
This is the **accepted version** of the journal article:

Cunha, Miguel F.; Pellino, Gianluca. «Environmental effects of surgical procedures and strategies for sustainable surgery». *Nature reviews*, Vol. 20, Num. 6 (June 2023), p. 399-410 DOI 10.1038/s41575-022-00716-5

This version is available at <https://ddd.uab.cat/record/325002>

under the terms of the  ^{IN}
COPYRIGHT license.

Environmental effects of surgical procedures and strategies for sustainable surgery

Miguel F. Cunha^{1,2} and Gianluca Pellino^{3,4†}

1 General Surgery Department, Algarve University Centre, Portimão, Algarve, Portugal;

2 Algarve Biomedical Centre, Portimão, Algarve, Portugal

3 Department of Advanced Medical and Surgical Sciences, Università degli Studi della Campania 'Luigi Vanvitelli', Naples, Italy

4 Colorectal Surgery, Vall d'Hebron University Hospital, Barcelona, Spain

†E-mail: gipe1984@gmail.com, gianluca.pellino@unicampania.it

ORCID: Miguel F. Cunha: 0000-0002-7353-2425
Gianluca Pellino: 0000-0002-8322-6421

Abstract

There is a bidirectional relationship between climate change and healthcare. Climate change threatens public health, and healthcare contributes to climate change. For example, surgery is the most energy-intensive practice in the healthcare sector, and gastrointestinal conditions are responsible for a substantial environmental burden.

However, environmental costs associated with healthcare are often overlooked. This issue has been examined more closely in the current intensive practice. However, there is still a lack of global awareness and guidance on sustainable surgical practices. This Perspective aims to reassess the evidence on healthcare and surgery carbon footprints, focusing on gastrointestinal conditions, identify issues that need to be addressed to achieve a more sustainable practice and develop perspectives for future surgical procedures. The proposed framework to mitigate the environmental effects of surgery could be translated to other healthcare sectors.

Introduction

Climate change is one of the greatest threats to public health worldwide. The association of air pollution, rising temperatures, flooding, and drought with changes in the spread of vector diseases present a risk to humanity¹. Also, the healthcare sector is one of the largest waste-generating entities contributing to climate change. In the United States, healthcare produces 655 million tons of carbon dioxide equivalents per year (CO_{2e}), representing 8–10% of all national greenhouse gas emissions¹.

Amongst healthcare sectors, operating theatres are the most energy-intensive sites, three to six times more energy intensive than the rest of the hospital, greatly contributing to this environmental burden^{1,2}. Thus, achieving sustainability in surgery is emerging as a strategy to reduce environmental effects³. Data on the surgical carbon footprint are emerging^{1,4}. However, there have been insufficient efforts to address this problem⁵. Finally, gastrointestinal diseases are one of the world's largest therapeutic areas representing a heavy global burden. Perry et al

75 showed that, annually, in the USA, there are more than 43.4 million ambulatory
76 visits and 3.8 million hospitalisations due to a primary gastrointestinal diagnosis.
77 Moreover, 284.844 new gastrointestinal cancers were diagnosed in 2019⁶. The
78 diagnosis of gastrointestinal diseases and their advanced management
79 substantially affect the generation of health-associated waste and the
80 consumption of environmental resources.⁷⁻⁹

81 This Perspective aims to reassess the evidence on healthcare, the carbon
82 footprint of surgery and gastrointestinal diseases, identify issues that need to be
83 addressed to achieve a more sustainable practice, and develop strategies for a
84 more environmentally friendly surgery and gastrointestinal practice.

Climate-change effects on health

Health promotion remains a development goal defined by the World Health Organization (WHO)¹⁰. Health professionals are crucial to this health promotion path, working directly with patients, from health centres to university hospitals. However, health facilities are greatly responsible for greenhouse gas emissions and global warming, directly related to health diseases¹⁰. Climate change affects public health, and the environmental footprint deserves all our attention regarding health promotion development.

Global warming affects health in several ways. For example, over the past 20 years, high temperatures and heat waves have been responsible for a globally 53.7% increase in heat-related mortality in people older than 65 years, owing to the exacerbation of cardiovascular and respiratory diseases^{10,11}. In addition, climate change represents the ideal setting for spreading both viral, bacterial and vector-borne infections^{12–14}. Since the 1950s, there has been a higher incidence and broader distribution of dengue, malaria, and *Vibrio* bacterial infections^{12,13}. As an example, the worldwide incidence of dengue has increased 30-fold over the past 50 years¹⁴, and the daily mean temperature, temperature variation, and precipitation extremes are considered the most important drivers¹⁴.

However, the effect of climate change on gastrointestinal diseases seems to go beyond global warming and infectious diseases tie-up. Seo et al.¹⁵, developed a mathematical model using meteorological factors and air pollutants obtained from eight metropolitan areas and showed a significant correlation between air pollutants, such as carbon monoxide, and gastroesophageal reflux disease (GERD), according to data from the GERD-related medical utilization of the Korean National Health Insurance Service between 2002 and 2007 ($r^2=0.22$; $p<0.001$).

Undernutrition due to challenges with food production and the mental health effects of floods and droughts are also outcomes of the emerging global warming crisis in China, Bangladesh, Ethiopia and South Africa.^{16,17}

Regarding pregnancy and obstetric outcomes, a 2020 systematic review, with 68 studies from United States of America analysing 32 798 152 births, concluded that air pollution and high-temperature exposure increased the risk of low birth weight and preterm labor¹⁸. These factors can exacerbate asthma in children, as

confirmed in two studies with 990 and 315 children^{19–21}. Fecht et al.²² observed higher rates of cardiac arrest and emergency admissions for stroke and asthma on high air pollution days in England. Research in this field is emerging, and it is anticipated that more health outcomes due to climate change will be observed soon¹⁰. Consequently, WHO predicts that by 2030, there might be 250,000 additional deaths globally per year due to climate change^{23,24}.

Carbon footprint definitions

Harmonising the definitions and technical aspects of climate change and carbon footprint is crucial because it enables researchers to share the same language across different sectors. For example, if one aims to analyse the overall carbon footprint of rectal cancer diagnostic workup, it is necessary to account for endoscopies, computerized tomography and magnetic resonance scans. However, it would be difficult to reach this understanding if the effect of these diagnostic procedures is measured in different units. On the other hand, if their functional units were converted to CO₂ equivalent (CO_{2e})²⁵ standard metric, adequate comparisons and summing could be performed. Most typically, the CO₂-equivalent emission is obtained by multiplying the emission of a greenhouse gas by its global warming potential for a 100-year time horizon. However, there are a number of ways to compute such equivalent emissions and choose appropriate time horizons²⁵. Thus, different entities have defined carbon footprint methods of estimation. Wiedmann T et al²⁶, elaborated on these different methods and the associated methodological issues. One can use 1) a process analysis, developed to understand the environmental impact of a product's lifecycle; 2) an environmental input-output analysis, that combines environmental data and economic data; 3) a hybrid approach, integrating both methods. The method of choice will depend on the investigator's aim and data availability²⁶. The Intergovernmental Panel on Climate Change guidelines define greenhouse gases as 'gaseous atmosphere constituents that absorb and emit radiant energy within the thermal infrared range', responsible for the greenhouse-gas effect²⁷. The term 'carbon footprint' was also defined as 'the greenhouse gas produced by activities of an organisation measured in units of CO_{2e}'^{10,25}.

Thus, the carbon footprint is an objective measure of the greenhouse gas emissions ‘emitted into the atmosphere by an individual, organisation, process, product, or event’ measured in CO_{2e}^{25,28}. However, the carbon footprint measurement is not limited to quantifying greenhouse gases. Life cycle assessments are part of this complex process because both the product and its production and disposal have an environmental effect¹⁹. Life cycle assessments integrate a “cradle to grave” analysis, including material manufacturing, transport, decontamination (for reusable products), and disposal³.

Familiarity with these definitions is crucial for understanding the effect of different sectors on the environment and identifying measures that can mitigate this impact (Box 2).

Healthcare Carbon Footprint

Healthcare Carbon Footprint

Climate change substantially affects public health and constitutes a barrier to health promotion. However, in the past years, attention has been drawn to the effect of the healthcare sector on climate change. Globally, the healthcare sector was responsible for 4.6% of global greenhouse gas emissions in 2017¹⁰. However, the figures might be higher per territory. For example, the healthcare sector in the United Kingdom accounts for approximately 6% of the country’s total CO_{2e} emissions²⁹; Australia’s healthcare contribution is 7%; the healthcare sector of the United States of America (USA) represents nearly 10% of the country’s total CO_{2e} emissions^{29,30}. Importantly, these estimates are not yet available for many territories, and the figures are getting higher. In the USA, for example, greenhouse gas emissions have increased by more than 30% over the past decade compared to the country previous emissions³¹.

The sources of these emissions can be: 1) directly related to healthcare activities, representing 17% of the sector’s worldwide carbon footprint, 2) indirect emissions related to energy consumption (electricity, temperature conditioning, and power), representing approximately 12% of the healthcare sector’s footprint, and 3) the healthcare chain supply (energy, transport, use, and disposal of materials),

representing approximately 71% of the total emissions^{30,32,33}. Finally, the use of goods and services, such as pharmaceuticals and medical devices, cannot be ignored because manufacturing is also energy demanding³⁰ (Fig. 1).

