-39].

Moreover, several non-invasive biomarkers can be used which allows endoscopy to be avoided in the diagnosis or follow-up of some GI diseases. For instance, the Baveno VI criteria (i.e., liver stiffness measured (LSM) < 20 kPa and PLT $> 150 \times 10^9$/L) can be used to predict patients with advanced chronic liver disease in whom the risk of varices is low, and upper endoscopy deemed unnecessary [40-41].

Concerning the lower GI tract, the faecal immunochemical test (FIT) is used as a primary screening method for colorectal cancer, ruling out non-at-risk patients in whom colonoscopy is not indicated [42].

Additionally, in patients with inflammatory bowel diseases (IBD), fecal calprotectin is used as a non-invasive marker of response, reducing the need for endoscopic follow-up and to rule out organic diseases in patients with functional disorders [43].

Biopsy sampling and histology

As discussed above, processing of biopsy samples taken during endoscopy is responsible for high GHG emission. Above all, this concerns all the steps necessary for the processing of the sample, the production and travel of chemical reagents, the production of waste, electricity consumption [33].

Therefore, it is essential to apply mitigation strategies aimed at limiting histological examination only to necessary cases, informed by guidelines and correct number of samples

[44-45].

Furthermore, innovations in endoscopic imaging (e.g. virtual chromoendoscopy and magnification) has improved mucosal visualization and endoscopic diagnosis. These improvements help to identify low-risk lesions such as hyperplastic polyps which enables a "resect-and-discard" and/or "diagnose and leave" approach, thus avoiding unnecessary histology [46].

Looking ahead, the implementation of artificial intelligence (AI) with computer-aided characterization (CADx) will allow a further gain in optical diagnosis in favor of strategies that do not require histology [47].

Minimize rescheduling of procedures

Another crucial area has to do with reducing the number of endoscopic exams that have to be rescheduled due to non-compliance with guidelines or quality measures. This frequently occurs in patients who perform colonoscopy without achieving an adequate bowel cleansing, patients who undergo upper GI and have not followed the dietary rules, or patients who perform operative procedures without the suspension of antiplatelet/anticoagulant agents, when requested.

This goal can be met by improving patient communication.

First, instructions on diet and bowel preparation must be provided in written form, the solution for preparation must be chosen among those recommended by the guidelines, performed in a split fashion, and colonoscopy must performed within 5 hours following bowel preparation [48-49].

Furthermore, at the preliminary colonoscopy interview, the concomitant therapy must be investigated, and the possible intake of antiplatelet and/or anticoagulant drugs managed preventively in accordance with the guidelines [50].

Resource optimization

Wasteful use of resources within an endoscopy unit leads to higher cost and environmental impact. Strategies aimed at optimizing resources should be adopted. For example, PPE-related waste may be minimized by bringing together at-risk patients on the same endoscopy list.

Sterile endoscopic water should also be limited to patients at high risk of infection such as immunocompromised patients. Tap water should be used routinely in the irrigation bottle, since it has been demonstrated to be as safe as sterile water. This would have both environmental and economic impacts [51].

Moreover, the adoption of washable and reusable accessories should be considered when feasible, but evaluated case by case since it is not always supported by robust solid scientific evidence.

Finally, the use of recyclable materials to increase the sustainability, and the purchase of local products that reduce transport distances.

Energy optimization

Energy consumption from electricity accounts for 10-30% of the environmental impact of individuals and healthcare systems [9].

The use of electricity is another element that contributes to the environmental impact of endoscopy. Green use of energy should be promoted in all endoscopy units: lights should be turned off when not in use for long periods, halogen should be replaced by LED lights, optimize heating and air conditioning necessary to maintain a comfortable ambient temperature, shutting down computers overnight, and use of renewable energies (e.g. photovoltaic) should be promoted when possible [9]. Finally, rechargeable batteries should be preferred over standard ones.

