Cerrahpaşa Med J 2026; 50: 1-9 ORIGINAL ARTICLE

Carbon Footprint of Gastrointestinal Endoscopy: A Prospective Procedure-Level Environmental Assessment

Yavuz Özden[1], Yasemin Kaldırım Armutçuoğlu[2], Haluk Tarık Kani[2,3]

[1]Department of Gastroenterology, Kayseri City Hospital, University of Health Sciences, Kayseri, Türkiye
[2]Department of Gastroenterology, Marmara University School of Medicine, İstanbul, Türkiye
[3]Marmara University Institute of Gastroenterology, İstanbul, Türkiye

Cite this article as: Özden Y, Kaldırım Armutçuoğlu Y, Kani HT. Carbon footprint of gastrointestinal endoscopy: a prospective procedure-level environmental assessment. *Cerrahpaşa Med J* 2026, 50, 0067, doi: 10.5152/cjm.2026.26067.

What is already known on this topic?

- *Gastrointestinal endoscopy contributes to healthcare-related greenhouse gas emissions and waste generation.*
- *Prospective procedure-level estimates remain limited and vary according to analytical system boundaries.*

What this study adds on this topic?

- *This prospective audit provides source-specific environmental data from 1300 endoscopic procedures.*
- *Patient transportation accounted for 70.3% of total emissions, whereas the 4 modeled single-use accessory categories accounted for 48.0% of intrinsic emissions.*
- *Longer procedure duration and greater modeled accessory use were associated with higher intrinsic emissions in an exploratory analysis.*

Abstract

Objective: Gastrointestinal endoscopy (GIE) contributes to healthcare-related greenhouse gas emissions; however, prospective procedure-level data remain limited. This study quantified procedure-level emissions and waste and examined operational factors associated with intrinsic (non-transportation-related) emissions.

Methods: This prospective environmental study included 1300 consecutive GIE procedures performed in adults at a tertiary referral center. Activity data included electricity, water, carbon dioxide insufflation, supplemental oxygen, selected single-use accessories, waste, and patient transportation. A partial cradle-to-gate life-cycle assessment was performed for 4 accessory categories. Emissions were calculated within the Greenhouse Gas Protocol framework. Exploratory multivariable regression examined associations with intrinsic emissions.

Results: Mean total emissions were 18.22 ± 4.10 kg CO_2e per procedure. Patient transportation was the largest contributor (12.81 kg CO_2e; 70.3%). Mean intrinsic emissions were 5.41 ± 1.80 kg CO_2e per procedure. Modeled upstream emissions from 4 accessory categories contributed 2.60 kg CO_2e, representing 48.0% of intrinsic and 14.3% of total emissions. Therapeutic procedures had higher intrinsic emissions than diagnostic procedures (7.01 ± 2.40 vs 4.41 ± 1.50 kg CO_2e; $P < .001$) and generated more waste (1.20 ± 0.30 vs 0.60 ± 0.20 kg; $P < .001$). Longer procedure duration and greater modeled accessory use were associated with higher intrinsic emissions; procedure category was not associated after adjustment. The model explained 68% of the variance (adjusted $R^2 = 0.68$).

Conclusion: Patient transportation dominated total emissions, whereas the 4 modeled single-use accessory categories constituted the largest intrinsic component. Findings should be interpreted within the single-center and partial life-cycle boundaries.

Keywords: Carbon footprint, endoscopy, gastrointestinal, greenhouse gases, medical waste, sustainable development

Introduction

Climate change poses a growing threat to human health and healthcare systems. Greenhouse gas (GHG) emissions, particularly carbon dioxide (CO_2), are central to this process.[1] Healthcare systems account for an estimated 4%-5.5% of national GHG emissions in high-income countries, with emissions continuing to rise in several regions.[2,3] Reducing healthcare-related emissions is therefore essential to climate-resilient care.[4]

Gastrointestinal endoscopy (GIE) is a high-volume, resource-intensive service central to disease assessment, surveillance, and the detection of early gastrointestinal neoplasia.[5-7] Endoscopy units generate substantial waste and depend on energy-intensive infrastructure.[8] Their emissions arise from single-use accessories and plastic consumables, energy- and water-intensive reprocessing, medical-gas use, waste management, and patient and staf transportation.[9] Yet sustainability is not routinely incorporated into endoscopy quality assessment or institutional performance reporting.

Recent prospective studies report waste generation of approximately 0.5-3.0 kg per procedure and carbon emissions ranging from approximately 4 kg CO_2e for intrinsic procedural sources to 38-70

Received: April 15, 2026 **Revision Requested:** July 06, 2026 **Last Revision Received:** July 16, 2026 **Accepted:** August 15, 2026 **Publication Date:** September 22, 2026
Corresponding author: Yavuz Özden, Department of Gastroenterology, Kayseri City Hospital, University of Health Sciences, Kayseri, Türkiye **e-mail:** yavuzozden@gmail.com
DOI: 10.5152/cjm.2026.26067

Content of this journal is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

kg CO_2e when patient transportation is included.[10,11] Given the global volume of endoscopic procedures, even modest per-procedure emissions may create a substantial cumulative burden.[12] Comparisons across studies remain difficult because of differences in analytical boundaries, emission scopes, procedure mix, and life-cycle assessment (LCA) methods. Prospective studies combining direct resource measurement with upstream accessory-related emissions remain limited.

Professional societies have issued guidance promoting environmentally responsible endoscopic practice.[13,14] Nevertheless, implementation remains inconsistent. In the LEAFGREEN survey, only 16% of respondents reported familiarity with structured sustainability principles.[15] Transparent procedure-level environmental data are therefore still needed.

The primary aim of this study was to quantify per-procedure carbon emissions and waste generation associated with diagnostic and therapeutic GIE within the Greenhouse Gas Protocol framework. Secondary aims were to explore associations between selected operational factors—procedure duration, modeled single-use accessory count, and broad procedure category—and intrinsic (non–travel-related) emissions; to evaluate carbon-intensity measures for routine practice; and to determine whether patient transportation was the largest component of the overall procedural footprint.

