Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Perception of sustainability and environmental pollution from the perspective of anesthesiologists in Colombia: a mixed-methods study

Cristhian Dorado
Universidad del Cauca
Daniela Collazos
Universidad del Cauca
Julián Velásquez
Universidad del Cauca
Markus Klimek
Erasmus University Medical Center Rotterdam
Jose A. Calvache
j.calvacheespana@erasmusmc.nl

Erasmus University Medical Center Rotterdam

Research Article

Keywords: Environmental pollution, environmental health, health personnel, health care sector, Attitude of health personnel

Posted Date: September 27th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10682581/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Additional Declarations: No competing interests reported.

Abstract

Background

Environmental pollution and global warming are major global concerns, with healthcare contributing approximately 4.4% of global greenhouse gas emissions. Perioperative and anesthesia services contribute substantially through the use of single-use materials and volatile anesthetics. However, evidence on sustainability in anesthesia is largely derived from high-income countries, with limited data from Latin America. This study aimed to assess anesthesiologists' perspectives, practices, and perceived barriers regarding environmental sustainability in daily clinical practice in a southwestern Colombian city.

Methods

A cross-sectional study using mixed methods (online survey and focus groups) was conducted with all active anesthesiologists and residents of anesthesiology (n = 85) in Popayán, Cauca, and surrounding areas, achieving a 100% response rate. Data collection involved an anonymous online survey with closed and open-ended questions, complemented by two semi-structured focus groups to explore perceptions, attitudes, and knowledge. Descriptive statistics were used for the survey results, and thematic analysis was applied to the qualitative data.

Results

Most participants were certified anesthesiologists (88.2%) and primarily practiced in public hospitals (74.1%). Overall, 95.3% agreed or strongly agreed that sustainability is important in their professional practice, and 94.1% reported that anesthesiology has a substantial environmental impact. Solid waste and single-use plastics were identified as the primary environmental concern by 50.6% of respondents, followed by anesthetic gases (37.6%). The most frequently reported sustainable practices were deliberate selection of anesthetic techniques, including low fresh-gas flows and regional anesthesia (27.1%), followed by supply optimization and recycling initiatives (22.4%). Systemic factors, including administrative constraints, cost considerations, and limited resources, were reported as the main barrier to broader implementation (42.4%).

Conclusions

We found a high degree of environmental awareness and ethical commitment among Colombian anesthesiologists. However, systemic barriers (administrative factors, cost, and inadequate infrastructure) demonstrate that enabling sustainable practice requires institutional policy and economic commitment to invest in cost-saving, high-impact strategies rather than solely relying on individual clinician motivation.

Clinical trial number: not applicable.

Background

Environmental pollution and global warming have emerged as priority issues globally in the last decade as they represent a growing threat to the planetary systems that sustain human life. The Antarctic ice shelf has shrunk by almost 2% since 1997, and the lifespan of forests in several regions of the world has been significantly reduced, demonstrating the acceleration of irreversible ecological processes (1, 2). Faced with this crisis, the

international community has adopted commitments to mitigate climate change, such as the agreements established at the United Nations Climate Change Conference (COP 26, Glasgow, 2021), in which more than fifty countries pledged to reduce carbon emissions and develop sustainable production systems, in many cases setting the goal of net-zero emissions by 2050 (3).

The healthcare sector, despite its life-preserving mission, contributes substantially to environmental degradation, accounting for approximately 4.4% of global greenhouse gas emissions (4, 5). This impact is driven by high energy consumption, extensive use of disposable materials, and significant waste generation, with perioperative services responsible for a disproportionate share of the sector's solid waste and carbon footprint (6). Within this context, anesthesia practice is a key contributor due to the use of volatile anesthetics—particularly desflurane, which has a global warming potential far exceeding that of carbon dioxide and persists in the atmosphere for years (7, 8). Although lower-impact alternatives exist, desflurane remains widely used, underscoring the need for anesthesiology to actively integrate sustainable practices into perioperative care (9).

In recent years, anesthesiologists' perceptions and attitudes toward environmental pollution have become a topic of growing interest. International studies suggest that, while most anesthesiologists recognize the importance of sustainability in their practice, knowledge gaps persist regarding the environmental impact of different anesthetic agents. González-Pizarro et al. reported that 64% of anesthesiologists use inhaled anesthetics daily and that 45% are unaware of which one has the largest carbon footprint (10). Similarly, Gasciauskaite et al. found that 89% of anesthesia providers consider environmental sustainability essential, although they identified structural and training barriers that limit its practical application (11). Other authors emphasize the need to strengthen environmental education in anesthesiology and to promote active leadership by anesthesiologists in implementing sustainable practices in the operating room (12).