Surgical Carbon Footprint

Hospitals are considered the second most energy-intensive buildings in the USA^{30,34}. Unsurprisingly, although operating theatres represent a small area in the hospital, in the USA they are more energy-intensive than clinical wards, and generate 50–70% of total hospital clinical waste². Indeed, in the USA, operating theatres are the most resource-intensive practice in the healthcare. For example, one surgical procedure generates the same amount of waste as a family of four weekly in the USA³⁶. Most operating theatres are ready to serve 24 hours a day, seven days weekly. Maintaining this level of activity requires lighting, heating, ventilation, and strict air conditioning settings¹. These requirements account for up to 40% of the global healthcare emissions^{19,37}.

The surgical pathway can be further divided into pre-procedure and intraprocedural timetables to determine the surgical carbon footprint and identify potentially approachable issues to address its environmental burden (Fig. 2).

Before the surgical procedure

The first step in this pathway is transferring the patient and staff to the hospital. In England, this journey occurs by public transport only in a minority of cases and accounts for up to 18% of the CO_{2e} healthcare emissions³⁸.

Second, before surgery, the patient usually needs to undergo a diagnostic workup whose carbon footprint is often substantial. For example, if a patient needs a computerised tomography, the environmental footprint will be 10.2 kg–15.8 kg CO_{2e} per patient³⁹. In contrast, the carbon footprint for a magnetic resonance is 22.4 kg CO_{2e} per patient⁴⁰. Finally, endoscopies are procedures with considerable environmental effects due to waste generation, accounting for approximately 3.09 kg of waste per bed per day, which is equivalent to 3 kg CO_{2e}⁴¹. In addition, the use of disposable equipment, the decontamination process of reusable scopes and patient travelling should be added to the endoscopic environmental burden⁴² (Fig. 2).

During the surgical procedure

After the diagnostic workup, the patient arrives at the operating theatre, and anaesthesia is the first vector for analysis. The current data show that an anaesthetic plan can considerably affect the environment. Inhaled anaesthetic agents mainly expire and are released directly into the atmosphere. These gases (sevoflurane, isoflurane, and desflurane) are potent greenhouse gases^{19,43,44}. A study comparing the carbon footprint of inhaled agents and propofol concluded that desflurane had the highest footprint, 15 times greater than isoflurane and 20 times greater than that of sevoflurane. Furthermore, 80% of all volatile anaesthetic pollution results from desflurane^{29,45}. Importantly, propofol had the lowest carbon footprint. In terms of global warming potential, desflurane has a global warming potential of 2540, sevoflurane 130 and isoflurane 510²⁹.

Moving to surgical hand disinfection, traditionally, it requires 18.5 L of water⁴⁶. Current guidelines recommend using water with antiseptic in the first operating theatre procedure and alcohol gel in the following procedures⁴⁷. Adopting these recommendations could save water and reduce costs⁴⁸. After hand disinfection, one must consider surgical linens such as gowns, drapes, and table covers. Despite the availability of reusable ones, disposables (single-use) ones are more commonly used worldwide⁴⁹.

Finally, for the surgery itself, surgical packs of sterile instruments are frequently opened before surgery begins⁵⁰. 80% of surgical solid waste is generated before the patient enters the operating theatre, and most of this waste is associated with packaging^{51,52}. There is a lack of robust evidence on how much waste could be avoided if sterile pack openings were delayed until the start of surgery. The introduction of minimally invasive surgery over the past 20 years has brought undeniable benefits to patients⁵³. However, it involves more single-use instruments (disposables)⁵⁴, mistakenly viewed as a more economical choice, and all hidden costs (e.g disposal, loss of resources when a not needed device is opened, maintaining a high volume inventory), are often skipped⁵⁴. Infection control is one of the premises used to justify using single-use instruments. However, the data show that the infection rates are comparable to reusable instruments^{5,55}. In a study with 100 patients submitted to appendicectomy using reusable or single-use instruments, the infection rates were similar (2% in each group; $p=0,536$)⁵⁶. In addition, when the environmental effects and costs are

accounted for, the negative impact of single-use instruments on the environment is evident^{5,57}. Notably, a multicentre audit in the UK concluded that 40% of the waste generated in operating theatres was potentially recyclable⁵⁸. However, operating-theatre recycling is not largely applied⁵⁹.

Studies have broadly examined minimally invasive surgery. Laparoscopic and robotic approaches are associated with higher carbon footprints compared with the open approach. Woods et al.⁶⁰ concluded that an abdominal hysterectomy performed using an open approach (laparotomy) accounted for 22.7 kg CO_{2e}. In comparison, the laparoscopic and robotic procedures were responsible for 29.2 Kg CO_{2e} and 40.3 Kg CO_{2e}, respectively (Table 1). Notably, data on the effect of different surgical approaches are scarce and limited by not considering all surgical pathways^{60–62}. Evaluating surgical procedures without assessing inpatient days and patient outcomes is reductive from the clinical and environmental perspectives.

Sustainable Surgery

Sustainability applied to health systems is defined by the WHO as a process to “improve, maintain, or restore health while minimising negative effects on the environment”^{63–65}. As health professionals working in a high-impact field, surgeons should be proactive and openly promote sustainable surgery. Guidance on this pathway was disclosed in 2012 by Kagoma et al.⁵, focusing on the 5 R principles of waste management (Reduce, Reuse, Recycle, Rethink, and Research) to outline solutions to decrease the waste generated in operating theatres⁵. However, in addition to solutions to decrease waste generation, these principles can be broadly applied as future strategies for a more sustainable surgical practice (Fig. 3). The authors of this Perspective believe that the proposed framework to mitigate the environmental effects of surgery could be translated to other fields.

Reduce

The reduction principle can be applied before and beyond surgery. For example, data published in 2015 showed that 143 million additional surgical procedures were required annually to prevent disability⁶⁶. The calculation was made using “the frequency of operation per WHO Global Health Estimate disease

subcategory” and then was applied “the estimated surgical frequency for each disease subcategory to condition prevalence data” for each global region⁶⁶. Thus, health promotion to reverse these statistics should be the first priority⁶⁶. Health promotion is a global responsibility involving patients, caregivers, health professionals, and governments. Reducing the disease burden through healthy behaviour could reduce disease-related healthcare requirements and surgical demand.

Addressing waste generation in operating theatres could further reduce the surgical carbon footprint. A correct segregation process, recycling⁵⁹, and reformulating prepackaged surgical kits and instrument boxes (by removing unessential items and plastic components)⁶⁷ could serve this purpose. A study on hand surgery showed that these measures alone reduced 2.3 kg of waste and saved USA \$10.64 per case⁶⁸. These principles could be further applied to endoscopy units.

Water waste from hand disinfection has already been addressed. According to current international guidelines, water consumption and its direct environmental effect can be easily reduced^{47,48}. Accordingly, after an adequate first-hand wash with water, choosing alcohol gel for the second-hand wash might reduce water consumption by 2.7 million litres over one year⁶⁷ and reduce costs by 67%⁶⁹.

Finally, energy consumption should also be addressed. As previously mentioned, operating theatres is the most energy-intensive sector in hospitals. However, operating theatres in North America are unoccupied up to 40% of the time over a 24-hour period⁵. For example, a Washington, USA, hospital reduced energy consumption by 60% by decreasing ventilation output during inactive periods^{63,70}.

Reuse

Reusable surgical linens and instruments are considered to be environmentally friendly. Preferring reusables will lead to less waste generation and reduce landfill and incineration costs. In addition, when all processes are accounted for, from production to sterilisation, the reusable carbon footprint remains favourable compared to disposable products⁵⁷. For example, using reusable surgical devices (port trocars and clip appliers) in laparoscopic cholecystectomy surgery can save approximately 122 kg of waste per case⁷¹. Moreover, reusable gowns could lead to a 70% final waste reduction. Currently, reusable gowns are

preferred by surgeons and operating theatre technicians; but disposable ones are still broadly used⁷².

The reprocessing of single-use devices is controversial. Healthcare personnel might think that reprocessing single use devices can be associated with and increased infection rate, but that this might not be correct^{36,73}. For example, a study with 590 patients comparing reprocessed versus original single-use endolaser probes in ophthalmologic surgery (215 versus 375 patients), had no infections in both groups⁷⁴. In a similar study involving 733 patients submitted to gastrointestinal surgery with original and reprocessed advance energy device and gastro intestinal staplers, there was no difference between the infection rates in the two groups (12.9% original and 13.4% reprocessed $p=0.664$)⁷⁵. However, devices initially labelled as single-use can often be repaired and sterilised, making their reuse safe⁷⁶. Although reprocessing is not a standard procedure and protocols might differ according to territory³⁶, in 2019, the United States Food and Drug Administration and the European Commission developed regulations to control in-hospital reprocessing⁷⁷. Moreover, outsourcing commercial reprocessing that complies with these regulations is emerging. According to the Association of Medical Device Reprocessors, 5,438,254 Kg of medical waste was diverted from incinerators worldwide through remanufactured single-use devices in 2020⁷⁸. Reuse per reprocessing and remanufacturing are expanding and offer environmental and financial benefits. For example, the authorities in the USA support reprocessing under approved conditions. However, reprocessing is not a standard procedure, and protocols differ according to country^{36,55,79}. Thus, awareness and support from the medical device industry are crucial for the broader implementation of this practice^{36,57}.

Recycle

80% of the operating theatre waste is generated preoperatively, 90% is misallocated, and 40% is potentially recyclable in England. Thus, implementing and disseminating the recycling process in OT and beyond is crucial^{52,63,80}.

