

The Role of the Nurse Anesthetist in Reducing the Environmental Footprint of Anesthesia Practice: A Literature Review

Review article

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KEYWORDS: anaesthesia, environmental impact, nurse anaesthetists, sustainable healthcare

ABSTRACT – Sustainable anaesthesia practice is recognised as a key element in reducing the healthcare system's environmental footprint, with nurse anaesthetists playing a central role in applying the measures that protect both the patients and the environment. The literature review conducted in July 2025 through PubMed, Web of Science, and Scopus included open-access studies in English, published between 2020 and 2025. 19 studies were analysed. Evidence shows that nurse anaesthetists can reduce the environmental impact by implementing low-flow techniques, transitioning to total intravenous anaesthesia (TIVA), rationally using reusable equipment, reducing and properly segregating waste, and educating teams. Identified practice models include nurse-led services and reorganised outpatient procedures, which cut resource use and strengthened the nursing role. The main barriers are lack of education, limited resources, and weak institutional support. Integrating these strategies into the curricula, national guidelines, and hospital protocols could accelerate sustainable anaesthesia in Croatia.

Pregledni znanstveni članek

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KLJUČNE BESEDE: anestezija; anesteziološke medicinske sestre; okoljski vpliv; trajnostno zdravstvo

POVZETEK – Trajnostna anesteziološka praksa je prepoznana kot ključen element pri zmanjševanju okoljskega odtisa zdravstvenega sistema, pri čemer imajo anesteziološke medicinske sestre osrednjo vlogo pri izvajanju ukrepov, ki hkrati varujejo paciente in okolje. Julija 2025 je bila izvedena pregledna raziskava v bazah PubMed, Web of Science in Scopus, ki je vključevala prosto dostopne angleške študije, objavljene med letoma 2020 in 2025. Analiziranih 19 študij. Dokazi kažejo, da lahko anesteziološke medicinske sestre zmanjšajo vpliv na okolje z uvedbo tehnik nizkega pretoka, prehodom na popolno intravensko anestezijo, racionalno uporabo večkratne opreme, zmanjšanjem in pravilnim ločevanjem odpadkov ter z izobraževanjem ekip. Kot uspešni modeli so bile prepoznane storitve pod vodstvom medicinskih sester ter reorganizacija ambulantnih posegov, ki so zmanjšale porabo virov in okrepile vlogo medicinskih sester. Glavne ovire so pomanjkanje izobraževanja, omejeni viri in šibka institucionalna podpora. Vključevanje teh strategij v kurikule, nacionalne smernice in bolnišnične protokole bi lahko pospešilo trajnostno anestezijo na Hrvaškem.

1 Introduction

Anaesthesiology, as one of the most dynamic and technically advanced branches of modern medicine, is indispensable to surgical care, but also makes a significant contribution to the negative environmental impact of the healthcare system (Harfaoui et al., 2024; Mathis et al., 2022). Operating rooms consume up to six times more energy per square meter compared to other hospital departments, while greenhouse gas emissions from inhalational anaesthetics, especially desflurane and nitrous oxide (N₂O), far exceed the emissions of carbon dioxide on a molecular level (Cappiel-

lo, 2024). For example, the global warming potential (GWP) of desflurane is about 2,540, meaning that one hour of its use has a climate effect equivalent to driving a car approximately 300,370 km (Zoghbi et al., 2022). In addition, significant amounts of waste are generated due to the use of single-use equipment, plastic products, packaging, and surplus medications that are often disposed of as medical waste (Bhutta, 2021). The combination of increasingly frequent procedures, sophisticated equipment, and unsustainable clinical routines positions anaesthesiology among the largest waste generators in the hospital system.

In the past decade, the concept of sustainable anaesthesia has been developing with growing intensity, involving the introduction of environmentally friendly clinical practices that ensure complete patient safety (McGain et al., 2020; White et al., 2022). The fundamental principles include rational selection of inhalational anaesthetics with lower GWP, use of low fresh gas flow techniques to reduce consumption, replacement of disposable instruments with reusables whenever possible, optimisation of drug and infusion use, digitisation of medical documentation, proper waste segregation, and systematic consumption monitoring through the so-called green internal audits (Cappellini & Schirru, 2024; Samad et al., 2025). These approaches are increasingly being incorporated into the strategic goals of healthcare institutions, especially in countries developing national plans for a transition toward a sustainable healthcare system.

In achieving these changes, nurse anaesthetists have a crucial and multi-dimensional role. As professionals who continuously monitor patients' vital functions, manage complex medical devices, prepare medications and consumables, they identify daily opportunities to rationalize consumption and reduce waste (Gasciauskaite et al., 2023). Nurses most often decide which materials will be opened and used, and can suggest the use of reusable equipment, participate in applying the optimal flow of oxygen and anaesthetic gases during procedures, and identify clinical practices that unnecessarily burden the environment. Their ability to monitor consumption, document usage, and communicate effectively with the rest of the team makes them natural leaders of sustainable clinical practice in anaesthesiology (Lindholm et al., 2023).

