Original research

Life cycle assessment of routinely used endoscopic instruments and simple intervention to reduce our environmental impact

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ABSTRACT

Objectives GI endoscopy units represent the third largest producers of medical waste. We aimed to determine endoscopic instrument composition and life cycle assessment (LCA) and to assess a sustainability proposal based on a mark on the instruments that identifies parts can be safely recycled or '*green mark*'.
Design Material composition analysis and LCA of forceps, snares and clips from four different manufacturers (A–D) were performed with four different methods. Carbon footprint from production, transportation and end of life of these instruments was calculated. In 30 consecutive procedures, we marked the contact point with the working channel. 5 cm away from that point was considered as *green mark*. One-week prospective study was conducted with 184 procedures evaluating 143 instruments (75 forceps, 49 snares and 19 haemoclips) to assess the efficacy of this recyclable mark.
Results Composition from different manufacturers varied widely. Most common materials were high global warming potential (GWP) waste (polyethylene, polypropylene and acrylonitrile) and low GWP waste (stainless steel). Significant differences were found for the forceps (0.31–0.47 kg of CO_2 equivalent (CO_2-eq)) and haemoclips (0.41–0.57 kg CO_2-eq) between the manufacturers. *Green mark* was established 131.26 cm for gastroscope and 195.32 cm for colonoscope. One-week activity produced 67.74 kg CO_2-eq. Applying our sustainability intervention, we could reduce up to 27.44% (18.26 kg CO_2-eq). This allows the recycling of 61.7% of the instrument total weight (4.69 kg).
Conclusion Knowledge of carbon footprint is crucial to select the most sustainable alternatives because there are large variations between brands. A mark to identify recyclable parts could reduce our environmental impact significantly.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ GI endoscopy units represent the third largest producers of medical waste, divided into regular waste, recyclable waste and biomedical waste (BMW), the latter to be incinerated at high temperature, resulting in harmful emissions.
⇒ Simple sustainability interventions such as team education in terms of waste handling, segregation and disposal result in significant decrease of carbon emissions.

WHAT THIS STUDY ADDS

⇒ In our daily practice, current global carbon footprint related to endoscopic procedures needs to be urgently evaluated.
⇒ Knowledge of instrument composition is crucial to select the most sustainable alternatives because there are large variations of the same instrument between brands.
⇒ A sustainability intervention based on a mark on the instruments that identifies parts that can be recyclable could be able to reduce the amount of BMW and increase recyclable medical waste.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ It is important to assess the carbon footprint in kilogram of CO_2 equivalent of our consumables to raise awareness and change our clinical decision making.
⇒ Through innovative industrial solutions, we can move towards a more sustainable endoscopy.

INTRODUCTION

Greenhouse gas (GHG) emissions derived from human activity play a crucial role in climate change.[1] Healthcare systems contribute significantly to the world's carbon footprint, representing 4.4%–5.4% of total GHG emissions around the world by the increasing use of disposable plastic medical and personal protective equipment.[2–4]

GI endoscopy units represent the third largest producers of medical waste, divided into regular waste, recyclable waste and biomedical waste (BMW), the latter to be incinerated at high temperature resulting in harmful emissions.[5 6] Each single endoscopy procedure generates on average up to 2.1 kg of general waste, being regular waste (63%), BMW (28%) and recyclable (9%) waste.[7] Simple sustainability interventions such as team education in terms of waste handling, segregation and disposal may result in a total decrease of carbon emissions by 31.6%.[8] The European Society of Gastrointestinal

Endoscopy has recently released a statement addressing several proposals to reduce our environmental footprint (EF) to avoid unnecessary procedures, favouring less invasive diagnostic tests creating recycling strategies.[9]

Reducing the carbon footprint of manufacturing is crucial, but details of material composition of commonly used endoscopic instruments are scarce. According to European legislation, these instruments are considered BMW; therefore, they must be incinerated, contributing to pollutant emissions, much more than landfill waste. We aimed to determine endoscopic instrument composition, life cycle assessment (LCA) and to assess a sustainability proposal based on a mark on the instruments that identifies parts that can be safety recyclable or a '*green mark*', to understand the environmental impact of our daily practice.