Methods

Study Design and Setting

This prospective observational environmental study was conducted at a high-volume tertiary referral gastroenterology center between December 3, 2025, and February 3, 2026. All consecutive endoscopic procedures performed in adults aged 18 years or older during the study period were included.

Procedures were classified before analysis as diagnostic or therapeutic. Diagnostic procedures included esophagogastroduodenoscopy and colonoscopy without therapeutic intervention. Therapeutic procedures included polypectomy, endoscopic mucosal resection, endoscopic retrograde cholangiopancreatography (ERCP), and endoscopic ultrasound (EUS)-guided interventions.

The study was approved by the Kayseri City Hospital Non-Interventional Clinical Research Ethics Committee (Decision No. 678; Date: December 2, 2025) and conducted in accordance with the Declaration of Helsinki. Because only anonymized operational and environmental data were analyzed, the requirement for informed consent was waived. No a priori sample-size calculation was performed because all eligible consecutive procedures conducted during the prespecified study period were included.

Analytical System Boundary

The procedure-level system boundary included intraprocedural resource use, endoscope reprocessing, upstream production emissions from selected single-use accessories, medical-gas use, waste treatment, and patient round-trip transportation. Staf commuting, capital-equipment manufacturing, infrastructure construction, pharmaceutical production, and upstream production of sedation-related consumables and airway-management supplies were excluded.

Emissions were categorized according to the Greenhouse Gas Protocol.[16] Scope 1 included direct emissions from CO_2 insufflation; Scope 2 included purchased electricity used during procedural, reprocessing, ancillary, and water-heating activities; and selected Scope 3 sources included upstream production of modeled accessories, medical-oxygen production and supply, water supply and wastewater treatment, waste disposal, and patient transportation. For source-level reporting, water-heating electricity was grouped with water-related emissions but remained classified as Scope 2 and was excluded from general electricity consumption to avoid double counting.

Data Collection

One trained research assistant, independent of the clinical team, coordinated prospective data collection using a standardized electronic form. Procedure type, duration, and sedation details were cross-checked against the electronic medical record. Procedure duration was defined as the interval from endoscope insertion to withdrawal.

Single-use accessories and personal protective equipment were recorded when opened, regardless of subsequent use. Equipment operating times were obtained from procedural and reprocessing records; water consumption from washer-disinfector logs and manual-cleaning flow measurements; waste from calibrated scales by disposal stream; and transportation data from structured post-procedure interviews. Reported travel distances were verified using digital mapping in a randomly selected 15% sample, with greater than 95% concordance.

There were no missing data for the prespecified primary variables, including procedure duration, modeled single-use accessory count, equipment operating time, waste weight, and transportation data. Consequently, no imputation was required, and all procedures were included in the final analysis.

Single-Use Accessories and Partial Life-Cycle Assessment

All opened single-use accessories and personal protective equipment were recorded, including biopsy forceps, snares, injection needles, polyp traps, suction valve caps, drapes, and masks. For the exploratory regression, modeled single-use accessory count was defined as the number of opened items in the 4 categories included in the partial life-cycle assessment: biopsy forceps, injection needles, polyp traps, and suction valve caps.

A partial cradle-to-gate life-cycle assessment was conducted for these 4 categories. Accessory-specific upstream emission factors ranged from 0.3 to 0.8 kg CO_2e per item. Peer-reviewed life-cycle studies were used preferentially; when unavailable, manufacturer environmental product declarations and then the Ecoinvent database, version 3.9.1, were consulted.[17] Upstream emissions were calculated by multiplying procedure-level counts by the corresponding accessory-specific factor.

Other single-use materials and personal protective equipment were recorded for resource-use and waste-quantification purposes but were not assigned upstream production emissions. The accessory-related estimate therefore represents a partial rather than comprehensive production footprint.

Electricity, Water, and Medical Gases

Electricity consumption was estimated by multiplying manufacturer-rated power by recorded active operating time during procedural, reprocessing, and ancillary phases. Manufacturer specifications were checked against direct measurements from representative equipment using plug-in power meters.

Water use was obtained from washer-disinfector logs and timed faucet flow-rate measurements for manual cleaning. Water supply and wastewater emissions were calculated from recorded volume. Energy required for water heating was estimated separately from water volume and temperature increase, grouped with water-related emissions for source-level reporting, and excluded from general electricity consumption.

Patient-level CO_2 use was not directly measured. For procedures using CO_2 insufflation, estimated volume was calculated as institutional standard flow rate multiplied by documented administration duration:

Estimated CO_2 volume (L) = standard flow rate (L/min) × documented administration duration (min).The volume was converted to kg CO_2e using the prespecified factor. These values therefore represent modeled estimates and may not fully capture intermittent insufflation, variation in actual flow, or active suction.

Supplemental oxygen volume was similarly estimated from the institutional flow rate and documented administration duration. Oxygen itself was not treated as a greenhouse gas; associated emissions reflected upstream medical-oxygen production and supply. Pharmaceutical manufacturing, anesthetic-drug production, and single-use airway-management consumables were outside the system boundary.

Patient Transportation and Waste

Round-trip distance and primary transport mode were obtained through structured interviews. Transportation emissions were calculated at the patient level by multiplying reported distance by the factor corresponding to the reported mode. Transportation was analyzed descriptively; no confounder-adjusted causal model was constructed because distance and mode were direct inputs to the derived estimate.

Waste was classified at generation as infectious clinical waste, general non-infectious waste, or recyclable packaging and weighed using calibrated scales with ± 10 g precision. Reprocessing waste, including cleaning brushes and detergent containers, was allocated across procedures by procedure volume. A sensitivity analysis compared this approach with time-based allocation.

Carbon-Emission Calculations

Emissions were expressed as kg CO_2e and calculated within the Greenhouse Gas Protocol framework.[16] The following factors were applied: electricity, 0.426 kg CO_2e/kWh; water supply and wastewater, 0.000298 kg CO_2e/L; CO_2 insufflation, 0.00183 kg CO_2e/L; supplemental oxygen supply, 0.0003 kg CO_2e/L; transportation, mode-specific factors—for example, 0.171 kg CO_2e/km for a petrol passenger vehicle—and disposal-specific factors for each waste stream.[18,19] Water-heating emissions were calculated using the electricity factor. Accessory-production emissions were calculated using category-specific cradle-to-gate factors.