However, recycling in the healthcare setting presents several challenges. Educating operating theatre staff on waste handling and strict infection control rules will help overcome the fear of contamination^{63,81}. A cohort study evaluating the waste generated by 237 operations concluded that recycling is not associated

with additional costs and has several advantages if the practice is globally expanded⁸².

Rethink

Sustainability should be a part of healthcare professionals' practice. Patient health and outcomes will always be the main focus. However, the consequences of climate change on current and future generations must not be ignored, and strategies to address this issue should not be delayed. Rethinking entails selecting the most sustainable choice to treat patients without causing any harm. For example, the American Society of Anesthesiologists Task Force on the Environment recommended using regional and total intravenous anaesthesia as the most sustainable option (instead of high-impact inhaled anaesthetics such as desflurane and sevoflurane) when clinically appropriate^{2,59}.

The severe acute respiratory syndrome coronavirus 2 pandemic forced us to rethink how we practice medicine. Telemedicine has emerged as an adequate solution that is appropriate for both professionals and patients for the follow-up of chronic conditions^{83–85}. This emergency and contingency solution can be maintained in the future when appropriate, as telemedicine reduces patient travel and vehicle emissions. Also, some applications could work with telemedicine, allowing patients to remotely monitor their health status, reducing pressure on oversaturated health systems^{85,86}. Furthermore, technology might be applied to training and education as a distance-learning tool, allowing telementoring in surgery and beyond. For example, this modality is gaining popularity at virtual conferences⁸⁷. Telementoring enables international networking avoiding unnecessary travel.

In addition, the medical device industry should be a part of this rethinking process. Single-use devices are more profitable for medical companies than reusable ones⁷⁸. For example, in a laparoscopic cholecystectomy study, including 1803 surgeries, the costs of disposables (including trocars, ports and clip applicators) were found to be 6.4 times higher than reusable ones⁷¹. Therefore, the creation and promotion of reusable medical devices are of utmost importance, and this reflection should begin within the industry, presenting sustainable devices to medical professionals.

The carbon cost of different treatment options for the same disease will also probably need to be equated in the future. Two multicentre studies^{88,89} on GERD surgery (288 patients) versus medical therapy (266 patients) were performed. The first multicentre study focused on clinical outcomes: for up to 3 years, 90% of the patients remained in remission in the surgical arm, versus 93% in the medical arm ($p=0.25$)⁸⁸. In the second study, Gatenby et al.⁹⁰ studied the carbon footprint of the two approaches. The surgical arm was more sustainable than the medical arm (30 kg CO₂ per annum, versus 100 kg CO₂ per annum). Even though these estimates pointed out methodological flaws, because the data used were collected from a large multicentre cohort created for another purpose and the model did not take into account different manufacturing origins, which can have different carbon footprints⁹⁰, this study raised questions regarding the need to equate carbon cost with different treatment options.

Finally, systematic measurement is necessary to reduce the surgical carbon footprint adequately. Scales to standardise carbon footprint measurement have been developed, such as the Spark2⁹¹ for the broad surgical process or the ones described for *Misrai et al*⁵² for the evaluation of disposable minimally-invasive surgical devices^{52,91}. Technology that will allow for global implementation of these scales is under development, and this will warrant a systematic measurement and identify healthcare sectors where a sustainable intervention is necessary⁹². In addition to the remote monitoring of patients, technology could be applied to monitor hospital material, track maintenance and replacement timings, and boost the efficiency of hospital supplies⁹³.

Research

Climate change and health have attracted the attention of scientists in the past few years, and novel data on the environment and health are being issued daily. However, only 9.2% of the available literature focuses on the environmental effects of the healthcare sector on health⁵⁷, and this topic has not received the attention it deserves by researchers⁹⁴. For example, endoscopy is an important diagnostic procedure for many surgical patients. Although there has been an increased focus on sustainable surgery, research on more sustainable endoscopy practices is still in its early stages of development.

Gastroenterologists and surgeons are leaders in wards, endoscopy units, operating theatres, and scientific research. There have been excellent examples of surgical leadership in developing and delivering global quality research that affects patients' lives and medical practices^{95,96}. It is time to gather the same energy and effort for sustainability in surgery and beyond. Sustainable surgery must be evidence-based, and there must be a real investment in quality research in this area to achieve this. Although the motivation of practitioners and researchers is crucial, the support of national and international entities is needed to address this issue adequately. Environmental choices are typically economical, and promoting a more sustainable surgical practice would advocate environmental protection and financial savings. This financial benefit is a strong argument, and further high-quality research demonstrating this premise is required.

Re-educate

The authors of this Perspective consider the lack of awareness and education on sustainability in surgery is a reality. The surgical carbon footprint has been demonstrated⁹⁷, and guidance on possible solutions to address some of the carbon footprint drivers has been available since 2012^{5,90,98–100}. However, a sufficient real-world effort has not been made.

A survey published in 2020 showed that 19% of ophthalmologic surgeons in New Zealand believe that climate change is not due to human activity and does not require any human action¹⁰¹. Moreover, 61% affirmed that they were not concerned about sustainability in their current practice¹⁰¹. In addition, less than 20% had received education or guidance regarding this subject. These data conclusively show that education regarding surgery sustainability is urgently needed.

The UK is at the forefront of sustainability education in healthcare. For example, the General Medical Council and Nursing Midwifery Council require education and the clinical application of sustainable methods^{102,103}. In addition, in the UK, guidance starts in universities with lectures on sustainable healthcare for prospective doctors and nurses¹⁰⁴.

The 're-education process' has already begun. Sustainability in surgery is being promoted by multiple organisations worldwide created to address this issue. Also,

European surgical societies like the European Society of Coloproctology¹⁰⁵ and European Society of Gastrointestinal Endoscopy¹⁰⁶ are developing campaigns to address sustainability^{3,105}. However, more focus should be placed on sustainability during surgical conferences, on social media channels, and in medical and surgical training to better educate current and future generations of surgeons.

Notably, accounting for clinical best practices and patient safety is mandatory in a sustainable surgical model. The ultimate goal of surgery is to cure and offer a good health-related quality of life. Clinical best practices are starting to recognise sustainability as an aim, and ‘doing no harm’ is starting to concern both patients and the environment^{59,107}. In the available studies on this topic, implementing sustainable policies in surgery did not increase the risk of adverse events nor result in suboptimal treatment outcomes^{54,108,109}. Patients must also be integrated into this novel approach to surgery^{1,19}. Future studies on sustainability in surgery should confirm the acceptability and safety of a ‘greener’ surgical path by evaluating patient-reported and surgical outcomes.^{1,19}

Gastroenterology and hepatology

Gastrointestinal conditions

In the USA, gastrointestinal diseases are a source of substantial burden and costs, and this burden is likely to continue increasing.^{6,8} Several considerations can be made, which explain why this field should be considered central for – and should likely lead – a change in practice towards a sustainable approach (Box 3). The prevalence of these conditions is one of the most important aspects, and the associated need for invasive treatment, such as appendicectomy, is among the most common procedures performed globally, with increasing figures over the past few years¹¹⁰. Screening and treatment for digestive cancers represent another major determinant. According to the International Agency for Research on Cancer of the WHO, in 2020, approximately 31,179 million people had cancer of the stomach, colon and rectum, or liver and intrahepatic bile ducts. Figures on these specific cancers, are expected to increase up to 36,795 million by 2040 (+59.7%)¹¹¹. Notably, although the rates and cumulative risk of prostate (age specific rate [ASR] 65.5) and lung (ASR 41.7) cancers were the highest globally

in men in 2010, gastrointestinal tract cancers (oesophagus, stomach, colon, rectum and anus, liver, gallbladder and pancreas) were by far the first if taken altogether (ASR 6.6, 15.9, 22.7, 16.3, 9.1, 2.3, 8.1, respectively)¹¹². The prevalence of obesity and overweight should also be considered because this affects the number of patients requiring surgical or endoscopic interventions for such conditions, often involving minimally invasive approaches and single-use consumables. An unprecedented adoption of minimally invasive surgery has been recorded during the past decade for treating gastrointestinal diseases¹¹³, which seem to have surpassed the rates of open surgery between 2012 and 2018 in USA, and the associated implications for the environment can easily be inferred. Thus, it becomes apparent that treating gastrointestinal diseases is a major player in determining the sustainability of healthcare – and at the same time, this sector represents an opportunity to drive the development and implementation of novel strategies to protect the environment (Box 3).

Digestive endoscopy principles

It has been estimated that between 11-15 million colonoscopies and 6-7 million upper gastrointestinal endoscopies are performed in one year in the USA only⁶. This Perspective deconstructs the carbon footprint of the surgical pathway, as discussed earlier, and, indeed, endoscopy is part of this pathway, and its carbon footprint is substantial^{41,42,114}. However, most endoscopy environmental effect drivers overlap the surgical ones, and these areas share solutions and barriers to mitigate climate change effects. Haddock R et al. emphasised the importance of energy and water use, waste generation and handling, minimising packaging, and educating the staff on sustainable activities such as recycling and reducing unnecessary resource use. This Perspective promotes applying the "reduce, reuse, and recycle" principles but acknowledges that funding benchmarking research and education are important efforts toward sustainability¹¹⁵. Thus, the previously presented solutions (5 R's plus 1) apply to the daily practice of endoscopy (Box 3).