METHODS

Study design

This study was a single-centre prospective study conducted at La Fe University Hospital from June 2022 to July 2022. It was designed to evaluate sustainability and composition–environmental impact of commonly used endoscopy instruments (biopsy forceps, polypectomy snares and haemostatic clips) from four different manufacturers, quantifying the parts that could be recycled.

Procedures

All instruments were analysed after the endoscopic procedure, adding a mark on the instruments to identify parts not in contact with the endoscope, outside the working channel, which could be recyclable. Composition analysis was performed at the Centre for Biomaterials and Tissue Engineering of the Universitat Politècnica de València. The study team was blinded to the type of brand.

Instruments from four different manufacturers (A, B, C and D) were selected: biopsy forceps (A, B and C), polypectomy snares (A, B and D) and haemostatic clips (A and B). Weight, chemical and thermal properties of the different parts of all these devices (packing, tip, body and handle) were analysed in detail using Fourier transform infrared (FTIR) spectroscopy, energy dispersive X-ray (EDX) analysis, differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA).

Carbon footprint was assessed as kilogram of CO_2 equivalent (CO_2-eq) released, a common measure of global warming potential (GWP) from an LCA (manufacture, transportation, use and end of life) of each instrument to quantify total carbon footprint.[10] The GHG emissions (eg, carbon dioxide, methane and nitrous oxide) across life cycle stages were converted into CO_2-eq using an LCA model 'cradle to grave'. The scope of our analysis includes extraction of material and energy resources, manufacturing, transport between sites in the production process to the hospital and disposal at end of life. Cradle-to-grave carbon emissions (manufacturing, transportation and incineration) were estimated for every instrument and represented as kg CO_2-eq.

EF was estimated using a free LCA software, OpenLCA V.1.11.0 (GreenDelta GmbH, Germany). The databases for life-cycle inventory analysis used include ecoinvent V.2.2, Agribalyse V.3.0 and EF Secondary Data sets V.EF 2.0. Impact assessment method applied was EF (midpoint indicator).

Laboratory detailed calculation of weight and composition of endoscopy instruments allowed us to precisely determine what kind of material components manufacturers use for production. GHG emissions derived from production of forceps, snares and clips from companies A–D were calculated. Therefore, most sustainable instruments were identified through LCA software. Several assumptions were made to estimate carbon emissions deriving from transportation. Based on manufacturing sites from different companies and ship-to-party, most frequent international routes were assumed. We calculated emissions from shipping by cargo container for transoceanic routes and diesel lorry for continental ones. Since the databases used do not consider manufacturing and assembly steps (injection, extrusion and lamination), they were not included in the calculations, even though their environmental impact falls around 15% of the total.[11]

As single-use equipment is required to be processed via high-temperature incineration, end-of-life emissions were estimated according to recent data of waste streams in the literature.[12–14] The incineration of general BMW was estimated as 1.074 kg CO_2-eq/kg[13] for non-plastics and 6 kg CO_2-eq/kg for plastics.[13] The procedure was assessed across several environmental impact categories (ionising radiation, ozone depletion, human toxicity cancer/not cancer effects and acidification).

Green mark proposal

Our hypothesis to develop a sustainability intervention is based on one simple proposal: some parts of the instrument may not be considered as BMW. Parts of the instrument body and the handle are not in contact with patient fluids or secretions. Our proposal consists in taking apart the instrument after the procedure (upper from the mark), sending the handle and part of the body to recycle and the rest (in contact with the working channel of the endoscope) to BMW management. An experiment was conducted in our daily practice to mark the proximal part of the instrument body not in contact with the working channel. Marking of the sheath was made during 30 consecutive diagnostic endoscopic procedures to determine this contact mark for gastroscopy and colonoscopy. Mean, median, range and SD of distance from the instrument tip to the marked point of the instrument body were calculated. Although the device has not been inside the endoscope, it would still be in contact with the hands of the endoscopist and the assistant, with multiple passes. To reduce the potential risk contamination, 5 cm away from the contact mark with the working channel was considered safe and marked as our recyclable mark or *green mark* (figure 1). After the procedure, in the same endoscopy room, instruments were cut into pieces with a wire cutter by the endoscopist.