Total emissions comprised intrinsic emissions plus patient transportation. Intrinsic emissions were defined as all included procedure-related emissions other than patient transportation.

Sensitivity Analysis and Carbon-Intensity Metrics

Electricity and transportation factors were varied by ± 20%, and accessory-related life-cycle factors by ± 15%. The effect on mean total emissions per procedure was assessed.

Three descriptive metrics were defined: procedural carbon intensity (kg CO_2e per procedure-minute), modeled accessory-related emissions per opened accessory, and therapeutic waste intensity (kg waste per therapeutic procedure).

Statistical Analysis

Continuous variables are summarized as mean ± SD or median and interquartile range, according to distribution assessed by the Shapiro–Wilk test and graphical methods. Categorical variables are reported as frequencies and percentages. Diagnostic and therapeutic procedures were compared using the independent-samples *t*-test or Mann–Whitney *U*-test, as appropriate, with 95% CIs for between-group differences.

An exploratory multivariable linear regression was performed with intrinsic emissions as the dependent variable and procedure duration, modeled single-use accessory count, and broad procedure category as prespecified covariates; diagnostic procedures were the reference category. The model was intended to examine operational associations rather than causal effects because duration and accessory use contributed directly or indirectly to the construction of the outcome.

Model fit was summarized using adjusted R^2. Assumptions were assessed using residual plots and standard diagnostics, and multicollinearity was evaluated using variance inflation factors. Tests were 2-sided; $P < .05$ was considered statistically significant, with values below .001 reported as $P < .001$. Analyses were performed using IBM Statistical Package for the Social Sciences Statistics for Windows, version 26.0 (IBM SPSS Corp., Armonk, NY, USA).

Use of Artificial Intelligence and Large Language Model Tools

This study used ChatGPT (OpenAI) solely to improve language and edit grammar during the preparation of the manuscript. However, all content of the study was reviewed and edited by the authors following the use of this artificial intelligence/large language model tool.

Results

Baseline Procedural Characteristics

A total of 1300 consecutive GIE procedures were included: 800 diagnostic (61.5%) and 500 therapeutic (38.5%). Of these, 715 (55.0%) involved the lower and 585 (45.0%) the upper gastrointestinal tract; 65 procedures (5.0%) were ERCP or EUS-guided interventions.

Therapeutic procedures were longer than diagnostic procedures (32 ± 10 vs 18 ± 6 minutes; mean difference, 14 minutes [95% CI: 13-15]; $P < .001$). Most procedures were performed under moderate sedation, and general anesthesia was used in 12 cases (0.9%). No adverse event or workflow disruption affected environmental data collection.

Overall Carbon Footprint

The estimated cumulative footprint of the 1300 procedures was 23 686 kg CO_2e, corresponding to 18.22 ± 4.10 kg CO_2e per procedure. Patient transportation was the largest source, contributing 12.81 kg CO_2e per procedure (70.3% of total emissions).

Mean intrinsic emissions were 5.41 ± 1.80 kg CO_2e per procedure. Modeled upstream emissions from the 4 selected single-use accessory categories were the largest intrinsic component (2.60 ± 0.60 kg CO_2e per procedure), accounting for 48.0% of intrinsic and 14.3% of total emissions. Electricity contributed 1.90 kg CO_2e per procedure (4.46 kWh), CO_2 insufflation 0.50 kg CO_2e, waste treatment 0.20 kg CO_2e, water-related emissions including heating 0.20 kg CO_2e, and supplemental oxygen supply 0.012 kg CO_2e. Source-specific estimates are presented in Figure 1 and Table 1.

Carbon-Intensity and Waste Metrics

Mean intrinsic carbon intensity was 0.24 ± 0.06 kg CO_2e per procedure-minute. The weighted mean cradle-to-gate factor across the 4 modeled accessory categories was 0.619 kg CO_2e per opened accessory. Therapeutic waste intensity was 1.20 ± 0.30 kg per procedure.

Total solid-waste generation was 1080 kg, corresponding to 0.83 ± 0.25 kg per procedure. Infectious clinical waste accounted

