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Review

Current and Future Sustainability Traits of Digestive Endoscopy

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Abstract: One of the most important parts of medical care is the endoscopy sector, like digestive endoscopy, which has gained extensive importance and is assumably going to increase in the future. We aimed to analyse and synthesize the impact of digestive endoscopy upon the environment and the possible measures that can be taken to minimize the negative effects of endoscopy related to environmental pollution and human health exposure. The means through which digestive endoscopy produces pollution have been analysed, considering the frame and the base of the last stage of a medical or pharmaceutical product. This research suggests a strategy for improving the impact of this sector on the sustainability of the healthcare system based on four pillars comprising the use of eco-friendly substances, materials, and devices, reducing the consumption of water and all possible devices and energy, reusing those components that can be safely reinserted in the endoscopic circuit and recycling everything that is possible. The conclusions highlight that there is a great need to take control of medical practice, admitting the impact that the healthcare system has on global warming and greenhouse gas emissions, acknowledging the limited assets and wealth of the planet, and applying standards and scales of sustainability that can lead to responsible services for patients.

Keywords: digestive endoscopy; sustainability; pollution; medical/pharmaceutical waste; last stage of a product

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1. Introduction

Pollution appears when any form of substance or any type of energy is scattered into nature in a proportion that is bigger than the capacity of dispersion or storage of the environment. Therefore, pollution, whether created by natural pollutants or by human interventions, is obviously harmful not only to the planet Earth itself but also to all its inhabitants [1].

Environmental pollution remains the world's greatest problem facing humanity and the leading environmental cause of morbidity and mortality [2]. As is commonly known, there are four main types of pollution (i.e., noise, radioactive, biological, and chemical) in different environments (i.e., air, water, and soil). The main causes of pollution are as follows: burning fossil fuels, all types of industrial activities [3,4], waste destroying processes, mining activities [5], domestic sources [6], construction [7,8], microbial decaying processes [9], and agriculture [10].

Among these causes of pollution, as recent data suggest, the medical sector is proven to provoke an important part of the global emissions of greenhouse gases and air pollutants: 4.4% of greenhouse gases, 2.8% of harmful particulate matter (air particles), 3.4% of nitrogen oxides, and 3.6% of sulphur dioxide [11]. Therefore, hospitals and all the other medical care units are the first sources for generating sanitary waste, with high risks for populations and, consequently, imposing strict protocols for handling wastes, from generating them to the final treatment [12].

It is evident from the continuous provision of healthcare benefits to the populace that healthcare can inadvertently inflict harm through a cascading process, as delineated in Figure 1.

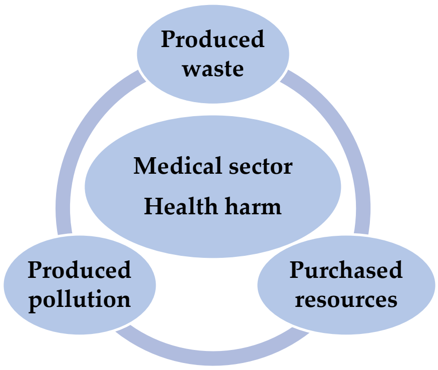


Figure 1. Mechanism of pollution in the heath sector.

One of the most important parts of medical care is the endoscopy sector, which has gained extensive importance lately due to a lot of factors such as real-time and optimal evaluation and diagnosis with minimally invasive procedures, the opportunity to collect tissue samples, and, more importantly, the ability to perform therapeutic manoeuvres with lower risks and less stress for the patient [13,14].

Almost all medical branches extensively use endoscopy procedures, considering:

- Gastroenterology (digestive endoscopy);
- Orthopaedic surgery (arthroscopy);
- Pulmonology and thoracic surgery (bronchoscopy and mediastinoscopy);
- Urology (cystoscopy and urethroscopy);
- Gynaecology (hysteroscopy);
- Various types of surgery (laparoscopy);
- Otolaryngology (laryngoscopy) [15].

Endoscopy is permanently advancing, and newer generations of endoscopes offer high-definition imaging and more and more therapeutic interventional possibilities in all the aforementioned medical specialties [16].

All over the world, due to the ever-increasing requirements in the field of health care, as well as the growing number of hospital units, clinics, laboratories, polyclinics, health centres, etc., imposed by the needs of the growing population, the variety and quantity of medical or pharmaceutical waste resulting from these health care activities have considerably increased [17]. These aforementioned wastes that result from the care of patients, through the provision of optimal health services, and through the promotion of health are themselves a serious threat not only to health but also to the environment in general [18].

According to a study carried out in several countries and published recently, in 2022, the generation rate of medical waste oscillated between 0.14 and 6.10 kg/bed/day. Of the total number of countries considered, approximately 25% selected medical waste, and 17% used the standard storage method for it. In addition, deficiencies found in the cases of some countries referred to the stages of collection, storage, transport, and transfer of these typical wastes, as well as the organization of the elimination of their management activities. In the same research, it was found that only a quarter of the investigated countries simultaneously applied three techniques for the elimination or treatment of sanitary waste (i.e., autoclaving, incineration, or storage), with 91% usually using incineration [19].

