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The environmental footprint of anaesthesia: a one-day comparative analysis of greenhouse gas emissions in anaesthesiology practice

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Abstract

The aim of the study was to assess the carbon footprint generated during anesthetic procedures using total intravenous anaesthesia (*TIVA*) and a mixed (intravenous–inhalational) strategy over the course of a single workday at a university hospital. The study was conducted by counting the waste generated by the anaesthesia team. Subsequently, the carbon footprint was calculated based on the weight of individual materials using appropriate emission factors (kg CO_2e/kg). Local and global carbon footprint values were compared based on data from the literature. We found that during a single anaesthesia procedure, an average of 12.92 kg CO_2e was generated per operating room. Procedures using TIVA generated an average of 3.10 kg CO_2e, while a mixed strategy with the use of sevoflurane generated 7.91 kg, and desflurane 195.40 kg of CO_2e. TIVA generates a significantly lower carbon footprint than a mixed strategy. These results provide a basis for promoting more environmentally friendly solutions in anaesthesiology and supporting efforts toward sustainable healthcare. *Anestezjologia i Ratownictwo 2026; 20: 133-139. doi:10.53139/AIR.20262011*

Keywords: carbon footprint, sevoflurane, desflurane, TIVA, inhalational anaesthetics, environmental considerations in anaesthesiology

Introduction

A carbon footprint refers to the greenhouse gas emissions, primarily CO_2, generated by the activities of a given entity - an individual, an institution (e.g. a building), or a country [1]. The healthcare sector accounts for approximately 4-5% of the world's total carbon footprint [2]. In operating rooms, the consumption of anaesthetic gases plays a key role, accounting for up to two-thirds of the emissions generated during a single procedure [3]. Among anaesthetics, nitrous oxide (N_2O) and desflurane have a significantly higher environmental impact [4]. There is an increasing discussion regarding the choice of anaesthesia method and its environmental impact, encouraging the replacement of desflurane with sevoflurane or even the complete elimination of inhaled anaesthetics. Total intravenous anaesthesia (*TIVA*) is emerging as a sustainable alternative, aiming to promote an eco-friendly solution in the healthcare sector [5]. The environmental impact of propofol is relatively small and estimated to be nearly 10,000 times lower than that of desflurane or nitrous oxide. Pollution is primarily caused by the electricity consumed by the syringe pump, rather than the drug's production or its direct release into the environment [6].

Aim of the study

The aim of this study was to investigate the anaesthesia-related carbon footprint emissions over the course of a single day in the operating room of a university hospital and to compare the data with global trends - specifically, the average emissions generated per procedure and the emissions associated with TIVA anaesthesia versus mixed anaesthesia strategies.

Materials and methods

The study was conducted over a single day (March 18, 2025) at a university hospital, between 7:30 a.m. and 3:30 p.m., and included only scheduled surgical procedures. Emergency surgeries were excluded, as their dynamic nature and unpredictability could significantly affect the reliability and consistency of the collected data.

The first stage of the study involved weighing individual components of medical supplies, categorized into glass, plastic, paper, metal and mixed materials. As mixed materials, we referred to equipment that did not fit into the previously mentioned categories, such as elements combined from plastic and metal. Composite items were separated into their constituent materials prior to measurement (e.g. syringe packaging was divided into paper and plastic components). Axis AD50 and Axis AG2000C scales were used for weighing. Measurements were performed with an accuracy of 0.001 g and 0.1 g, respectively.

The second stage of the study involved quantifying used disposable medical supplies, categorized into plastic, metal, paper, and glass. Data were collected on the study day by six medical students in collaboration with anaesthesia teams (physicians and nurses), who had been informed in advance. Each student was assigned to two operating rooms, where they observed the activities of the anaesthesia team to ensure that waste was properly disposed of in designated medical waste bags which ensured precise and consistent data collection. The students were present during the induction of anaesthesia and at the time of patient emergence. The collected data were supplemented with information obtained from anaesthesia records and anaesthesia machines, including the volume of inhaled anaesthetic used, as indicated by the machine.

The analysis included waste generated in 12 operating rooms in which surgical procedures were performed on the study day, covering the following specialties: neurosurgery, otorhinolaryngology, orthopedics, general surgery, transplant surgery and maxillofacial surgery.