Beyond the operational role, nurse anaesthetists also have an important function in educating other members of the healthcare team, from students and interns to experienced colleagues. By conducting internal educational activities, developing guidelines, and actively participating in hospital initiatives focused on environmental conservation, nurses can significantly contribute to fostering a culture of ecological responsibility (Swerdlow et al., 2020). In collaboration with anaesthesiologists, biomedical engineers, environmental protection specialists, and waste management personnel, their professional role extends beyond operational responsibilities. A growing number of international publications and professional associations emphasize the need for active involvement of nurses in the design and implementation of strategies for environmentally responsible anaesthesia and sustainable operating theatres.

Despite numerous initiatives and increasing awareness of the health impacts of climate change, the scientific literature that systematically analyzes the role of nurses

in sustainable anaesthesia practice is still limited (Luque-Alcaraz et al., 2022). The lack of clear and standardized guidelines, the weak representation of sustainability topics in educational programs, the low visibility of the nursing profession's contributions, and the absence of tools for a systematic evaluation of all aspects of sustainable practice represent significant barriers to broader implementation (Capella et al., 2025; Skraastad et al., 2025). In Croatia, despite the increasing awareness of the environmental impact of healthcare, there are currently no national guidelines or structured educational programs specifically addressing sustainable anaesthesia practice, which highlights the importance of recognising the role of nurse anaesthetists in this field. It is therefore necessary to identify the existing knowledge sources, analyze examples of good practice, and develop concrete recommendations that formally recognize and empower the role of nurses in the process of "green transition" in anaesthesia care.

This review paper aims to analyze the available scientific literature, published in the last five years, regarding the role of nurses in sustainable anaesthesia practice. The paper focuses on identifying concrete measures that nurses can undertake to reduce the environmental footprint of anaesthesia procedures, including resource optimisation, team education, waste reduction, and implementation of "green audit" tools. Additionally, the goal is to recognize the existing challenges and provide recommendations for the future development of systematic sustainable practices in anaesthesiology, with an emphasis on the nursing role.

2 Methodology

The scientific literature search was conducted in July 2025 using three databases: PubMed, Web of Science, and Scopus. It focused exclusively on the research and review papers examining sustainable anaesthesia in the context of nursing practice to include the most relevant clinical and professional sources. The following types of publications were considered: quantitative and observational studies, qualitative studies, review articles, strategic papers, quality improvement reports, and continuing education modules. Publications classified as expert opinion, commentary, letters to the editor, conference abstracts, protocols, or papers without sufficient analytical value were excluded from the synthesis. In order to avoid methodological mixing, the included studies were classified according to study design and analysed within separate categories.

The search was carried out using predefined keywords and logical operators, including combinations of "sustainable anaesthesia", "nurse" and "nurse anaesthetist", with consistent use of these terms across all three databases. The keywords had to be present in the title, abstract, or keywords of an article to ensure thematic relevance to the topic. In the first step of the selection, the PubMed database identified a total of 86 records, Web of Science 128 records, and Scopus 34 records, making a total of 248 records found during the initial search phase.

After combining the results from all three databases, duplicate records were removed. This step was performed in Zotero, which automatically identifies and flags

duplicate references. After verification and removal of duplicates, 222 unique records remained, forming the initial corpus for further analysis.

In the next selection phase, additional inclusion criteria were applied to ensure methodological consistency and quality of the literature (Table 1). We included only works published from January 2020 to mid-2025, which ensured a coverage of the recent scientific insights. Furthermore, a condition for inclusion was free access to the full text (open access) to enable a transparent and thorough content analysis. Additionally, a language criterion was applied, considering only works written in English, in line with the aim of reviewing international literature.

Applying these criteria, in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, enabled a structured and repeatable selection process. After the full-text review, 59 papers were excluded from further analysis based on the clearly defined reasons:

- 14 papers were not focused on the topic of anaesthesia, placing them outside the primary scope of this research.
- 21 papers did not contain environmental or sustainability components, which were a key requirement for inclusion.
- 11 papers did not involve nurses at all or did not include nurses working in anaesthesia departments, therefore not meeting the nursing perspective criterion.
- 7 papers dealt with the topic of anaesthesia, but had no connection to sustainable practice.
- 6 papers belonged to subject areas outside the interest of this study, such as dermatology, nutrition, and medical ethics.

After applying all criteria and evaluating the full content, a total of 19 papers were included in the final synthesis and qualitative analysis. These papers form the basis for presenting the findings in the next chapter.