Despite the global increase in literature on sustainability in anesthesia, most studies have been conducted in high-income countries, with little information coming from Latin America. In Colombia, where efforts toward hospital sustainability are recent and heterogeneous, the perceptions of anesthesiologists regarding their role in environmental pollution and climate change are largely unknown. Understanding these perceptions is fundamental for designing educational and institutional strategies that promote more sustainable anesthetic practices. We aimed to explore the perspectives of anesthesiologists in a southwestern city of Colombia regarding environmental sustainability in their daily practice.

Methods

Study design

This was a mixed-methods observational study with a cross-sectional quantitative component and a qualitative component based on focus group discussions. The study is reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines to enhance completeness (13).

Setting and participants

The study population comprised all certified anesthesiologists and anesthesiology residents actively practicing in Popayán, Cauca, a mid-sized city in southwestern Colombia. Participants were identified and contacted at level II and III hospitals via the Colombian Society of Anesthesiology and Resuscitation (SCARE) and the

Caucana Association of Anesthesiology and Resuscitation (ACAR), which consolidate anesthesiology professionals and residents at the national and departmental levels, respectively.

Eligible participants were board-certified anesthesiologists and anesthesiology residents who were actively engaged in clinical practice within the study region at the time of data collection. We used a convenience sample of all available and consenting anesthesiologists and residents within the study setting. Given the exploratory and descriptive nature of the study, no formal sample size calculation was performed. Professionals not currently involved in perioperative care or who declined participation were excluded.

Data collection

Data collection was carried out in two phases: a) Online survey: A structured questionnaire was administered, consisting of closed-ended questions (demographic characteristics, professional role, work environment, and levels of agreement using a Likert-type scale regarding the importance of sustainability in anesthetic practice) and open-ended questions to capture spontaneous responses about perceived challenges, actions adopted, and barriers. (Supplementary material). b) Focus groups: Two in-person semi-structured sessions were conducted, each lasting approximately one hour. Discussions explored topics such as anesthetic choices, environmental pollution, institutional practices, and the need for continued education on sustainability. Sessions were audio-recorded with participant consent and transcribed verbatim for qualitative analysis.

Primary variables included participant demographic and professional characteristics, perceptions of environmental sustainability, self-reported sustainable practices, and perceived institutional and personal barriers. Qualitative outcomes focused on thematic exploration of attitudes, beliefs, and contextual factors influencing environmentally sustainable anesthetic practice.

To minimize selection bias, all eligible anesthesiologists and residents in the defined geographic area were invited to participate through institutional and professional channels. Anonymity of responses and voluntary participation were emphasized to reduce social desirability bias. During qualitative analysis, investigator triangulation was used to enhance interpretive credibility.

Data analysis

Survey data were analyzed using descriptive statistics. Categorical variables were summarized as frequencies and percentages, and continuous variables were described using means and standard deviations or medians and interquartile ranges, as appropriate. Survey responses were reviewed for completeness and consistency prior to analysis. Focus group transcripts were analyzed using thematic content analysis. Two independent researchers reviewed the transcripts, coded the data inductively, and identified emerging themes. Qualitative transcripts were verified against audio recordings to ensure fidelity and discrepancies were resolved through discussion to achieve consensus. Representative quotations were selected to illustrate key findings. Data collection, management, and analysis followed standardized procedures to ensure completeness, accuracy, and reproducibility.

Approval and consent

The study protocol was reviewed and approved by the Faculty Research and Postgraduate Committee of the Universidad del Cauca on April 22, 2025 (ID6423) and ratified the departmental endorsement and authorized

the project to continue its registration process before the Vice-Rector's Office for Research and waived the need for ethical approval for the cur-rent study. The participants' consent to participate was implied by their completion of the questionnaire and its submission. In this way, the informed consent was obtained from all the participants. Participation was voluntary and without financial compensation.

RESULTS

Popayán is the capital of Colombia's Cauca Department, located in the country's southwest between the Central and Western Andes mountain ranges, at an elevation of approximately 1,760 meters above sea level. According to Colombia's National Administrative Department of Statistics, the city has an estimated population of approximately 355,000 inhabitants (2026 projection). As the principal referral center for the department, Popayán has a well-established healthcare network that includes several level II and III institutions providing perioperative services. These include Hospital Universitario San José, Hospital Susana López de Valencia, Clínica La Estancia, and Clínica San Rafael, as well as several smaller private clinics that provide surgical care.

A total of 85 anesthesiologists from Popayán, Cauca and surrounding areas completed the online survey (100% response rate). Most clinicians were male (n=55, 64.7%), with a median age of 43.0 years old and a median of 12.0 years of work experience in anesthesia. Detailed information on the study participants is provided in table 1.

Table 1. Demographic characteristics and professional profile of the study participants (n=85).