Waste minimization, reuse, and recycling

Waste management and proper disposal contribute to reducing GHG emissions.

As discussed above, the waste-management hierarchy should be based on the concept of the “3Rs”: reduce, reuse, and recycle (Figure 3).

The most preferable approach should be avoiding the production of waste as much as possible and minimizing the quantity entering the waste stream. Where feasible, according to best practice, recovering items for secondary use is the most preferable option. Waste that cannot be recovered must then be dealt with by least preferable options, such as treatment or land disposal, to reduce its health and environmental impacts [52].

Endoscopy rooms should have a plan for proper waste disposal, with separate bins dedicated to each item (paper, plastic, glass, etc.) to ensure proper recycling.

Telemedicine and electronic records

The migration of patients towards tertiary treatment centers, which are generally located at greater distances, can add to transport-associated emissions.

The COVID pandemic has accelerated the spread of telemedicine, which now represents a fundamental resource of the healthcare system. Data shows that telemedicine is highly effective and financially beneficial. Moreover, it may reduce transport-associated emissions with carbon footprint savings ranging between 0.70-372 kg CO^2 per consultation [53].

Additionally, the use of paperless communication, electronic reports/letters, and encouraging patients to sign up to view their results online would save both paper and gas mileage [22]. Adopting double sided printing or reducing the number of printed copies can also have a small but positive environmental effect [11].

Telemedicine can be used for follow-up visits in patients with chronic diseases (e.g. chronic liver diseases, IBD etc.) or reviewing laboratory tests or histological reports (e.g. following endoscopy) [54-56].

In addition, teleconsultation can be used for consultations between specialists and meetings with multidisciplinary teams (MDT).

Moreover, in the field of digital technologies, the use of electronic medical records (EMRs) as well as the generation of digital reports over paper copies, may improve not only the accessibility of information, but also the environmental impact.

THE ROLE OF INSTITUTIONS AND SCIENTIFIC SOCIETIES

Institutions will play a key role in determining the environmental sustainability of endoscopy. Firstly, increasing physician and staff awareness is needed, which can be achieved by implementing educational programs.

Secondly, partnering with industry is important for creating a shared vision aimed at reducing direct and indirect emissions. It will be crucial to share strategies with manufacturers aimed at optimizing production, product packaging, and distribution.

Furthermore, providing financial incentives may support eco-friendly projects and facilitate sustainable transitions.

Scientific societies will play a decisive role in this process. Many of them have already issued consensus statements which summarize the guidelines to be adopted for a green endoscopy including the Association of the European Society of Gastrointestinal Endoscopy (ESGE) and European Society of Gastroenterology and Endoscopy Nurses and Associates (ESGENA) [57], the British Society of Gastroenterology (BSG) [58], and the Italian Association of Hospital Gastroenterologists and Digestive Endoscopists (AIGO) [34].

In the future, it would be desirable for other national scientific societies to fit this job by issuing tailored position statements at the national level, based on geographical differences and local needs. In addition to formal recommendations, a periodic audit to verify the adherence of individual endoscopy units to recommended standards, at least to the essential and evidence-based ones, and accreditation of green endoscopy on the national level will be necessary [10].

Moreover, scientific societies should act to encourage educational models and promote further research on green endoscopy which can be aided with the provision of sustainability grants.

Finally, they should promote regulation regarding the environmental sustainability of educational events. These represent another relevant source of carbon footprint derived from the consumption of electricity, the production of waste, and the travel necessary to reach the venue etc. In this regard, the frequency of in-person events, their duration, as well as the number of participants should be limited, in favor of online or hybrid ones. Furthermore, in-person meetings should also respect sustainability criteria related to low energy consumption, absence of non-recyclable material, etc.

The next step is to seek individuals who can support the change both at management and grass roots levels, creating a “guiding coalition” and constant presence. This would involve making the changes that are easy to achieve by staff members but have a significant impact [11].

