PROSPECTIVE STUDY ON A RECYCABLE POINT THROUGH MATERIAL COMPOSITION ANALYSIS AND LIFE-CYCLE ASSESSMENT OF COMMONLY USED ENDOSCOPIC INSTRUMENTS

Short title: Carbon footprint of endoscopic instruments

Authors

P. López-Muñoz[1]*; R. Martín-Cabezuelo[1, 2]*; V. Lorenzo-Zúñiga[1]; G. Vilariño-Ferrer[2]; I. Tort-Ausina[2, 3], A. Vidaurre[2, 3], V. Pons-Beltrán[1].

[1]La Fe University and Polytechnic Hospital/IISLaFe, Valencia, Spain

[2]Centre for Biomaterials and Tissue Engineering, CBIT, Universitat Politècnica de València, 46022 Valencia, Spain

[3]CIBER de Bioingeniería, Biomateriales y Nanomedicina, Instituto de Salud Carlos III

Con formato: Español (España)

*** Equal contribution**

Address for correspondence:

Vicente Lorenzo-Zúñiga, MD. PhD.

Endoscopy Unit

Hospital Universitari i Politècnic La Fe/IISLaFe.

Av. Fernando Abril Martorell 106

46026 Valencia.

Spain.

E-mail: vlorenzozuniga@gmail.com

SUMMARY

Objective: Gastrointestinal endoscopy units represent the third largest producers of medical waste. We aimed to determine endoscopic instrument composition, life-cycle assessment (LCA) and assess the environmental impact of a sustainability proposal based on a recyclable point or *Green Mark*, to understand the environmental impact of our daily practice.

Design: Material composition analysis and LCA of biopsy forceps, polypectomy snares and hemostatic clips from four different manufacturers (A-D) was performed. Thermogravimetric analysis and differential scanning calorimetry were used to determine the material composition. Carbon footprint (kg CO_2-eq) from production, transportation and end-of-life of these instruments was calculated. One-week prospective study was conducted to assess the efficacy of a green mark. It was placed to separate the handle and section of the instrument body that does not enter into the working channel, which can potentially be recyclable.

Results: Composition from different manufacturers varied widely. Most common materials were high global warning pollution (GWP) waste (polyethylene, polypropylene, acrylonitrile) and low GWP waste (stainless steel). Higher LCA was found with stainless steel (forceps 35-59%, haemoclips 12-54%) and acrylonitrile (haemoclips 23-53%, snares 0-50%). Significant differences were found for the forceps (0.31-0.47 kg CO_2-eq) and haemoclips (0.41-0.57 kg CO_2-eq) between the manufacturers. Green study evaluated 184 procedures (75 forceps, 49 snares and 19 haemoclips) with 67.74 kg CO_2-eq. Applying our sustainability proposal, environmental impact could be reduced up to 27.1% (18.26 kg CO_2-eq). This allows the recycling of up to 60% of the instrument total weight.

Conclusion: Knowledge of instrument composition is essential to select the most sustainable alternatives. A recyclable point could reduce our environmental impact significantly.

KEYWORDS: Green endoscopy, material composition, endoscopic instruments, life-cycle assessment, recyclable point.

What is already known on this topic

- Gastrointestinal endoscopy units represent the third largest producers of medical waste, divided into regular waste, recyclable and biomedical waste, 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

- Knowledge of endoscopic instrument composition and assessing the environmental impact is essential to select the most sustainable among different manufacturers.
- A simple sustainability intervention, such as a recyclable point or Green Mark, could be able to reduce the amount of biomedical waste and increase recyclable medical waste.

How this study might affect research, practice or policy

- 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.
- Through industrial innovative 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].

Gastrointestinal endoscopy units represent the third largest producers of medical waste, divided into regular waste, recyclable 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]. European Society of Gastrointestinal Endoscopy (ESGE) has recently released a statement addressing several proposals to reduce our environmental footprint to avoid unnecessary procedures, favoring less invasive diagnostic tests and to create strategies to recycle [9].