Characteristic	Participants (n=85)
Sex	
Male	55 (64.7%)
Female	30 (35.3%)
Age in years, Median (IQR)	43 (38–53)
Years of work experience in anesthesia, Median (IQR)	12 (6–20)
Role	
Anesthesiologist	75 (88.2%)
Resident (1st, 2nd, and 3rd year)	10 (11.8%)
Main Hospital Type	
Public	63 (74.1%)
Private	20 (23.5%)
Other	2 (2.4%)

Anesthesia provider's perception of environmental sustainability importance in their professional practice

A total of 81 participants (95.3%) agreed or totally agreed with the statement: "Environmental sustainability is important to me and in my professional practice". A detailed distribution of responses to this question is shown

in Figure 1.

When asked to identify the main environmental challenges in their daily practice, anesthesia providers highlighted issues primarily related to supply management and the environmental impact of volatile anesthetic agents. Consistent with these perceptions, the vast majority of participants (n = 80; 94.1%) agreed or strongly agreed that their professional anesthesia practice has a significant impact on the environment.

Anesthesia-related waste management

A total of 43 participants (50.6%) emphasized that one of the biggest environmental challenges in anesthesia is the production and poor management of single-use waste and plastics. Participants' answers highlighted the frustration with the large amount of waste:

"The use of plastics and those supplies that cannot be reused for biological safety reasons." (Discussion 1, participant 1).

"We use too many syringes, too much plastic, too much rubber". (Discussion 1, participant 3).

Use of disposables

The use of disposables was a dominant subtopic in waste management, specifically identified as excessive waste was the use of surgical barrier kits (stockinettes), in addition to syringes and disposable drapes:

"I am concerned about... syringes and disposable drapes" (Discussion 1, participant 3)

"The surgical barrier kits... an immense expense" (Discussion 2, participant 3)

"I see there is a lot of waste of medications... for a single patient" (Discussion 1, participant 2)

Environmental impact of anesthetics

A total of 32 participants (37.6%) mentioned the ecological impact caused by anesthetic gases (halogenated agents) as a significant concern.

"Anesthesia... is one of the specialties that generates the most pollution, especially due to the use... of halogenated agents" (Discussion 1, participant 3)

"Polluting gases... what affects us the most" (Discussion 1, participant 2)

Wasteful electricity consumption

The unnecessary consumption of other resources was identified by 13 participants (15.3%). This includes direct mentions of energy waste:

"We have chargers connected all the time in the operating room" (Discussion 2, participant 3)

"We leave the monitor on... and the whole (ligasure) connected and turned on, like that all night" (Discussion 2, participant 3)

Actions to make daily anesthesia practice more environmentally sustainable

A total of 84 participants (98.9%) stated that they would like to learn more or continue learning about environmental sustainability. Anesthesiologists primarily focus on modifying anesthetic administration and being more conscious in the use of supplies.

Environmentally preferable choice of anesthetics

The most reported measure to reduce pollution was the conscious choice of anesthetics (23 participants, 27.1%). This includes minimizing gas use through "low flows" and choosing Total Intravenous Anesthesia (TIVA) or regional anesthesia.

"Anesthesia with the lowest possible flows" (Discussion 1, participant 3)

"Always prioritize regional anesthesia" (Discussion 1, participant 1)

"I avoid desflurane." (Discussion 2, participant 3)

Conscious planning of anesthetic supplies

A subtopic of supply management is the conscious planning of supplies (19 participants, 22.4%), including optimization and recycling. Actions include maintaining sterility to allow for sharing and reuse:

"I draw up my dilutions separately. I try to keep my dilutions and my syringes" (Discussion 2, participant 3)

"The sterility (of the medication) is preserved, and we use it in several cases" (Discussion 1, participant 2)

Recycling and reusing

Reuse and recycling (which includes supply optimization in the survey) was mentioned by 19 participants (22.4%).

"They reuse facial masks; they sterilize them." (Discussion 2, participant 2)

"Use, reuse anesthesia circuits, using filters." (Discussion 1, participant 2)

Encouraging ecological behavior

Energy saving is a practice consciously reported in main Anesthesiologists:

"I disconnect the computer from the power source; I try to turn everything off." (Discussion 2, participant 3)

"Limit the electronic devices we use, (and) the monitors, try to save energy." (Discussion 2, participant 1)

Barriers that anesthetists face when achieving environmental sustainability in their daily practice

The most frequently mentioned barrier was related to administrative, cost, and resource factors (36 participants, 42.4%).