CONCLUSIONS

The climate crisis calls for quick and decisive action. In this setting, the healthcare system contributes significantly to the climate crisis, but it has the opportunity to be part of the solution. Therefore, it must be involved in raising awareness and helping to develop regulatory guidelines aimed at mitigating GHG emissions.

Concerning endoscopy, the near future goal is to make endoscopy units ‘green’ through uniform worldwide action. Measures aimed at reducing emissions have been mentioned above; the careful evaluation of the indications for endoscopic and histological examinations, the rationalization of disposable devices, careful management of PPE, optimization of energy use and correct waste disposal are practical strategies.

Moreover, a fundamental role will be played by telemedicine to reduce the environmental impact linked to the transport of patients for follow-up visits.

Looking ahead, endoscopy units will have to be evaluated in terms of performance and efficiency globally. To this end, sustainability should now be considered a central domain of quality in healthcare, extending the responsibility of health services to both current and future patients.

We believe that healthcare institutions will also play a key decision-making role in this green transition. Economic investments and partnership with stakeholders in terms of enhancing healthcare's economic, social, and environmental impacts will be essential to achieving these goals.

However, the cultural aspect also plays a key role. Therefore, in addition to focusing on general regulation, it will be necessary to invest in the education of the younger generations. To this end, schools should include curriculum focused on a greener climate.

For trainees, it is crucial that the concept of green endoscopy is formally included into the endoscopy training program from the beginning.

In conclusion, it is time to act at multiple levels to ensure green endoscopy worldwide.

While this requires massive change, we can no longer continue hearing examples of how many football fields are needed to accommodate the waste of a hospital ward or how many acres of forest would be needed to clean up the CO_2 emitted by a hospital. We need to move the conversation forward with sustainable action. We must work closely together to ensure the present and future sustainability of our planet and health.

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LEGEND

Figure 1. Estimate energy consumption and carbon emissions in endoscopy units.

Figure 2. The waste-management hierarchy.

Figure 3. The ‘3 Rs’ strategy for reducing GHG emissions in endoscopy.

Table 1. Current studies estimating the carbon footprint in endoscopy.

Table 2. Digestive findings that might not require endoscopic surveillance.

Table 1. Current studies estimating the carbon footprint in endoscopy.

Author	Year	Study	Country	Endoscopic procedures	Carbon footprint estimate	Other considerations
Gayam S [10]	2020	Retrospective	United States	18 million endoscopic procedures annually	Endoscopy generates 13,500 tons of plastic waste, 10,800 tons of which are nonrecyclable. The GHG emissions produced are equivalent to nearly 88,108,062 miles driven by an average vehicle. These procedures emit enough CO2 to equal more than 3,995,448 gallons of gasoline consumed.	It would take 46,371 acres of forest over a year to sequester the CO2 produced by these procedures.
Siau K [9]	2021	Review	United States	18 million endoscopic procedures annually	Annual CO2 emissions of 85,768 metric tonnes are equivalent to more than 9 million gallons of gasoline consumed, 94 million pounds of coal burned, and 212 million miles driven in an average non-electric car.	To offset these CO2 emissions, an additional 112,000 acres of new forest would be needed each year.
Lacroute J [16]	2021	Retrospective	France	Medium-sized Endoscopy Unit (8524 procedures / 6070 patients)	A French ambulatory endoscopy unit estimated GHG emissions of 28 kg CO2e per endoscopic procedure, with travel (patients and staff) accounting for 45% of the unit's footprint (74% of patients travelled by car). Medical and non-medical equipment (32%), energy consumption (12%), consumables (7%), waste (3%), freight (0.4%), and medical gases (0.005%) were the other sources of emissions.	The production of equipment such as wash disinfectors and endoscopes was responsible for one-third of the emissions.
Lacroute J [16]	2021	Retrospective	France	524 endoscopic procedures / 6070 patients	GHG emissions at the center were estimated to be 241.4 tonnes CO2e, resulting in a carbon footprint of 28.4 kg CO2e for one GIE procedure. The main source of GHG emissions, accounting for 45% of total emissions, was travel to and	NA