Table 1

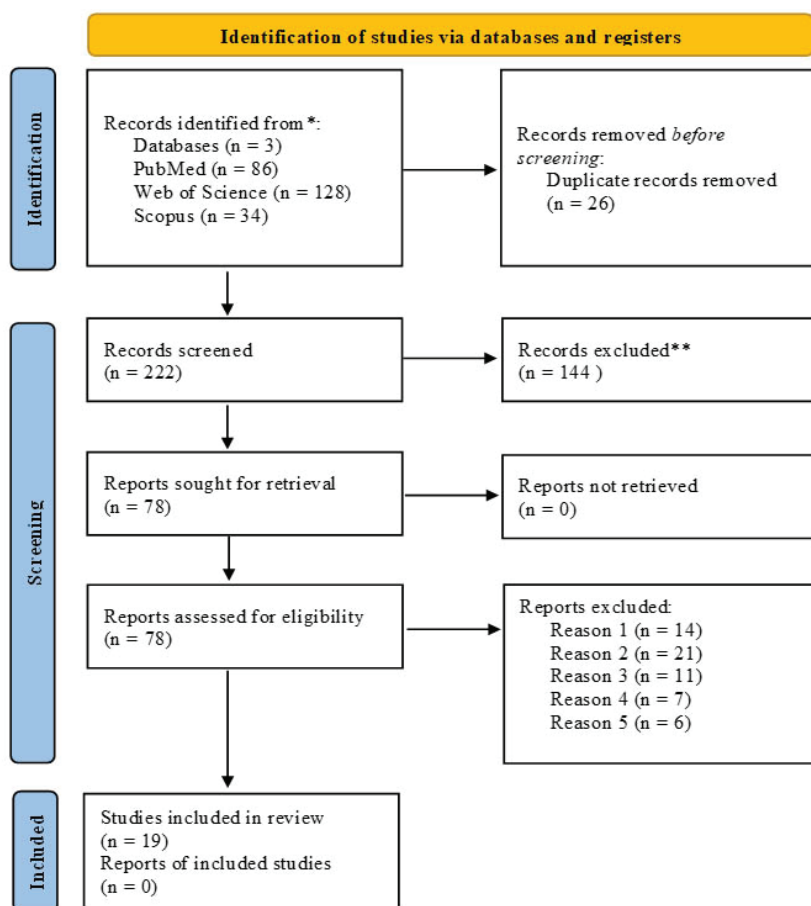
Inclusion and exclusion criteria/Vključitveni in izključitveni kriterij

<i>Inclusion criteria</i>	<i>Exclusion criteria</i>
Studies published from January 2020 to July 2025	Studies published before 2020
Studies written in English	Studies in languages other than English
Studies with accessible abstract or full text	Studies without an available abstract or full text
Studies addressing sustainable (green) anaesthesia practice	Studies dealing exclusively with technical, pharmacological, or veterinary aspects of anaesthesia
Studies explicitly including the role of nurses or nurse anaesthetists	Studies that do not involve nursing practice or an interdisciplinary clinical context
Types of works: quantitative and observational studies, qualitative studies, review articles, strategic papers, quality improvement reports, and continuing education modules	Expert opinions, commentaries, letters to the editor, conference abstracts, protocols, and papers without sufficient analytical value.
Focus on resource optimisation, waste reduction, low-flow techniques, team education	Studies not related to environmental impact or sustainability in practice

The schematic flow of the search and selection process is presented in the PRISMA flow diagram (Figure 1), and the characteristics of the included studies are summarized in Table 2. The included papers vary in design (clinical trials, observational studies, review articles, and continuing education modules) and encompass experiences from different parts of the world (Europe, North America, Africa, Asia). To improve methodological clarity, the included papers were grouped according to study design and type of evidence. The synthesis is therefore presented in three categories: quantitative and observational studies, qualitative studies, and review, strategic, and educational papers. Expert opinions and commentaries were not included as a separate evidence category.

Figure 1

PRISMA flow chart/Shema poteka PRISMA



* Records identified from the selected databases (PubMed, Web of Science, and Scopus).

** Records excluded after title and abstract screening.

3 Results

To perform the review and identify relevant scientific literature, a systematic approach was used by searching the three most commonly used and relevant databases in the field of biomedicine and health sciences: PubMed, Web of Science, and Scopus. According to the defined criteria, a total of 19 papers were ultimately included in the review.

Review, Strategic, and Educational Papers

Several review, strategic, and educational papers emphasize the need to implement sustainable practices in anaesthesia, surgery, and nursing to reduce the healthcare sector's environmental footprint. In anaesthesiology, the so-called "5R" rule – reduce, reuse, recycle, rethink and research – is highlighted as the foundation for reducing the environmental impact of anaesthesia (Beloeil & Albaladejo, 2021), with an emphasis on the need for a multidisciplinary collaboration of the entire medical team.

The Austrian guidelines for "green" anaesthesia (Hammer et al., 2024) and a recent review of the achievements and challenges of sustainability in anaesthesia and intensive care (Bouvet et al., 2023) provide a number of concrete strategies, from a more rational use of anaesthetics to the optimisation of energy consumption. Both publications particularly stress the importance of continuous staff education and stronger institutional support for successful implementation of sustainable initiatives.

Quantitative and Observational Studies

Several quantitative and observational studies indicate that the healthcare workers' awareness of the environmental effects of their practice remains insufficient. A nationwide cross-sectional survey conducted in France by Tordjman et al. (2022) proposed concrete nursing measures for reducing medical waste, using more environmentally friendly materials, and improving education on sustainability in the operating room. A survey of the anaesthesia personnel in California, USA (Shah et al., 2023) revealed a low level of knowledge about the environmental consequences of using inhalational anaesthetics, while a similar study among the anaesthesiologists in South Africa (Giuricich et al., 2024) showed that most respondents do not follow sustainable guidelines in daily practice.