Need for knowledge/teaching

The lack of knowledge or teaching was a barrier reported by 12 participants (14.1%),

indicating a need for "continuous training"

"Sustainable anesthesia... has not been addressed sufficiently" (Discussion 1, participant 1)

"I believe it is work we should do from the bottom up... and start with education" (Discussion 2, participant 1)

Missing opportunities to implement sustainable practices

Lack of resources and infrastructure limitations are key obstacles:

"Barriers of an economic, administrative nature" (Discussion 1, participant 3)

"I do not have access to other neuromonitoring devices (for safe TIVA)" (Discussion 1, participant 2)

Unwillingness to change established norms and adopt new approaches

Resistance to change was reported by 3 participants (3.5%). Participants pointed to the inertia and lack of interest among some colleagues:

"It is not easy to change protocols. It is more due to resistance" (Discussion 1, participant 2)

"If they had better results with desflurane, well, desflurane forever and ever and nothing else matters" (Discussion 2, participant 3)

Patient safety and hygiene standards

Patient safety, although the main reason for non-compliance is also perceived as a barrier that drives the use of disposables:

"How do we manage to reduce our waste without having to put the patient's biological safety at risk?" (Discussion 1, participant 3)

Factors leading to non-compliance with internal anesthesia sustainability guidelines

Patient-related/medical reasons

Patient safety or medical reasons were the second most cited factors (15 participants, 17.6%) for occasional non-compliance with more ecological practices. Patient safety is an absolute priority in clinical decisions. The most common clinical scenario is the contaminated patient or contaminated surgery, which necessitates the disposal of all items in the room, even if unused.

"My priority is the patient, regardless of how many gloves I have to use" (Discussion 2, participant 3)

"The clinical aspect is always paramount" (Discussion 1, participant 2)

Adherence to established habits and key messages for cultural change

Comfort and habit were reported by 8 participants (9.4%). This is linked to a lack of interest or institutional inertia, where routine habits prevail. The participants emphasized the need for collective responsibility and suggested more impactful education strategies to promote sustainability beyond individual actions.

"Adherence to habits/comfort." (Discussion 2, participant 3)

"I believe it is very difficult to raise awareness because it depends on each individual." (Discussion 2, participant 4)

Collective ethical responsibility

Anesthesiologists highlighted that sustainability is an ethical imperative that must go beyond personal concern. There is an awareness of the global impact of local practices and the need to integrate all healthcare personnel into the effort to reduce the environmental footprint.

"Every action of ours must generate a social, environmental, ethical responsibility to try to do the best things to avoid harm to others" (Discussion 2, participant 3)

"We are all in an environment and a world that we are sharing, and it depends on each one of us if we want others to be well in the future" (Discussion 2, participant 3)

"And I believe it is very important to seek strategies that everyone knows and understands what actions can be taken to try to reduce the impact we make" (Discussion 2, participant 3)

Political and administrative will

Participants stressed that, although there are ideas and willingness from clinical staff, the implementation of large-scale strategies requires institutional and financial commitment.

Institutions must show "political and economic will" to implement the necessary strategies, as the ideas exist. (Discussion 1, participant 3)

Impactful awareness strategies

To overcome inertia and lack of interest, it was proposed to use visual and emotionally resonant communication methods.

“It is suggested to use visual tools (such as AI) to show future scenarios of the impact of pollution” (Discussion 2, participant 3).

Table 2 presents the key themes identified through thematic content analysis of the focus group transcripts.

Table 2. Summary of thematic analysis of open-ended responses (n = 85)

Main theme	Subtheme	Participants	Percentage (%)	Representative expression
Negative impacts				
Waste and plastics	Single-use / poor management	43	50.6%	*"We use too many syringes, too much plastic, too much rubber." (Discussion 1, participant 3)*
Environmental impact of anesthetics	Anesthetic gases	32	37.6%	*"Anesthesia... is one of the specialties that generates the most pollution, especially due to the use... of halogenated agents." (Discussion 1, participant 3)*
Resource consumption	Energy / Water / Noise	13	15.3%	*"We have chargers connected all the time in the operating room." (Discussion 2, participant 3)*
Measures for sustainable practice				
Conscious choice of anesthetics	Low flows / TIVA / Regional	23	27.1%	*"Anesthesia with the lowest possible flows." (Discussion 1, participant 2)*
Supply/Waste management	Recycling and optimization	19	22.4%	*"They reuse facial masks; they sterilize them." (Discussion 2, participant 2)*
Obstacles to sustainability				
Systemic factors	Administrative, cost, and resource	36	42.4%	*"Barriers of an economic, administrative nature." (Discussion 1, participant 3)*
Knowledge/Attitude barriers	Lack of knowledge/Teaching	12	14.1%	*"Sustainable anesthesia... has not been addressed sufficiently." (Discussion 1, participant 1)*
Resistance to change/Habits	Attitude/resistance to change	3	3.5%	*"It is not easy to change protocols. It is more due to resistance." (Discussion 1, participant 2)*

Reasons for non-compliance				
Economic and infrastructure factors	Lack of resources/equipment/cost	32	37.6%	*"I do not have access to other neuromonitoring devices." (Discussion 1, participant 2)*
Patient safety	Medical reasons	15	17.6%	*"My priority is the patient, regardless of how many gloves I have to use." (Discussion 2, participant 3)*
Comfort and habit	Adherence to habits/comfort	8	9.4%	*"Adherence to habits/comfort"* *(Discussion 2, participant 3)*