Decreasing the total amount of BMW 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 assess the environmental impact of a sustainability proposal based on a recyclable point or *Green Mark*, to understand the environmental impact of our daily practice.

Methods

Study design

This study was a single-center 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 hemostatic clips) from 4 different manufacturers, quantifying the parts that could be recycled. The study protocol was approved by the ethics committee of La Fe University Hospital (approval no. 2022-787-1).

Procedures

All instruments were analyzed after the endoscopic procedure, adding a mark to identify parts not in contact with the endoscope, outside the working-channel. Composition analysis was performed at the Center for Biomaterials and Tissue Engineering of the Universitat Politècnica de València.

Instruments from 4 different manufacturers (A, B, C, D) were selected: biopsy forceps (A, B, C), polypectomy snares (A, B, D) and hemostatic clips (A, B). Weight, chemical and thermal properties of the different parts of all these devices (packing, tip, body and handle) were analyzed in detail using Fourier transform infrared spectroscopy (FTIR), energy dispersive X-Ray analysis (EDX), differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA).

Carbon footprint was assessed as kilograms of CO_2 equivalents (CO_2-eq) released, a common measure of global warming potential from a LCA (manufacture, transportation, use and end-of-life) of each instrument to quantify total carbon footprint [10]. The greenhouse gas (GHG) emissions (e.g. carbon dioxide, methane, nitrous oxide) across life cycle stages, were converted into CO_2-eq, using a 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.

Environmental footprint was estimated using a free life cycle assessment software *OpenLCA© 1.11.0 (GreenDelta GmbH, Germany).* The databases for lifecycle inventory analysis used include *Ecoinvent 2.2*, *Agribalyse 3.0* and *Environmental Footprint (EF) secondary data sets version EF 2.0*. Impact assessment method applied was *Environmental Footprint (Mid-point 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.

As single use equipment is required to be disposed via high temperature incineration, end-of-life emissions were estimated according to recent data of waste streams in the literature [11-13]. The incineration of general biomedical waste was estimated as 1.074 kg CO_2-eq/kg [12] for non-plastics and 6 kg CO_2-eq/kg for plastics [13]. The procedure was assessed across several environmental impact categories (ionizing 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 biomedical waste. Part 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, 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 determine which parts of endoscopy instruments have no contact with the patient or the working channel of the endoscope. Five centimeters away from the contact point with the working channel was considered safe and marked as our recyclable point: "*Green Mark"* (Figure 1). Marking of the sheath was made during thirty consecutive diagnostic endoscopic procedures to determine our *Green Mark* for gastroscopy and colonoscopy. Mean, median, range and standard deviation of distance from the instrument tip to the marked point of the instrument body were calculated.

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 hemostatic clips used during the 1-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 (confidence interval [CI] 95%) or proportions as required. Comparison of means among groups was done using the one-way ANOVA or its corresponding non-parametric (Kruskal-Wallis) test, with a two-sided $p<0.05$ indicating statistical significance. Comparisons of proportions among groups were made with the χ^2-test. All statistical analyses were performed using SigmaPlot 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- and high-density polyethylene (LDPE, HDPE), acrylonitrile butadiene styrene copolymer (ABS), and polypropylene (PP), along with stainless steel (SS). Composition and weight from different manufacturers A-D varied widely. To allow comparisons of the global warming potentials (GWP) 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

Cradle-to-grave carbon emissions (manufacturing, transportation, incineration) were estimated for every instrument and represented as kg CO_2-eq. 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, 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, D (0.38-0.44 kg CO_2-eq) ($p= 0.108$). These 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 14000 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 point or *Green Mark*

During thirty consecutive procedures, we marked the proximal part of the instrument body in contact with the working channel. Distance from this mark to the tip was measured for gastroscope (125.90 cm; confidence interval [CI] 95%, 125.54-126.26 cm) and colonoscope (190.03 cm; CI 95%, 189.71-190.32 cm). Green mark to split the non-contaminated part of the instrument was established as five centimeters away from the upper limit of the confidence interval (131.26 cm for gastroscope and 195.32 cm for colonoscope). This action allowed to avoid 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 (28,1-40,3% CI [95%)) (Figure 4)