Moreover, Siddhi et al. highlighted that the challenges to achieving an environmentally sustainable endoscopic practice range from a standardised and reproducible carbon footprint measurement to transforming industrial, governmental and public health policies¹¹⁶. The same multi-disciplinary approach

needs to be implemented in surgery and other healthcare sectors to mitigate the climate change burden. Lastly, some endoscopy-specific factors should be considered—the first concerns endoscope re-use, which is currently a source of major debate¹¹⁷. Reprocessing entails costs, but manufacturing, assembly, and transportation might result in a higher environmental burden. Secondly, faecal immunohistochemical testing could be a sustainable strategy to triage patients based on the risk of harbouring colorectal cancer and potentially be used to prioritise endoscopic procedures¹¹⁸. However, further research and cut-off levels adjustment might be needed¹¹⁸.

Sustainability invasive procedures

Disease prevention and prompt treatment are of utmost importance in addressing diseases' indirect environmental burden. Furthermore, climate change can negatively affect the gastrointestinal tract and its function. The incidence of gastrointestinal infectious disease parallels global warming¹¹⁹, , and the number of GERD-related medical utilisation increases in air polluted environments (defined according to Carbon monoxide and particulate matter with a diameter $\leq 2.5 \mu\text{m}$)¹⁵. However, if these are relatable associations, other correlations may not be straightforward, such as those linking functional gastrointestinal diseases to climate change^{17,120} and inflammatory bowel diseases (IBD) to aeroallergens and air pollution¹²¹. It is very difficult to tackle environmental challenges beyond clinicians' practice. Clean energy promotion toward a fossil-free recovery and recognising the importance of biodiversity preservation are some of the measures in the COP 26 special report by WHO, focusing on 'the health argument for climate action'¹²². However, there are potential paths for health professionals and healthcare administrations regarding diseases such as IBD that might result in more sustainable practice compared to current practice.

For example, biosimilars are bending the cost curve¹²³ and might represent wider global access to therapy for IBD and cancer patients than currently. The wider availability of these therapies might allow for the reduction of the disease burden, which is a sustainable measure as it promotes health. Also, the emergence of subcutaneous alternatives to the conventional biologic agents' formulations for IBD reduces unnecessary patient travelling and hospital burden because patients can now administrate these therapies at home¹²⁴. IBD and other chronic

gastrointestinal disorders might lead to iron deficiency anaemia. Comorbid anaemia is an important predictor of an increased risk of hospitalisation and patient mortality. There is evidence regarding the using ferric carboxymaltose as the most sustainable intravenous iron preparation due to the lower number of infusions needed, reducing hospital burden and costs related to individual patient management¹²⁵.

Another example is patients with chronic liver diseases (CLD), which are high-need and high-cost. Governmental health agencies should implement policies to prevent hepatitis transmission, counteract alcohol abuse and encourage lifestyles that prevent obesity and metabolic syndrome¹²⁶. As stated, these interventions advocating a healthier lifestyle could further reduce the need for obesity surgery and bariatric endoscopy. Hepatitis B vaccine equity, recommended for all newborns and individuals in high-risk groups, could profoundly affect not only reducing hepatocellular carcinoma burden worldwide but also reducing low and lower-middle-income countries' disease vulnerability. As stated by WHO, “until everyone is safe, no one is safe”¹²².

Barriers to sustainable healthcare

A variety of barriers (‘roadblocks’ that prevent the adoption of strategies to reduce climate change) have been reported and categorised throughout the past years¹²⁷. However, these barriers are not health systems’ specific hurdles. Various contexts, such as healthcare, household, cities, and agriculture, will share barriers holding back climate change mitigation; these are all relevant when developing a sustainable medical and surgical practice. For example, barriers faced by cities aiming to reduce greenhouse gas emissions and become more resilient to face the effects of climate change (e.g., “access to funding is the single biggest obstacle to cities delivering greater climate action”) are similar to the barriers faced by health systems (e.g. “the financial environment of healthcare conflict with climate change mitigation”)¹²⁸ (Box 4).

Health systems operate in a constrained context aiming for optimal clinical care delivery, and sustainability considerations are seldomly made¹²⁰. Nevertheless, there is evidence that initiatives to promote sustainable development are being made. However, healthcare system transformations to address climate deterioration will require paradigm shifts in healthcare aims and practices¹²⁹, and

changing behaviours is challenging. This necessity suggests the importance of an additional principle to the "5 Rs rule" because re-education can be a pillar in facilitating a cultural change, which should not be neglected.

Conclusion

Surgery is the most energy-intense sector, and achieving sustainability in surgery is an emerging strategy for decreasing the carbon footprint of the healthcare system (Box 1). However, environmental costs associated with surgical care are often overlooked, and this issue has been largely ignored in the past but is gaining increased recognition. Therefore, it is vital to undertake high-quality research to demonstrate that promoting a more sustainable surgical practice protects the environment and results in financial savings that would serve political interests. Specific areas for further investigation include the environmental burden of different surgical approaches, the implementation of operating theatres recycling, the promotion of reusables, advocacy for sustainable anaesthetic options, the environmental gains associated with telemedicine, telementoring and technological developments, and looking beyond specific surgical procedures to the overall surgical pathway.

In conclusion, climate change and environmental burdens are global problems. However, the environmental effect of health systems goes beyond surgical practice. Indeed, endoscopy, gastroenterology and hepatology are versatile areas in which sustainability interventions are also pertinent. The framework presented here to mitigate the effects of surgery can be easily transferred to other departments and health services. The insights provided in a stepwise manner can be applied to surgical departments and beyond (hospitals and health services) within a multidisciplinary perspective, leading to the implementation of climate change mitigation efforts

References

1. Rizan, C. *et al.* The Carbon Footprint of Surgical Operations: A Systematic Review. *Ann. Surg.* **272**, 986–995 (2020).
2. MacNeill, A. J., Lillywhite, R. & Brown, C. J. The impact of surgery on global climate: a carbon footprinting study of operating theatres in three health systems. *Lancet Planet. Heal.* **1**, e360–e367 (2017).

3. Rizan, C. & Bhutta, M. F. Strategy for net-zero carbon surgery. *Br. J. Surg.* **108**, 737–739 (2021).
4. Alshqaaq, F., Amin Esmaeili, M., Overcash, M. & Twomey, J. Quantifying hospital services by carbon footprint: A systematic literature review of patient care alternatives. *Resour. Conserv. Recycl.* **154**, (2020).
5. Kagoma, Y., Stall, N., Rubinstein, E. & Naudie, D. People, planet and profits: The case for greening operating rooms. *CMAJ* **184**, 1905–1911 (2012).
6. Peery, A. F. *et al.* Burden and Cost of Gastrointestinal, Liver, and Pancreatic Diseases in the United States: Update 2018. *Gastroenterology* **156**, 254–272.e11 (2019).
7. Baddeley, R., Aabakken, L., Veitch, A. & Hayee, B. Green Endoscopy: Counting the Carbon Cost of Our Practice. *Gastroenterology* **162**, 1556–1560 (2022).
8. Chudy-Onwugaje, K. & von Rosenvinge, E. C. Improving global digestive health: the gastroenterologists' role. *The Lancet Gastroenterology and Hepatology* **5**, 882–883 (2020).
9. Peery, A. F. *et al.* Burden of gastrointestinal disease in the United States: 2012 update. *Gastroenterology* **143**, (2012).
10. Watts, N. *et al.* The 2020 report of The Lancet Countdown on health and climate change: responding to converging crises. *Lancet* **397**, 129–170 (2021).
11. Xu, Z., FitzGerald, G., Guo, Y., Jalaludin, B. & Tong, S. Impact of heatwave on mortality under different heatwave definitions: A systematic review and meta-analysis. *Environment International* **89–90**, 193–203 (2016).
12. Lyon, B., Dinku, T., Raman, A. & Thomson, M. C. Temperature suitability for malaria climbing the Ethiopian Highlands. *Environ. Res. Lett.* **12**, 064015 (2017).
13. Semenza, J. C. *et al.* Systemic resilience to cross-border infectious disease threat events in Europe. *Transbound. Emerg. Dis.* **66**, 1855–1863 (2019).
14. Ebi, K. L. & Nealon, J. Dengue in a changing climate. *Environ. Res.* **151**, 115–123 (2016).
15. Seo, H. S., Hong, J., Jung, J. & Jung, J. Relationship of meteorological factors and air pollutants with medical care utilization for gastroesophageal reflux disease in urban area. *World J. Gastroenterol.* **26**, 6074–6086 (2020).
16. Herring SC, Christidis N, Hoell A, Hoerling MP, S. P. Explaining extreme events of 2018 from a climate perspective. *Bull. Am. Meteorol. Soc.* **101**, 1–128 (2020).
17. Leddin, D. *et al.* Uniting the Global Gastroenterology Community to Meet the Challenge of Climate Change and Non-Recyclable Waste. *Gastroenterology* **161**, 1354–1360 (2021).
18. Bekkar, B., Pacheco, S., Basu, R., Basu, R. & Denicola, N. Association of Air Pollution and Heat Exposure with Preterm Birth, Low Birth Weight, and Stillbirth in the US: A Systematic Review. *JAMA Netw. Open* **3**, (2020).
19. Yates, E. F. *et al.* Empowering Surgeons, Anesthesiologists, and Obstetricians to Incorporate Environmental Sustainability in the Operating Room. *Ann. Surg.* **273**, 1108–1114 (2021).

