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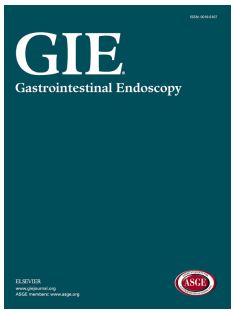

The carbon cost of inappropriate endoscopy

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ABSTRACT

Background and aims: Digestive endoscopy is a resource-intensive activity with a conspicuous carbon footprint and an estimated rate of inappropriateness. However, the carbon costs of inappropriate endoscopic procedures still remains obscure. The aim of this study is to evaluate the environmental impact of inappropriate endoscopic examinations.

Methods: We calculated the carbon cost of a standard endoscopic procedure (esophagogastroduodenoscopy (EGD) and colonoscopy (CLS)), taking into account the items (e.g. disposable materials, personal protective equipment) and the energy required for the endoscopy procedure itself and the cleaning process. The rates of inappropriateness and the mortality cost of carbon (MCC) of endoscopic examinations in different scenarios were calculated.

Results: EGD and CLS presented a carbon cost of 5.43 kg and 6.71 kg of carbon dioxide (CO_2), respectively. Different scenarios were evaluated, according to the number of endoscopic procedures performed in Italy per 1,000 inhabitants and the reported data on their inappropriateness. The carbon cost of inappropriate EGD and CLS in Italy was 4,133 CO_2 metric tons per year (MCC 0.93), ranging from 3,527 to 4,749, and equivalent to 1,760,446 liters of gasoline consumed. Applying the same data to the European population, the estimated carbon footprint of inappropriate digestive endoscopy in Europe was 30,804 metric tons.

Conclusions. The environmental impact of inappropriate endoscopic procedures in Italy and Europe is remarkable. These results highlight the need to adopt novel strategies aimed at reducing both the carbon footprint of digestive endoscopy and the rate of inappropriate procedures.

INTRODUCTION

Global climate change is by far the hardest challenge of the 21st century. Greenhouse gases (GHG), especially carbon dioxide (CO_2), produced by human activities are the main culprits, due to their impact on thermal energy retention in the atmosphere.[1,2] Healthcare systems and the industry have a relevant impact on GHG emissions, thereby affecting the health of humans and patients.[3] It has been estimated that the combined healthcare sectors of the United States (US), Australia, Canada and the United Kingdom (UK) emit an estimated 748 million metric tons of GHG each year.[4] Thus, when it comes to cutting CO_2 costs, the aim of building a "greener" healthcare system should be balanced against the intrinsic need to provide patients with safe, hygienic and efficient care. This model should certainly be applied to endoscopy, which is one of the most polluting and waste-generating activities of gastroenterology, especially now that single-use endoscopes can be adopted.[5–9] It is believed that a certain amount of waste generated derives from procedures without specifci indications. In fact, together with prevention, the single most effective measure to improve the carbon cost of endoscopic care is improving the appropriateness level of procedures.[10] In 2008, the European Panel on the Appropriateness of Gastrointestinal Endoscopy (EPAGE) produced criteria for the appropriateness of colonoscopy in several clinical endoscopic scenarios.[11] However, the rate of inappropriate upper gastrointestinal (GI) endoscopy is considerable, estimated to range from 9% to 42%.[12–14] In a 2021 meta-analysis by Frazzoni et al.[15], the colonoscopy appropriateness indication rate was 71%, far below the 85% threshold proposed by the European Society of Gastrointestinal Endoscopy (ESGE).[15,16] However, to date, the environmental impact of inappropriate endoscopic procedures still remains poorly assessed.

The aim of the present study is to estimate the carbon footprint of inappropriate endoscopy on a large scale.