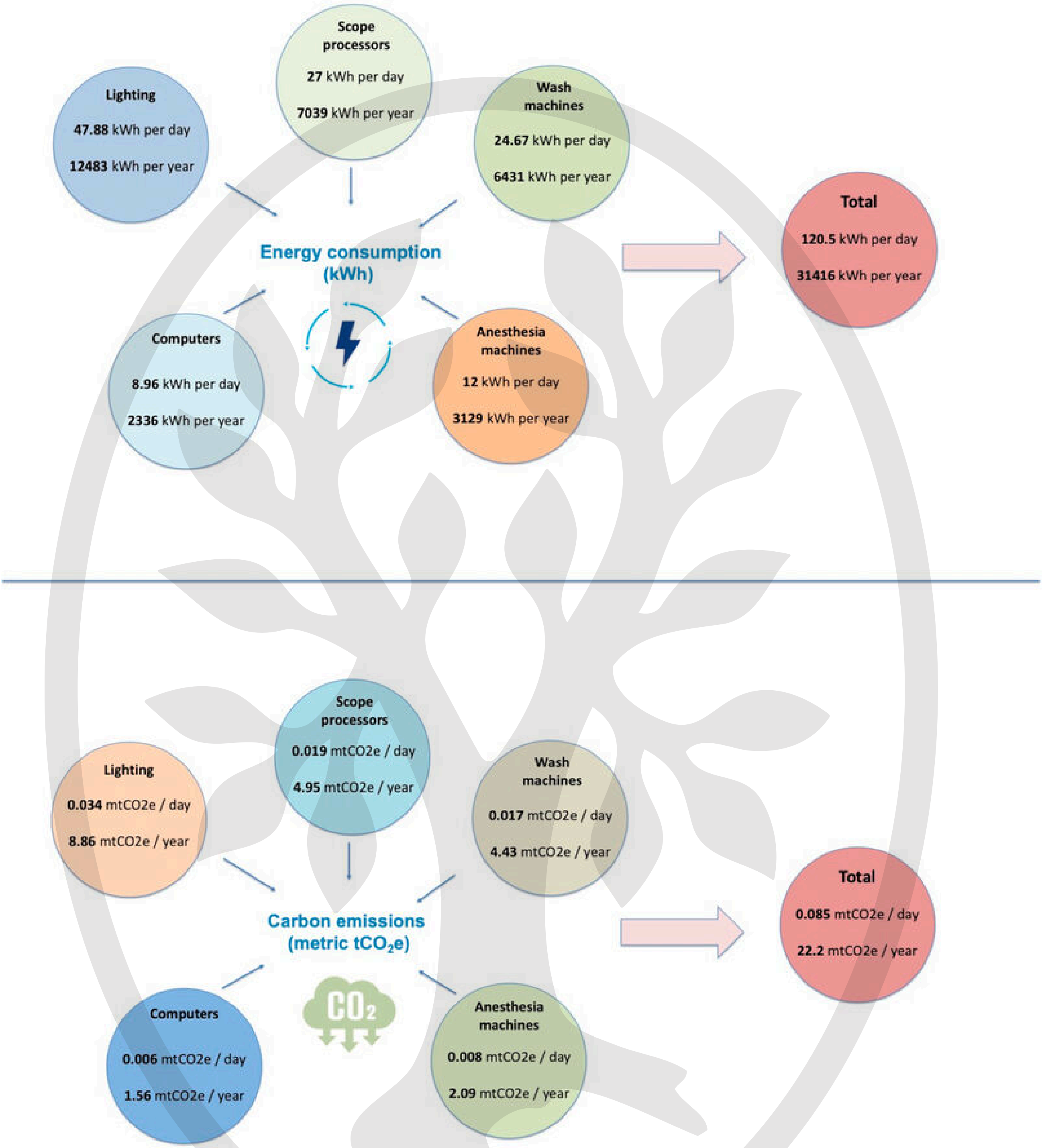
					from the center by patients and center staff. Other sources of emissions included medical and non-medical equipment (32%), energy consumption (12%), consumables (7%), waste (3%), freight (0.4%), and medical gases (0.005%), in that order.	
Henniger D [18]	2022	Retrospective	Germany	Medium-sized Endoscopy Unit (8000 procedures per year)	The total amount of carbon dioxide equivalents emitted was 62.72 tons. Emissions from self-controlled sources: 35.91 tons were associated with the consumption of natural gas for heating; 26.81 tons total indirect emissions (manufacturing, processing, packaging, and transportation of purchased accessories).	This assessment excluded emissions from patient and staff travel as well as the manufacture of capital equipment such as endoscopes.
Le NNT [26]	2022	Prospective	United States	NA	The manufacture, transportation, use, and reprocessing of a reusable duodenoscope produces 1.53 kg CO2e.15 A single-use duodenoscope would generate up to 47-fold more GHG emissions in this model, with more than 90% of these emissions generated during the manufacturing process of the single-use endoscope.	The study used approximations to estimate emissions associated with endoscope production, and the assessment also accounted for the electricity and detergents required during high-level disinfection.
Donnelly L [11]	2022	Review	UK	2.1 million procedures were performed in 2019	The NHS discards approximately 133 000 tonnes of plastic each year, with only about 5% of this waste currently being recovered. NHS operations are responsible for 6.3% of total UK carbon emissions and 5% of total air pollution.	0.29 kg CO2e for each biopsy pot or 0.79 kg CO2e for three biopsy pots, corresponding to 0.7 to 2.0 miles driven.
Namburar S [14]	2022	Cross-sectional study	United States	278 endoscopies/ 243 patients endoscopies at two US academic medical centres with low and a high endoscopy volume (2000 and 13 000	Each endoscopy generated 2.1 kg of disposable waste (46 L volume). 64% of waste was going to the landfill, 28% represented biohazard waste and 9% was recycled. The estimated total waste generated during all endoscopic	If all endoscopic procedures were performed with single-use endoscopes and accounting for reprocessing, the net waste mass would increase by 40%.