20. Schildcrout, J. S. *et al.* Ambient air pollution and asthma exacerbations in children: an eight-city analysis. *Am. J. Epidemiol.* **164**, 505–517 (2006).
21. Mann, J. K. *et al.* Short-term effects of air pollution on wheeze in asthmatic children in Fresno, California. *Environ. Health Perspect.* **118**, 1497–1503 (2010).
22. Fecht, D. *et al.* Exposure to Elevated Nitrogen Dioxide Concentrations and Cardiac Remodeling in Patients With Dilated Cardiomyopathy. *J. Card. Fail.* (2022). doi:10.1016/j.cardfail.2021.11.023
23. IEA. SDG7: Data and Projections. *SDG7: Data and Projections* 1–9 (2020). Available at: <https://www.iea.org/reports/sdg7-data-and-projections>. (Accessed: 25th January 2022)
24. WHO. Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s. (2014).
25. Ginarskiy, M. L. the Refinement To the 2006 Ipcc Guidelines for National Greenhouse Gas Inventories. *Fundam. Appl. Climatol.* **2**, 5–13 (2019).
26. Wiedmann, T. & Minx, J. A Definition of ‘ Carbon Footprint. *Science* (80-.). **1**, 1–11 (2007).
27. Stern, N. Annex I: User guide and access to more detailed information. *STERN Rev. Econ. Clim. Chang.* (2006).
28. Pandey, D., Agrawal, M. & Pandey, J. S. Carbon footprint: Current methods of estimation. *Environ. Monit. Assess.* **178**, 135–160 (2011).
29. McGain, F., Muret, J., Lawson, C. & Sherman, J. D. Environmental sustainability in anaesthesia and critical care. *British Journal of Anaesthesia* **125**, 680–692 (2020).
30. Eckelman, M. J. & Sherman, J. Environmental impacts of the U.S. health care system and effects on public health. *PLoS One* **11**, 1–14 (2016).
31. Institute, W. R. CAIT Climate Data Explorer [web tool]. *CAIT Historical - Explore Historic Greenhouse Gas Emissions* **2018**, (2018).
32. Chung, J. W. & Meltzer, D. O. Estimate of the Carbon Footprint of the US Health Care Sector. *JAMA Surg.* **302**, 1970–1972 (2009).
33. Karliner, J. *et al.* Health Care’s Climate Footprint. *Heal. Care Without Harm* 1–48 (2019).
34. EIA. CBECS 2012: Energy Usage Summary. *US Gov* (2016). Available at: <https://www.eia.gov/consumption/commercial/reports/2012/energyusage/>. (Accessed: 25th January 2022)
35. Thiel, C. L. *et al.* Environmental impacts of surgical procedures: Life cycle assessment of hysterectomy in the United States. *Environ. Sci. Technol.* **49**, 1779–1786 (2015).
36. Sanabria, A. *et al.* Considerations for environmentally sustainable head and neck surgical oncology practice. *Am. J. Otolaryngol. - Head Neck Med. Surg.* **41**, 102719 (2020).
37. FSM, A. & S, M. The Study of Sustainable Green HVAC Systems in Health Care Facilities. *J. Archit. Eng. Technol.* **05**, 1–10 (2015).
38. Tomson, C. Reducing the carbon footprint of hospital-based care. *Futur. Hosp. J.* **2**, 57–62 (2015).
39. Esmaeili, A. *et al.* Scope for energy improvement for hospital imaging services in the USA. *J. Health Serv. Res. Policy* **20**, 67–73 (2015).
40. Esmaeili, A. *et al.* Environmental impact reduction as a new dimension for quality measurement of healthcare services The case of magnetic

- resonance imaging. *Int. J. Health Care Qual. Assur.* **31**, 910–922 (2018).
41. Vaccari, M., Tudor, T. & Perteghella, A. Costs associated with the management of waste from healthcare facilities: An analysis at national and site level. *Waste Manag. Res.* **36**, 39–47 (2018).
42. Maurice, J. B. *et al.* Green endoscopy: a call for sustainability in the midst of COVID-19. *Lancet Gastroenterol. Hepatol.* **5**, 636–638 (2020).
43. Ryan, S. M. & Nielsen, C. J. Global warming potential of inhaled anesthetics: Application to clinical use. *Anesth. Analg.* **111**, 92–98 (2010).
44. Guetter, C. R. *et al.* Greening the operating room. *Am. J. Surg.* **216**, 683–688 (2018).
45. Sherman, J., Le, C., Lamers, V. & Eckelman, M. Life cycle greenhouse gas emissions of anesthetic drugs. *Anesth. Analg.* **114**, 1086–1090 (2012).
46. Jehle, K., Jarrett, N. & Matthews, S. Clean and green: Saving water in the operating theatre. *Ann. R. Coll. Surg. Engl.* **90**, 22–24 (2008).
47. Loveday, H. P. *et al.* Epic3: National evidence-based guidelines for preventing healthcare-associated infections in nhs hospitals in england. *J. Hosp. Infect.* **86**, S1–S70 (2014).
48. Javitt, M. J., Grossman, A., Grajewski, A. & Javitt, J. C. Association between Eliminating Water from Surgical Hand Antisepsis at a Large Ophthalmic Surgical Hospital and Cost. *JAMA Ophthalmol.* **138**, 382–386 (2020).
49. McQuerry, M., Easter, E. & Cao, A. Disposable versus reusable medical gowns: A performance comparison. *Am. J. Infect. Control* **49**, 563–570 (2021).
50. Rosenblatt, W. H., Chavez, A., Tenney, D. & Silverman, D. G. Assessment of the economic impact of an overage reduction program in the operating room. *J. Clin. Anesth.* **9**, 478–481 (1997).
51. Donaldson, K. Save the Planet: Recycling in the OR. *Infect. Control Today* (2000).
52. Misrai, V. *et al.* A standardized method for estimating the carbon footprint of disposable minimally invasive surgical devices. *Ann. Surg.* (2021). doi:10.1097/AS9.0000000000000094
53. Kamarajah, S. K. *et al.* Robotic versus conventional laparoscopic pancreaticoduodenectomy a systematic review and meta-analysis. *European Journal of Surgical Oncology* (2019). doi:10.1016/j.ejso.2019.08.007
54. Siu, J., AG, H. & AD, M. Systematic review of reusable versus disposable laparoscopic instruments: costs and safety. *ANZ J. Surg.* **87**, 28–33 (2017).
55. Grantcharov, P., Ahmed, S., Wac, K. & Rivas, H. Reprocessing and reuse of single-use medical devices: Perceptions and concerns of relevant stakeholders toward current practices. *Int. J. Evid. Based. Healthc.* **17**, 53–57 (2019).
56. Mihanović, J. *et al.* Comparison of new versus reused Harmonic scalpel performance in laparoscopic appendectomy in patients with acute appendicitis—a randomized clinical trial. *Langenbeck's Arch. Surg.* **406**, 153–162 (2021).
57. Weiss, A. *et al.* Environmentalism in surgical practice. *Curr. Probl. Surg.* **53**, 165–205 (2016).

58. Hutchins, D. C. J. & White, S. M. Coming round to recycling. *BMJ (Online)* **338**, 746–748 (2009).
59. Sherman, J. D. *et al.* The Green Print: Advancement of Environmental Sustainability in Healthcare. *Resour. Conserv. Recycl.* **161**, (2020).
60. Woods, D. L. *et al.* Carbon footprint of robotically-assisted laparoscopy, laparoscopy and laparotomy: A comparison. *Int. J. Med. Robot. Comput. Assist. Surg.* **11**, 406–412 (2015).
61. Rizan, C. & Bhutta, M. F. Environmental impact and life cycle financial cost of hybrid (reusable/single-use) instruments versus single-use equivalents in laparoscopic cholecystectomy. *Surg. Endosc.* (2021). doi:10.1007/s00464-021-08728-z
62. Power, N. E., Silberstein, J. L., Ghoneim, T. P., Guillonneau, B. & Touijer, K. A. Environmental impact of minimally invasive surgery in the United States: An estimate of the carbon dioxide footprint. *J. Endourol.* **26**, 1639–1644 (2012).
63. Wong, Y. L., Noor, M., James, K. L. & Aslam, T. M. Ophthalmology Going Greener: A Narrative Review. *Ophthalmol. Ther.* **10**, 845–857 (2021).
64. Urquhart, R. *et al.* Defining sustainability in practice: Views from implementing real-world innovations in health care. *BMC Health Serv. Res.* **20**, 1–7 (2020).
65. WHO Regional Office for Europe. *Environmentally Sustainable Health Systems.* (2015).
66. Meara, J. G. *et al.* Global Surgery 2030: Evidence and solutions for achieving health, welfare, and economic development. *Lancet* **386**, 569–624 (2015).
67. Chaplin, C. L., Wernham, A. G. H. & Veitch, D. Environmental sustainability in dermatological surgery. *Br. J. Dermatol.* **184**, 952–953 (2021).
68. Van Demark, R. E., Smith, V. J. S. & Fiegen, A. Lean and Green Hand Surgery. *Journal of Hand Surgery* **43**, 179–181 (2018).
69. Tavalacci, M.-P. *et al.* Prevention of Nosocomial Infection and Standard Precautions: Knowledge and Source of Information Among Healthcare Students. *Infect. Control Hosp. Epidemiol.* **29**, 642–647 (2008).
70. Greenhealth, P. The Business Case for Greening the OR Greening the Operating Room Checklist Implementation Modules Medical Device Reprocessing OR Kit Reformulation Moving (Back) to Reusables in the OR Regulated Medical Waste Segregation and Minimization in the OR Medical. Available at: https://www.c4spgh.org/HCW1_Presentations/GOR_FullSet_Guidance Docs_Web_042711.pdf. (Accessed: 1st March 2022)
71. Slater, M., Booth, M. I. & Dehn, T. C. B. Cost-effective laparoscopic cholecystectomy. *Ann. R. Coll. Surg. Engl.* **91**, 670–672 (2009).
72. Conrardy, J., Hillanbrand, M., Myers, S. & Nussbaum, G. F. Reducing medical waste. *AORN J.* **91**, 711–721 (2010).
73. Thiel, C., Duncan, P. & Woods, N. Attitude of US obstetricians and gynaecologists to global warming and medical waste. *J. Heal. Serv. Res. Policy* **22**, 162–167 (2017).
74. Zacharias, L. C. *et al.* Safety and cost-effectiveness of single-use endolaser probe reprocessing in vitreoretinal surgery. *Int. J. Retin. Vit.* **7**, (2021).