Prospective sustainability intervention

During a week of standard work in a tertiary hospital, 184 diagnostic-therapeutic procedures (gastroscopy and colonoscopy) were performed and considerable amount of single-use endoscopy instruments were expended: 75 biopsy forceps (A), 49 polypectomy snares (A) and 19 hemostatic clips (B). According to our life cycle assessment in terms of environmental impact, GHG emissions reached up to 67.74 kg CO_2-eq. Considering the handle and part of the instrument body as recyclable or disposable via general waste, we reduced the environmental impact up to 27.44% (18.8 kg CO_2-eq) and saved 61.67% of instrument weight (4.69 kg) (Figure 5).

Discussion

Knowledge of endoscopic instrument composition and assessing the environmental impact is essential to select the most sustainable among different manufacturers. Otherwise, a simple sustainability intervention, such as Green Mark, could be able to reduce the amount of BMW and increase recyclable medical waste.

In our daily practice it is crucial to decrease the total amount of BMW and our current global carbon footprint 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) minimize the histopathology in appropriate clinical pathways (5) maximize availability of reusable personal protective equipment in certain scenarios, among others [9, 14].

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. Firstly, the exact weight, material composition and their GWP of biopsy forceps, polypectomy snares and hemostatic clips of several manufacturers is calculated. Secondly, according to these particular materials, the environmental impact of its production, transport and disposal is estimated. Lastly, 1-week intervention 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 realize 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 (PC) 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 y B was 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). Stainless-steel 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 ionizing radiation (0.071 kilo becquerels per kg). The authors believe that, apart from technical features and economic costs, manufacturers should provide information about environmental impact and 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).

LCA of one single instrument (0.31-0.57 kg CO_2-eq) amounts to carbon emissions from production up to 9 plastic bottles of water. Applying our sustainability intervention during a whole year of work, the spared emissions would be equivalent to producing 12000 plastic bottles of water, traveling a 17000 km rail journey and heating an apartment for 3 years.

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, 3, 8.9 and 2.6 kg of waste, respectively [11, 15-17]. In gastrointestinal endoscopy, several publications have estimated the total waste of a single endoscopy procedure (0.5-2.1 kg) [7, 8, 18]. In our study, only taking into account biopsy forceps, polypectomy snares and hemostatic 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 minimize 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, not only we analyzed waste, but also characterized different material components 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 [19, 20]. Safest method for disposing of 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 gasses, resulting in environmental risks such as freshwater eutrophication and heavy metals migration [5]. Therefore, reduction of BMW waste in the endoscopy unit is key to mitigate environmental impact. According to this strategy, during our 1-week interventional period, by cutting with pliers, we fragmented instruments over Green Mark to avoid incineration and sent for laboratory analysis. However, in accordance with current European legislations, in the end the recyclable parts had to be sent for high temperature incineration, so spared carbon emissions were achieved only on theoretical grounds, which represents a major limitation. The purpose of this report is to set the scene for development of new partially-recyclable endoscopy equipment.

Our study found other limitations to calculate environmental impact. Transportation from extraction of raw materials to manufacturing sites and BMW from hospital 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, metals). Consequently, incineration had to be estimated according to literature references [12, 13].

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 [21]. Our sustainability proposal represents an innovative solution to reduce impact derived from consumables, by transforming them in partially-recyclable.

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. Finally, through industrial innovative solutions, we can move towards a more sustainable endoscopy.

Data availability statement: Data are available upon reasonable request

Patient consent for publication: Not applicable

Contributors: PLM, RMC, VLZ, AV and VPB conceived and designed the study. PLM and RMC acquired the data and did the statistical analyses. All authors analysed and interpreted the data. PLM wrote the manuscript and all authors critically revised the manuscript. All authors approved the final version of the manuscript and agreed to be accountable for the accuracy of the work. VLZ, AV and VPB supervised the study and should be considered seniors authors of the manuscript. VLZ is the article guarantor.