The third stage of the study involved calculating the carbon footprint using the following formula depending on the type of material:

Carbon Footprint [kg CO_2e]= weight of raw material [kg] × emission factor [kg CO_2e/kg]

Carbon footprint (kg CO_2e) = volume of anaesthetic gas (mL) × emission factor (kg CO_2e/mL)

Emission factors used for the calculation of the carbon footprint associated with the combustion of each material are presented in Table 1 and Table 2.

Table 1. Emission factors for waste materials [7,8,9,10,11]

material	carbon emission factor (kg CO_2e/kg)
plastic	2.70
paper	0.02
mixed materials	1.00
metal	0.02
glass	0.03

Table 2. Emission factors for anaesthetic gases [12]

material	carbon emission factor (kg CO_2e/kg)
sevoflurane	0.20
desflurane	3.69

In the fourth stage of the study, a literature review was conducted using the PubMed and Google Scholar databases to identify information on CO_2e emissions in hospitals associated with anaesthesia teams. The following search terms were used: 'carbon footprint general anaesthesia', 'carbon footprint TIVA', 'carbon footprint inhaled anaesthesia', and 'carbon footprint per procedure'.

All data collected during the study were anonymized and used exclusively for scientific purposes. The study was conducted in accordance with research ethics principles, with strict confidentiality maintained regarding staff and patient information

Results

On the day of the study, a total of 30 surgical procedures were performed, including neurosurgery (n = 4), general surgery (n = 4), maxillofacial surgery (n = 4), transplant surgery (n = 6), otolaryngology (n = 6), and orthopedic surgery (n = 6).

Nineteen procedures involved female patients and eleven involved male patients. All patients were adults, with a mean age of 50.3 years (SD = 18.61). The mean age was 53.9 years (SD = 18.29) for women and 31.9 years (SD = 17.97) for men.

Of the 30 procedures, 4 were performed under regional anaesthesia and 26 under general anaesthesia. Within the regional anaesthesia group, 1 procedure used subarachnoid anaesthesia, 1 used nerve block, and 2 used a combination of both. In this group three patients received analgosedation (propofol or midazolam + fentanyl), whereas one patient was treated with midazolam sedation only.

Within the general anaesthesia group, 2 procedures (7%) were performed using TIVA, while 24 procedures (93%) involved the use of inhalational

Table 3. Statistical summary of carbon footprint emissions (kg CO_2e) on the study day, according to type of anaesthesia and waste type

Type of anaesthesia	Material	Number of procedures (N)	Total	Mean	SD	Min	Max
All anesthesia types *(TIVA, mixed, regional)*	plastic kg CO_2e	30	66.60	2.22	1.11	0.68	5.85
	paper kg CO_2e	30	0.06	0.00	0.00	0.00	0.00
	mixed materials kg CO_2e	30	8.45	0.28	0.21	0.05	0.70
	metal kg CO_2e	30	0.04	0.00	0.00	0.00	0.00
	glass kg CO_2e	30	0.06	0.00	0.00	0.00	0.01
	sevoflurane kg CO_2e	23	124.00	5.39	4.90	1.40	23.80
	desflurane kg CO_2e	1	191.88	value for a single procedure			
Regional anaesthesia	plastic kg CO_2e	4	6.93	1.73	0.80	0.68	2.49
	paper kg CO_2e	4	0.01	0.00	0.00	0.00	0.00
	mixed materials kg CO_2e	4	1.42	0.35	0.21	0.18	0.64
	metal kg CO_2e	4	0.00	0.00	0.00	0.00	0.00
	glass kg CO_2e	4	0.00	0.00	0.00	0.00	0.00
TIVA	plastic kg CO_2e	2	5.47	2.73	0.65	2.27	3.20
	paper kg CO_2e	2	0.01	0.00	0.00	0.00	0.00
	mixed materials kg CO_2e	2	0.69	0.35	0.04	0.32	0.37
	metal kg CO_2e	2	0.00	0.00	0.00	0.00	0.00
	glass kg CO_2e	2	0.01	0.01	0.00	0.00	0.01
Mixed anaesthesia with sevoflurane	plastic kg CO_2e	23	51.22	2.23	1.19	1.01	5.85
	paper kg CO_2e	23	0.04	0.00	0.00	0.00	0.00
	mixed materials kg CO_2e	23	5.80	0.25	0.19	0.05	0.70
	metal kg CO_2e	23	0.04	0.00	0.00	0.00	0.00
	glass kg CO_2e	23	0.00	0.00	0.00	0.00	0.00
	sevoflurane kg CO_2e	23	124.00	5.39	4.90	1.40	23.80
Mixed anaesthesia with desflurane	plastic kg CO_2e	1	2.98	value for a single procedure			
	paper kg CO_2e	1	0.00				
	mixed materials kg CO_2e	1	0.54				
	metal kg CO_2e	1	0.00				
	glass kg CO_2e	1	0.00				
	desflurane kg CO_2e	1	191.88				

Note: Values presented in the table have been rounded to two decimal places. In the original dataset, full numerical precision (i.e., more decimal places) was retained. As a result, minimum and maximum values may appear as 0.00, although their true values are non-zero but very small.

anaesthetic agents, specifically desflurane (4%) and sevoflurane (88%). The duration of anesthesia with desflurane was 285 minutes.