75. De Sousa Martins, B., Melo, J. Q. E., Logarinho Monteiro, J., Rente, G. & Bastos, P. T. Reprocessing of Single-Use Medical Devices: Clinical and Financial Results. *Port. J. Public Heal.* **36**, 150–156 (2018).
76. Kwakye, G., Pronovost, P. J. & Makary, M. A. Commentary: A call to go green in health care by reprocessing medical equipment. *Academic Medicine* **85**, 398–400 (2010).
77. Association of Medical Device Reprocessors. Legislation/Regulation - AMDR. *AMDR-Generated Resource* (2019). Available at: <http://amdr.org/legislationregulation/>. (Accessed: 29th May 2022)
78. Association of Medical Device Reprocessors. Reprocessing by the Numbers. *AMDR-Generated Resource* (2019). Available at: <http://amdr.org/reprocessing-by-the-numbers/>. (Accessed: 29th May 2022)
79. French-Mowat, E. & Burnett, J. How are medical devices regulated in the European Union? *J. R. Soc. Med.* **105 Suppl**, S22 (2012).
80. Kwakye, G., Brat, G. A. & Makary, M. A. Green surgical practices for health care. *Archives of Surgery* **146**, 131–136 (2011).
81. Southorn, T., Norrish, A. R., Gardner, K. & Baxandall, R. Reducing the carbon footprint of the operating theatre: a multicentre quality improvement report. *J. Perioper. Pract.* **23**, 144–146 (2013).
82. McGain, F., Jarosz, K. M. ari., Nguyen, M. N. go. H. H. uon., Bates, S. & O'Shea, C. J. an. Auditing Operating Room Recycling: A Management Case Report. *A A case reports* **5**, 47–50 (2015).
83. Urrea, C. & Venegas, D. Automatized follow-up and alert system for patients with chronic hypertension. *Health Informatics J.* **26**, 2625–2636 (2020).
84. Dixon, R. F. & Rao, L. Asynchronous virtual visits for the follow-up of chronic conditions. *Telemed. e-Health* **20**, 669–672 (2014).
85. Buyting, R. *et al.* Virtual Care With Digital Technologies for Rural Canadians Living With Cardiovascular Disease. *CJC Open* **4**, 133–147 (2022).
86. Bokolo, A. J. Exploring the adoption of telemedicine and virtual software for care of outpatients during and after COVID-19 pandemic. *Irish Journal of Medical Science* **190**, (2021).
87. A. Butt, K. & Augestad, K. M. Educational value of surgical telementoring. *J. Surg. Oncol.* **124**, 231–240 (2021).
88. Lundell, L. *et al.* Comparing laparoscopic antireflux surgery with esomeprazole in the management of patients with chronic gastro-oesophageal reflux disease: A 3-year interim analysis of the LOTUS trial. *Gut* **57**, 1207–1213 (2008).
89. Epstein, D. *et al.* Laparoscopic fundoplication compared with medical management for gastro-oesophageal reflux disease: Cost effectiveness study. *BMJ* **339**, 152–155 (2009).
90. Gatenby, P. A. C. Modelling the carbon footprint of reflux control. *Int. J. Surg.* **9**, 72–74 (2011).
91. Ewbank, C. *et al.* The Development of a Surgical Care and Climate Change Matrix: A Tool to Assist With Prioritization and Implementation Strategies. *Ann. Surg.* **XX**, e50–e51 (2020).
92. Open Medical | Pathpoint Clinical Workflows | United Kingdom. Available at: <https://www.openmedical.co.uk/>. (Accessed: 5th March 2022)

93. Loopcycle. Available at: <https://loopcycle.io/>. (Accessed: 5th March 2022)
94. Bhopal, A. & Norheim, O. F. Priority setting and net zero healthcare: How much health can a tonne of carbon buy? *BMJ* **375**, 1–5 (2021).
95. Collaborative, Covids. Timing of surgery following SARS-CoV-2 infection: an international prospective cohort study. *Anaesthesia* **76**, 748–758 (2021).
96. Bhangu, A. *et al.* Mortality and pulmonary complications in patients undergoing surgery with perioperative sars-cov-2 infection: An international cohort study. *Lancet* **396**, 27–38 (2020).
97. MacNeill, A. J., Lillywhite, R. & Brown, C. J. The impact of surgery on global climate: a carbon footprinting study of operating theatres in three health systems. *Lancet Planet. Heal.* **1**, e360–e367 (2017).
98. Morris, D. S., Wright, T., Somner, J. E. A. & Connor, A. The carbon footprint of cataract surgery. *Eye (Basingstoke)* **27**, 495–501 (2013).
99. EA, S., SM, S., Chang, Y., DW, R. & DL, B. Environmental impact of accelerated clinical care in a high-volume center. *Surgery* **142**, 343–349 (2007).
100. Khajuria, A. Robotics and surgery: A sustainable relationship? *World J. Clin. Cases* **3**, 265 (2015).
101. Chandra, P., Gale, J. & Murray, N. New Zealand ophthalmologists' opinions and behaviours on climate, carbon and sustainability. *Clin. Exp. Ophthalmol.* **48**, 427–433 (2020).
102. Nursing and Midwifery Council. Standards of Proficiency for Midwives. *Nurs. Midwifery Counc.* 10–50 (2019).
103. General Medical Council. Outcomes for graduates - GMC. *General Medical Council* (2020). Available at: <https://www.gmc-uk.org/education/standards-guidance-and-curricula/standards-and-outcomes/outcomes-for-graduates>. (Accessed: 3rd March 2022)
104. Tun, M. S. Fulfilling a new obligation: Teaching and learning of sustainable healthcare in the medical education curriculum. *Med. Teach.* **41**, 1168–1177 (2019).
105. ESCP Goes Green | European Society of Coloproctology. Available at: <https://www.escp.eu.com/news/2277-escp-goes-green>. (Accessed: 3rd March 2022)
106. Rodríguez De Santiago, E. *et al.* Reducing the environmental footprint of gastrointestinal endoscopy: European Society of Gastrointestinal Endoscopy (ESGE) and European Society of Gastroenterology and Endoscopy Nurses and Associates (ESGENA) Position Statement. *Endoscopy* **54**, 797–826 (2022).
107. Simpson, K. R. Choosing wisely. *MCN The American Journal of Maternal/Child Nursing* **41**, 196 (2016).
108. Thiel, C. L. *et al.* Cataract surgery and environmental sustainability: Waste and lifecycle assessment of phacoemulsification at a private healthcare facility. *J. Cataract Refract. Surg.* **43**, 1391–1398 (2017).
109. Goel, H. *et al.* Improving productivity, costs and environmental impact in International Eye Health Services: Using the 'Eyeefficiency' cataract surgical services auditing tool to assess the value of cataract surgical services. *BMJ Open Ophthalmol.* **6**, 642 (2021).
110. Surgical operations and procedures statistics - Statistics Explained. *Eurostat* (2015).

111. Global Cancer Observatory. Cancer Tomorrow. *International Agency for Research on Cancer : World Health Organization* 1–2 (2021). Available at: https://gco.iarc.fr/tomorrow/en/dataviz/tables?mode=population&cancers=8_9_11_7&group_cancers=1&multiple_cancers=1. (Accessed: 19th June 2022)
112. Global Cancer Observatory. Cancer Over Time. *International Agency for Research on Cancer : World Health Organization* (2021). Available at: https://gco.iarc.fr/overtime/en/dataviz/tables?populations=3600_7600_10000_17000_11200_12400_15200_15600_19100_20300_20800_21800_23300_25000_27600_35200_35600_37200_37600_38000_41000_41400_42800_44000_47000_52800_55400_57800_61600_70300_70500_18800_39200_. (Accessed: 19th June 2022)
113. Sheetz, K. H., Clafin, J. & Dimick, J. B. Trends in the Adoption of Robotic Surgery for Common Surgical Procedures. *JAMA Netw. Open* **3**, (2020).
114. Gayam, S. Environmental Impact of Endoscopy: ‘Scope’ of the Problem. *Am. J. Gastroenterol.* **115**, 1931–1932 (2020).
115. Haddock, R., De Latour, R., Siau, K., Hayee, B. & Gayam, S. Climate Change and Gastroenterology: Planetary Primum Non Nocere and How Industry Must Help. *American Journal of Gastroenterology* **117**, 394–400 (2022).
116. Siddhi, S., Dhar, A. & Sebastian, S. Best Practices in Environmental Advocacy and Research in Endoscopy. *Techniques and Innovations in Gastrointestinal Endoscopy* **23**, 376–384 (2021).
117. Agrawal, D. & Tang, Z. Sustainability of Single-Use Endoscopes. *Techniques and Innovations in Gastrointestinal Endoscopy* **23**, 353–362 (2021).
118. Bjørsum-Meyer, T., Toth, E. & Koulaouzidis, A. Carbon footprint from superfluous colonoscopies: potentialities to scale down the impact. *Gut* [gutjnl-2021-326587](https://doi.org/10.1136/gutjnl-2021-326587) (2022). doi:10.1136/gutjnl-2021-326587
119. Altizer, S., Ostfeld, R. S., Johnson, P. T. J., Kutz, S. & Harvell, C. D. Climate change and infectious diseases: From evidence to a predictive framework. *Science* **341**, 514–519 (2013).
120. Desmond, S. Implementing climate change mitigation in health services: The importance of context. *J. Heal. Serv. Res. Policy* **21**, 257–262 (2016).
121. Herman, S. M., Zaborniak, K. & Bernstein, C. N. Insight into Inflammatory Bowel Disease Pathogenesis: Is the Answer Blowing in the Wind? *Inflammatory Bowel Diseases* **28**, 486–491 (2022).
122. World Health Organization. *COP26 Special Report on Climate Change and Health. The Health Argument for Climate Action.* (2021).
123. Bria, E. & Conte, P. Biosimilars as a strategy to improve sustainability. *ESMO Open* **2**, 10–11 (2017).
124. Fierens, L. *et al.* Introduction of Subcutaneous Infliximab CT-P13 and Vedolizumab in Clinical Practice: A Multi-Stakeholder Position Statement Highlighting the Need for Post-Marketing Studies. *J. Crohn’s Colitis* (2022). doi:10.1093/ECCO-JCC/JJAC009
125. Poscia, A. *et al.* Sustainability of Endovenous Iron Deficiency Anaemia Treatment: Hospital-Based Health Technology Assessment in IBD Patients. *Biomed Res. Int.* **2017**, (2017).
126. Galle, P. R. *et al.* EASL Clinical Practice Guidelines: Management of