MATERIALS AND METHODS

Endoscopic inappropriateness

An extensive Pubmed search was performed to search articles on upper (esophagogastroduodenoscopy, EGD) and lower (colonoscopy, CLS) endoscopy, from 2005 to today: The following MeSH term was used to search for articles relevant to estimating the rate of inappropriate upper endoscopy (esophagogastroduodenoscopy, EGD) and lower endoscopy (colonoscopy, CLS): (("appropriate"[All Fields] OR "appropriated"[All Fields] OR "appropriately"[All Fields] OR "appropriateness"[All Fields] OR "appropriates"[All Fields] OR "appropriating"[All Fields] OR "appropriation"[All Fields] OR "appropriations"[All Fields]) AND ("colonoscopy"[MeSH Terms] OR "colonoscopy"[All Fields] OR "colonoscopies"[All Fields] OR ("gastroscopy"[MeSH Terms] OR "gastroscopy"[All Fields] OR ("upper"[All Fields] AND "endoscopy"[All Fields]) OR "upper endoscopy"[All Fields]))). Meta-analyses following the American Society for Gastrointestinal Endoscopy (ASGE) [17] and/or EPAGE[18,19] indications were considered in evaluating the appropriateness (or not) of endoscopic procedures (a summary of the main EGD and CLS indications is reported in supplementary Table 1). When available, data from national registries[20] were used to estimate the number of endoscopic procedures performed per 1,000 inhabitants per year and, consequently, to evaluate the number of inappropriate endoscopies. Based on the rates of inappropriate endoscopies, different scenarios (from the best to the worst) were calculated to define the possible CO_2 emissions. The equivalents of the CO_2 emissions, in terms of consumed gasoline and power plants,

were calculated using the USA environmental protection agency calculator.[21] The mortality cost of carbon (MCC) was calculated using the Bressler equivalence.[2]

Carbon footprint evaluation

We estimated the average amount of CO_2 produced during an endoscope reprocessing, the energy (electricity) required to operate endoscopes, the use of personal protective equipment (PPE), the adoption of single-use endoscope accessories, the need for vascular access, as well as the cleanliness, climate and lighting of the endoscopic room, the use of computers and the paper to print the report and pictures. Histology carbon footprint was evaluated according to a study by Gordon et al.[22]. For each disposable item, when CO_2 equivalents were not specified by the manufacturer, we recorded the weight of constituent materials and estimated the carbon footprint, taking into account the energy (kWh/kg) used to produce the product and its final destination in the end-of-life cycle. To evaluate this in detail, we considered the materials which the components mainly contain and drew the carbon footprint values from the best scientific documentation; subsequently, we estimated the global carbon footprint per endoscopic procedure[23–27]. The standard procedure and the values were initially calculated for EGD, and then for CLS. Regarding the latter, we doubled the energy requirements, taking in consideration the longer procedural time (currently considered twice as long when compared to an EGD).

To calculate electricity consumption into the carbon footprint, the Italian values were derived from the indices of the latest 2022 report of the Higher Institute for Environmental Protection and Research [28] and from the 2021 emission factors report of the International Energy Agency (IEA), which contains the same indices for many countries around the world.[29] It should be noted that in a highly variable and turbulent

energy context, these values may undergo significant variations in the coming years.[30] Based on the energy source mix of each country, we estimated the estimated carbon costs to other countries, both European (e.g. France, Poland and Great Britain) and non-European (e.g. USA and China) such as the subdivision in direct and indirect emissions (scope 1, 2 and 3)[31].

It is worth noting that the carbon footprint considered all of the component materials and should also include energy consumption during the manufacture and transportation of these (scope 3). However, in our analysis this has been kept constant given the usual practice of an almost uniform and standard use of such products. The CO_2 footprint has been expressed in metric tons.

RESULTS

According to data from the Italian Association of Hospital Gastroenterologists (AIGO), 45 endoscopic investigations are performed per 1,000 patients in Italy each year: 54% EGD and 46% CLS.[20,32] The rate of inappropriate endoscopic examinations can be inferred from two previous studies on this topic: a systematic review with meta-analysis conducted on 53,392 patients by Zullo et al.[33] for EGD, and a second systematic review with meta-analysis investigating 19,822 patients by Frazzoni et al.[15] for CLS. A confidence interval (CI) for inappropriate endoscopy was available in both studies; thus, the lowest value of the confidence interval and the highest value of the CI were considered, respectively, to evaluate the best-case scenario and the worst-case scenario for endoscopy inappropriateness (Table 1).