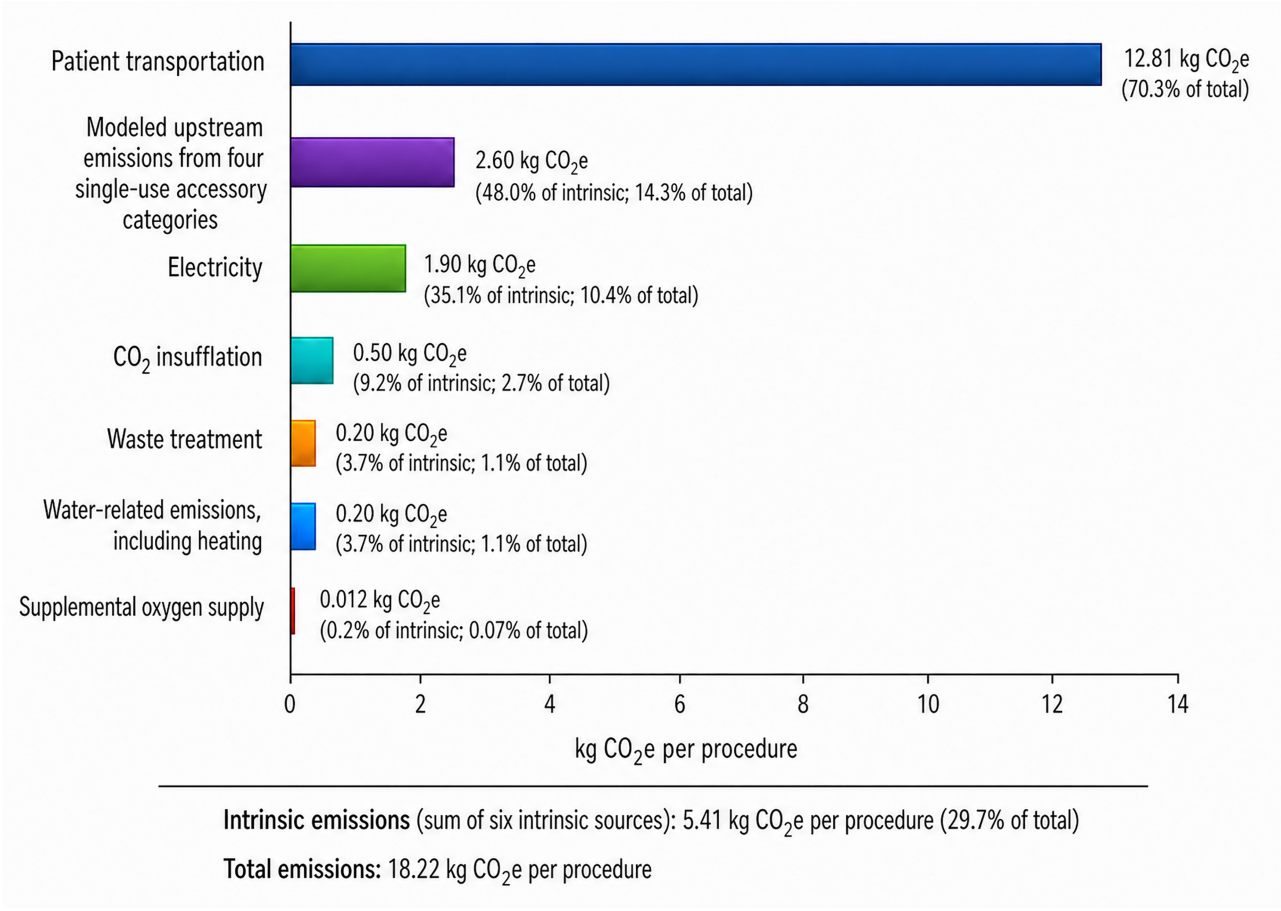


Figure 1 . Mean per-procedure carbon emissions by emission source. Patient transportation contributed 12.81 kg CO_2e per procedure, corresponding to 70.3% of total emissions. Intrinsic procedure-related emissions totaled 5.41 kg CO_2e per procedure. Modeled upstream emissions from the 4 selected single-use accessory categories constituted the largest intrinsic component, contributing 2.60 kg CO_2e per procedure, corresponding to 48.0% of intrinsic emissions and 14.3% of total emissions. The remaining intrinsic sources were electricity consumption (1.90 kg CO_2e), CO_2 insufflation (0.50 kg CO_2e), waste treatment (0.20 kg CO_2e), water-related emissions including heating (0.20 kg CO_2e), and supplemental oxygen supply (0.012 kg CO_2e). Percentages may not total exactly 100 because of rounding.

for 58%, general non-infectious waste for 32%, and recyclable packaging for 10% (Figure 2).

Environmental Impact by Procedure Type

Therapeutic procedures generated higher intrinsic emissions than diagnostic procedures (7.01 ± 2.40 vs 4.41 ± 1.50 kg CO_2e per procedure; mean difference, 2.60 kg CO_2e [95% CI: 2.37-2.83]; $P < .001$) and more waste (1.20 ± 0.30 vs 0.60 ± 0.20 kg; mean difference, 0.60 kg [95% CI: 0.57-0.63]; $P < .001$) (Table 2). Travel-related emissions were similar between groups, averaging approximately 12-13 kg CO_2e per procedure.

Operational Factors Associated with Intrinsic Emissions

In the exploratory multivariable model, longer procedure duration (standardized $\beta = 0.41$; $P < .001$) and greater modeled single-use accessory count (standardized $\beta = 0.67$; $P < .001$) were associated with higher intrinsic emissions. Broad procedure category was not associated after adjustment (standardized $\beta = 0.08$; $P = .15$).

The model explained 68% of the variance in intrinsic emissions (adjusted $R^2 = 0.68$). Variance inflation factors ranged from 1.6 to 2.4, suggesting no substantial multicollinearity (Table 3); standardized coefficients are shown in Figure 3. Because procedure duration and modeled accessory count contributed directly or indirectly to construction of the outcome, these associations should not be interpreted as independent causal efects.

Discussion

This prospective environmental audit provides a procedure-level assessment of carbon emissions and waste generation associated with gastrointestinal endoscopy. By combining prospectively collected procedural and reprocessing data with measured waste, modeled upstream emissions from selected single-use accessories, and patient transportation data, the study ofers a practice-based estimate of the environmental burden of routine endoscopic care. Patient transportation accounted for most total emissions, whereas the 4 modeled accessory categories represented the largest intrinsic component.

Mean intrinsic emissions were 5.41 kg CO_2e per procedure, placing the estimate within the lower range reported from European and North American centers when patient transportation was excluded.[11,20] Comparisons should nevertheless be made cautiously because studies difer in analytical boundaries, procedure mix, electricity factors, waste-management practices, and included upstream sources. The analysis excluded staf commuting, capital-equipment manufacturing, infrastructure construction, pharmaceutical production, and upstream emissions from single-use materials other than the 4 modeled categories. These

Table 1. Activity Data, Emission Factors, and Mean Per-Procedure Carbon Emissions by Source