- hepatocellular carcinoma q. (2018). doi:10.1016/j.jhep.2018.03.019
127. Eisenack, K. *et al.* Explaining and overcoming barriers to climate change adaptation. *Nature Climate Change* **4**, 867–872 (2014).
128. 3 Biggest Barriers Holding Cities Back on Climate Change. Available at: <https://nextcity.org/urbanist-news/cities-acting-against-climate-change>. (Accessed: 19th September 2022)
129. Setoguchi, S., Leddin, D., Metz, G. & Omary, M. B. Climate Change, Health, and Health Care Systems: A Global Perspective. *Gastroenterology* **162**, 1549–1555 (2022).

Acknowledgements

The authors thank Prof. Pedro Castelo Branco for his insights during manuscript revision and Dr. Joana Roseira for her support with this article.

Author contributions

The authors contributed equally to all aspects of the article.

Competing interests

The authors declare no competing financial and non-financial interests.

Peer review information

Nature Reviews XXX thanks [Referee#1 name], [Referee#2 name] and the other, anonymous, reviewer(s) for their contribution to the peer review of this work.

Publisher's note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Table 1. Environmental burden of the different processes during the surgical pathway: a summary of recent articles that measured the environmental effect of diagnostic modalities (computerized tomography, magnetic resonance, digestive endoscopy), surgical procedures (hysterectomy, cholecystectomy), and surgical approaches (open, laparoscopic and robotic).

<u>Study</u>	<u>Method</u>	<u>Aim</u>	<u>Speciality</u>	<u>Environmental effect measure</u>	<u>Outcome</u>
Esmaeili et al., 2015	Multicentric, retrospective cohort study	"Provide quantitative information to radiologists so that they can be involved in making energy improvements while maintaining quality patient care."	Radiology - computerized tomography (CT)	Life cycle assessment (energy & consumables) kg CO _{2e}	CT 5.1–7.3 kg CO _{2e}
Esmaeili et al., 2018	Multicentric, retrospective cohort study	"Provide a detailed accounting of energy and materials consumed during magnetic resonance imaging (MRI)."	Radiology - MRI	Life cycle assessment (energy & consumables) kg CO _{2e}	MRI 22.54 kg CO _{2e}
Woods et al., 2015	Unicentric, retrospective cohort study	"Our research intends to quantify the carbon footprint of the procedures based on their energy consumed and waste produced."	Gynaecology - hysterectomy (robotic; laparoscopic; open approach)	Waste & energy kg CO _{2e}	Robotics 40.3 Kg CO _{2e} Laparoscopic 29.2 kg CO _{2e} Open 22.7 kg CO _{2e}
Cassandra et al., 2018	Unicentric, prospective cohort study	"To determine the carbon footprint of various sustainability interventions used for laparoscopic hysterectomy."	Gynaecology - hysterectomy (laparoscopic approach)	Hybrid environmental life cycle assessment kg CO _{2e}	Laparoscopic hysterectomy 562 kg CO _{2e}
Rizan et al., 2021	Unicentric	"Compare the environmental and financial life cycle cost of currently available hybrid instruments for laparoscopic cholecystectomy and compare these to single-use equivalents."	General Surgery; cholecystectomy	Life cycle assessment of the single-use and non-single-use (hybrid) kg CO _{2e}	Hybrid: 1,756 kg CO _{2e} Single-use: 7,194 Kg CO _{2e}
Vaccari et al., 2018	Unicentric, Prospective, Cohort study	"Understand the nature of the relationship between generation patterns hazardous healthcare waste."	All Specialties (anaesthetics, paediatric; intensive care unit (ICU); digestive endoscopy)	Amount of hazardous waste kg	Anaesthetics 5.96 kg per day per bed ICU 3.37 kg per day per bed Digestive endoscopy 3.09 kg per day per bed

CO_{2e}, carbon dioxide equivalent; kg, kilograms; CT scan, computerized tomography scan; MRI, magnetic resonance imaging

Figure 1. Healthcare impact on the environment. Healthcare directly contributes to climate change. This contribution comes from different vectors. Anaesthetic gases, waste generation, and disposable devices are considered direct vectors. Energy use, such as electricity and temperature conditioning, also contribute to healthcare's carbon footprint. Indirect vectors, like fossil fuel used for patient and healthcare providers' transport, the life cycle assessment of the health supply manufacturer (since its production, including transportation and water use), are all contributors to this environmental impact. CO₂: Carbon dioxide

Figure 2. Surgical carbon footprint. Surgical environmental impact can be

evaluated before, during and after surgery. Patient and staff transportation are responsible for 18% of all healthcare emissions. The diagnostic workup before surgery accounts for a significant impact driven by CT scans, MRI, and endoscopy. During surgery, there are multiple vectors to consider: water waste due to hand disinfection; the anaesthetic gases are responsible for 40% of the “surgical emissions”; operating theatre energy and temperature conditioning; disposable surgical linens; and single-use devices. Moreover, different surgical approaches have different carbon footprints. Data on hysterectomy shows that laparotomy has a lesser carbon footprint, followed by laparoscopy and robotics. *CO_{2e}: carbon dioxide equivalent; kg: kilograms; CT scan: computerized tomography scan; MRI: magnetic resonance imaging*

Figure 3. Areas querying action to make the surgical pathway more sustainable.

Before patient admission, health promotion measures and the use of sustainable means of transport by patients, healthcare professionals and products are important interventions. At the hospital, using renewable energy sources and optimising electricity and cooling systems should be considered. During surgery, avoiding anaesthetic gases and promoting intravenous and local anaesthesia can have a remarkable impact. Additionally, reducing disposables and implementing recycling would reduce waste production. Telemedicine represents a good example of how technology can facilitate sustainability. Research and education are important to evaluate the impact of sustainable actions and can help to continue this process across generations. *CO_{2e}: carbon dioxide equivalent*

Key Points:

Box 1: Key points on environmental effects of surgical procedures and strategies for sustainable surgery.

Key Points
1- Climate change dramatically threatens public health and the healthcare sector.
2- Surgery is the most energy-intensive practice, directly contributing to climate change.
3- Gastrointestinal diseases are among the most common conditions requiring invasive diagnostic and therapeutic procedures globally.

4-	Sustainable gastroenterology and endoscopy practices are still in their early stages of development.
5-	The “5 Rs plus 1 principle” (Reduce, re-use, recycle, rethink, research and re-educate) can be used as a template for a more sustainable surgical practice. It can be easily applied to other healthcare fields.
6-	Sustainability in surgery encompasses a surgical pathway aiming to achieve patients’ best outcomes in an environmental-friendly way.
7-	The impact of the healthcare sector should be addressed from a multi-disciplinary perspective, including health professionals, patients, companies, healthcare managers, and governments.

Box 2: Definitions and nomenclatures commonly used to characterise climate change and measure its impact

Concept	Definition
Greenhouse gas	Gaseous constituents in the atmosphere that absorbs and emits radiant energy within the thermal infrared range
Carbon footprint	An objective measure of the quantity of greenhouse gas emissions emitted into the atmosphere by an individual, organisation, process, product or event” measured in CO _{2e}
Carbon dioxide equivalents (CO _{2e})	A standard metric measure used to compare the emissions from various Greenhouse Gases based on their global warming potential over a specified timescale to express a carbon footprint
Life Cycle Assessments	Methodologic and detailed way to assess the financial cost and environmental impact of a product from its production until its disposal

Box 3: Relevance of Gastroenterology and Hepatology on Sustainable Healthcare practices

Gastroenterology and Hepatology on Sustainable Healthcare Practices	
Priority	<ul style="list-style-type: none"> Epidemiological relevance (GERD; functional disorders; gastrointestinal infections; CLD; IBD; gastrointestinal cancer) One of the world’s largest therapeutic areas representing a heavy global burden Advanced management demand (endoscopy, surgery) Endoscopy is a burdensome practice due to waste generation, disposable equipment, energy, and water consumption
Sustainable Applications	<ul style="list-style-type: none"> Disease prevention (vaccination, policies to counteract alcohol abuse, and healthy lifestyle advocacy) Use of lower impact, and wider accessible, medications that are safe and effective (e.g., biosimilars)

	<ul style="list-style-type: none"> • Reduce unnecessary patient traveling (subcutaneous alternatives to intravenous, teleconsultation) • “5 R’s plus one” interventions in endoscopy units and gastroenterology departments
Ethics	<ul style="list-style-type: none"> • Re-use per reprocessing and remanufacturing (regulation development and advice from the medical device industry) • Ensure acceptability and safety of sustainable choices through outcome measures (patient-reported; productivity estimates)

CLD, chronic liver disease; GERD, gastroesophageal reflux disease; IBD, inflammatory bowel disease

Box 4: Common barriers to adopting a sustainable approach that applies to healthcare.