Qualitative Studies

Qualitative studies provided a deeper insight into the barriers to a sustainable anaesthesia practice. Gasciauskaite et al. (2023) identified a lack of sustainability education, limited resources, and insufficient institutional support as key obstacles to implementing "green" initiatives. Yezu et al. (2025) underscored that nurse anaesthetists are essential for the sustainable access to anaesthesia in rural areas with a shortage of physicians, while Sjöberg et al. (2023) emphasized the importance of improvisation, professional responsibility, and sustainable care in international humanitarian missions.

Quality Improvement and Nurse-Led Service Models

In Canada, a continuing education module was developed with an emphasis on “reduce, reuse, recycle” strategies and the use of life cycle analysis of products (Petre & Malherbe, 2020). During the COVID-19 pandemic, in England, a nurse-led “see and treat” model was established for urgent plastic trauma care. This model enabled 98% of patients to be managed surgically within a single day and without complications, thereby reducing repeat visits, patient travel, and generation of medical waste (Flanagan & Janes, 2023). The innovation was retained after the pandemic as an example of sustainable practice in surgical care.

A number of papers address more sustainable approaches in anaesthesia practice, focusing on reducing anaesthetic gas emissions and medical waste. A prospective study in Turkey confirmed that using low-flow anaesthesia, compared with the standard technique, significantly reduces greenhouse gas emissions and anaesthetic costs, with no adverse impact on patient outcomes (Sen et al., 2025). In line with these findings, some authors advocate a wider use of total intravenous anaesthesia (TIVA) instead of inhalational anaesthetics and a switch to reusable equipment wherever possible to further decrease medical waste (Mishra et al., 2024; Samad et al., 2025).

Environmental sustainability is considered in contexts beyond anaesthesia itself. An analysis of the carbon footprint of intensive care in Turkey (Ozkan, 2025) showed that intensive care units significantly contribute to a hospital’s overall emissions, implying that everyday clinical routines, including nursing care, need to be directed toward reducing resource consumption. A review of specific “green” initiatives in surgery, anaesthesia, and pathology (Asfaw et al., 2021) emphasizes that many sustainable practices, aside from reducing the environmental footprint, simultaneously lead to financial savings for healthcare institutions, and it offers seven concrete recommendations on how to connect environmental and economic sustainability.

Finally, the literature highlights the important role of nurses in initiating and carrying out sustainable changes. Examples include a health policy study from South Africa, which underscores that nurse anaesthetists are essential for a sustainable access to anaesthesia in rural areas with a shortage of physicians (Yezu et al., 2025), as well as the experiences of nurse anaesthetists on international humanitarian missions, which confirm that improvisation and personal responsibility are crucial for providing care in conditions of extremely limited resources (Sjöberg et al., 2023).

However, alongside these positive examples, the literature also notes numerous barriers to the wider adoption of sustainable practices. The most common barriers cited are insufficient staff knowledge and awareness, lack of material resources, and lack of institutional support (Almukhtar et al., 2024; Gasciauskaite et al., 2023). Overcoming these obstacles requires systemic support, from continuous education to the development of clear guidelines and policies that encourage sustainable behaviour. For instance, Nigeria has developed a national strategy for sustainable surgery that identifies nurses as key agents of change, emphasizing education and rational use of resources (Seyi-Olajide et al., 2021). Overall, the available evidence suggests that sustainable practices in anaesthesiology and surgery bring multiple benefits: besides

reducing the environmental footprint of healthcare activities, they can improve process efficiency, enhance patient safety, and in the long term reduce healthcare system costs.

Table 2

Overview of the included studies on the role of nurses in the sustainable anaesthesia practice/Pregled vključenih raziskav o vlogi medicinskih sester v trajnostni anesteziološki praksi

<i>Authors, year</i>	<i>Study type</i>	<i>Aim</i>	<i>Country</i>	<i>Key findings</i>
Tordjman et al., 2022	Cross-sectional study	Analyze sustainable nursing practices and provide guidelines to reduce environmental footprint in care	France	Suggests concrete practices to reduce waste, use eco-friendlier materials, and educate nurses
Shah et al., 2023	Quantitative analysis	Investigate the level of knowledge of anaesthesia personnel about the environmental effects of inhalational anaesthetics	USA	Revealed a low level of awareness and the need for education and changes in clinical practice
Sjöberg et al., 2023	Qualitative study	Examine nurse anaesthetists' experiences on international missions	Sweden	Emphasized the importance of sustainability, improvisation, and responsibility in the context of limited resources
Seyi-Olajide et al., 2021	Descriptive report	Present national strategies for sustainable surgery and the role of nurses	Nigeria	Nurses recognized as key to sustainable surgery, with emphasis on education and rational use of resources
Yezu et al., 2025	Qualitative study	Investigate the role of nurse anaesthetists in the sustainability of the healthcare system	South Africa	Nurse anaesthetists are crucial for sustainable anaesthesia availability in rural areas
Ozkan, 2025	Quantitative analysis	Calculate the carbon footprint of ICUs (intensive care units)	Turkey	Highlights the significance of ICU carbon emissions and implies the need to change nursing practice
Almukhtar et al., 2024	Systematic review	Investigate barriers and facilitators to sustainable behaviour in operating rooms using the Theoretical Domains Framework	UK	Knowledge, resources, and social influence are key barriers; intention is the main driver for implementation
Asfaw et al., 2021	Narrative review	Present examples of green initiatives in surgery, anaesthesia, and pathology	USA	Emphasizes the importance of an intersectoral approach and education of healthcare professionals