DISCUSSION

In this study we identified four key findings. First, anesthesiologists demonstrated a high level of awareness and ethical commitment to environmental sustainability, recognizing both its relevance to professional practice and the considerable environmental footprint of anesthesia. Second, waste generation—particularly from single-use plastics and disposable supplies—was perceived as the most pressing environmental concern, even surpassing the impact attributed to volatile anesthetic agents. Third, participants expressed a clear willingness to adopt more sustainable practices, mainly through more conscious anesthetic choices, optimization and potential reuse of supplies, and energy-saving behaviors. Fourth, despite this individual motivation, the implementation of sustainability principles into routine practice remains limited by systemic and institutional barriers, including administrative and financial constraints, insufficient training, resistance to change, and the prioritization of patient safety.

These findings reflect a broader transformation within anesthesiology, where environmental stewardship is increasingly recognized as part of professional responsibility and patient-centered care (1). The ethical framework identified in our study suggests that sustainability is no longer considered solely a technical or administrative issue, but rather an extension of the physician's duty to protect health, closely aligned with the principles of planetary health and preventive medicine. This finding is particularly notable given that Popayán is not one of Colombia's main metropolitan centers; nevertheless, the level of training and environmental awareness among its anesthesiologists appears comparable to international standards (4).

Waste generation—particularly related to single-use plastics and disposable supplies—emerged as the most prominent environmental concern, with participants prioritizing this issue over anesthetic gas emissions. This prioritization differs from global scientific evidence identifying volatile anesthetics as one of the most significant and modifiable sources of healthcare-related greenhouse gas emissions (14). This discrepancy may reflect the operational realities of resource-limited health systems, where the visible accumulation of plastic waste represents a more immediate and tangible environmental problem. Operating rooms are known to generate a disproportionate amount of hospital waste and account for a substantial proportion of healthcare resource consumption (15).

Participants reported a clear willingness to adopt more sustainable practices. Frequently reported strategies included conscious anesthetic selection, adoption of low-flow anesthesia techniques, increased use of regional anesthesia, and implementation of TIVA. These approaches align with internationally recommended mitigation strategies aimed at reducing anesthetic-related emissions and improving environmental sustainability in perioperative care (16). However, implementing these strategies in practice requires careful consideration of contextual factors. Although TIVA is often considered environmentally preferable due to its lower carbon footprint compared with inhalational anesthesia, its implementation may increase disposable material use and often requires advanced monitoring technologies to ensure patient safety (17). In Colombia, national data have shown that the use of TIVA remains variable and is frequently limited by the availability of infusion technology, depth-of-anesthesia monitoring, and clinician experience, which restricts its routine implementation (18).

This apparent discrepancy underscores a broader dilemma in sustainable anesthesia: environmental interventions rarely reduce all forms of environmental impact simultaneously. For example, replacing volatile anesthetics with TIVA may decrease greenhouse gas emissions but can increase the consumption of syringes, infusion sets, intravenous fluids, and other single-use plastics. Likewise, while volatile anesthetic delivery can be stopped immediately at the end of a procedure, unused intravenous drugs or partially administered fluid bags frequently become unavoidable waste. These contrasting waste streams illustrate that sustainability cannot be evaluated by considering a single environmental metric alone. Instead, clinicians must balance greenhouse gas emissions, material waste, costs, and clinical effectiveness.

Our analysis also revealed that systemic and institutional barriers represent the main obstacles to implementing sustainable anesthesia practices. Administrative constraints, limited financial resources, insufficient institutional policies, and lack of infrastructure were frequently reported by participants. These findings highlight a structural gap between clinicians' environmental awareness and the capacity of healthcare systems to support sustainable practices. Similar challenges have been described in other healthcare systems, where sustainability initiatives depend heavily on institutional leadership, policy development, and organizational commitment (19). Importantly, several studies have demonstrated that interventions such as low-flow anesthesia, optimization of supply chains, and operating room sustainability programs can generate both environmental and economic benefits (19).

In resource-constrained settings, these trade-offs are further amplified by financial limitations, which may restrict the implementation of greener practices while placing the economic burden of sustainability initiatives on healthcare institutions with limited resources. Ultimately, decisions about environmentally sustainable anesthesia require balancing individual patient benefit—selecting the most appropriate anesthetic technique for each patient—with broader public health and environmental objectives, highlighting the need for life-cycle assessments and context-specific strategies rather than universal recommendations.

Nevertheless, recent national policy developments in Colombia demonstrate increasing institutional recognition of the environmental impact of healthcare systems. The Ministry of Health and Social Protection has developed the Plan Integral de Gestión del Cambio Climático del Sector Salud (PIGCCS-Salud) 2026–2035, a strategic framework designed to strengthen climate resilience and promote mitigation actions within the healthcare sector. Complementary initiatives seek to quantify emissions associated with healthcare delivery and identify opportunities for their reduction (20).