In this review paper, we aimed to analyse and summarize the current impact of digestive endoscopy on the environment through the waste it inevitably generates. Also, we considered the possible measures that can and should be taken in an attempt to minimize the negative effects of pollution caused by this medical field in an effort to create such a useful and sustainable sector. The idea of this study started with the desire to make digestive endoscopy as "ecological"/"green" as possible in an era where patients are becoming more and more dependent on the procedures offered by the health care system.

2. Last Stage of a Medical/Pharmaceutical Product

About 10 years ago, it was found in a sample of investigated countries that only a little more than half of the spaces dedicated to health care had systems and equipment considered necessary for the safe disposal of medical-pharmaceutical waste [20]. There is therefore a combination of factors that lead to the appearance of numerous problems regarding the approach to sanitary waste. Often, one of the most serious situations is the wrong use of incineration when waste of non-clinical origin is mixed with clinical (hazardous) waste, unnecessarily choosing internal incineration for the first of the mentioned categories of waste. The result is deficient and weak, leading to overcrowding of the installation, overloading of the incineration installation, and overloading of the personnel who handle it [21]. Biomedical waste is categorized into ten distinct groups (Figure 2), covering a wide array of materials, including human anatomical waste, animal waste, microbiological specimens, sharps, discarded medicines, soiled items, solid disposables, liquid waste, incineration ash, and chemical waste. These categories guide the scientific management and disposal of biomedical waste [22].

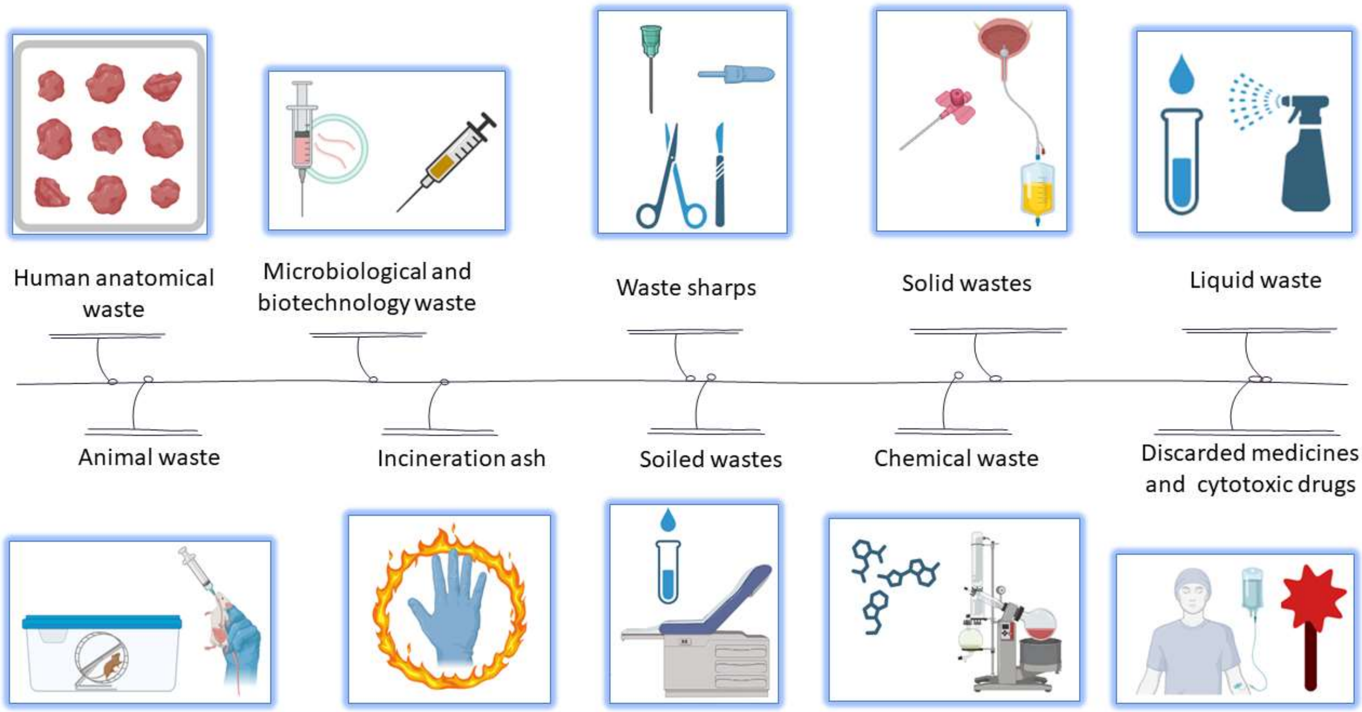


Figure 2. Biomedical waste categorization into ten key categories.

Most of the published research addresses the first three stages of the life of a medical-pharmaceutical product, which are in order as follows: design, manufacture, and use. The last stage in the life of any type of product is recycling or the management of the final waste, which is the result of the end of the respective product's life cycle. Therefore, the details of the approach to this last stage in the case of medical-pharmaceutical waste must be known, applied, and evaluated [23].

In this sense, an essential role is that of the medical staff, who must be educated in this sense and be fully aware of their own role in the optimal management of waste resulting from health care activities. They are the ones responsible for sorting waste exactly at the place of its generation. Non-clinical staff are often less aware of the importance of this selection, having at the same time less experience and knowledge in this area of waste treatment and segregation. Therefore, the medical assistance staff must know the ways to reduce the volume of waste, which implicitly leads to a reduction in their management costs as well as the operational efficiency of the respective sanitary unit. These desired goals can be achieved by implementing appropriate activities, appropriate measures, and even strict protocols that allow the correct flow of medical waste [24].