The carbon footprint of each evaluated endoscopy item and energy consumption is shown in supplementary Table 2. The conversion from material and energy to CO_2 is reported in supplementary Table 3. Analysing all the items and the energy required, we estimated a total of 5.43 kg of CO_2 emitted for EGD and 6.71 kg of CO_2 for CLS in the Italian scenario (Figure 1). Plastic alone is responsible for the 35% of the CO2 emissions from endoscopic procedures. Direct emissions (scope 1) represent the 71% and 58% in case of EGD and CLS, respectively; indirect emossions (power supply, scope 2) are responsible for the remaing part (see supplementary Table 2). On 1 January 2022, Italy had a population of 59,983,122 inhabitants;[34] thus, about 2,699,239 endoscopies are performed per year, corresponding to 1,457,589 EGD and 1,241,650 CLS. In the case of EGD, when considering the rate of inappropriateness reported in Table 1, the metric tons of CO_2 emitted from the lowest, average and highest values of the 95% CI were 1,694, 1,717 and 1,750, respectively. In the case of CLS, when considering the rate of inappropriateness reported in Table 1, the tons

of CO_2 emitted from the lowest, average and highest limit of the 95% CI were 1,833, 2,416 and 2,999, respectively. The total carbon footprint of inappropriate endoscopies (Italian energy parameters) is 4,133 tons, ranging from 3,527 to 4,759 (see Table 2 for equivalents). The MCC, due to CO_2 emissions caused by inappropriate endoscopies, was 0.93, ranging from 0.79 to 1.07, when considering the best-case and worst-case scenarios, respectively.

If we apply these findings to the European Union and its population of 447,000,000 [35], some 20,115,000 endoscopies are performed each year (10,862,100 EGD vs 9,252,900 CLS). Among these, 2,357,075 EGD and 2,683,341 CLS could be considered inappropriate, with an estimated carbon footprint of 30,804 tons (MCC 6.96). The EGD and CLS carbon footprints of some different European and non-European countries is reported in Fig. 2.

Discussion

CO_2 emissions from inappropriate endoscopic procedures are remarkable when evaluated on a national (Italy) scale, ranging from 3,500 to 4,700 metric tons per year. These carbon footprint values are strongly influenced by the energy mix of each nation, resulting in much higher rates in those nations exploiting more carbon fossils in their energy plans (Fig. 2).

Inappropriateness is a significant issue for endoscopy because it increases costs, overloads waiting lists and reduces the diagnostic yield of procedures.[36] From the other hand a forced and strict endoscopic triage, as during the COVID-19 pandemic, could lead to delays in diagnosing ulcers, tumors, inflammatory bowel disease, celiac disease and other diseases.[13,37–40] Far from this scenario, a balance reducing the number of inappropriate endoscopies, nowadays attested arounf 30%, is auspicable. In the present study, we evaluated for the first time the environmental impact of EGD and CLS with inappropriate indications, showing a dramatic carbon cost and ensuing increase of mortality (MCC). Carbon cost also appeared relevant when European data were evaluated. This negative environmental impact induced by inappropriate endoscopies would induce to adopt strategies aimed at limiting the rate of endoscopies performed without a clear indication. A solution to reduce this phenomenon could be provided by a pre-endoscopy triage. Preliminary assessments were already adopted during the COVID-19 pandemic, when the need to limit access to endoscopy and hospitals forced endoscopic units to temporarily suspend open access.[41] Although the pandemic scenario remains exeptional, a speciliast (tele)consultation before prescribing invasive procedures (as EGD and CLS) without a widely accepted indicaction could support an appropriatness increase.

Despite the scarcity of data on the rate of inappropriate endoscopy, our calculated carbon cost of endoscopic procedures is in line with the previous findings.[7] While 6.4 kg of CO_2 per endoscopy might, at first, appear acceptable, when calculated against the backdrop of the total number of endoscopic procedures performed in a modern developed economy like Italy, the amount of CO_2 emitted should be considered as environmental impacting. Furthermore, the present finding is corroborated by previous studies evaluating the amount of waste generated every day in the endoscopic room; in fact, each endoscopic procedure produces 2.1 kg of waste and leads to 38,000 metric tons of waste produced annually by the endoscopy units in the USA.[42] It is estimated that this figure could quadruple if single-use endoscopes are adopted on a larger scale.[42] The use of disposable endoscopes has raised doubts about the sustainability of these accessories. Although single-use duodenoscopes have been introduced to reduce the rate of infections after endoscopic retrograde colangiopancreatography, the wide adoption of single-use gastroscopes and colonoscopes could appear less reasonable.[5,6,43] Questions, such as “What level of infection risk can be acceptable?”, and “What are the environmental implications and sustainability if the single-use model will be extended to include gastroscopes and colonoscopes?”[44], still remain open. Strategies for reducing endoscopic costs without increasing infection risks are needed. To mitigate the environmental impact of disposable accessories, appropriate pre-procedure planning is recommended to prevent excess and the inadvertent use of accessories.[45] Moreover, the digitalization of GI endoscopy, such as related health-care data, patient’s reports and instructions for bowel preparation, could help to reduce paper waste. All medical reports should be accessible to all healthcare staff on a single digital platform, so that they can be easily consulted by general doctors or by other specialists to reduce time and costs.[46,47]