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FIGURES

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

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

Figure 3: Life cycle assessment of endoscopy instruments from different manufacturers (A-D) in kgCO_2e. Carbon emissions from production, transportation and end-of-life (incineration) are represented in blue, green and red, respectively.

Figure 4: Life cycle assessment of endoscopy instruments from different manufacturers (A-D) in kg CO_2-eq after applying a sustainability intervention

Figure 5: Total carbon emissions derived from production, transportation and incineration of commonly used endoscopy instrument during 1-week endoscopic practice before (BSI) and after (ASI) a sustainability intervention

TABLES

Table 1. Material composition, weight and thermochemical properties of analyzed biopsy forceps, polypectomy snares and hemostatic clips

	Forceps	Snares	Haemoclips	p-value
Total Weight (SD), g	57.08 (9.45)	57.05 (6.53)	71.29 (20.30)	0.398
Device Weight (SD), g	45.82 (10.80)	42.96 (3.93)	54.60 (15.57)	0.488
Packaging Weight (SD), g	11.31 (1.39)	14.10 (2.73)	16.69 (4.72)	0.211
Composition (%)				
PE	32.00 (17-51%)	45.33 (36-50%)	53.50 (24-30%)	0.582
PP	19.33 (0-34%)	11.66 (0-35%)	-	0.645
ABS	-	28.00 (0-50%)	14.50 (23-53%)	0.581
SS	45.00 (38-59%)	14.33 (14-15%)	35.00 (13-53%)	0.147

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

Emissions (SD), kg CO_2-eq	Forceps	Snares	Haemoclips	p-value
Production	0.25 (0.075)	0.18 (0.005)	0.3 (0.169)	0.379
Transportation	0.02 (0)	0.02 (0.005)	0.015 (0.007)	0.988
Incineration	0.15 (0.038)	0.22 (0.021)	0.17 (0.049)	0.139
Total	0.41 (0.089)	0.41 (0.030)	0.49 (0.113)	0.518

Figure 1: Green mark, 5-cm away from contact point with working-channel

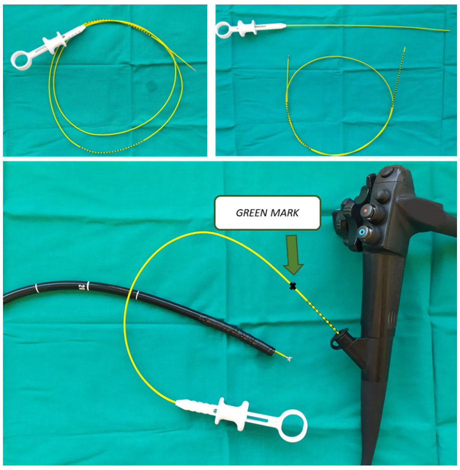

Figure 2: Weight and material composition of endoscopy instruments from different manufacturers (A-D), grouped by global warming potential (GWP) waste.