A one-week prospective study was conducted with 184 procedures evaluating 143 instruments: 75 biopsy forceps (A), 49

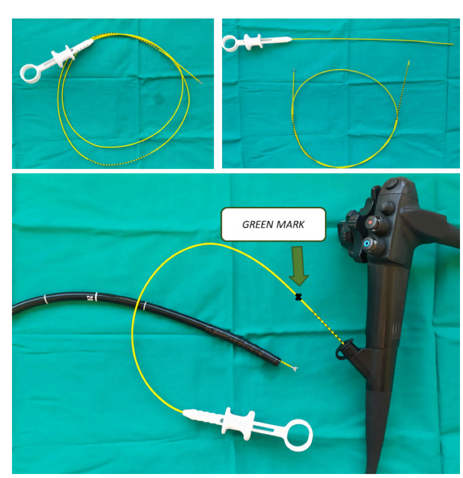

Figure 1 *Green mark*, 5 cm away from the contact point with working channel.

Table 1 Material composition, weight and thermochemical properties of analysed biopsy forceps, polypectomy snares and haemostatic clips

	Forceps	Snares	Haemoclips
Total weight (g) (range)	57.08 (64.46–46.39)	57.05 (64.58–52.92)	71.29 (85.63–56.93)
Device weight (g) (range)	45.82 (54.60–33.75)	42.96 (47.46–40.28)	54.60 (65.60–43.58)
Packaging weight (g) (range)	11.31 (12.63–9.86)	14.10 (17.12–11.8)	16.69 (20.03–13.35)
Composition (%)			
Polyethylenes	32.00 (17–51)	45.33 (36–50)	53.50 (24–30)
Polypropylene	19.33 (0–34)	11.66 (0–35)	–
Acrylonitrile butadiene styrene	–	28.00 (0–50)	14.50 (23–53)
Stainless steel	45.00 (38–59)	14.33 (14–15)	35.00 (13–53)

polypectomy snares (A) and 19 haemostatic clips (B), to assess the efficacy of this *green mark*.

Outcomes
The primary outcome was the determination of endoscopic instrument composition and environmental impact with LCA of the total number of biopsy forceps, polypectomy snares and haemostatic clips used during the one-week period. The secondary outcome was to perform a prospective intervention based on a *green mark* to evaluate differences in terms of carbon footprint.

Statistics
All continuous variables are expressed as mean (95% CI) or proportions as required. Comparison of means among groups was done using one-way analysis of variance or its corresponding non-parametric (Kruskal-Wallis) test, with a two-sided p value of <0.05 indicating statistical significance. Comparisons of proportions among groups were made with the χ^2 test. All statistical analyses were performed using SigmaPlot V.12.5 (Systat Software GmbH, Erkrath, Germany).

RESULTS
Material composition
Thermochemical analysis was performed using FTIR, EDX, DSC and TGA to estimate the most likely type of plastic or metal used for endoscopic equipment. Material composition, weight and thermochemical properties of all instruments are shown in table 1. The major components of commonly used single-use instruments were identified as low-density polyethylene (LDPE) and high-density polyethylene (HDPE), acrylonitrile butadiene styrene (ABS) copolymer and polypropylene (PP), along with stainless steel (SS). Composition and weight from different manufacturers A–D varied widely. To allow comparisons of the GWPs of different components, they were classified as high GWP waste (LDPE, HDPE, ABS and PP) or low GWP waste (SS). Snares SS composition from different manufacturers was similar (14%–15%), but significant differences were found between forceps (38%–59%) and haemoclips (13%–53%). More significant differences were found for other materials among instruments from different manufacturers (figure 2).

Environmental impact
Mean carbon footprint was significantly higher in haemostatic clips (0.49 kg CO_2-eq range 0.41–0.57) than in snares (0.41 kg CO_2-eq range 0.38–0.44) and forceps (0.41 kg CO_2-eq range 0.31–0.47) ($p<0.001$). LCA of all instruments sorted by production, transportation and incineration is represented in table 2. We found significant differences ($p<0.001$) in carbon footprint among manufacturers A, B and C for forceps (0.31–0.46 kg CO_2-eq) and for haemoclips (0.41–0.57 kg CO_2-eq) but not among snares A, B and D (0.38–0.44 kg CO_2-eq) ($p=0.108$). These