Histological analysis has emerged as a crucial issue, with a relevant carbon footprint.[22] In the near future, optical diagnostics and the use of artificial intelligence (AI) could reduce the use of histology[48]; a careful evaluation is, therefore, required to assess the balance between GHG emissions and the potential savings of AI usage in clinical practice.[49]

Another strategy to reduce the carbon footprint may involve improvements to logistics in waste recycling. However, most manufacturers of endoscopic equipment and disposable devices still do not disclose their specific carbon footprint, thereby hampering the adoption of "green" policies in the choice of endoscopic facilities. Additionally, the primary barrier to recycling in many endoscopy units is the lack of awareness by most endoscopy staff members on the expenses and correct categorization of endoscopic waste.[50] A 2022 study demonstrated how educational programs on waste handling can considerably reduce medical waste and, consequently, the carbon footprint in the endoscopy field.[51] These simple precautions could reduce regulated medical waste production by employing the correct recycling process in an easy and sustainable way over time, without compromising endoscopy performance.[51]

Furthermore, it must be noted that sustainability and carbon costs are not static factors. In our study, we investigated the CO_2 emissions per endoscopy, taking into account the Italian energy mix (and others). In this context, it must be emphasized that sustainability is a fluid concept influenced by numerous factors. For example, the availability and price of resources can influence CO_2 emissions. This factor was particularly evident in 2022 due to the war in Ukraine, which triggered and worsened a global supply chain crisis, limiting access to materials that are vital to the health care industry.[30] As a consequence, the financial, social and environmental sustainability of

human activities may change over time and the sustainable practices of today could become the unsustainable practices of tomorrow.[52]

Our study presents some limitations; in the absence of manufacturers to declare the carbon footprint of their products, the strategy we used to calculate the carbon footprint of a “standard” EGD or CLS could be both underestimated or overestimated. Despite our low rate of inappropriate endoscopy, we did not investigate more specialist endoscopic procedures, such as ultrasound endoscopy, enteroscopy and ERCP. The difficulty in obtaining information about the composition, place of origin, and transportation of the materials used in the endoscopic unit is another aspect that was not considered in our analysis. As a consequence, despite evaluating the place of origin of the materials, it is difficult to completely evaluate the CO_2 emissions derived from scopes 3, leading to an underestimation of carbon footprint. [53]

Notably, the annual estimated carbon footprint in Italy amounts to approximately 355,000,000 tons, whereas inappropriate endoscopy contributes just 4,133 tons. [54] It is essential to note that despite the relatively small percentage (less than 0.001%) of the total carbon footprint attributed to inappropriate endoscopy, fostering sustainability should be regarded as a personal responsibility. Every segment of society must adopt a sustainable mindset to work towards the goal of achieving a net-zero health system for the future.

In conclusion, it is possible to partially reduce the inappropriate rate of endoscopy if everyone strives for small changes in their daily routines. Reducing the rate of inappropriate endoscopic examinations coould be a first step (reduce) to mitigate the environmental impact of GI endoscopy and increasing sustainability, although a multifactors approach is pivoltal (Fig. 3). While awaiting greater advances in the industry that will guarantee more sustainable and safer devices, a clinical decision

process favoring the transition to environmental sustainability should be adopted also during hour daily clinical practice.

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Conceptualization, analysis of the data, writing and drafting the manuscript: LE, MV, GET; Data analysis, software, results analysis, writing the manuscript: SLM, LS, AR; Conceptualization, data research, drafting and critical revision of the manuscript: FM, MS, FB, FC, AS, NN, DN, MT, AP, MC, MM.

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FIGURE LEGENDS

Figure 1. Carbon footprint of esophagogastroduodenoscopy (EGD), colonoscopy (CLS) and its composition.

Figure 2. CO_2 footprint of esophagogastroduodenoscopy (EGD) and colonoscopy (CLS) in different countries.

Figure 3. Flowchart to increase sustainability.