Emission Source	Mean Activity Volume Per Procedure	Applied Emission Factor	Measurement or Modeling Approach	Mean kg CO_2e Per Procedure	Intrinsic Emissions, (%)	Total Emissions, (%)
Patient transportation*	74.9 km, round trip	Transport-mode-specific factors; distance-weighted cohort mean, 0.171 kg CO_2e/km	Patient-reported distance and primary transport mode	12.81	—	70.3
Modeled upstream emissions from selected single-use accessories†	4.2 items across four modeled categories	Weighted mean, 0.619 kg CO_2e/item; device-specific range, 0.3-0.8 kg CO_2e/item	Procedure-level counts of biopsy forceps, injection needles, polyp traps, and suction valve caps	2.60	48.0	14.3
Electricity‡	4.46 kWh	0.426 kg CO_2e/kWh	Equipment power ratings multiplied by recorded operating times during procedural, reprocessing, and ancillary operations	1.90	35.1	10.4
CO_2 insufflation§	273 L	0.00183 kg CO_2e/L	Institutional flow rate multiplied by documented efective administration duration	0.50	9.2	2.7
Waste treatment	0.83 kg across all waste streams	Stream-weighted mean, 0.24 kg CO_2e/kg	Measured waste mass classified according to disposal stream	0.20	3.7	1.1
Water supply, wastewater, and heating¶	15 L plus 0.459 kWh of water-heating energy	Water supply and wastewater, 0.000298 kg CO_2e/L; heating electricity, 0.426 kg CO_2e/kWh	Water-use records and independently calculated water-heating energy	0.20	3.7	1.1
Supplemental oxygen supply#	40 L	0.0003 kg CO_2e/L	Institutional flow rate multiplied by documented administration duration	0.012	0.2	0.07
Intrinsic emissions subtotal	—	—	Sum of intrinsic source estimates	**5.41**	**100.0**	**29.7**
Total emissions	—	—	Intrinsic subtotal plus patient transportation	**18.22**	—	**100.0**

Percentages were calculated from the displayed component values and may not total exactly 100 because of rounding. Intrinsic emissions exclude patient transportation. Medical-gas volumes were modeled rather than directly metered at the individual-procedure level.
CO_2e, carbon dioxide equivalent.
*Transportation emissions were calculated at the patient level by multiplying each patient's reported round-trip distance by the emission factor corresponding to the reported primary transport mode. The distance-weighted mean transport factor across the cohort was 0.171 kg CO_2e/km.
†The partial cradle-to-gate assessment included biopsy forceps, injection needles, polyp traps, and suction valve caps only. It does not represent the complete upstream production footprint of all single-use materials or personal protective equipment.
‡Mean electricity consumption was 4.46 kWh per procedure, based on equipment power ratings and recorded operating times. Applying the factor of 0.426 kg CO_2e/kWh yielded 1.90 kg CO_2e per procedure. Electricity used for water heating was excluded from this category to avoid double counting.
§Mean CO_2 use was 273 L per procedure, calculated from the institutional flow rate and documented efective administration duration. Applying the factor of 0.00183 kg CO_2e/L yielded 0.50 kg CO_2e per procedure.
¶Water-related emissions comprised water supply and wastewater treatment (15 L × 0.000298 kg CO_2e/L = 0.0045 kg CO_2e) and separately calculated water-heating energy (0.459 kWh × 0.426 kg CO_2e/kWh = 0.1955 kg CO_2e). Water-heating electricity was excluded from the general electricity category to avoid double counting.
#Supplemental oxygen emissions were modeled rather than directly metered at the individual-procedure level.

diferences may partly explain why the estimate was lower than some previous reports.

Patient transportation contributed 12.81 kg CO_2e per procedure and accounted for 70.3% of total emissions, consistent with reports showing that mobility-related Scope 3 emissions can substantially influence outpatient procedural care.[21] Travel-related emissions are highly context dependent and may vary with referral geography, urban density, transport infrastructure, public transport availability, vehicle mix, and the organization of pre-procedural care. The study was also conducted during winter, and seasonal variation in travel behavior was not assessed. These findings should therefore not be extrapolated to other settings without recalculation using local travel data and emission factors.

The estimated cumulative footprint of the 1300 procedures was approximately 23.7 metric tons CO_2e. Applying a petrol passenger-vehicle factor of 0.171 kg CO_2e/km, this corresponds to approximately 138 500 km of travel.[19] This comparison is illustrative

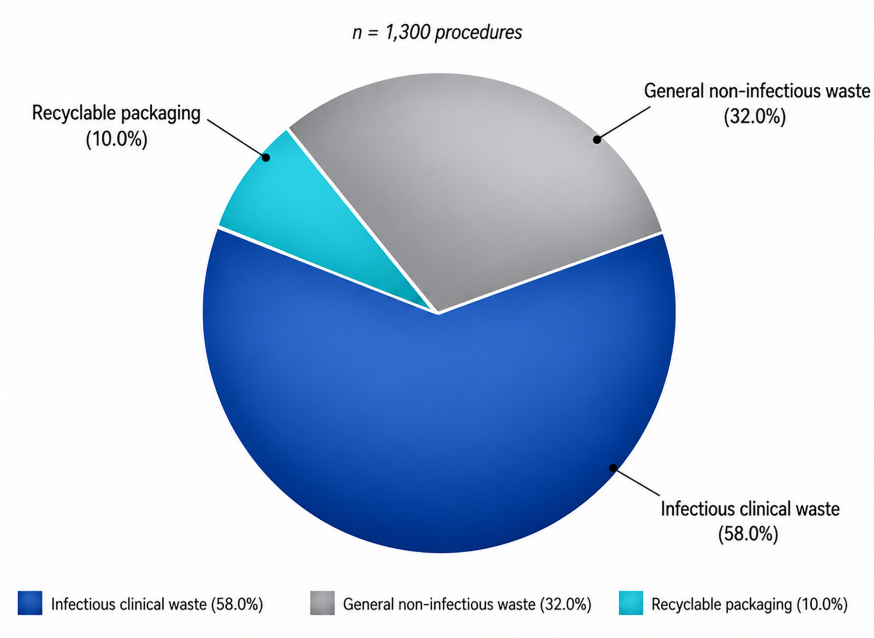


Figure 2 . Distribution of solid waste by waste stream. Infectious clinical waste accounted for 58% of total solid waste, general non-infectious waste for 32%, and recyclable packaging for 10%. A total of 1080 kg of solid waste was generated, corresponding to a mean of 0.83 kg per procedure across 1300 procedures.

rather than a formal life-cycle equivalence. Potential approaches to reducing avoidable travel include telemedicine-based pre-procedural assessment, coordinated scheduling, fewer unnecessary in-person visits, and selective decentralization.[22] Their environmental, clinical, and organizational efects require prospective evaluation before routine implementation.