For implementing a recycling economy, the following stages were suggested:

- Elimination of waste generation;
- Reuse of waste;
- Emphasizing waste recycling;
- Energy recovery;
- Compliant disposal.

Respecting these stages, the application of those activities that result in the reduction of sanitary waste must be the responsibility of the front-line medical care staff [25]. In Romania, regarding the sanitary waste management activity, there are numerous deficiencies, mainly generated by the following:

- A lack of coherent, clear legislation with simple procedures, easily applicable by both citizens and medical and pharmaceutical units;
- High costs are incurred in the collection of sanitary waste from patients, pharmacies, and medical units;
- Personnel responsible for the initial selection of this waste face a lack of sufficient information.

However, some solutions have already been identified in the published literature:

- Effective and complex waste reduction policies and the establishment of clear responsibilities for the personnel who handle it;
- A continuous information system for nurses and pharmacists regarding the effective management of the resulting waste;
- Awareness of patients and health personnel regarding the importance of correct management of medical-pharmaceutical waste;
- Removing or reducing the financial impact of waste storage;
- Risk identification, etc. [26].

An unfortunate consequence of the improper use and disposal of medical and/or pharmaceutical products is their presence as waste in the environment (images of masks on all the beaches of the world and in the most inappropriate places have made the rounds of the planet after the pandemic). Moreover, due to extensive farming practices, wastes, including antibiotics and hormones, are often found in the excrement of domestic animals, such as cows and poultry [6,27], posing a direct threat to ecosystems and human health [9].

The National Health Service of England has issued a document developing the "*Principles for the disposal of pharmaceutical waste used in community health services*". Through it, coherent guidelines directly related to the correct disposal of sanitary waste are promoted. There are ways to select the pharmaceutical waste separately by class and ways of specific and correct colouring of the coded boxes and their corresponding seals when they are full, after which they will be assigned a transfer note. The mentioned document is an efficient, safe, and responsible example of managing a type of waste resulting from health care activity with minimized impact on the toxicity of chemical substances and reduced harmful exposure to the environment [28].

The Context of Waste and Packaging Materials in the Endoscopy Suite

The concept of "Green Endoscopy" involves implementing effective strategies to reduce waste and optimize the use of equipment and supplies in the endoscopy sector, benefiting both patients and the environment. Medical waste disposal is significantly costlier and has a larger environmental footprint in terms of carbon emissions compared to regular waste [29].

At the University of Michigan's Medical Procedure Unit, the management of waste was switched from reusable biopsy forceps to disposable ones due to cost savings. This economic choice, however, has led to a notable increase in waste generation, which must be managed properly to prevent environmental problems [30].

In recent years, there has been a shift from multi-use to single-use endoscopes and supplies. While this reduces infection risks, it raises concerns about increased costs, inventory management complexities, and waste production. Whether this shift is environmentally friendly and cost-effective remains a subject of debate [31–33].

Educating healthcare professionals about proper waste classification and disposal is crucial in creating a sustainable endoscopy unit. Research indicates that a significant percentage of endoscopy staff incorrectly dispose of accessories as regulated medical waste or sharps [34].

There are limited global data on waste generated by endoscopy services, but reports suggest that they are significant waste producers. In Italy, gastroenterology/endoscopy was the second-highest waste generator per procedure [35]. Research conducted in Japan, which assessed the quantity of waste generated in endoscopy facilities across three different hospitals, revealed an average range of 110.2 to 179.9 g of waste produced per procedure, with a predominant 92.9% portion categorized as infectious waste [30].

To address and alleviate the environmental impact associated with endoscopy procedures, a range of strategic measures can be implemented. Firstly, fostering enhanced clinical oversight and conducting internal audits are vital steps. These activities should be complemented with appropriate corrective actions, thereby ensuring that procedures are conducted in an environmentally responsible manner. Secondly, sustainable procurement practices are crucial. These encompass efforts to diminish emissions throughout the entire supply chain, emphasizing the importance of selecting eco-friendly products and suppliers who adhere to green standards [36].

The adoption of renewable energy sources to power hospitals and endoscopy units represents another essential facet of this endeavour. Transitioning to sustainable energy solutions can significantly reduce the carbon footprint associated with healthcare operations. Furthermore, healthcare institutions can leverage their anchor status to influence suppliers. By compelling these suppliers to disclose their carbon footprint and embrace sustainable practices, the healthcare sector can further promote environmentally responsible procurement [37].

Innovative medical alternatives can also contribute to a reduction in the environmental impact. Exploring less invasive procedures, such as the utilization of Cytosponge, offers eco-friendly alternatives to traditional methods. Materials used in endoscopy procedures can be replaced with compostable or recyclable plastics, diminishing the burden on landfills and encouraging sustainable waste management practices [36].

The emphasis on the use of recyclable equipment and the prioritization of multi-use and easily repairable devices are measures that can substantially decrease waste generation and resource consumption. Consideration of the entire lifecycle of procured items when making choices between single-use and reusable devices is essential. Evaluating the environmental impact throughout the product's life cycle can guide more eco-conscious decisions [38,39].