Beloeil & Albaladejo, 2021	Narrative review	Present initiatives to reduce the environmental impact of anaesthesia	France	Advocates the 5R rule (reduce, reuse, recycle, rethink, research) and the need for multidisciplinary collaboration
Bouvet et al., 2023	Literature review	Analyze achievements and challenges of sustainability in anaesthesia and intensive care	France	Calls for standardization of practices and stronger institutional support
Gasciauskaite et al., 2023	Qualitative study	Examine anaesthesia providers' perceptions of sustainable practice	Lithuania	Identified barriers including lack of education and institutional support
Giuricich et al., 2024	Descriptive study	Assess knowledge and practice of sustainable anaesthesia	South Africa	Found low knowledge among anaesthesiologists; most practices not aligned with sustainable guidelines
Hammer et al., 2024	Qualitative study	Present Austrian guidelines for sustainable anaesthesia	Austria	Offers concrete strategies and highlights the importance of education
Kampman & Weiland, 2023	Strategic review	Analyze the economic impact of sustainable anaesthesia	Netherlands	Provided 7 concrete recommendations and noted cost savings with sustainable practices
Mishra et al., 2024	Narrative review	Analyze the benefits and implications of switching to intravenous anaesthesia to reduce environmental footprint	India	Highlights the negative impact of inhalational anaesthetics; advocates transitioning to TIVA and using reusable equipment to reduce emissions and waste
Petre & Malherbe, 2020	Continuing education module	Inform anaesthesiologists about sustainable practice in Canada	Canada	Focuses on "reduce, reuse, recycle" strategies; highlights the importance of life cycle analysis (LCA)
Samad et al., 2025	Strategy overview	Present approaches to minimize the environmental impact of anaesthesia	Pakistan	Recommendations include education, use of low-flow systems, and substitution of anaesthetic gases
Sen et al., 2025	Experimental study	Compare the impact of low-flow vs. standard anaesthesia on emissions	Turkey	Low-flow anaesthesia significantly reduces emissions and costs
Flanagan & Janes, 2023	Quality improvement (prospective)	Develop a sustainable nurse-led "see and treat" model for plastic trauma during the COVID-19 pandemic	England	Nurse-led service enabled same-day procedures for 98% of patients with no complications. Carbon footprint was reduced (less waste and travel). The model was retained post-pandemic as a new sustainable practice.

4 Discussion

4.1 Main Findings and Alignment with the Guidelines

This narrative review covered 19 recent papers, published between 2020 and 2025, which explore sustainable anaesthesia practice from a nursing perspective. The results confirm that nurses, especially nurse anaesthetists, have a key role in implementing strategies aimed at reducing the environmental footprint of perioperative and intensive care. In most of the analyzed studies, interventions such as reducing anaesthetic gas consumption (using low fresh gas flows and avoiding unnecessary use of nitrous oxide), substituting volatile anaesthetics with intravenous techniques, using reusable equipment instead of single-use, rational waste management, and conducting education and optimisation protocols (such as Enhanced Recovery After Surgery, ERAS programs) were highlighted. These measures not only contribute to environmental preservation, but also improve resource use efficiency and patient safety.

The findings are consistent with the international guidelines of the European Society of Anaesthesiology and Intensive Care (ESAIC) and the World Federation of Societies of Anaesthesiologists (WFSA), which call for the integration of sustainable practices into the daily work of anaesthesia teams. In 2023, the ESAIC adopted the Glasgow Declaration on Sustainability, and in 2024, it published a consensus document with practical recommendations in four key areas: reducing direct anaesthetic emissions, optimising energy consumption, sustainable management of supply chains and waste, and promoting staff well-being and sustainable transport (Buhre, 2023). The recommendations include choosing anaesthetic agents with low global warming potential, applying low-flow anaesthesia, avoiding desflurane and nitrous oxide where possible, implementing the 5R strategy, optimising operating room ventilation systems, and encouraging the use of reusable equipment.

Examples from the literature, such as the study by Tordjman et al. (2022) and the review by Beloeil & Albaladejo (2021), confirm the effectiveness of the strategies aimed at reducing waste and emissions in the clinical setting. The study by Sen et al. (2025) and the review by Mishra et al. (2024) provide measurable evidence that the use of low-flow anaesthesia and a shift to TIVA can significantly reduce greenhouse gas emissions and anaesthetic agent consumption, while maintaining patient safety and the quality of outcomes.

Several of the described interventions contribute to both the environmental and financial sustainability of healthcare institutions. Switching from inhalational anaesthetics to TIVA reduces emissions and the costs of procuring volatile agents, while introducing ultra-low fresh gas flows (<0.5 L/min) further decreases the amount of anaesthetic used. Kampman and Weiland (2023) point out that many “green” measures, such as using reusable equipment, optimising ventilation systems, and reducing waste, also lead to financial savings, which can strongly motivate healthcare institutions to adopt sustainable practices.