				procedures annually)	procedures performed in the USA annually would weigh 38 000 metric tons (equivalent of 25 000 passenger cars) and cover 117 soccer fields to 1 m depth.	
Baddeley R [13]	2022	Commentary	United States	18 million endoscopic procedures annually	86,000 tonnes of CO2 equivalent of greenhouse gas emissions, the equivalent of 213,000,000 miles driven in a passenger car	**Administration of an Endoscopy Service**: Each endoscopy bed-day is estimated to generate 3 kg of waste, with the specialty responsible for 13,500 tons of plastic waste per year; **Procedural considerations**: Processing three GI biopsy pots is equivalent to driving two miles. Reprocessing reusable endoscopes is a resource-intensive process that requires large amounts of water (30 gallons per cycle), disinfectants, detergents, and electricity (24.67 kWh per day). With an assumed infection rate of 0.02%, using single-use endoscopes would result in 20 times the CO2 emissions of reusable duodenoscopes; **Single-Use Consumables:** Thermal technologies that compress used polypropylene products like personal protective equipment and other single-use plastics into rectangular blocks that can be sold and converted into pellets for new plastic products reduce the amount of waste that must be transported offsite. Trackable inventory systems can assist in reducing waste from expired supplies.

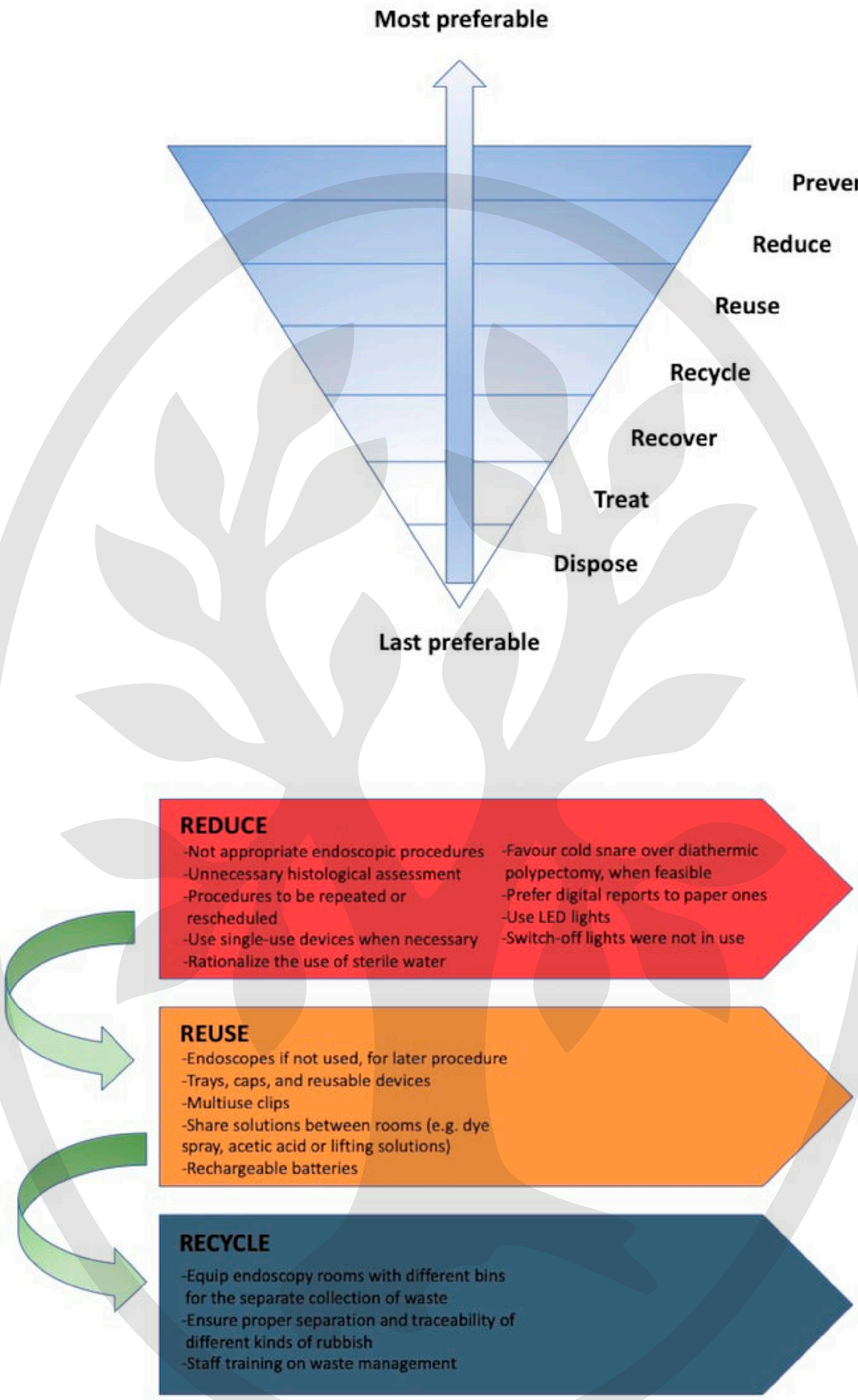
López-Muñóz P [59]	2022	Process-based analysis	France	NA	When the emissions from the production of a reusable endoscope were averaged over its lifetime, they were very low. Energy accounted for only 12% of the French center's emissions (this reflects, in part, France's high nuclear fraction in their energy mix as well as the relative efficiency of a dedicated ambulatory unit).	NA
Elli L [36]	2023	Review	Italy	Endoscopic procedures performed per 1,000 inhabitants	The carbon cost of inappropriate EGD and colonoscopy was 4,133 CO2 metric tons per year, ranging from 3,527 to 4,749 liters of gasoline consumed. Using the same data, the estimated carbon footprint of inappropriate digestive endoscopy in Europe was 30,804 metric tons.	NA
López-Muñóz P [24]	2023	Thermochemical analysis	Spain	NA	The study team was able to conduct a process-based life cycle assessment (LCA) using this material composition data, reporting GHG emissions of 0.31-0.57 kg CO2e per accessory.	NA