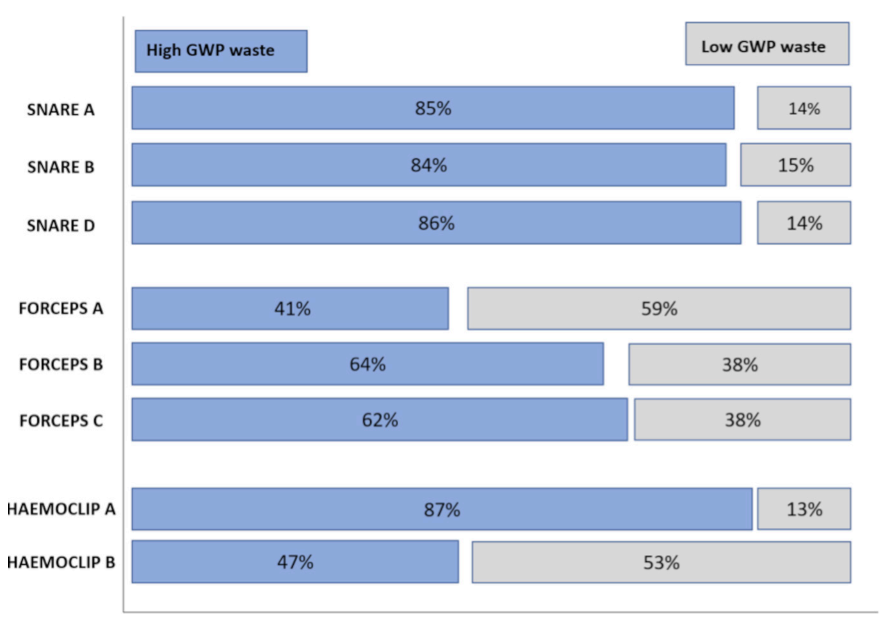

Figure 2 Weight and material composition of endoscopy instruments from different manufacturers (A–D), grouped by GWP waste. GWP, global warming potential.

Table 2 Life cycle assessment (production, transportation and incineration) of all instruments

Emissions (SD), kg CO_2-eq	Forceps	Snares	Haemoclips
Production	0.25 (0.075)	0.18 (0.005)	0.3 (0.169)
Transportation	0.02 (0)	0.02 (0.005)	0.015 (0.007)
Incineration	0.15 (0.038)	0.22 (0.021)	0.17 (0.049)
Total	0.41 (0.089)	0.41 (0.030)	0.49 (0.113)

differences are mainly due to production emissions in forceps (0.17–0.32 kg CO_2-eq) and haemoclips (0.18–0.42 kg CO_2-eq) ($p<0.001$) (figure 3). Incineration was the main culprit of emissions in instruments whose composition was mostly plastics (high GWP waste), such as snares and haemoclip A (0.20–0.24 kg CO_2-eq).

Assumed transportation by the shortest international route from manufacturing sites to ship-to-party were 14 000 km cargo ship (A), 8000 km cargo ship plus 800 km diesel lorry (B), 1200 km diesel lorry plus 6000 km cargo ship (C) and 18 000 km cargo ship (D).

Determination of recyclable mark or *green mark*

Distance from the instrument tip to the contact mark with the working channel was calculated for gastroscope (125.90 cm, 95% CI 125.54 to 126.26 cm) and colonoscope (190.03 cm, 95% CI 189.71 to 190.32 cm). *Green mark* to split the non-contaminated part of the instrument was established as 5 cm away from the upper limit of the CI (131.26 cm for gastroscope and 195.32 cm for colonoscope). This action allowed avoidance of high-temperature incineration of 60%–63% of endoscopy instruments weight to recycle. The application of this sustainability intervention implies a reduction of 34.3% of emissions (95% CI 28.1% to 40.3%) (figure 3).

Prospective sustainability intervention

According to our LCA in terms of environmental impact, GHG emissions reached up to 67.74 kg CO_2-eq during our one-week prospective study. By applying our sustainability intervention based on a *green mark*, we could reduce our environmental impact up to 27.44% (18.26 kg CO_2-eq). This allows the recycling of 61.7% of the instrument total weight (4.69 kg) (figure 4).