Implications and Future Directions

Anesthesiologists in Popayán, a southwestern city of Colombia, demonstrated high awareness of environmental sustainability and a strong commitment to environmentally responsible anesthesia. Although participants recognized the environmental impact of anesthetic practice, organizational, financial, and logistical constraints prevented the consistent adoption of sustainable practices in routine care. This distinction is important because generating knowledge alone is rarely sufficient to change clinical practice (21, 22).

From an implementation science perspective, these findings illustrate an implementation gap—the disconnect between evidence supporting more sustainable practices and their consistent adoption in routine anesthetic care (23). Our results indicate that this gap is shaped primarily by institutional and structural barriers rather than individual knowledge or attitudes, underscoring the importance of system-level implementation strategies.

Implementation science recognizes that evidence alone is insufficient to change practice. Successful implementation requires adapting interventions to the local context, identifying barriers and facilitators, and deploying context-specific implementation strategies that promote the sustained adoption of evidence-based practices (22). From this perspective, improving environmental sustainability in anesthesia should move beyond educational initiatives toward implementation-focused interventions (24). In resource-constrained settings such as ours, priorities may include institutional leadership, procurement policies that facilitate sustainable choices, local champions, audit and feedback, and context-specific guidelines that integrate environmental considerations into everyday clinical decision-making. Such approaches are more likely to achieve lasting practice change than relying solely on increasing clinicians' environmental knowledge.

Accordingly, advancing sustainable anesthesia will require coordinated institutional support, including the development of formal policies, investment in appropriate infrastructure, and strategic optimization of resource utilization. Integrating sustainability into medical education, institutional protocols, and professional guidelines may facilitate long-term change. Future research should evaluate the effectiveness of institutional interventions and expand this work to other regions and healthcare systems to support evidence-based strategies for reducing the environmental impact of anesthetic. Table 3 presents a potential list of barriers and facilitators to sustainable anesthesia practice among Colombian anesthesiologists.

Table 3
Barriers and facilitators to sustainable anesthesia practice among Colombian anesthesiologists

Implementation domain	Barriers	Facilitators
Individual characteristics	Limited awareness of the relative environmental impact of anesthetic gases compared with visible waste	Strong environmental awareness and ethical commitment to sustainable practice
Intervention characteristics	Perceived complexity, costs, and uncertainty regarding implementation of low-flow anesthesia and equipment reprocessing	Deliberate selection of anesthetic techniques to reduce environmental impact
Inner setting	Administrative barriers, limited financial resources, and insufficient institutional support	Existing initiatives for supply optimization and waste segregation/recycling
Outer setting	Lack of national or regional policies, incentives, and infrastructure supporting sustainable anesthesia	Growing international evidence and professional guidance on environmentally sustainable anesthesia
Implementation process	Sustainability dependent on individual initiative rather than standardized institutional protocols	Clinicians' willingness to engage in sustainability initiatives and organizational change

Limitations

This study has some limitations to consider. First, the cross-sectional design captures self-reported practices at a single point in time, limiting the ability to draw how perceptions and practices may change in response to time-dependent institutional interventions. Second, although a 100% response rate strengthens internal validity, the sample was drawn from a single geographic area (Popayán, Cauca) with a total size of 85 participants, which may limit generalizability to anesthesiologists in other Colombian (more or less developed) regions or Latin American countries, particularly those working mainly in private practice rather than the predominantly public-hospital context studied here. Finally, reported sustainable practices relied on self-report rather than direct observation or objective measures (e.g., fresh-gas-flow audits, waste quantification), raising the possibility of social desirability bias and a gap between perceived and actual clinical behavior

Conclusion

Colombian anesthesiologists show strong awareness, ethical commitment, and willingness to adopt sustainable practices. However, implementation is constrained mainly by systemic and institutional barriers rather than individual motivation. Bridging this gap will require institutional leadership, infrastructure investment, and integration of sustainability into clinical protocols and education, aligning environmental responsibility with healthcare quality and system resilience.

Abbreviations

LFA: Logical Framework Approach.

COP 26: The 26th United Nations Climate Change Conference of the Parties

STROBE: Strengthening the Reporting of Observational Studies in Epidemiology

DANE: Colombia's National Administrative Department of Statistics

TIVA: Total Intravenous Anesthesia

PIGCCS SALUD : Plan Integral de Gestión del Cambio Climático del Sector Salud Colombia

Declarations

Acknowledgements

We express our sincere gratitude to Staff Anesthesiologist Drs. Maria Virginia Rodriguez, Ingrid Muñoz, Luz Ángela Flórez, Diana Rodriguez, Danilo Osorio and Gustavo Angel for their valuable collaboration and support during the development of this research. Also to Caucana Association of Anesthesiology and Resuscitation (ACAR) for their support.