In the exploratory multivariable model, longer procedure duration and greater modeled single-use accessory use were associated with higher intrinsic emissions, whereas broad procedure category was not associated after adjustment. The model explained 68% of the observed variance, and variance inflation factors did not indicate substantial multicollinearity. Because duration and accessory use contributed directly or indirectly to construction of the outcome, these findings should be interpreted as operational associations rather than independent causal efects. The absence of an adjusted association with broad procedure category should also not be interpreted as environmental equivalence among individual therapeutic procedures, particularly because advanced interventions represented a small proportion of the cohort.

Table 2. Intrinsic Environmental Impact by Procedure Type, Excluding Patient Transportation

Procedure Type	n	Intrinsic Emissions, kg CO_2e Per Procedure, Mean ± SD (95% CI)	Waste, kg Per Procedure, Mean ± SD (95% CI)
Diagnostic	800	4.41 ± 1.50 (4.31-4.51)	0.60 ± 0.20 (0.59-0.61)
Therapeutic	500	7.01 ± 2.40 (6.80-7.22)	1.20 ± 0.30 (1.17-1.23)
P	—	< .001	< .001

Patient transportation-related emissions were excluded from this analysis. The weighted mean intrinsic emission across the diagnostic and therapeutic groups was 5.41 kg CO_2e per procedure. The between-group mean diference was 2.60 kg CO_2e (95% CI, 2.37-2.83) for intrinsic emissions and 0.60 kg (95% CI, 0.57-0.63) for waste generation.
CO_2e, carbon dioxide equivalent; SD, standard deviation.

Modeled upstream emissions from the 4 selected accessory categories were 2.60 kg CO_2e per procedure, corresponding to 48.0% of intrinsic and 14.3% of total emissions. The assessment was limited to biopsy forceps, injection needles, polyp traps, and suction valve caps. Other single-use accessories and personal protective equipment were recorded for resource-use and waste-quantification purposes but were not assigned upstream production emissions. The reported value therefore likely underestimates the full upstream burden of material consumption.

Previous life-cycle studies suggest that reusable platforms may have a lower environmental impact under specific operational conditions.[23,24] However, this study did not compare reusable and single-use systems. Decisions regarding reusable alternatives should consider local reprocessing energy and water use, infection-control requirements, procedure volume, device performance, procurement practices, and end-of-life waste management, with clinical performance and patient safety remaining central.[25] Avoiding unnecessary opening of accessories may ofer a more immediate target. Prospective interventions during screening colonoscopy have reduced material use without adversely afecting procedural performance.[26] The findings support further evaluation of device-use optimization but do not establish the efectiveness of any specific intervention.

Mean solid-waste generation was 0.83 kg per procedure, lower than the 3.03 kg reported in a previous US-based study.[10] Diferences in procedure mix, packaging practices, waste classification, and disposal policies may account for this variation. Improved segregation and handling may reduce the environmental burden of endoscopy-related waste, although the magnitude of benefit will depend on local treatment pathways.[27]

Professional society statements have outlined priorities for environmentally responsible endoscopic care, but sustainability principles and measurable performance indicators are not yet routinely incorporated at the unit level.[13,15] The metrics used in this

Table 3. Collinearity Diagnostics for the Exploratory Multivariable Model

Variable	VIF
Procedure duration	1.9
Modeled single-use accessory count	2.4
Procedure type, therapeutic vs. diagnostic	1.6

Diagnostic procedures were used as the reference category. The model was considered exploratory because procedure duration and modeled single-use accessory use contributed directly or indirectly to the construction of the intrinsic-emissions outcome.
VIF, variance inflation factor.

study—kg CO_2e per procedure-minute, modeled accessory-related emissions per opened accessory, and waste mass per therapeutic procedure—may support benchmarking and quality-improvement work. Their use is consistent with efforts to standardize sustainability reporting, including the Endoscopic Sustainability PrimAry Reporting Essentials initiative.[28] Such indicators should be interpreted alongside established clinical quality measures and reported with transparent activity data and analytical boundaries.

Strengths of this study include prospective inclusion of consecutive procedures, procedure-level environmental data capture, and assessment of Scope 1, Scope 2, and selected Scope 3 sources within a predefined Greenhouse Gas Protocol framework.[16] Travel distances were also checked against digital mapping in a randomly selected subset.

Several limitations should be acknowledged. This single-center study was conducted at a tertiary referral hospital, and local geography, referral patterns, transport infrastructure, and the winter study period limit generalizability. Transportation data were partly self-reported, and comorbidity, procedural indication, socioeconomic characteristics, referral pathways, and access to local services were not included in a confounder-adjusted model. CO_2 insufflation and supplemental oxygen volumes were modeled from institutional flow rates and documented administration durations rather than measured directly; variation in actual flow, intermittent insufflation, or active suction may therefore not have been fully captured. The life-cycle assessment was partial and excluded upstream emissions from other single-use materials, personal protective equipment, pharmaceuticals, capital equipment, and infrastructure. The exploratory regression also included a limited set of operational variables, whereas heterogeneity among therapeutic procedures and the small numbers of ERCP/EUS and