4.2 Role of Nurses in Sustainable Practice

The results of the review clearly show that nurses, as direct care providers and managers of resources, are often the drivers of innovation for greater sustainability. Because of their close patient contact and involvement in operational processes, nurses are in an ideal position to spot opportunities to reduce waste and use resources more rationally, for example, by deciding not to open an unnecessary set of instruments or suggesting that a particular patient be managed with TIVA instead of inhalational anaesthesia to cut down on gas emissions. Numerous examples from the literature confirm this role. In the United Kingdom, during the COVID-19 pandemic, Flanagan and Janes (2023) devised and implemented a “see and treat” model for urgent plastic trauma, which resulted in a significant reduction in duplicated visits and overall medical waste. That model, although developed out of a crisis situation, was retained after the pandemic as a permanent innovation that benefits both patients and the environment.

The role of nurse anaesthetists is especially critical in resource-limited settings. Yezu et al. (2025) note that in rural hospitals in South Africa, nurse anaesthetists are crucial for the sustainability of anaesthesia care, because they ensure the continuity of services and provide the training for the local staff, thus reducing the need to transport patients to distant centres (Sjöberg et al., 2023).

In addition to their clinical work, nurses have an important role in education and mentorship. They often educate junior colleagues on the rational use of materials, encourage the team to properly segregate waste, and participate in creating the internal guidelines. The analysis indicates that sustainable initiatives have the greatest chance of success when there is a clearly recognized local champion of change, and in anaesthesia teams, that role is frequently assumed by the nurse anaesthetist.

4.3 Obstacles and Challenges in the Implementation

Despite the recognized benefits, the implementation of sustainable practices in anaesthesiology faces numerous challenges. The most frequently mentioned are related to insufficient knowledge and awareness about the environmental consequences of clinical decisions. Shah et al. (2023) showed that a significant portion of anaesthesia staff in the USA are not familiar with the concept of the carbon footprint of anaesthetics or with existing “green OR” guidelines, while Giuricich et al. (2024) in South Africa found similar results. Inadequate formal education on sustainability, especially among more experienced healthcare workers, further limits the willingness to change (Carvalhais et al., 2025).

A second obstacle is represented by material and infrastructure limitations. Almukhtar et al. (2024) stress that without investment in equipment, such as waste anaesthetic gas capture systems or sterilization capacity for reusable equipment, sustainable practices struggle to take hold. Even when there is staff willingness, a lack of resources, equipment, time, or funding often constrains the implementation of changes.

A third obstacle is the lack of institutional support. Gasciauskaite et al. (2023) highlighted that in institutions where sustainability is not integrated into the quality

management system, implementation depends solely on individual enthusiasm. Resistance to change, scepticism, and fears that sustainable measures could compromise patient safety further complicate implementation, even though most studies, including Sen et al. (2025) confirm that properly executed measures do not adversely affect the quality of care.

4.4 Implications for Practice and Recommendations

The findings of this review point to several clear guidelines for the practice. Education is paramount, topics of sustainable development should be included in the curricula of nursing and anaesthesia training, as well as in the continuous professional development. Petre and Malherbe (2020) demonstrated that online educational modules and courses can significantly increase the awareness and knowledge of sustainable practices.

The second recommendation is the development of local guidelines and protocols, for example, recommendations to avoid desflurane, to routinely apply low-flow anaesthesia, and to switch to TIVA when clinically justified. The Austrian guidelines described by Hammer et al. (2024) and the proposals by Tordjman et al. (2022) can serve as a foundation for local adaptation.

Thirdly, it is important to introduce the systems for monitoring and feedback, the so-called “green audits,” in which nurses would play a key role in collecting the data on resource consumption and waste. Kampman and Weiland (2023) note that regular monitoring not only identifies the areas for improvement but also motivates teams by providing visible results.

At the institutional and national level, management support and the inclusion of sustainability in strategic plans are crucial for a successful long-term implementation. The national plan for sustainable surgery in Nigeria, described by Seyi-Olajide et al. (2021), is an example of how strategic documents can recognize nurses as principal drivers and leaders of change.

4.5 Limitations of the Review and Future Research

This review has several limitations. The search was limited to the works in English with full-text availability, which may have led to the omission of the relevant studies in other languages. Focusing on the period 2020–2025 provided an insight into the most recent trends, but older research was outside the scope.

The heterogeneity of the included studies, in terms of methodology and healthcare system context, makes a direct comparison of the results difficult. Furthermore, the relatively small number of papers explicitly examining the role of nurses in sustainable anaesthesia practice means that, in most cases, the nursing perspective had to be inferred from a broader multidisciplinary context.

Future research is needed that would focus specifically on nurse-led interventions, along with the development of standardized indicators for measuring sustainability in anaesthesia. Formalized guidelines dedicated to sustainable anaesthesia practice from a nursing perspective would be a significant step toward a systematic implementation.

Despite the limitations, these findings clearly demonstrate that nurses have both the potential and the responsibility to lead sustainable changes in anaesthesiology. By integrating environmental principles into the daily practice, they can contribute to environmental protection, patient safety, and the long-term sustainability of the healthcare system.

5 Conclusion

This integrated overview of recent scientific insights highlights the pivotal role of nurses in sustainable anaesthesia practice, emphasising concrete measures demonstrated in the literature to be both effective and feasible without compromising patient safety. Unlike most previous studies, which examined sustainable anaesthesia primarily from the perspective of physicians or technical solutions, this paper provides a structured synthesis of the available evidence on nursing interventions and highlights their strategic and operational importance in reducing the environmental footprint. The contribution of this review is also in connecting the international guidelines with the practical examples of the implementation, thereby building a bridge between the theoretical recommendations and everyday clinical practice.