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Figure 1. Carbon footprint of esophagogastroduodenoscopy (EGD), colonoscopy (CLS) and its composition in Italy.

Figure 2. CO_2 footprint of esophagogastroduodenoscopy (EGD) and colonoscopy (CLS) in different countries.

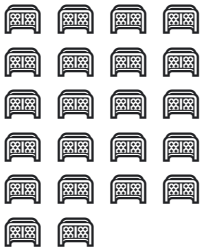
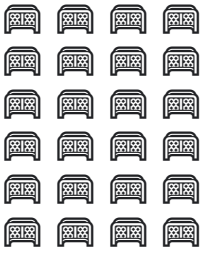
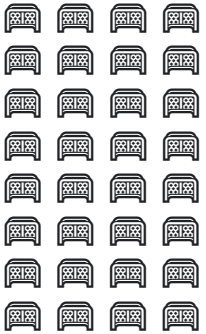
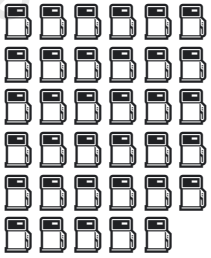
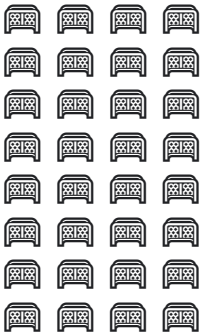
Figure 3. Flowchart to increase sustainability.

Table 1. Evidence on the rate of inappropriateness for esophagogastroduodenoscopy (EGD) and colonoscopy (CLS).

Study	Study Type	Endoscopy type	No. patients	Average value of inappropriateness	Lower CI 95%	Upper CI 95%
Zullo et al. 2019[33]	Meta Analysis	EGD	53,392	21.7 %	21.4 %	22.1 %
Frazzoni et al. 2021[15]	Meta Analysis	CLS	19,822	29 %	22 %	36 %

Table 2. Estimated CO_2 production and equivalents in different scenarios of inappropriate esophagogastroduodenoscopies (EGD) and colonoscopies (CLS).

Procedure Type number	**Lowest inappropriate rate** Number CO_2 tons	**Equivalents**	**Average inappropriate rate** Number CO_2 tons	**Equivalents**	**Highest inappropriate rate** Number CO_2 tons	**Equivalents**
EGD 1,457,589	311,924 1,694	 (721,560 L)  (811 ha)  (28,000)	316,297 1,717	 (731,356 L)  (822 ha)  (28,391)	322,127 1,750	 (745,725 L)  (838 ha)  (28,940)
CLS 1,241,650	273,163 1,833	 (780,763 L)	360,078 2,416	 (1,029,093 L)	446,994 2,999	 (1,277,420 L)

		 (878 ha)  (30,310)	 (1,157 ha)  (39,950)		 (1,436 ha)  (49,589)
EGD + CLS 2,699,239	585,087 3,527	 (1,502,323 L)  (1,689 ha)	676,375 4,133	 (1,760,446 L) 	769,121 4,749	 (2,022,832 L) 

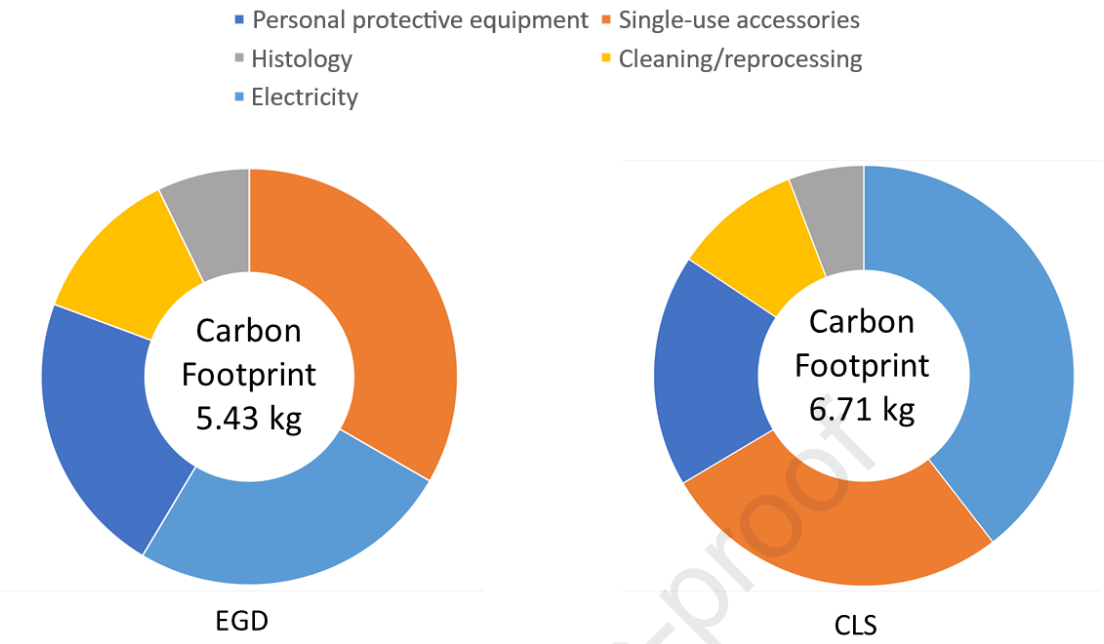
	 (58,319)	 (1979 ha) (68,340)	 (2274 ha)  (78,525)