Author's contributions

Conceptualization: CD, JAC; Data Analysis: DC, JV; Writing – Original Draft Preparation: CD, DC, JV; Writing – Review & Editing: CD, DC, JV, MK, JAC; Visualization: JV; Supervision: MK, JAC; Project Administration: JAC. All authors meet the criteria for authorship and have approved the final manuscript.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

This study was approved by the Faculty Research and Postgraduate Committee of Universidad del Cauca, which ratified the departmental endorsement and authorized the project to continue its registration process before the Vice-Rector's Office for Research (April 22, 2025 - ID6423), in accordance with institutional regulations and ethical standards. The approval was granted on January 29, 2025.

All participants received detailed written information regarding the study objectives, procedures, voluntary nature of participation, confidentiality safeguards, potential benefits, and the absence of foreseeable risks. Written informed consent was obtained from all participants prior to survey completion and participation in focus groups. Anonymity and confidentiality were guaranteed, and audio recordings were used solely for transcription and research purposes, with prior authorization from participants.

Conflicts of Interest

None declared.

References

1. Romanello M, et al. The 2022 report of the Lancet Countdown on health and climate change: health at the mercy of fossil fuels. Lancet. 2022;400(10363):1619–54.
2. The Lancet. Global heating: an urgent call for action to protect health. Lancet. 2022;400(10363):1557.
3. Intergovernmental Panel on Climate Change (IPCC). Climate Change 2023: Assessment Report. Available from: https://www.ipcc.ch/report/ar6/wg1/
4. Lenzen M, et al. The environmental footprint of health care: a global assessment. Lancet Planet Health. 2020;4(7):e271–9.
5. Eckelman MJ, Sherman JD. Environmental impacts of the U.S. health care system and effects on public health. PLoS ONE. 2016;11(6):e0157014.
6. Roletto A, et al. Environmental impact of energy consumption in radiology: a systematic review. Eur Radiol Exp. 2024;8(1):35.
7. Sulbaek Andersen MP, Nielsen OJ, Wallington TJ, Karpichev B, Sander SP. Assessing the impact on global climate from general anesthetic gases. Anesth Analg. 2012;114(5):1081–5.
8. Gaya da Costa M, Kalmar AF, Struys MMRF. Inhaled anaesthetics: environmental role, occupational risk, and clinical use. J Clin Med. 2021;10(6):1306.
9. Varughese S, Ahmed R. Environmental and occupational considerations of anesthesia: a narrative review and update. Anesth Analg. 2021;133(4):826–35.
10. Gonzalez-Pizarro P, Koch S, Muret J, Trinks A, Brazzi L, Reinoso-Barbero F, et al. Environmental sustainability in the operating room: a worldwide survey among anaesthesiologists. Eur J Anaesthesiol Intensive Care. 2023;2(4):e0025.
11. Gasciauskaite G, Lunkiewicz J, Spahn DR, Von Deschwanden C, Nöthiger CB, Tscholl DW. Environmental sustainability from anesthesia providers' perspective: a qualitative study. BMC Anesthesiol. 2023;23:377.
12. Kagoma YK, et al. Greening operating rooms. CMAJ. 2012;184(17):1905–11.
13. Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP, STROBE Initiative. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE)statement: guidelines for reporting observational studies. J Clin Epidemiol. 2008;61(4):344–9.
14. Sherman JD, et al. The green print: sustainability in healthcare. Resour Conserv Recycl. 2020;161:104882.
15. Pillay L, Winkel KD, Kariotis T. Developing the green operating room: exploring barriers and opportunities to reducing operating room waste. Med J Aust. 2024;221(5):279–84.
16. McGain F, Muret J, Lawson C, Sherman JD. Environmental sustainability in anaesthesia and critical care. Br J Anaesth. 2020;125(5):680–92.
17. Jabaudon M, Vallabh B, Bacher HP, Badenes R, Kehl F. Balancing patient needs with environmental impacts for best practices in general anesthesia: narrative review and clinical perspective. Anaesth Crit Care Pain Med. 2024;43(4):101389.
18. Echeverry-Marín PC, Arévalo J, Pinzón P, Vanegas-Saavedra A, Leguizamón M. Use of total intravenous anaesthesia in Colombia: a national survey among active anaesthetists in Colombia. Rev Colomb