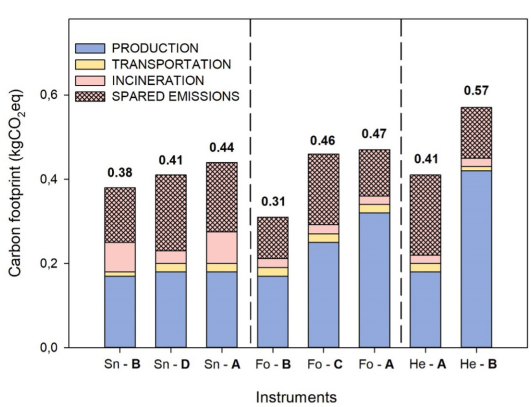

Figure 3 Life cycle assessment of endoscopy instruments from different manufacturers (A–D) in kg CO_2-eq. Carbon emissions from production, transportation end-of-life (incineration) and after applying a sustainability intervention are represented in blue, yellow, pink and shaded areas, respectively. Spared emissions represent the carbon footprint to be reduced when our sustainability intervention is implemented. Fo, forceps; He, haemoclip; Sn, snare.

DISCUSSION

Knowledge of endoscopic instrument composition and assessing the environmental impact is essential to select the most sustainable among different manufacturers. Otherwise, a sustainability intervention such as a *green mark* idea could be able to reduce the amount of BMW and increase recyclable medical waste. To our knowledge, this is the first article that describes an option for 'green' purchasing.

In our daily practice, current global carbon footprint related to endoscopic procedures needs to be urgently evaluated. To our knowledge, this is the first study which has precisely established material composition of commonly used single-use instruments and its environmental LCA. Change in clinical standards in order to introduce sustainability enhancement interventions without compromising the patient care is mandatory. Many strategies have been suggested, such as (1) strict adherence to surveillance guidelines to avoid unnecessary procedures, (2) same-day upper and lower GI endoscopy, (3) strict use of single-use endoscopes to selected indications,(4) minimising the histopathology in appropriate clinical pathways and (5) maximising availability of reusable personal protective equipment in certain scenarios, among others.[9 15]

This multidisciplinary prospective interventional study combines basic research in a laboratory setting, technical innovation to create a sustainability proposal, and clinical interventional research to validate and evaluate the environmental impact. First, the exact weight, material composition and the GWP of biopsy forceps, polypectomy snares and haemostatic clips of several manufacturers are calculated. Second, according to these particular materials, the environmental impact of its production, transport and disposal is estimated. Lastly, the cummulative effect of service interventions during 1 week is calculated to evaluate the potential improvement of our sustainability proposal.

At the bioengineering laboratory, instruments were selectively fragmented, sorted by different parts and weighted. Several thermochemical techniques (FTIR, EDX, DSC and TGA) were used for each fragment to verify real instrument components. During LCA software calculations, we came to realise that most sustainable materials for production were HDPE, LDPE and PP (2.07–2.3 kg CO_2-eq per kg of production), whereas other polymers commonly used for manufacturing of endoscopy instruments and single-use endoscopes such as ABS and polycarbonate were far less sustainable (3.22 and 3.73 kg CO_2-eq per kg). Instruments handle composition from snares B and D, and haemoclips A and B were ABS instead of more sustainable alternatives such as LDPE, HDPE and PP. SS contributed much more to GHG emissions than any other material (6.88 kg CO_2-eq per kg). SS instruments were the largest contributors to climate change, acidification, freshwater ecotoxicity and resource use (water, minerals and metals). However, SS was the most potentially recyclable material and lowest contributor to ionising radiation (0.071 kilobecquerels per kg). The authors believe that, apart from technical features and economic costs, manufacturers should provide information about environmental impact and the material composition of their products. When choosing between the preference of one or other manufacturer, significant differences in terms of carbon footprint have to be taken into account, particularly for forceps (0.31–0.46 kg CO_2-eq) and haemoclips (0.41–0.57 kg CO_2-eq). It is assumed the inclusion