On the day of the study, a total of 40.09 kg of waste was generated, of which 61.54% was plastic. The mean amount of waste per procedure was 1.34 kg (SD = 0.63), ranging from 0.53 to 2.99 kg.

On that day, the total carbon footprint (CO_2e) generated by the anaesthesia team amounted to 391.10 kg CO_2e, with anaesthetic gases accounting for 80.77% of total emissions (315.88 kg CO_2e). Anaesthesia with the use of sevoflurane was the most frequently chosen technique, accounting for 76.67% of all anaesthetic procedures and 88.46% of general anaesthetics.

Emissions varied depending on the type of procedure. Among patients undergoing regional anaesthesia, emissions ranged from 0.90 to 2.55 kg CO_2e. In contrast, in the general anaesthesia group, emissions ranged from 3.14 to 195.41 kg CO_2e. Overall, emissions on the study day ranged from 0.90 to 195.41 kg CO_2e, with a mean of 12.92 kg CO_2e per operating room.

Summary statistics are presented in Table 3.

<u>Anaesthetic gases and carbon footprint emissions on the day of the procedure</u>

The average carbon footprint per procedure was lowest for TIVA (3.10 kg CO_2e). In comparison, the use of sevoflurane and desflurane increased emissions by 155% and 6203%, respectively. In operating rooms where sevoflurane was used, the mean carbon footprint was 7.91 kg CO_2e, whereas the use of desflurane resulted in a substantially higher mean of 195.40 kg CO_2e. The elevated emissions associated with desflurane were directly attributable to its use, accounting for up to 98.19% of total procedure-related emissions.

Total carbon footprint emissions on the study day were markedly lower in patients receiving TIVA compared to those receiving inhalational anaesthesia (6.18 kg vs. 376.56 kg CO_2e, respectively). Similarly, the mean emissions per procedure were lower in the TIVA group (3.10 kg CO_2e) than in the inhalational anaesthesia group (15.59 kg CO_2e). When expressed per hour of anaesthesia, TIVA was associated with the lowest carbon footprint (0.72 kg CO_2e/h), compared with 3.66 kg CO_2e/h for sevoflurane and 41.14 kg CO_2e/h for desflurane.