Barriers to the adoption of a sustainable approach that apply to healthcare	
Barriers	<ul style="list-style-type: none"> • Economic and financial – access to funding to implement greater climate action • Policy and leadership – difficulties in implementing long-term measures when governments usually change on a shorter-term cycles • Institution, regulatory, and legislative - conflicting interests • Information and knowledge – lack of global awareness and advice • Social and cultural – influence, adaptation, change and decision making • Technology and infrastructure • Physical and human context – adaptative capacity limited by human resources

[ToC blurb] Healthcare contributes to the climate change burden, and measures should be taken to mitigate these effects. This Perspective discusses the carbon footprint of surgery in gastroenterology and hepatology and offers an overview of sustainable strategies.

Figure 1

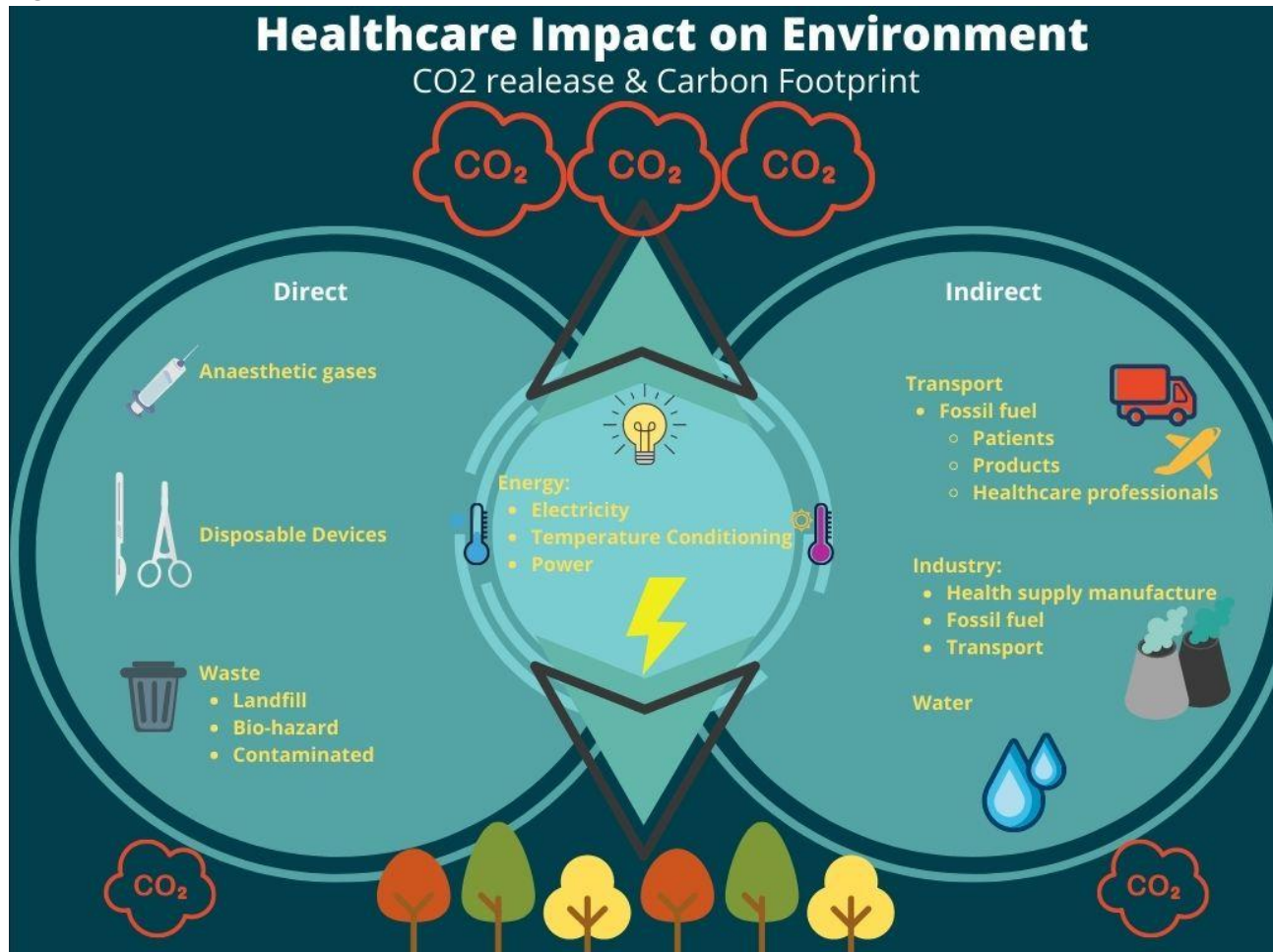


Figure 2

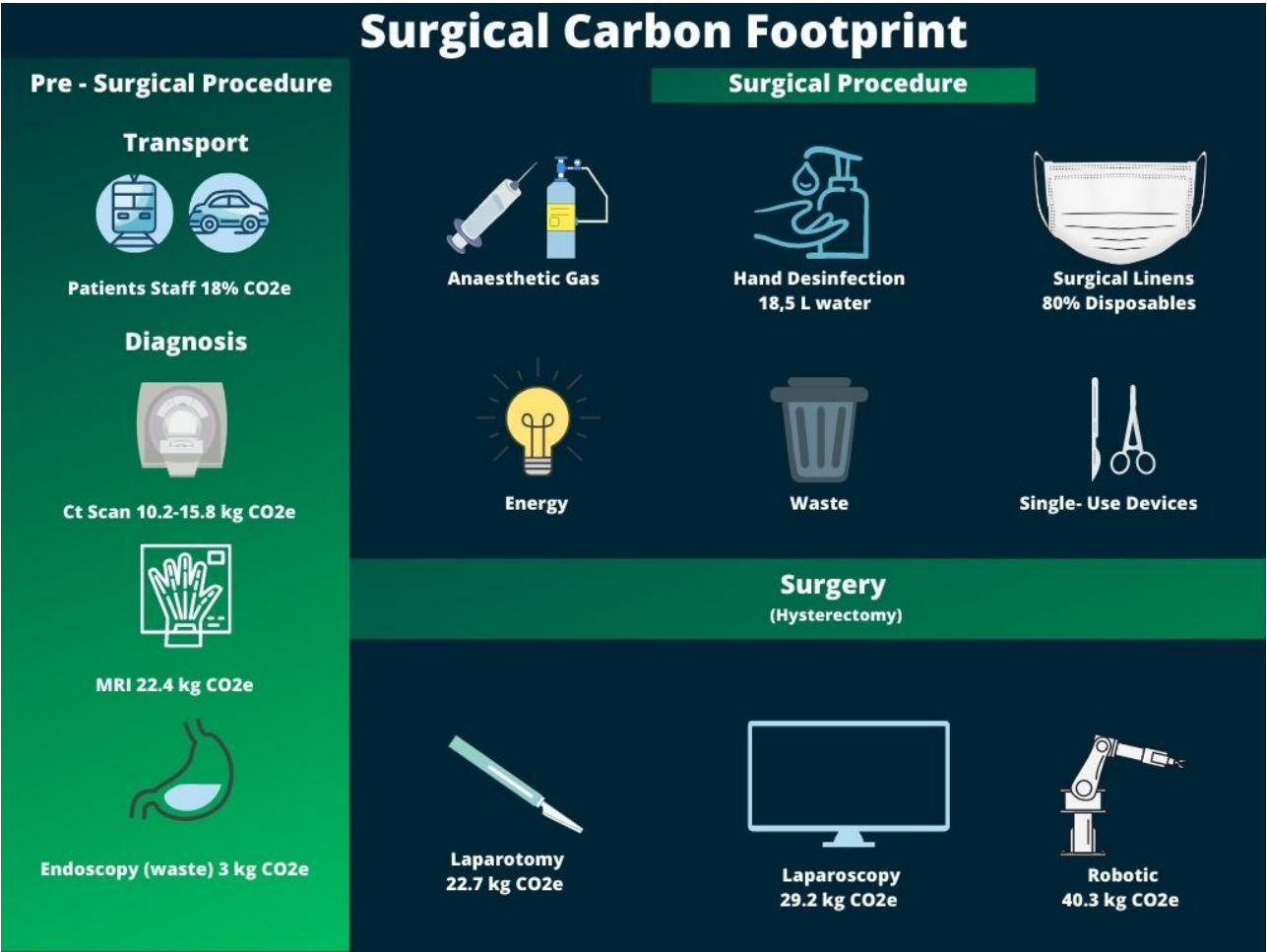


Figure 3