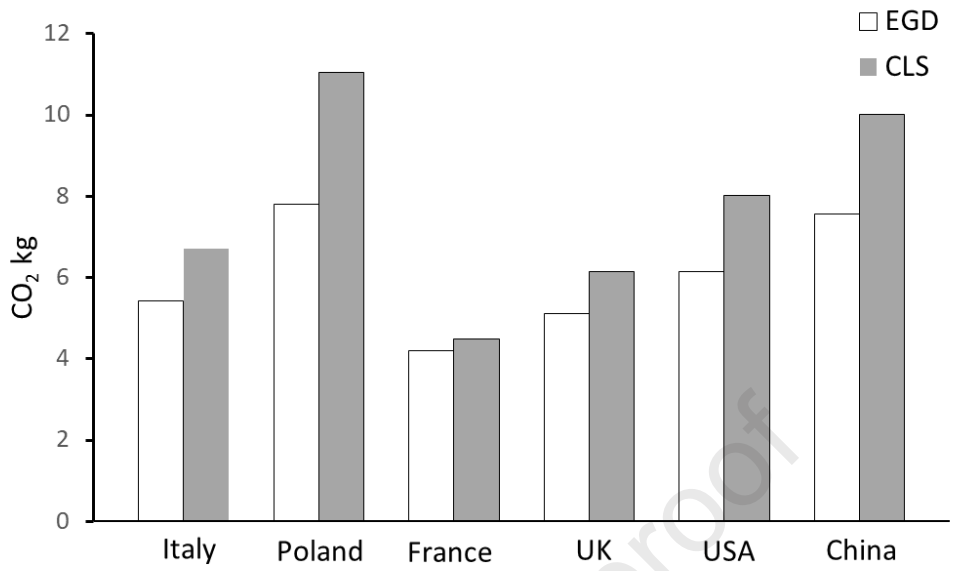
Equivalent Legend (from https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator)