A reduction in the use of nitrous oxide, a potent greenhouse gas, and the maintenance of equipment to minimize gas leaks are essential steps in decreasing the ecological footprint of endoscopy procedures. Efficiency in the decontamination process is equally crucial. Streamlining the resources required for decontamination can contribute to a reduction in waste generation and energy consumption within the healthcare setting [40].

Collectively, these measures are designed to promote the transformation of endoscopy units into more environmentally sustainable entities while simultaneously reducing their ecological impact.

3. Means and Ways Digestive Endoscopy Produces Pollution

3.1. Air and Water Pollution

Air pollution is defined as the contamination of the indoor or outdoor environment by a mixture of any chemical, physical, or biological agent that modifies the natural atmosphere [41].

The indoor quality of the air and maintaining its proprieties [42] are matters of great importance for the health of every person who spends a lot of time in the same confined space, and also for interior objects, especially when they are of patrimony (books, paintings, furniture, etc.) [43]. Besides the toxic pollutants that arise from the construction, building materials, products, and installations used for the maintenance of a construction, etc. [7,8,44,45], or working in an environment that is constantly affected by air pollutants produced by different activities puts the workers or the people living in those buildings at high risk for pulmonary, cardiovascular, and other diseases. These air pollutants are mostly carbon dioxide (CO_2), volatile organic compounds (VOCs), particulate matter that has a diameter of <2.5 µm ($PM_{2.5}$), nitrogen dioxide (NO_2), carbon monoxide (CO), and ozone [46].

In this context, digestive endoscopy can contribute to these types of air pollution in multiple ways. First, to a smaller extent, there can be expulsions of gastrointestinal gas from the patients during the endoscopic procedure and coagulation of tissues through carbonation (haemostasis through thermal coagulation devices, endoscopic mucosal or submucosal resection procedures). Also, one of the most important parts of a lower gastrointestinal endoscopy is the insufflation of the bowel/digestive tract with environmental air, or CO_2, to assure space and visibility. CO_2 insufflation is known to do this with less distress (less abdominal pain) for the patient, but of course, it leaks out into the air. If it reaches a high concentration, it can obviously affect the personnel's health [47,48].

In Sweden, there are national occupational exposure limits (OELs) for CO_2. There are two commonly used OEL values: the level limit value (LLV) and the short-term exposure limit (STEL). LLV is the OEL value for exposure during a working day, normally eight hours (limit value (LLV) of 5000 ppm). STEL is the OEL value for a reference period of 15 min of exposure (highest accepted value 10,000 ppm) [49].

However, extensive reviews showed that linear physiological changes in the circulatory, cardiovascular, and autonomic systems become evident in the human body upon exposure to CO_2 at concentrations ranging from 500 to 5000 ppm. Therefore, is CO_2 insufflation safe for the air quality, or can it also contribute to the air pollution from the endoscopy unit? Research data are rather scarce regarding the CO_2 levels from digestive endoscopy units, as not many studies have been performed in this field. Nevertheless, we found an interesting small study from 2020 on laparoscopies in the operating rooms during 20 laparoscopic procedures using CO_2 insufflation. With the help of a gas detector (i.e., TM Dräger X-am 5600, Lübeck, Germany), they recorded point measurements of CO_2 concentrations during the surgeries. The CO_2 concentration during the surgeries was measured at 400–1100 ppm and never exceeded 22% of the LLV at 5000 ppm [49].

Second, and of course to a much bigger extent, the reprocessing of the endoscopes (cleaning and disinfection stages), which are of course repetitive after each procedure, produces chemically volatile vapours that can be inhaled and high amounts of contaminated water that need to be discarded into the sewer. This air pollution can potentially affect the health of medical personnel (nurses, doctors, etc.) that spend a lot of their time in the endoscopy unit and, to a lesser extent, the patients that undergo digestive endoscopy manoeuvres [47].

Moreover, there are no current standards for indoor air quality in the endoscopy unit, and no specific measurements are performed for air quality checks. Endoscope reprocessing is regulated by multiple local country guidelines, which clearly indicate all the compulsory stages and the chemical solutions that must be used [50].

3.2. Pollution Produced through the Reprocessing Sequence

According to the Spaulding Classification System [51], digestive endoscopes are devices that need high level disinfection (Table 1).

Table 1. Endoscope classifying according to Spaulding sorting system.

Spaulding Classification	Examples of Devices	Risk of Infection Transmission	Disinfection Level
Critical (enters tissues or vascular system)	Implants, scalpels, needles, other surgical instruments, etc.	High	Sterilization
Semi critical (touches mucous membranes)	Flexible endoscopes, endotracheal tubes	Medium	High-level
Noncritical (touches intact skin)	Stethoscopes, bed pans, etc.	Low	Intermediate or low

In general, as a consensus, most reprocessing guidelines recommend the following sequence: precleaning, cleaning, rinsing, disinfection, final rinsing, drying, and finally storage. Air and water pollution can appear during this process. Ideally, the reprocessing of the endoscopes has two components: a manual stage, which means that all the external and accessible internal components are exposed to a low-foaming, endoscope-compatible detergent (usually a nonenzymatic detergent is preferred), followed by the automatic disinfection, rinsing, and drying of all exposed parts of the endoscopes using specific chemicals or detergent [52].

It must be mentioned that although it is advisable that high-level disinfection be obtained using an automatic reprocessing or washing machine, it is still carried out manually in many units, meaning that the exposure of the medical stuff dedicated to this job is still high.