The results clearly indicate that nurses, particularly nurse anaesthetists, have the potential to be key leaders of change: not only through the adoption of sustainable techniques, but also through team education, advocacy for changes at the institutional level, and leadership in “green audit” projects. Recognising and formally supporting this role could create opportunities for the development of specific educational modules, national guidelines, and measurement tools that could accelerate the transition toward sustainable anaesthesia in the Croatian healthcare system.

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Vloga medicinske sestre anesteziologinje pri zmanjševanju okoljskega odtisa anesteziološke prakse: pregled literature

Operacijske dvorane sodijo med energetske najbolj intenzivne in okoljsko obremenjujoče dele vsake bolnišnice. Porabijo bistveno več energije na kvadratni meter kot večina drugih oddelkov, ustvarjajo velike količine reguliranih in nereguliranih odpadkov ter uporabljajo hlapne anestetike in didušikov oksid, ki imajo toplogredni potencial večkrat večji od ogljikovega dioksida. V tem okoljsko zahtevnem okolju imajo anesteziološke medicinske sestre edinstven položaj, da trajnostna načela prenesejo v varno in ponovljivo klinično prakso ob bolnikovi postelji. Pripravljajo in upravljajo opremo ter zdravila, titrirajo sisteme za dovajanje anestezije, v realnem času spremljajo fiziološke parametre, usklajujejo delo s kirurgi in osebjem v dvorani ter pogosto odločajo, kateri potrošni materiali bodo uporabljeni in kateri ne. Te vsakodnevne od-

ločitve, ponovljene več tisočkrat v bolnišnicah, oblikujejo okoljski odtis perioperativne oskrbe. Čeprav so mednarodne organizacije izdale splošna priporočila za okolju prijaznejšo anestezijo, so praktični ukrepi, ki jih vodijo medicinske sestre na ravni posameznega primera, še vedno pomanjkljivo opisani, številni zdravstveni sistemi pa nimajo nacionalnih smernic in strukturiranega izobraževanja. Na Hrvaškem se zavest o okoljskem vplivu zdravstva povečuje, a trajnostna anestezija še ni sistematično vključena v politike, kurikule ali bolnišnične protokole. Pregled literature zato povzema nedavne dokaze, objavljene med letoma 2020 in 2025, s poudarkom na prispevku medicinskih sester ter predlaga praktične, varne ukrepe za hitro uvedbo v hrvaške bolnišnice, uporabne tudi v širšem regionalnem kontekstu.

Literaturo smo identificirali z usmerjenim iskanjem po bazah PubMed, Web of Science in Scopus julija 2025 z uporabo kombinacij izrazov, povezanih s trajnostjo, anestezijo in zdravstveno nego. Študije so bile vključene, če so bile objavljene med januarjem 2020 in julijem 2025, napisane v angleščini, prosto dostopne v celotnem besedilu in so obravnavale trajnostno anestezijo v kliničnem negovalnem ali interdisciplinarnem kontekstu. Upravičeni dizajni so vključevali randomizirane kontrolirane preizkuse, prospektivne raziskave, opazovalne in kvalitativne študije, sistematične in narativne preglede, strateške preglede, poročila o izboljšanju kakovosti ter module za stalno izobraževanje. Izključeni so bili prispevki, osredotočeni zgolj na tehnične, farmakološke ali veterinarske vidike, povzetki konferenc brez analitične vrednosti ter študije brez sodelovanja medicinskih sester. Od 248 začetno pridobljenih zapisov je bilo po odstranitvi dvojnikov pregledanih 222 enkratnih enot. Po uporabi meril in oceni celotnih besedil je bilo izključenih 59 del, v končno kvalitativno sintezo pa je bilo vključenih 19 študij. Iz teh so se oblikovali sklopi praks, v katerih imajo anesteziološke medicinske sestre odločilno vlogo: optimizacija dovajanja anestetikov, zmanjševanje in ločevanje odpadkov, racionalna izbira in ponovna uporaba opreme, izobraževanje in revizija ter prenova storitev pod vodstvom medicinskih sester.

Optimizacija dovajanja anestetikov se nanaša na neposredne emisije in porabo zdravil, ki izhajajo iz hlapnih sredstev in didušikovega oksida. Tehnike nizkega pretoka svežih plinov zmanjšajo porabo inhalacijskih sredstev brez ogrožanja intraoperativne stabilnosti ali kakovosti prebujanja, če se uporabljajo z nadzorom koncentracije na koncu izdiha in jasnimi varnostnimi mejami. Medicinske sestre so ključne za doseganje teh ciljev, saj sproti uravnavajo pretoke, kalibrirajo vaporizatorje ter vrednotijo globino anestezije glede na klinične znake. Enako pomembna sta opustitev uporabe sredstev z visokim toplogrednim potencialom, zlasti desflurana, in izogibanje rutinski uporabi didušikovega oksida, razen ob dobro utemeljenih indikacijah. Povečana uporaba popolne intravenske anestezije za ustrezne posege se podpira kot učinkovita strategija za zmanjšanje emisij, pri čemer medicinske sestre standardizirajo infuzijske sisteme, pripravljajo zdravila z minimalnimi izgubami, zagotavljajo pravilno nastavitve črpalk ter budno spremljajo vitalne parametre.