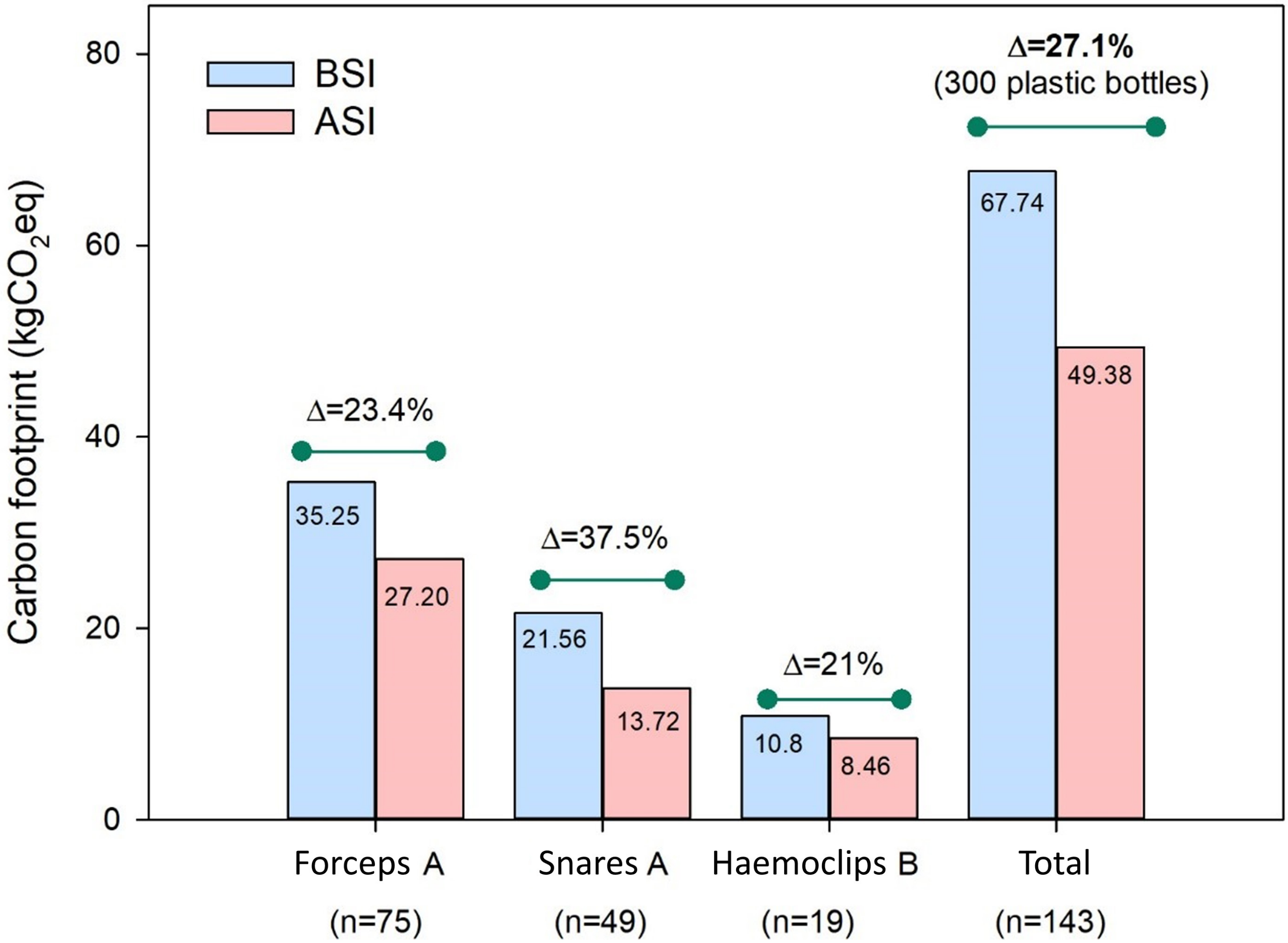

Figure 4 Total carbon emissions derived from production, transportation and incineration of commonly used endoscopy instrument during one-week endoscopic practice BSI and ASI. ASI, after sustainability intervention BSI, before sustainability intervention.

of the name of the companies involved would be preferred by the global health community. Despite performing a material composition analysis using four different methods, we did not add brand names because details of the material composition are not publicly available and there are not regulations to force them to do it. Our objective in this area is to motivate companies to change their instrument design and provide us detailed composition and sources of materials they use.

LCA of one single instrument (0.31–0.57 kg CO_2-eq) amounts to carbon emissions from production up to nine plastic bottles of water. Phases involved in the assembly and manufacturing process could increase slightly the final values of carbon footprint estimation, but the same increase will apply for all instruments considered because similar processes are involved. Still, the main contribution to the carbon emissions, that is, the material composition, has been determined in detail. Applying our sustainability intervention during a whole year of work, we found that the spared emissions would be equivalent to producing 12 000 plastic bottles of water, travelling a 17 000 km rail journey and heating an apartment for 3 years. However, we need a standardised approach to performing LCA in our field.