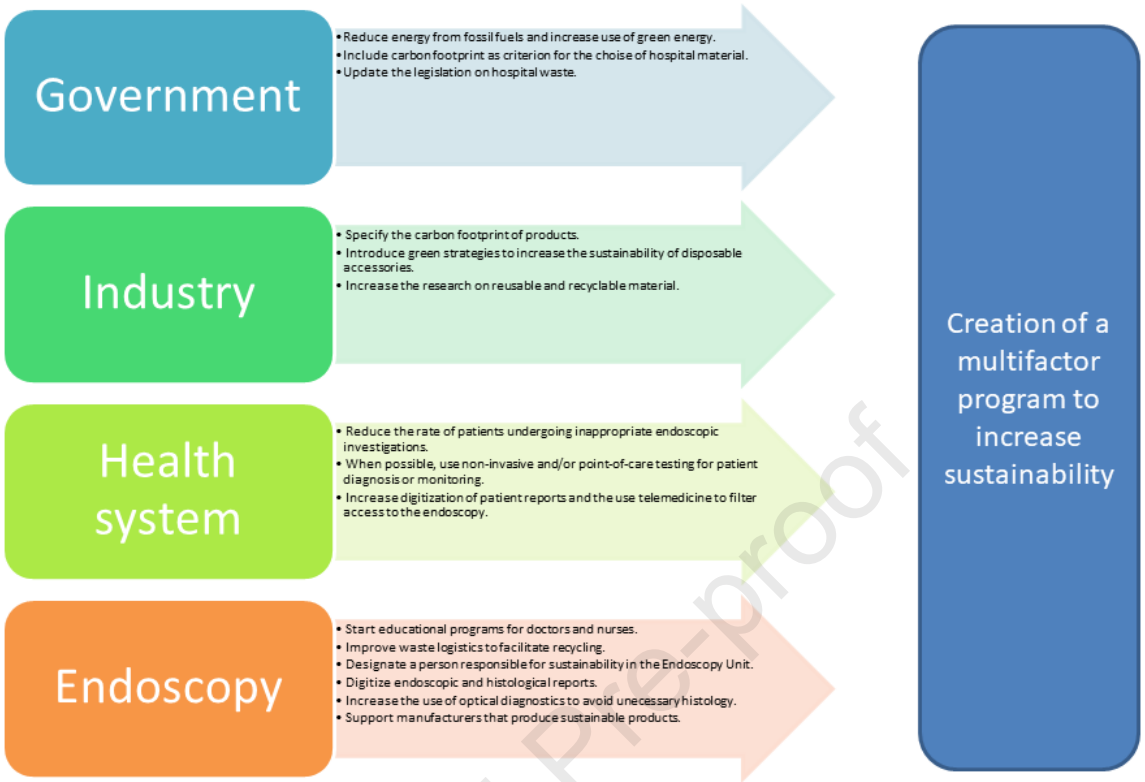
 = 50.000 liters of gasoline consumed

 = 100 soccer fields of forest needed to sequestrate the emitted CO_2

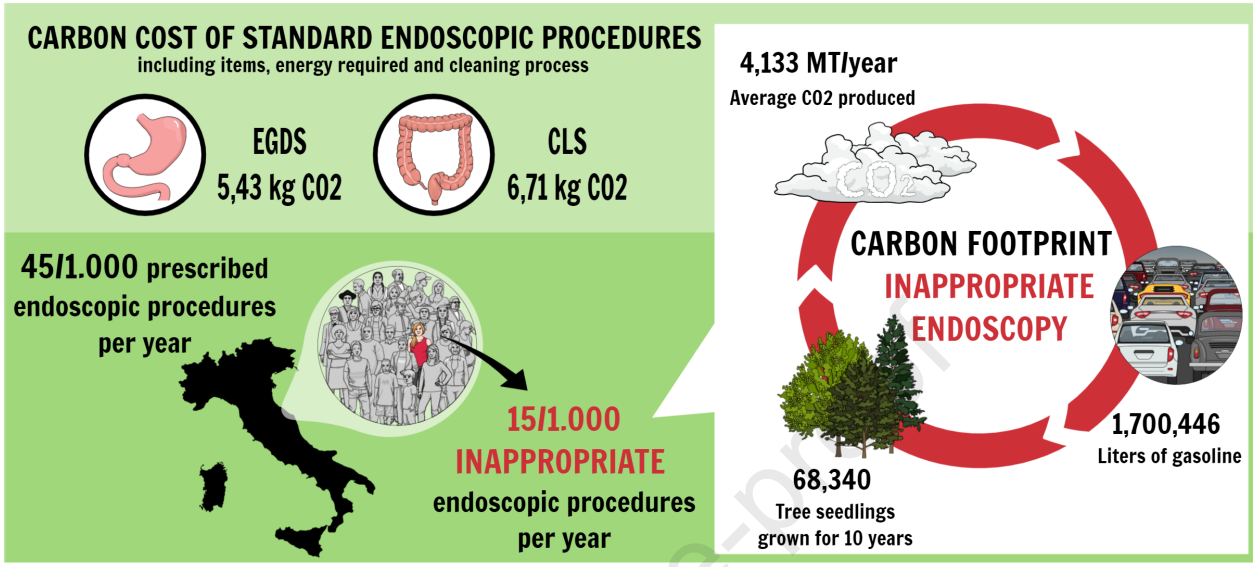
 = 10.000 tree seedlings, grown for 10 years, needed to sequestrate the emitted CO_2







THE CARBON COST OF INAPPROPRIATE ENDOSCOPY



Abbreviation list

AI artificial intelligence

CLS colonoscopy

EGD esophagogastroduodenoscopy

MCC mortality cost of carbon

PPE personal protective equipment