3.3. Chemicals Used in Disinfection Process of Digestive Endoscopes

Below, the most used disinfectants are described as follows:

a. Glutaraldehyde (2.4–3.5%), which is not expensive, and it is highly effective and readily available, with practically no damage to the endoscopes. Unfortunately, glutaraldehyde elicits adverse effects on individuals involved in its manipulation, and substantial reductions in atmospheric levels of glutaraldehyde have been recommended. Due to this major disadvantage, this agent was withdrawn from use in some countries. Also, its disposal is a concern, and it should not be directly emptied into the sewage system [51].
b. Orthophthal aldehyde (OPA) (0.55–0.60%) is a more stable alternative disinfectant that has a lower vapor pressure than glutaraldehyde, but it is more expensive. It has a barely perceptible odor. It is advisable that sprays, mists, and aerosols are not used during the use of OPA. All OPA solutions must be neutralized to inactivate the disinfectant before disposal into the sewer [53].
c. Peracetic acid is a highly effective disinfectant that may prove to be a suitable alternative to glutaraldehyde or OPA. It is considered a sustainable disinfectant because it decomposes in oxygen, water, and biodegradable acetic acid, thus not affecting the environment [54,55] (Table 2). Thus, it offers many sustainability advantages, like decomposition in environmentally friendly compounds, as mentioned above; toxic by-products are not generated during its use; and due to its potency, it is resource efficient [56].
d. Hydrogen peroxide (2–7.5%), also used in the terminal disinfection of endoscopes, is usually found in a dual formula that comprises vaporized hydrogen peroxide and ozone. It assures high-level disinfection of all types of digestive endoscopes, including duodenoscopes [57]. Hydrogen peroxide is largely considered eco-friendly as it decomposes in water and oxygen (Table 2). However, in high amounts, hydrogen

peroxide can be toxic if ingested, inhaled, or through contact with the skin or eyes, or if it is evacuated into the water, especially for phytoplankton. The toxicity level of exposure varies with the duration and exposure dose [58].

e. Hypochlorous acid (HOCL) is basically a weak acid that results when chlorine is dissolved into water (Table 2). Due to this behaviour, it becomes clear that it represents no harm for the medical personnel and can be disposed of with no risk of producing toxic waste. Thus, hypochlorous acid 650–675 ppm is another potent disinfectant. It was declared by WHO, in 2021 during the Corona Virus pandemic, as the most potent and environmentally safe disinfectant available with a wide range of efficacy against many human pathogens, including the SARS-CoV-2 coronavirus, and it can also be used in digestive endoscopy [59]. The beneficial effects of HOCL as well as its safety for medical personnel and the environment depend on the purity of the solution and the avoidance of contaminating molecular species of aqueous chlorine (such as hypochlorite a.s.o.) [60]. HOCL can be degraded into an anion called hypochlorite (ClO^-). Usually, this compound can be combined with cations to form salts like sodium and calcium hypochlorite (NaClO). These hypochlorite solutions (i.e., bleach, as commonly known and widely used as a whitening, cleaning, and disinfectant agent) represent toxic compounds, which prompts the usage of personal protective equipment and special disposal measures, as they are an environmental hazard. If the manufacturing process is not properly performed according to strict regulations, HOCl products may lack stability in storage, lose part of their antiseptic efficacy, or even cause toxicity through contaminants that can be harmful to the environment and people [61,62].

Table 2. Types of digestive endoscopy disinfectants, their characteristics, and impact upon the environment.

Disinfectant	Advantages	Disadvantages
Glutaraldehyde (3.5%) *	Over 30 years of use in medical sector Excellent biocidal activity Cheap	Healthcare personnel exposure Air pollution Water pollution (requires neutralization)
Ortho-phal-aldehyde (0.55%)	Fast acting Excellent microbiocidal activity (superior to GA) Better material compatibility	More expensive Healthcare personnel exposure Air pollution Water pollution (may require neutralization before exposure)
Peracetic acid	Short time of action even at low temperatures Environmentally friendly Compatibility with many materials	More expensive Can corrode some types of material Unstable when diluted Serious eye and skin damage at high concentration
Hydrogen peroxide	Active against a wide range of microorganism No disposal issues	Material compatibility issues Health care personnel issues (excessive exposure may produce irreversible tissue damage, and vapours can severely affect the respiratory system)
Hypochlorous acid/hypochlorite	Cheap Efficient against many pathogens, including SarsCov2	If turned into hypochlorite, it can corrode some types of material Hypochlorite solutions can cause health care issues

* Adapted after: SGNA Practice Committee 2013–14 Guideline for Use of High-Level Disinfectants & Sterilant for Reprocessing Flex. Gastrointestinal Endoscopes.

Regarding all the above-mentioned disinfectants used in the reprocessing sequence of endoscopes, their impact upon the environment is summarized in Table 2 [63].

Depending on the chemical solutions used, the reprocessing sequences of the endoscopes are synthetized in Figure 3.