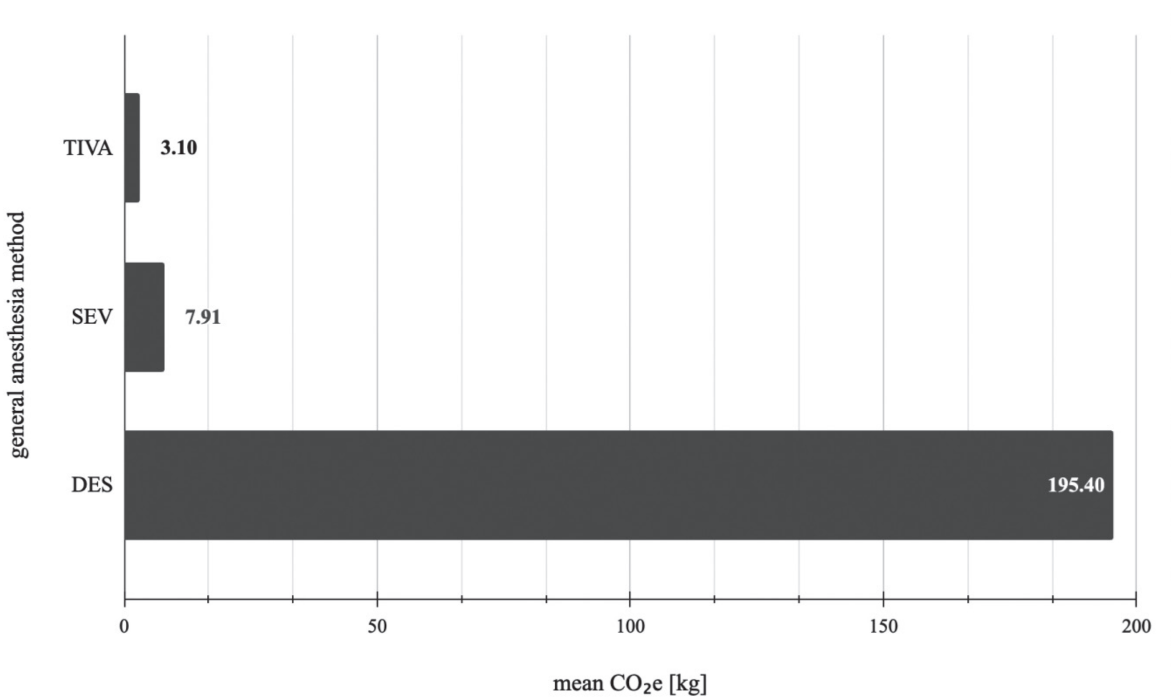

Figure 1. Mean CO_2e per procedure for TIVA and inhalational anaesthesia (sevoflurane [SEV], desflurane [DES]) based on study-day data

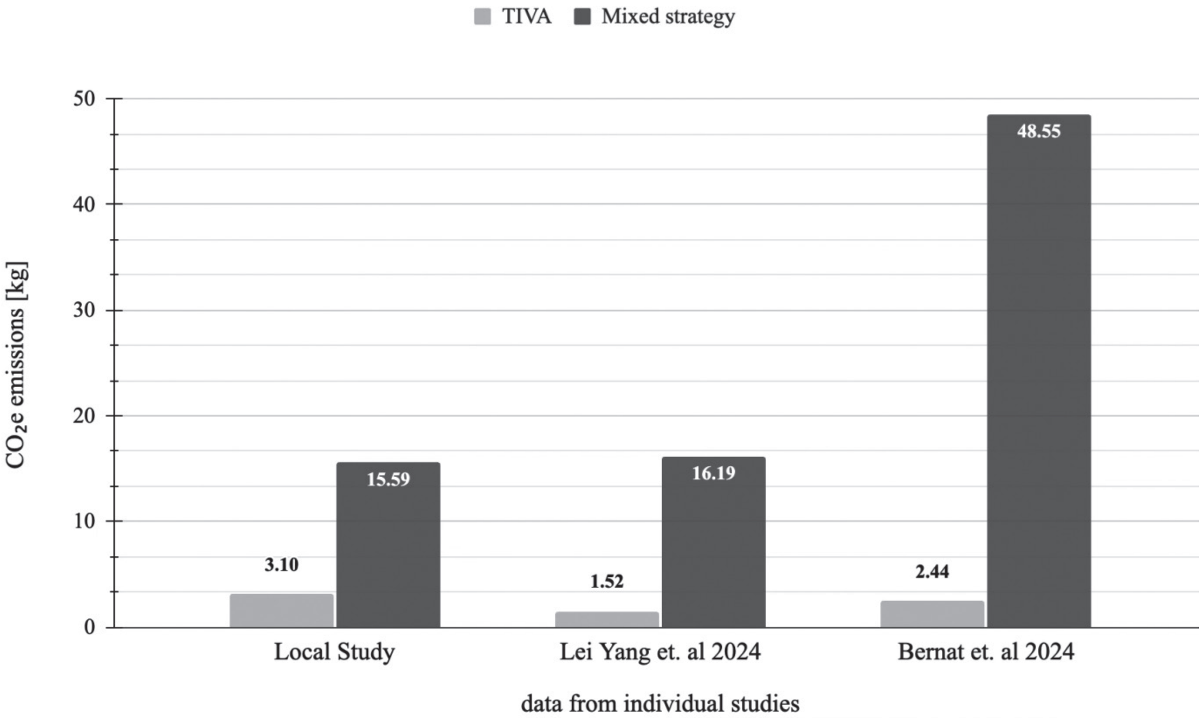

Figure 2. Mean CO_2e emissions (kg per patient) by anaesthesia technique (TIVA vs. mixed) compared with published data [14,15]

Discussion

In the present study, CO_2 emissions at the university hospital ranged from 0.90 to 195.41 kg CO_2e per procedure. By comparison, de'Angelis et al. (2024) reported a broader range of 4.00 to 814.00 kg CO_2e per procedure [13]. With regard to waste generation, the local values ranged from 0.53 to 2.99 kg per procedure, whereas global data indicate a range of 0.20 to 4.00 kg [13]. These differences may be attributed to variations in surgical type, hospital characteristics, and geographic region.