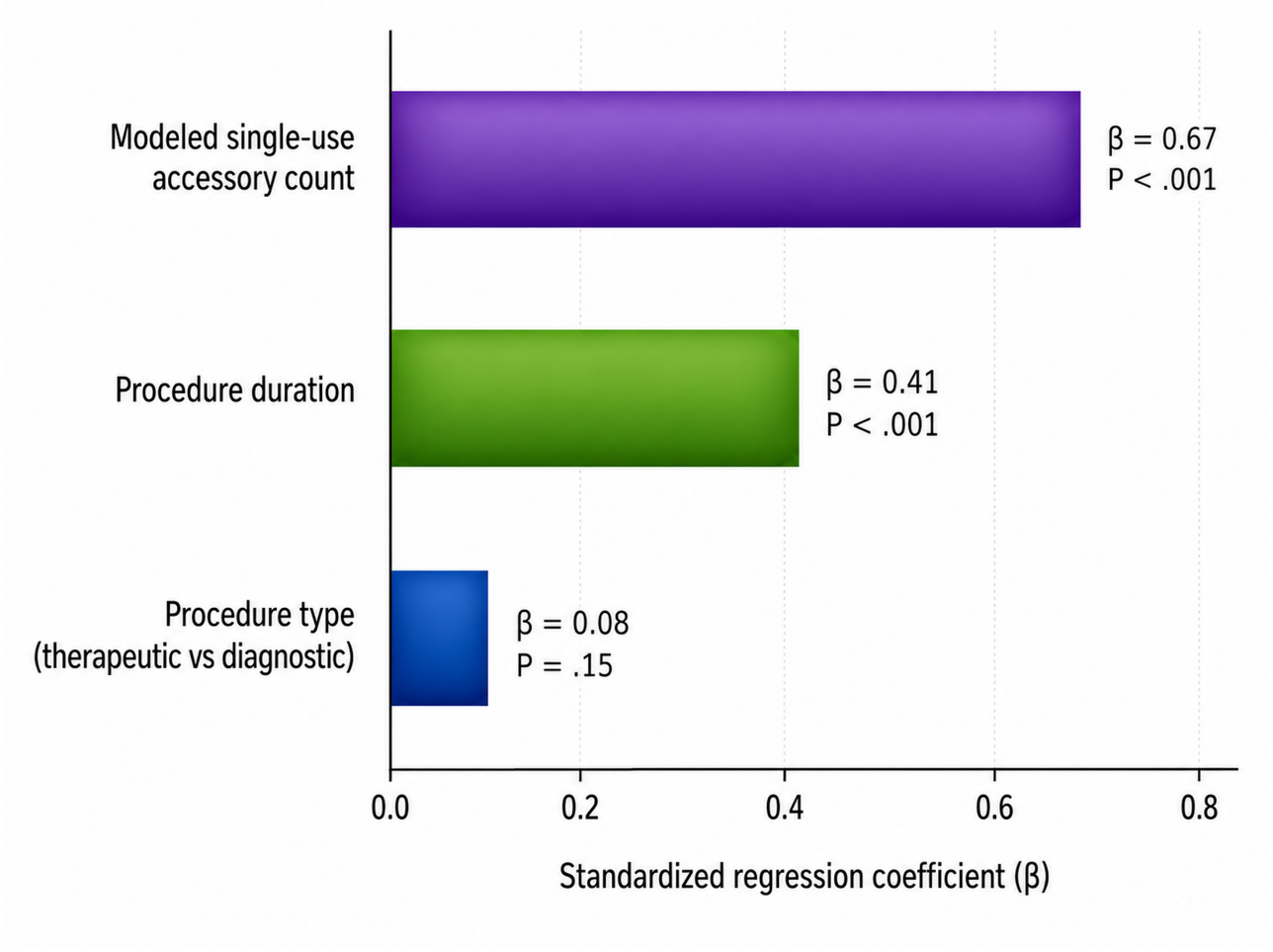


Figure 3 . Operational factors associated with intrinsic carbon emissions in the exploratory multivariable model. Standardized regression coefficients are shown for modeled single-use accessory count (β = 0.67; P < .001), procedure duration (β = 0.41; P < .001), and procedure type, therapeutic vs. diagnostic (β = 0.08; P = .15). Because procedure duration and modeled accessory use contributed directly or indirectly to construction of the intrinsic-emissions outcome, these associations should not be interpreted as independent causal efects.

general-anesthesia cases limited procedure-specific analyses. No a priori sample-size calculation was performed because all consecutive procedures completed during the prespecified period were included.

Future multicenter studies should apply standardized analytical boundaries, include a broader range of advanced procedures, and evaluate regional and seasonal variation in patient transportation. Comparative assessments of reusable and single-use systems should integrate environmental performance with clinical safety, infection control, operational feasibility, and economic outcomes.[25] Prospective studies are also needed to determine whether telehealth pathways, accessory-use interventions, workflow changes, and improved waste segregation reduce emissions without compromising access, procedural quality, or patient safety.

Gastrointestinal endoscopy was associated with a measurable environmental footprint in this prospective procedure-level audit. Patient transportation was the largest component of total emissions, whereas modeled upstream emissions from 4 selected single-use accessory categories constituted the largest intrinsic component. Because travel emissions depend strongly on local service configuration and the accessory assessment was partial, these estimates should be interpreted within the predefined analytical boundary.

The findings identify areas for further evaluation, including avoidance of unnecessary accessory opening, workflow refinement, improved waste segregation, and care pathways that may reduce avoidable travel. Reusable systems and telemedicine require prospective, context-specific assessment before routine adoption.

Standardized reporting of procedure-level environmental metrics may support benchmarking and sustainability initiatives alongside established measures of clinical quality and patient safety.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

Artificial Intelligence Usage Statement: ChatGPT (OpenAI) was used solely for language editing and grammatical refinement during the preparation of the manuscript. All content of the study was reviewed and edited by the authors following the use of this AI/LLM tool, and the authors take full responsibility for the manuscript.

Ethics Committee Approval: Ethical committee approval was received from the Kayseri City Hospital Non-Interventional Clinical Research Ethics Committee (Approval no: 678, Date: December 2, 2025).

Informed Consent: Because only anonymized operational and environmental data were analyzed, the requirement for informed consent was waived by the ethics committee.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – Y.Ö., H.T.K.; Design – Y.Ö., Y.K.A., H.T.K.; Supervision – H.T.K.; Resources – Y.Ö.; Materials – Y.Ö.; Data Collection and/or Processing – Y.Ö., Y.K.A.; Analysis and/or Interpretation – Y.Ö., Y.K.A., H.T.K.; Literature Search – Y.Ö., Y.K.A.; Writing Manuscript – Y.Ö.; Critical Review – Y.K.A., H.T.K.

Declaration of Interests: The authors have no conflicts of interest to declare.

Funding: The authors declare that this study has received no financial support.