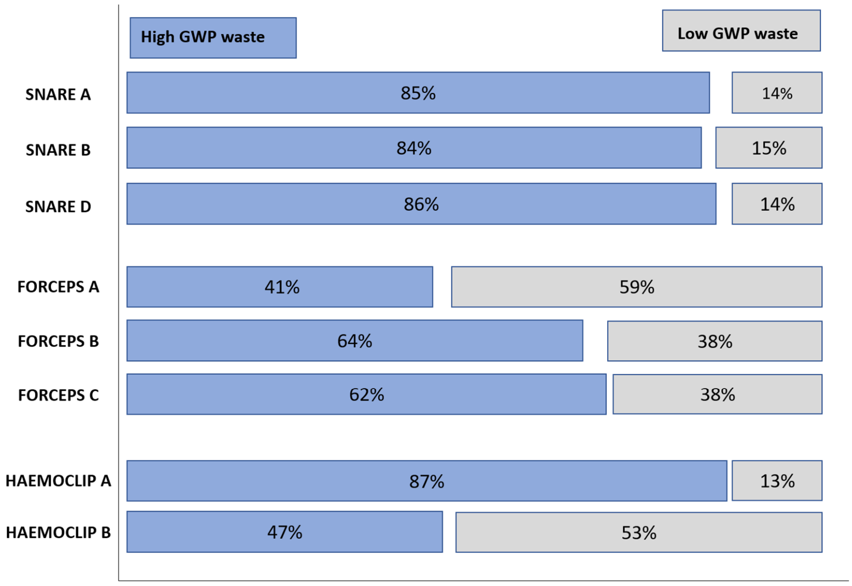

Figure 3: Life cycle assessment of endoscopy instruments from different manufacturers (A-D) in kg CO_2-eq. Carbon emissions from production, transportation, and end-of-life (incineration) are represented in blue, green and red, respectively.

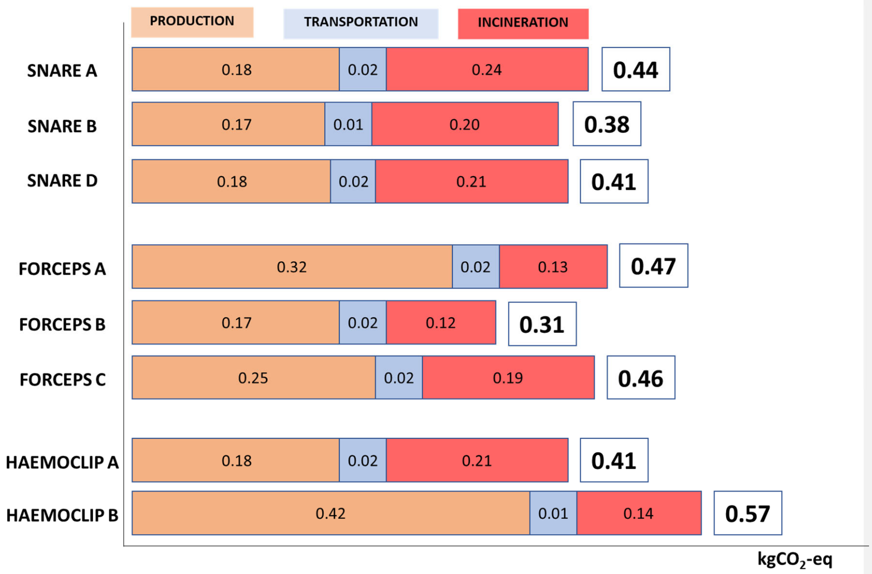

Figure 4: Life cycle assessment of endoscopy instruments from different manufacturers (A-D) in kg CO_2-eq after applying a sustainability intervention

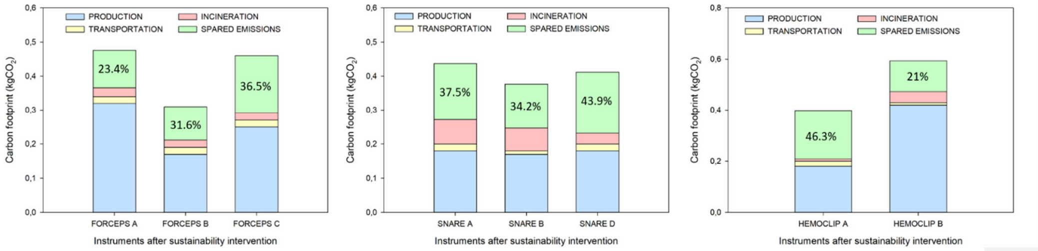

Figure 5: Total carbon emissions derived from production, transportation and incineration of commonly used endoscopy instrument during 1-week endoscopic practice before (BSI) and after (ASI) a sustainability intervention