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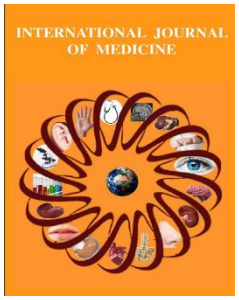

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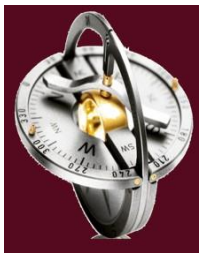

Review Article

Green Anesthesia: Towards a Sustainable Future in Perioperative Practice

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Abstract

Background: Climate change is a big health concern, and healthcare contributes about 5-10% of global greenhouse gas emissions. Anesthesia and surgery care use a lot of energy, release harmful gases, and create waste.***Objective***: This review looks at how anesthesia affects the environment, explores eco-friendly methods, and suggests ways to make surgery care greener.***Methods***: We reviewed studies from PubMed, Scopus, and Google Scholar (2012-2025) using terms like green anesthesia, sustainability, perioperative care and low-flow anesthesia. We included research on the environmental impact of anesthetic gases, eco-friendly tools, waste handling, and policies.***Results***: Desflurane and nitrous oxide cause the most warming. Using low-flow anesthesia, choosing total intravenous anesthesia (TIVA), reusing equipment, and better waste management can greatly lower environmental harm. Support from hospitals, training, and clear rules help these changes happen. ***Conclusion***: Green anesthesia is important for ethical and professional healthcare. Switching to eco-friendly practices can cut carbon emissions without risking patient safetys.

Keywords: Green anesthesia, sustainability, low-flow anesthesia, volatile anesthetics, carbon footprint, perioperative care, global warming potential

Introduction:

Climate change is one of the biggest threats to global health today. Ironically, healthcare systems meant to improve health also harm the environment[1]. Worldwide, healthcare causes about 5% of total greenhouse gas emissions, with operating rooms (ORs) contributing a large share due to high energy use, anesthetic gases, and waste[2]. Anesthesia in the OR adds significantly to emissions through inhaled anesthetics, nitrous oxide, and disposable tools[3]. Gases like desflurane, isoflurane, sevoflurane, and nitrous oxide are powerful greenhouse gases. For example, desflurane has a global warming potential of 2540 and stays in the atmosphere for 14 years[4]. Using desflurane for an hour at 2 L/min fresh gas flow equals driving over 300 km in a petrol car[5]. Sevoflurane and isoflurane have lower global warming potential of (130 and 510)[6].

Green Anesthesia, means using eco-friendly anesthesia practices that reduce environmental harm without affecting patient care[7]. This includes lowering gas flows, choosing less harmful agents, cutting waste and setting sustainable policies8

This review gives an overview of anesthesia's environmental effects, discusses green strategies, and suggests how to include these ideas in surgical care.

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Methodology

This review was done from January 2012 to october 2025 using PubMed, Scopus, and Google Scholar. Search terms included 'green anesthesia, sustainable perioperative care, anesthetic gases, low-flow anesthesia and carbon footprint. We included peer-reviewed articles on environmental impact, solutions, policies, and innovations in anesthesia. Reports from organizations like ASA and NHS were also used. Articles only about clinical outcomes were excluded.

We collected data on greenhouse gas emissions, global warming potential of anesthetic agents, life cycle assessments, waste management, and hospital strategies. The results were organized into themes: environmental impact, principles, strategies and future directions.

Environmental Impact of Anesthetic Practice

Anesthesia contributes a lot to healthcare's carbon footprint through volatile gases, nitrous oxide and energy-heavy OR activities[9]. Each gas has different GWP and atmospheric lifetime affecting its impact. Desflurane has very high GWP (2540) lasting 14 years; sevoflurane (130) and isoflurane (510) are less harmful. Nitrous oxide lasts 114 years and also harms the ozone layer9.

Life Cycle Assessments show inhaled anesthesia with desflurane or N_2O creates 10-20 times more emissions than total intravenous anesthesia (TIVA)[10]. For example, a two-hour case using desflurane at 6 L/min emits over 60 kg CO_2 equivalent-like driving 200 km in a petrol car. Gas leaks from pipes and equipment add another 5-10% wastage[11].

The operating room uses much more energy than other hospital areas because of constant heating/cooling (HVAC), lighting, and monitoring systems. Disposable surgical supplies add to waste, operating rooms produce up to 30% of hospital waste volume with much being non-

infectious but not properly sorted[12].

These facts show we need focused emission cuts using low-flow methods, better gases, equipment improvements, and energy-saving changes.

Table 1: Global Warming Potential & Atmospheric Lifetime of Common Anesthetic Agents

Agent	GWP (100 years)	Atmospheric Lifetime (years)
Desflurane	2540	14
Isoflurane	510	3.2
Sevoflurane	130	1.1
Nitrous oxide	298	114

Principles of Green Anesthesia

Green anesthesia follows the '4Rs': Reduce, Reuse, Recycle, Rethink[13]. This means lowering gas flows, reusing sterilized tools, recycling plastics, choosing clinical options like regional anesthesia over general when possible; avoiding desflurane and nitrous oxide, preferring sevoflurane or TIVA[14].