Table 2. Digestive findings that might not require endoscopic surveillance.

	CONDITION	PREVALENCE	MALIGNANCY RISK
Esophagus	Inlet patch	0.1 % – 12 %	0 – 1.6 % risk of dysplasia
	Erosive esophagitis LA grade A or B	11%	0 – 9 % risk of Barrett's esophagus
	< 1 cm columnar-lined esophagus	10%	No increased risk of esophageal cancer
Stomach	Intestinal metaplasia or atrophy limited to one location (i. e., antrum or corpus only) without dysplasia	Up to 25%	0.55 % risk of progression to gastric cancer
	Fundic gland polyps	13%-77%	No documented risk of gastric cancer if < 1 cm and no suspicious features
Subepithelial lesions	Leiomyoma	0.08% - 0.43%	Benign lesion
	Lipoma	0.2%	Benign lesion
	Pancreatic rest	0.6%-13.7%	Anecdotal malignant transformation
Duodenum	Duodenal peptic ulcer	2%-13%	No cancer risk
Pancreas	Serous cystic neoplasm	Up to 16% of pancreatic cystic neoplasms	Benign lesion
Colon	Low-risk adenomas (adenoma <10 mm without high grade dysplasia, or < 4 adenomas, or serrated polyp < 10 mm without dysplasia).	~15 % – 30 %	No increased risk versus general population



Scope processors
27 kWh per day
7039 kWh per year
Lighting
47.88 kWh per day
12483 kWh per year
Wash machines
24.67 kWh per day
6431 kWh per year
Energy consumption (kWh)
Total
120.5 kWh per day
31416 kWh per year
Computers
8.96 kWh per day
2336 kWh per year
Anesthesia machines
12 kWh per day
3129 kWh per year
Scope processors
0.019 mtCO2e / day
4.95 mtCO2e / year
Lighting
0.034 mtCO2e / day
8.86 mtCO2e / year
Wash machines
0.017 mtCO2e / day
4.43 mtCO2e / year
Carbon emissions (metric tCO_2e)
Total
0.085 mtCO2e / day
22.2 mtCO2e / year
CO2
Computers
0.006 mtCO2e / day
1.56 mtCO2e / year
Anesthesia machines
0.008 mtCO2e / day
2.09 mtCO2e / year


Most preferable
Prevent
Reduce
Reuse
Recycle
Recover
Treat
Dispose
Last preferable
REDUCE
-Not appropriate endoscopic procedures
-Unnecessary histological assessment
-Procedures to be repeated or rescheduled
-Use single-use devices when necessary
-Rationalize the use of sterile water
-Favour cold snare over diathermic polypectomy, when feasible
-Prefer digital reports to paper ones
-Use LED lights
-Switch-off lights were not in use
REUSE
-Endoscopes if not used, for later procedure
-Trays, caps, and reusable devices
-Multiuse clips
-Share solutions between rooms (e.g. dye spray, acetic acid or lifting solutions)
-Rechargeable batteries
RECYCLE
-Equip endoscopy rooms with different bins for the separate collection of waste
-Ensure proper separation and traceability of different kinds of rubbish
-Staff training on waste management