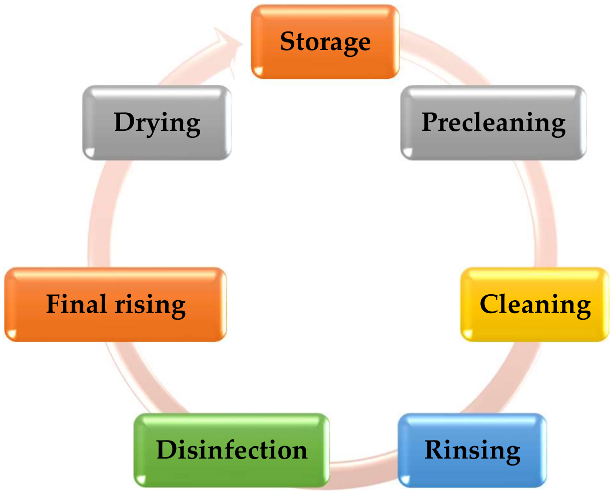


Figure 3. Disinfection scheme and stages of the endoscopes.

3.4. Waste through Disposable Materials and Instruments

Another important part regarding the sustainability of the endoscopy sector is the waste production before, during, and after the procedures take place. The endoscopy sector seems to be in 3rd place for waste production in hospitals [64]. According to recent sources, endoscopy is generating around 3.09 kg of waste per bed day, which represents a rather important addition to the environmental footprint [39]. It was estimated that a single endoscopy produces around 2 kg of waste from periprocedural medical and nonmedical materials and disposable devices [65]. Also, the study of Gayam et al. made an estimation regarding the production of plastic waste in endoscopy departments, and seemingly, about 13,500 tons of waste are made per year in high volume units that reach 40 endoscopies per one day [66].

The following sources of waste are produced in the endoscopy sector:

- Non contaminated/regular waste;
- Contaminated waste;
- Sharps;
- Recyclable waste.

Depending on this classification, these are the main sources of waste in each of the categories from above (Figure 4).

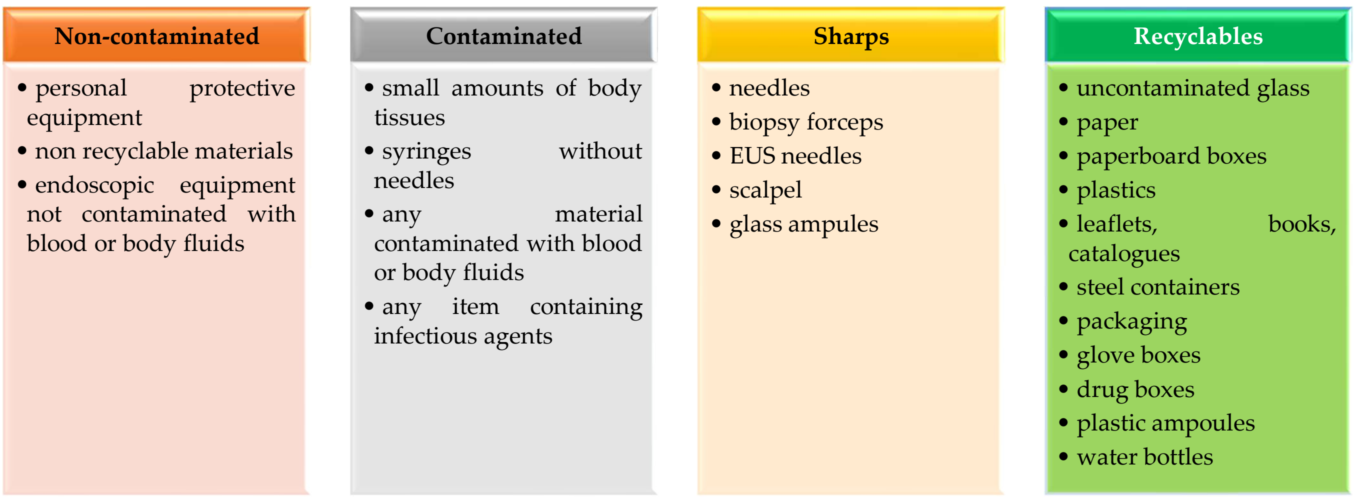
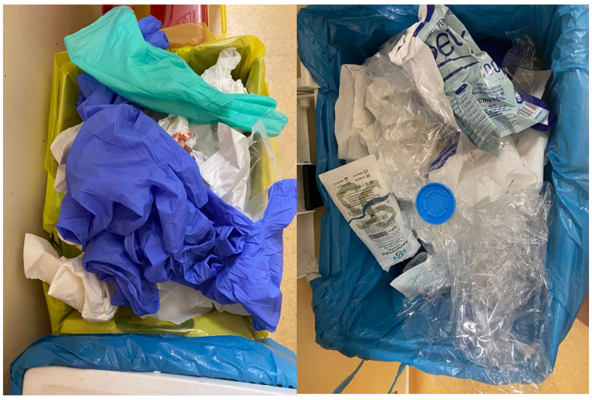


Figure 4. Waste categories in endoscopy sector.

If the types of materials are analysed, the majority of endoscopy materials and subsequently endoscopy waste are composed of plastic, followed by mixed materials (plastic and metals), only metals, and other materials (cotton, fabric, paper) as seen in the pictures below (Figure 5a,b).



(**a**) (**b**)

Figure 5. (**a**,**b**). Pictures from the authors' endoscopy unit with different types of waste (personal collection).

Published studies showed that plastic used in endoscopy represents the majority of disposable non-biohazard waste (54%) and personal protective equipment (PPE) was 8% of the disposable waste. Out of these materials, 48% of non-biohazard and 35% of all waste were candidates for recycling [65].