References

1. Lenzen M, Malik A, Li M, et al. The environmental footprint of health care: a global assessment. *Lancet Planet Health*. 2020;4(7):e271-e279. [CrossRef]
2. Pohl H, Baddeley R, Hayee B. Carbon footprint of gastroenterology practice. *Gut*. 2023;72(12):2210-2213. [CrossRef]
3. Henniger D, Windsheimer M, Beck H, et al. Assessment of the yearly carbon emission of a gastrointestinal endoscopy unit. *Gut*. 2023;72(10):1816-1818. [CrossRef]
4. Romanello M, Di Napoli CD, Green C, et al. The 2023 report of the Lancet Countdown on health and climate change: the imperative for a health-centred response in a world facing irreversible harms. *Lancet*. 2023;402(10419):2346-2394. [CrossRef]
5. Torun M, Uzun O, Gülmez S, et al. Clinical pathological outcomes and survival in patients undergoing surgery for early stage gastric cancer. *Cerrahpaşa Med J*. 2025;49(1):1-4. [CrossRef]
6. Inci I, Celik ZS, Kani HT. Assessing the disease activity in Crohn's disease, nothing is enough alone. *Turk J Gastroenterol*. 2025;37(2):279-280. [CrossRef].
7. Koker G, Gorgulugil GZ, Coskuner MA, Durmus ME. Machine learning-based prediction of histopathological classification in colorectal polyps. *Turk J Gastroenterol*. 2025;36(10):700-707. [CrossRef]
8. Sebastian S, Dhar A, Baddeley R, et al. Green endoscopy: British Society of Gastroenterology (BSG), Joint Accreditation Group (JAG) and Centre for Sustainable Health (CSH) joint consensus on practical measures for environmental sustainability in endoscopy. *Gut*. 2023;72(1):12-26. [CrossRef]
9. Gayam S. Environmental impact of endoscopy: "scope" of the problem. *Am J Gastroenterol*. 2020;115(12):1931-1932. [CrossRef]
10. Desai M, Campbell C, Perisetti A, et al. The environmental impact of gastrointestinal procedures: a prospective study of waste generation, energy consumption, and auditing in an endoscopy unit. *Gastroenterology*. 2024;166(3):496-502.e3. [CrossRef]
11. Rughwani H, Kalapala R, Katrevula A, et al. Carbon footprinting and environmental impact of gastrointestinal endoscopy procedures at a tertiary care institution: a prospective multi-dimensional assessment. *Gut*. 2025;74(6):926-934. [CrossRef]
12. Jung Y, Kim JW, Im JP, Cho YK, Lee TH, Jang JY. Safety of gastrointestinal endoscopy in Korea: a nationwide survey and population-based study. *J Korean Med Sci*. 2022;37(4):e24. [CrossRef]
13. Rodríguez de Santiago E, Dinis-Ribeiro M, Pohl H, 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*. 2022;54(8):797-826. [CrossRef]
14. Duijvestein M, Sidhu R, Zimmermann K, et al. The United European gastroenterology green paper-climate change and gastroenterology. *U Eur Gastroenterol J*. 2024;12(9):1292-1305. [CrossRef]
15. Cunha Neves JA, Rodriguez de Santiago E, Pohl H, et al. Perspectives and awareness of endoscopy healthcare professionals on sustainable practices in gastrointestinal endoscopy: results of the LEAFGREEN survey. *Endoscopy*. 2024;56(5):355-363. [CrossRef]
16. World Resources Institute, World Business Council for Sustainable Development. *The Greenhouse Gas Protocol: a Corporate Accounting and Reporting Standard*. rev ed. Washington, DC: World Resources Institute; 2004
17. Wernet G, Bauer C, Steubing B, Reinhard J, Moreno-Ruiz E, Weidema B. The ecoinvent database version 3 (part I): Overview and methodology. *Int J Life Cycle Assess*. 2016;21(9):1218-1230. [CrossRef]
18. Intergovernmental Panel on Climate Change (IPCC). *Climate Change 2021 – the Physical Science Basis*. Cambridge University Press: Cambridge; 2023. [CrossRef]
19. Department for Environment, Food and Rural Afairs. Greenhouse gas reporting: conversion factors 2023. Accessed March 10, 2026. https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2023
20. Gayam S, Gordon IO, Smolen K, et al. Carbon footprint of routine endoscopic procedures: a comprehensive assessment in three U.S. endoscopy units. *Gastrointest Endosc*. 2025;101(5):S248. [CrossRef].
21. Klose MA, Becker A, Blank V, Eisenmann S, Rosendahl J, Walldorf J. Role of patient and staf mobility in scope 3 emissions in GI endoscopy. *Gut*. 2024;73(8):1232-1234. [CrossRef]
22. Galts C, Anvari S, Tu KA. 1011: telemedicine as a tool for sustainable gastroenterology practice: quantifying emissions reductions. *Gastroenterology*. 2025;169(1):S1302. [CrossRef]

23. Pioche M, Pohl H, Cunha Neves JA, et al. Environmental impact of single-use versus reusable gastroscopes. *Gut*. 2024;73(11):1816-1822. [CrossRef]
24. López-Muñoz P, Martín-Cabezuelo R, Lorenzo-Zúñiga V, et al. Life cycle assessment of routinely used endoscopic instruments and simple intervention to reduce our environmental impact. *Gut*. 2023;72(9):1692-1697. [CrossRef]
25. Anderson S, Patterson K, Skolarikos A, Somani B, Bolton DM, Davis NF. Perspectives on technology: to use or to reuse, that is the endoscopic question-a systematic review of single-use endoscopes. *BJU Int*. 2024;133(1):14-24. [CrossRef]
26. Harne PS, Harne V, Rehman A, Thosani N, Desai M. First step to environmentally sustainable endoscopy practice: a prospective study of minimizing multiple device use during screening colonoscopy at a large tertiary center. *Endoscopy*. 2025;57(5):500-503. [CrossRef]
27. Welsch L, Friedrich-Rust M, Tal A, et al. Cutting waste in endoscopy: a multicentre observational study in the German healthcare system. *Gut*. 2025;74(12):1989-1994. [CrossRef]
28. Cunha Neves JA, Baddeley R, Pohl H, et al. Endoscopic Sustainability PrimAry Reporting Essentials (E-SPARE): European Society of Gastrointestinal Endoscopy (ESGE) position statement. *Endoscopy*. 2025;57(6):674-688. [CrossRef]