Zmanjševanje in ustrezno ločevanje odpadkov na mestu nastanka je drugo ključno področje. Odpadni tokovi v operacijskih dvoranh so heterogeni, nepravilno odlaganje neinfekcijskih materialov med regulirane odpadke pa povečuje stroške in ogljični

odtis. Protokoli, ki jih vodijo medicinske sestre in vključujejo odpiranje potrošnega materiala le po potrebi, racionalizacijo instrumentarija glede na zahteve posega ter jasno označevanje v dvorani, dokazano zmanjšujejo količino neuporabljenih materialov in medicinskih odpadkov. Ker so medicinske sestre odgovorne za pripravo dvorane in cirkulacijo med posegom, lahko sproti nadzorujejo ločevanje, usposabljaajo sodelavce in prepoznavajo ponavljajoče se vire odpadkov.

Tretji sklop se nanaša na izbiro in ponovno uporabo opreme. Kadar standardi nadzora okužb in smernice proizvajalcev to dovoljujejo, imajo večkratne naprave pomembne prednosti pred enkratnimi. Prehod zahteva zanesljive postopke sterilizacije, pravočasno pripravo in zaupanje osebja v varnost. Medicinske sestre pogosto posredujejo med temi zahtevami: poznajo klinične indikacije, predvidijo potrebe posega, sodelujejo s službami za sterilizacijo instrumentov in medicinske opreme in preverijo pripravljenost naprav pri bolniku. Njihove praktične povratne informacije pomagajo pri nabavnih odločitvah, kjer se trajnost ocenjuje skupaj z zmogljivostjo in varnostjo.

Izobraževanje in revizija tvorita četrti sklop. Znanje o okoljskem vplivu anestezioloških odločitev je med osebjem še vedno omejeno. Kratke, na primerih utemeljene učne enote, povezane z vsakodnevnimi poteki dela, skupaj z mislijo na življenjski cikel izdelkov, povečujejo ozaveščenost. Vendar je potrebna tudi povratna informacija. Enostavni revizijski cikli, ki spremljajo porabo anestetikov, pretoke plinov, uporabo didušikovega oksida in količino odpadkov, ekipam omogočajo merjenje napredka. Medicinske sestre pogosto delujejo kot lokalne nosilke teh revizij, zbirajo podatke, pripravljajo grafične prikaze in predstavljajo rezultate sodelavcem.

Končni sklop kaže, da trajnost ni omejena le na tehnične izbire, ampak jo je mogoče vključiti v organizacijo storitev. Omenjen je model »see and treat« pod vodstvom medicinskih sester, uveden za obravnavo travmatskih poškodb v času pandemije COVID-19, ki je zmanjšal ponovne obiske, potovanja pacientov in odpadke ter se obdržal kot trajna praksa.

Identificirane ovire odražajo realnost operacijskih dvoran: pomanjkanje znanja, previdnost izkušenih zdravnikov pri zelo nizkih pretokih plinov ali rutinski uporabi TIVA, časovni pritiski ter materialne omejitve, kot so nezadostne kapacitete sterilizacije ali pomanjkanje sistemov za zajem plinov. Ključen je institucionalni angažma. Ko je trajnost vključena v sistem vodenja kakovosti, imajo pobude medicinskih sester več možnosti za dolgoročno izvajanje.

Za Hrvaško so implikacije neposredne. Brez nacionalnih smernic lahko bolnišnice razvijejo lokalne protokole, ki določajo trajnostne privzete prakse, izobraževanja ter vključitev trajnostnih vsebin v kurikule in stalno izobraževanje. Spremljanje je bistveno: nadzorne plošče, ki prikazujejo mesečno porabo anestetikov, pretoke plinov, količino odpadkov in skladnost z ločevanjem, preoblikujejo trajnost iz ambicije v prakso. Medicinske sestre so primerne, da vodijo takšne procese in povezujejo okoljske koristi z ekonomskimi prihranki.

Omejitve pregleda vključujejo omejitev na angleško govoreče, prosto dostopne objave, heterogenost dizajnov ter redke študije, ki so izrecno obravnavale medicinske

sestre. Potrebne so prihodnje raziskave z uporabo standardiziranih kazalnikov trajnosti in spremljanjem izidov pacientov.

Kljub omejitvam ugotovitve kažejo, da je trajnostna anestezija izvedljiva in klinično varna, če se izvaja z dokazi podprtimi protokoli, stalnim izobraževanjem in transparentnim merjenjem. Medicinske sestre anesteziologinje so v središču te preobrazbe. Njihova stalna prisotnost ob bolniku, upravljanje materialov, izobraževalna vloga in avtoriteta pri revizijah jim dajejo edinstveno moč za zmanjšanje ogljičnega odtisa perioperativne oskrbe brez kompromisov pri varnosti.

Data Availability Statement

This article is based on research data obtained from existing and publicly available sources (textual sources, databases), which are listed in the References section.

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