One of the most important sources of waste in hospitals and digestive endoscopy units, that increased dramatically during the COVID-19 pandemic, is PPE, leading to notable environmental implications [67,68].

Notably, ancillary disposable devices such as snares, needles, filters, clips, balloons, biopsy forceps, etc., employed during endoscopy are numerous. Most often, these items are single-use and made of plastic, thereby generating approximately 2 kg of waste per procedure [65].

Depending on each country and the legislation in place, the storage and disposal of medical waste can be more expensive than that of regular waste, as this process requires special containers and transport to incineration facilities as well as proper disposal at a landfill [30]. Therefore, the segregation of different types of waste must be compulsory due to recycling reasons versus more complex ways of waste disposal like incineration.

3.5. Single-Use Devices and Endoscopes versus Reusable Ones

This domain was always dominated by a constant shift between single-use medical devices and reusable ones. Debates are still ongoing, but we will try to summarize the current conclusions and facts in our work.

Comparable to the general non-medical trend of exchanging reusable with single-use products, the medical sector has also done this during the last years. This change was probably driven by the large access to plastics that are much cheaper and lighter in weight. However, the most important advantage that needs to be outlined in this setting is that single-use devices used in endoscopy guarantee for infection-free procedures. From single-use endoscopes to single-use secondary devices, the actual producing market is offering a high variety of products that are at hand. With the emergence of therapeutic digestive endoscopy, the need for sterilization, not only high-level disinfection, seemed obvious, so single-use devices rapidly became, where available, the preferred option among doctors (Figure 6).


(**a**) (**b**)

Figure 6. Images of (**a**) single-use endoscope (personal collection), and (**b**) reusable endoscope (per CC BY-SA, [69]).

Regarding single-use endoscopes and compatible devices, we can speak of two types of sustainability: economic sustainability and environmental sustainability. Economical sustainability refers to the financial viability that interests any hospital facility. When it comes to endoscopy, it seems that single-use endoscopes are more financially beneficial for hospitals due to the avoidance of reprocessing costs and hospitalization costs secondary to endoscopy related infections.

There are many studies that focused on these financial elements, and they support the idea of a strategy based on single-use endoscopes and devices as being more cost efficient, with a saving amount between USD 124 and USD 261 per procedure [70,71]. When it comes to environmental sustainability of single-use endoscopes, it is clear that they are producing a substantial amount of waste [72].

Published results demonstrated that the total amount of waste produced by the reprocessing cycle of a reusable endoscope during its entire lifetime generates approximately 610 kg of waste, while single-use endoscopes (for the same number of procedures) generate 2520 kg of waste, accounting for a 4.1-fold rise in waste [65].

Disposable endoscopic accessories gained a lot of popularity during the last decade, due to the advantage of clarity in use, large variety, and comfort of sterility, but all this popularity is burdened by the waste disposal issue of these devices. Studies show that small units with low volume work, might shift their preferences towards these devices, whereas high volume units might consider evaluating these practices more attentively to obtain a sustainable course [73,74]. Current guidelines advise that single-use endoscopes should be restricted to select indications and environmental impact should be taken into account [29].

3.6. Other Sources of Increased Carbon Footprint from Digestive Endoscopy

Apart from the specific aspects of digestive endoscopy, like any other hospital department, endoscopy units also have some general ways to produce pollution like electricity, heating and cooling, paper use and printing, products transportation, etc., that need to be addressed when it comes to improving sustainability (Figure 7).

The British Guideline recommends, with the purpose of reducing auxiliary sources of pollution, the use of electronic documentation and dissemination to provide medical information for the patient and for colleague referrals in digital versions. Also, it recommends encouraging the patient to come to the endoscopy unit with his own personal reusable objects (mugs, water bottles, etc.) to reduce pollution caused by single-use objects. At the same time, it is advisable to pay great attention to any secondary source of energy consumption like computers, printers, etc., which should all be switched off when not in use [29].

Also of note, we need to mention the pollution caused by electricity, lighting, heating, and cooling systems that work almost non-stop in endoscopy units, which should also be addressed. Therefore, energy-efficient bulbs and motion-driven sensors should be used, and small adjustments in the degrees of temperature of heating and cooling systems should be taken into consideration for reducing energy expenditure. Studies show that the reduction or rise in the temperature by one degree in winter and summer can reduce energy costs by 5% [75].

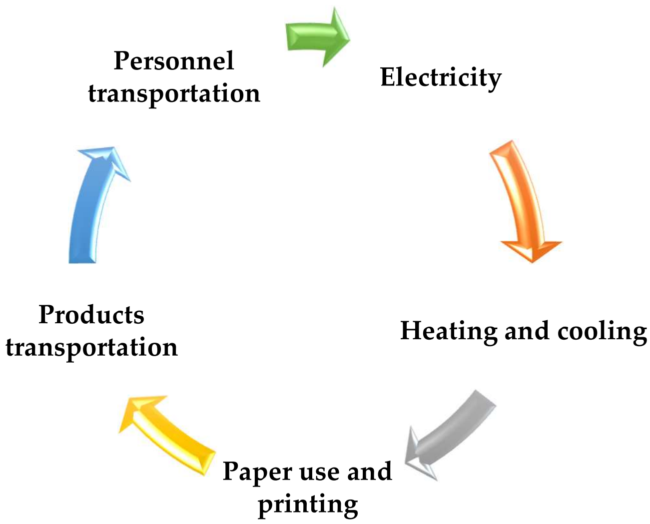


Figure 7. Other sources of pollution in digestive endoscopy.