Strategies for Sustainable Perioperative Practice

1. Low-Flow Anesthesia:
   Using fresh gas flows under 1 L/min cuts volatile agent use by 60–75% without risking safety when modern monitors are used. Sevoflurane works best for low-flow because it dissolves less in blood and doesn't produce harmful compounds under normal conditions[15].
2. Total Intravenous Anesthesia (TIVA):
   TIVA with propofol releases no gases into the air. Life cycle studies show propofol causes up to 80% less CO_2 than desflurane-based anesthesia. But leftover propofol is toxic to water life so must be burned or treated properly-not poured down drains[16].
3. Regional & Day-Case Anesthesia:
   Multimodal and non opioid analgesia or using nerve blocks or day surgeries reduces anesthetic gases used and shortens hospital stays which lowers waste. Ultrasound guidance helps precision reducing drug waste and complications.[17,32]
4. Reusable vs Disposable Equipment:
   Reusable tools cost more upfront but have less environmental impact over time than single-use items,for example reusable laryngeal masks cut CO_2 by 70% over many uses[18].
5. Energy-Efficient OR Design:
   LED lights, smart HVAC systems, motion sensors can reduce OR energy use by up to 40%[19]. Turning off power when not needed helps too.
6. Digital & Paperless Workflow:
   Switching to electronic records cuts paper waste and helps track carbon footprints.

Table 2: Sustainable Strategies & Expected Impact

Strategy	Action	Impact
Low-flow anesthesia	Use FGF <1 L/min	Less volatile agent use & emissions
TIVA	Use IV agents correctly	Lower global warming potential
Reusable equipment	Sterilize & reuse	Less solid waste
Energy management	LED lighting & HVAC	Lower energy consumption
Waste segregation	Follow biomedical rules	Better recycling & less landfill

Waste Management in the Operating Room

Proper biomedical waste handling is key for sustainability[20]. OR waste includes plastic syringes, IV sets, packaging-much can be recycled if sorted well. Rules require color-coded bins and treating infectious waste safely. Programs like Practice Green health promote recycling in ORs plus drug take-back schemes[21]. Sustainable OR waste steps include:

- Reprocessing some devices for reuse
- Sorting clean plastics for recycling
- Cutting drug waste with pre-filled syringes & tracking doses
- Encouraging suppliers to take back packaging[21]

Education, Policy & Institutional Support

Teaching environmental sustainability should be part of anesthesia training[22]. Hospitals can form green teams, do carbon audits, use sustainability scorecards[23]. Global plans like NHS Net Zero or ASA guidelines provide helpful frameworks[24].

Barriers & Challenges

Challenges include lack of awareness, resistance to change at institutions, cost concerns for reusable items, infection control worries[25]. Leadership support plus education and financial incentives help overcome these barriers[26].

Innovations & Future Directions

New ideas include capturing anesthetic gases for reuse[27], Artificial intelligence based systems aiding decision making during anesthesia and optimizing gas use automatically[28,29], biodegradable equipment[30]; hospitals aiming for carbon neutrality like NHS by 2040 set examples[31]

Conclusion

Green anesthesia is not just a new idea; it is a professional duty and ethical responsibility in modern surgical care. While healthcare aims to improve health, it also causes significant environmental damage. Anesthetic gases, high energy use in operating rooms and many disposable items make up a large part of healthcare's carbon footprint. Therefore, anesthesiologists must protect the environment while providing excellent care.

Using low-flow anesthesia, switching to less harmful gases, total intravenous anesthesia and regional techniques can cut greenhouse gas emissions by over 70%. Replacing desflurane and nitrous oxide with safer options like sevoflurane or TIVA, using proper gas capture systems, and sorting medical waste properly are key steps. Using reusable tools, designing energy-efficient operating rooms, and following waste management rules also help protect the environment.

However, making anesthesia sustainable is not just about technology-it requires teamwork across different fields, strong

leadership, supportive policies, and ongoing education. Regular checks on carbon output, buying eco-friendly supplies and reporting sustainability efforts should become routine.

In the end, green anesthesia follows the ethical rule of, do no harm, extending it from patients to the planet. It shows that patient safety, effective treatment and caring for the environment can all work together. Moving to sustainable methods now means anesthesia will help heal people without harming Earth's health.

Recommendations:

To reach net-zero emissions in anesthesia, we need innovation, education, and aligned policies. Future recommendations should include:

1. Technological Innovations

- Capturing and recycling anesthetic gases with advanced systems to greatly reduce emissions.
- Using artificial intelligence to optimize gas flow and drug delivery, minimizing waste while maintaining safety and precision.
- Developing biodegradable airway tools, syringes, and circuits that control infection without harming the environment.
- Promoting multimodal,non-opioid or opioid free analgesic techniques

2. Research and Evidence-Based Policies

- Expanding life cycle assessments (LCA) comparing TIVA inhaled agents and mixed methods to guide sustainable choices.
- Studying how environmental actions affect patient outcomes and costs to encourage wider use
- Creating standard carbon measurement methods for surgery services to help hospitals compare and report progress.

3. Education and Training

- Adding green anesthesia topics into medical Educations and residency programs.
- Offering continuing education workshops on sustainability practices and carbon tracking.
- Recognizing healthcare workers who use eco-friendly techniques.

4. Institutional and Policy Frameworks

- Adopting instutional purchasing protocol that favor reusable, recyclable, and low-impact products.
- Setting up Green Hospital Committees and sustainability leaders in anesthesia departments.
- Providing financial rewards for hospitals that meet certified sustainability standards.

5. Global and Regional Collaboration

- Working with international groups like WHO and world federation societies of Anesthesiologists (WFSA) to share best practices.
- Creating guidelines tailored to local resources and policies in different regions.
- Building national registries to track progress and share successful strategies.

6. Ethical and Legal Integration

- Making environmental care a key part of clinical governance.
- Including environmental standards in hospital accreditation and ethical codes for practitioners.
- Requiring environmental audits as part of hospital licensing and quality checks.

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