The findings of de'Angelis et al. (2024), which also included emissions generated by the surgical team, demonstrated that anaesthetic gases constitute the largest share of total emissions per procedure [13]. This is consistent with the present study, where anaesthetic gases were the dominant contributor to the overall carbon footprint.

Comparative analyses of anaesthesia techniques confirm that TIVA is associated with lower emissions than inhalational or mixed strategies. Lei Yang et al. (2024), in a study of 604 patients undergoing transcatheter aortic valve implantation (TAVI), reported mean emissions of 1.52 kg CO_2e per procedure for TIVA, compared to 16.19 kg CO_2e for inhalational anaesthesia [14]. Similarly, Bernat et al. (2024), in a large multicenter study including 47.157 procedures, demonstrated lower emissions for TIVA compared to mixed anaesthesia (2.42 kg vs. 48.85 kg CO_2e per procedure) [15].

In the present study, the same trend was observed. Mean CO_2e emissions were significantly lower for TIVA (3.10 kg) than for mixed anaesthesia (15.59 kg), as illustrated in Figure 2. However, the absolute values differed from those reported in the literature. Emissions associated with TIVA in the local study were higher than those reported by Lei Yang et al. (2024) and Bernat et al. (2024), by 104% and 27%, respectively. In contrast, emissions associated with the mixed strategy were lower, corresponding to 96% of the values reported by Lei Yang et al. (2024) and 32% of those reported by Bernat et al. [14,15].

These discrepancies may be explained by several factors. First, the present study was limited to a single day of routine operating room activity, resulting in a relatively small and potentially non-representative sample size, particularly in the TIVA group. Second, the analysis did not include the full life cycle assessment (LCA) of products or energy consumption associated with anaesthesia equipment, which may have influenced the results. Furthermore this study focused exclusively on the anaesthesia process, from induction to emergence. Preoperative preparation and postoperative recovery were not included in the analysis. Additionally, energy consumption associated with anaesthesia and surgical equipment, as well as operating room lighting and ventilation, was not considered. Finally, the study was limited to a single day of operating room activity.

No directly comparable 'single-day' studies were identified in the literature; therefore, studies with longer observation periods were included for comparison. Due to the limited availability of strictly anaesthesiology-focused data, the literature search was expanded to include surgical studies. Only studies comparing intravenous and mixed anaesthesia techniques were included, while studies focusing exclusively on inhalational anaesthesia or pediatric populations were excluded.

The review was intended only to reflect the general trend, which showed that TIVA anaesthesia results in lower emissions than the mixed strategy

Importantly, all analyzed studies - both local and global - demonstrate a consistent increase in emissions associated with the use of inhalational or mixed anaesthesia techniques. Within this group, desflurane was identified as a particularly significant contributor to emissions. In our study, a single procedure using desflurane generated more CO_2e than all procedures performed with sevoflurane combined. It should also be noted that nitrous oxide was not used in the study setting, and desflurane was used in only one case, whereas sevoflurane was used more frequently.

These findings highlight the potential for anaesthesiologists to reduce the carbon footprint of clinical practice through conscious selection of anaesthetic techniques. For example, Park et al. (2024) demonstrated that targeted staff education led to a 50% reduction in desflurane use, contributing to more environmentally sustainable practice [16]. Similarly, Kampman et al. (2025) recommended prioritizing TIVA whenever feasible and reserving inhalational anaesthesia for cases where it is necessary [17]. Implementing educational interventions among anaesthesia providers at the study institution may be a reasonable strategy, followed by an evaluation of their impact on emission reduction.

Conclusions

This single-day study evaluated the environmental impact of the daily clinical practice of the anaesthesia team. Based on the analysis of a small patient group, it may be inferred that total intravenous anaesthesia is associated with a lower carbon footprint compared to combined intravenous–inhalational anaesthesia. The use of desflurane appears to be associated with higher carbon footprint emission. Although the study group was small, the observed trend is consistent with findings reported in the global literature. These results therefore suggest that patterns identified in larger-scale studies may also be present in local clinical practice. The environmental impact associated with the choice of anaesthetic technique is an important consideration in the context of environmental sustainability and could be taken into account in clinical decision-making. However, it should be emphasized that it is not the overriding factor, as patient safety and clinical efficacy remain paramount.

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Conflict of interest
None

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