4. What Can We Do to Increase Digestive Endoscopy Sustainability?

In an attempt to make endoscopy green, there are several statements that address this aspect, but there are also many unmet needs. Of course, the best way to make endoscopy more sustainable is to reduce the number of procedures performed on a single patient; this target can be achieved using more specialized triage by following specific guidelines that address screening strategies and clear indications of endoscopic procedures.

Unfortunately, it is clear, as studies are showing that most of the waste produced in the digestive endoscopy units is not handled properly and that most of the personnel (medical and auxiliary) are not sufficiently informed and trained about medical waste and disposal rules [34].

A good strategy to improve the impact of this sector upon the sustainability of the healthcare system must be based on four pillars, as schematized in Figure 8:

- Use eco-friendly substances, materials, and devices;
- Reduce the unnecessary consumption of water and all possible materials, devices, energy, etc.;
- Reuse those components that can be safely reinserted in the endoscopic circuit;
- Recycle everything that is possible.

Finally, our suggestions for improving the sustainability of the digestive endoscopy sector, which can also be considered future directions, are as follows:

- Raising perceptions among medical personnel and the auxiliary team about the risks and long-term implications of waste and pollution;
- Establishing clear standards for indoor air quality in the endoscopy unit and performing specific measurements for air quality checks, maybe even CO_2 monitoring devices;
- Performing all the disinfection stages of the endoscopes in a dedicated room or space with proper ventilation or even with air extraction devices;
- Making more efforts to reduce the waste quantity;
- Better understanding of sorting out the waste;
- Improving the standards of disposal practices;
- Stewardship towards safer and greener methods for the sterilization of medical devices (autoclaving, etc.) over incineration;
- Work education of the personnel regarding hazards associated with manoeuvring, storing, transporting, and processing wastes;
- Following guidelines;

- Promoting continuously wise resource distribution and safer practice.

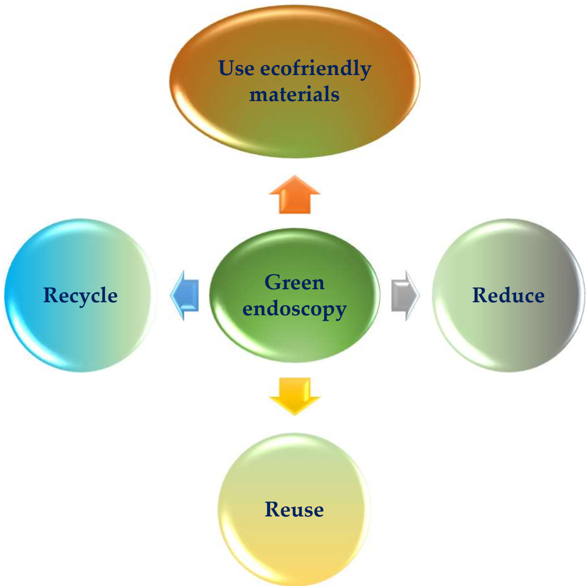


Figure 8. The 4 pillars of a sustainable digestive endoscopy.

Healthcare waste generates substantial costs annually [76] and is influenced by a range of factors specific to each hospital, including the hospital's size in terms of the number of beds, its classification (e.g., general hospital, specialized clinic), the range of medical services it provides, the volume of annual inpatients, the duration of patient stays, the quantity of scheduled surgeries, the presence of specialized units like Intensive Care Units, and the total workforce size [77,78].

Moreover, these factors, which impact healthcare waste generation, along with the financial implications, offer valuable insights for hospital management and governmental authorities. They can guide decision-makers in understanding what changes are necessary and what policies and action plans should be implemented to achieve environmental protection, reduce operational costs in healthcare facilities, and promote sustainable practices [79].

In the endeavour to achieve sustainability within the healthcare sector, a multifaceted approach is proposed. Firstly, a tailored and efficient healthcare waste management system should be established, accommodating the diverse characteristics of healthcare facilities. Secondly, comprehensive training programs for healthcare professionals are essential, focusing on both waste management and occupational safety. Thirdly, the implementation of a healthcare waste management policy and a customized Standard Operating Procedure ensures consistency and best practices. A critical evaluation of the existing legislation and policymaking is imperative to facilitate necessary revisions. The integration of cutting-edge medical waste treatment technologies and the promotion of recycling practices are pivotal for environmental responsibility. Furthermore, the development of standardized guidelines at national and international levels for healthcare waste management is essential. Lastly, concerted efforts are needed to minimize costs and risks associated with healthcare waste management, ensuring economic efficiency while upholding environmental and public health standards [80].

5. Conclusions

Gastrointestinal endoscopy is a domain of great importance and is, assumably, only going to increase in the next few years. Therefore, there is a great need to take control of our practice, admit the impact that the healthcare system has on global warming and greenhouse gas emissions, acknowledge the limited assets and wealth of the planet, and apply standards and scales of sustainability that can improve and make the services more responsible for the patients. The pollution print of the endoscopy sector is not fully established, but more and more work can be carried out in this field as it becomes clearer that there is a definite need to lower the pollution in this domain where a high volume of work and procedures are carried out.

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