Other disciplines have previously examined the overall weight of disposable materials per single procedure. In the surgical field, laparoscopic hysterectomy, cataract surgery, neurosurgery and skin cancer surgery produce 12.0, 3.0, 8.9 and 2.6 kg of waste, respectively.[12 16–18] In GI endoscopy, several publications have estimated the total waste of a single endoscopy procedure (0.5–2.1 kg).[7 8 19] In our study, only taking into account biopsy forceps, polypectomy snares and haemostatic clips, total BMW per procedure was approximately 0.05 kg. Cunha Neves *et al* demonstrated that after an educational staff intervention, it was possible to reduce general landfill waste and BMW, and thus minimise waste carbon footprint.[8] They achieved a reduction of total waste and BMW by 12.9% and 41.4%, respectively, and a total decrease of carbon footprint by 31.6%.[8] However, both waste and different material components were characterise and provided data about full LCA (production, transportation and disposal) of single-use instruments, and then determined total carbon footprint.

Investigations into the impact of end-of-life management on plastic waste have found incineration in the worst amount of GHG emissions, followed by landfilling and recycling.[20 21] The safest method for disposing a BMW is high-temperature incineration. Incinerators reduce waste to one-tenth of its original volume going to landfill sites. However, incineration is a thermal process involving combustion of waste under controlled conditions for converting it into inert material and gases, resulting in environmental risks such as freshwater eutrophication and heavy metal migration.[5] Therefore, reduction of BMW waste in the endoscopy unit is key to mitigate environmental impact. According to this strategy, during our one-week interventional period, by cutting with pliers, we fragmented instruments over *green mark* to avoid incineration and sent for laboratory analysis. Mandating assessments of environmental impact is part of the EU medical device regulation. In our study, we have assumed all instrument parts have to be sent to high-temperature incineration, so spared carbon emissions were achieved only on theoretical grounds. However, regulations can vary by country, and the beneficial effect of our *green mark* idea may differ based on different waste management policies, which represents a major limitation. The purpose of this report is to set the scene for developing new environmentally designed endoscopy equipment with reusable handles, partially recyclable devices or completely recyclable instrument parts that do not need to be cut. In our study, instruments were cut into pieces after the procedure at the endoscopy room, but there is no EU legislation to cover this, so alternatively, it could be sent to a waste management company to do this. Infection control is a concern, and in our study, we did not perform microbiological studies to assess the potential risk of contamination of the part outside the working channel. This is an interesting research area we should focus on in the near future to design new barrier devices with higher infection control.

Our study found other limitations determining environmental impact. Transportation from extraction of raw materials to manufacturing sites and BMW from hospitals to incinerators were not taken into account. When assessing end-of-life emissions, we could not find LCA software databases which include information about emissions derived from incineration of different materials (polymers and metals). Consequently, incineration had to be estimated according to literature references.[13 14]

The results obtained in our study do not reflect the total carbon footprint related to endoscopy. We focused our action on commonly used disposable endoscopy instruments, a certain part of the overall endoscopy carbon footprint. According to Whiting *et al*, consumables (32%) and energy (58%) were major contributors to the carbon footprint of surgery.[22] Our sustainability proposal represents an innovative solution to reduce impact derived from consumables by transforming them into partially recyclable ones.

In conclusion, our study highlights the fact that knowledge of material composition of single-use endoscopy instruments is key to select the most sustainable alternatives. Additionally, it is important to assess the carbon footprint in kg CO_2-eq of our consumables to raise awareness and change our clinical decision making. Our data confirm there is an option for green purchasing, to purchase similar quality instruments presenting lower environmental impact. Through innovative industrial solutions, we can move towards a more sustainable endoscopy. This opens up a new competition in the market for instruments that are produced with sustainable principles.

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Contributors PL-M, RM-C, VL-Z, AV and VPB conceived and designed the study. PL-M and RM-C acquired the data and did the statistical analyses. All authors analysed and interpreted the data. PL-M wrote the manuscript. VL-Z, AV and VPB supervised the study and should be considered senior authors of the manuscript. VL-Z is the article guarantor. All authors critically revised the manuscript and approved the final version of the manuscript and agreed to be accountable for the accuracy of the work.

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Patient and public involvement Patients and/or the public were not involved in the design, conduct, reporting or dissemination plans of this research.

Patient consent for publication Not applicable.

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