Anestesiol. 2017;45(2):122–7.
19. Mortimer F, Isherwood J, Wilkinson A, Vaux E. Sustainability in quality improvement: redefining value. Future Healthc J. 2018;5(2):88–93.
20. Colombia M, de Salud y Protección Social. Resolución 228 de 2026, por la cual se adopta el Plan Integral de Gestión del Cambio Climático del Sector Salud (PIGCCS Salud) 2026–2035 y se dictan otras disposiciones. 10 de febrero de 2026.
21. Graham ID, Logan J, Harrison MB, Straus SE, Tetroe J, Caswell W, Robinson N. Lost in knowledge translation: time for a map? J Contin Educ Health Prof. 2006 Winter;26(1):13–24. 10.1002/chp.47. PMID: 16557505.
22. Nilsen P. Rethinking barriers and facilitators in implementation science: conceptual, methodological, and practical challenges, and ways forward. Implement Sci Commun. 2026;7(1):64. 10.1186/s43058-026-00901-6. . PMID: 41851803; PMCID: PMC13045074.
23. Kitson A, Straus SE. The knowledge-to-action cycle: identifying the gaps. CMAJ. 2010;182(2):E73–7. 10.1503/cmaj.081231.
24. Damschroder LJ, Aron DC, Keith RE, Kirsh SR, Alexander JA, Lowery JC. Fostering implementation of health services research findings into practice: a consolidated framework for advancing implementation science. Implement Sci. 2009;4:50. 10.1186/1748-5908-4-50.

Figures

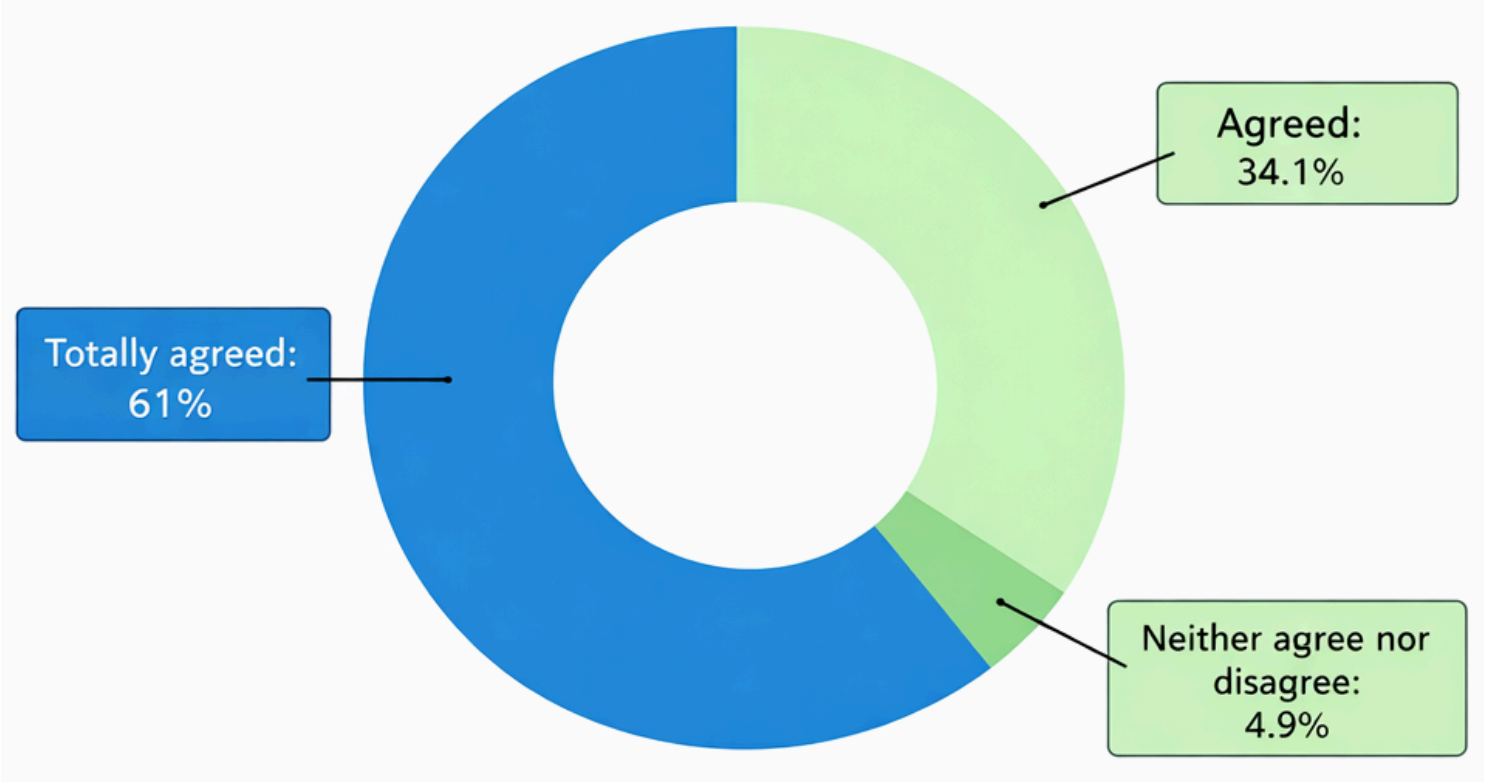


Figure 1

Distribution of responses to the statement: environmental sustainability is important to me and in my professional practice.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Supplementarymaterial.docx