ORIGINAL CLINICAL RESEARCH REPORT

OPEN

The Power of Education to Reduce the Carbon Footprint of Volatile Anesthetics in Clinical Practice

Arne Schwiethal, MSc,[1] Sascha Treskatsch, MD,[2] Jannis Michael, MSc,[1] Moritz Höft, MD,[3] Claudia D. Spies, MD,[3] and Susanne Koch, MD[3,4,5]

BACKGROUND: Due to their chemical nature as fluorinated hydrocarbon compounds, volatile anesthetics are highly potent greenhouse gases, with desflurane having by far the largest CO_2-equivalent (CO_2e) footprint. In everyday clinical practice, the CO_2e footprint can easily be reduced through the increased use of propofol or sevoflurane as well as low- and minimal-flow techniques or through the more frequent use of regional anesthesia techniques. We wanted to assess to what extent educational measures on sustainability aspects of the use of volatile anesthetics had an impact on daily practice in anesthesiology departments and to what extent this influenced the hospital's CO_2e emissions.

METHODS: We conducted an observational data analysis of the consumption of anesthetics (sevoflurane, desflurane, isoflurane, and propofol) at all 3 clinical Charité campuses in the period from 2015 to 2023. The CO_2e emissions were calculated for sevoflurane, desflurane, and isoflurane. External and internal (top-down or bottom-up) educational measures focusing on sustainability in anesthesia took place from September 2018 on. Shifts in CO_2e emissions related to the educational measures are shown in a run chart. The number of surgeries, surgery duration, and purchasing costs were included in the analysis.

RESULTS: CO_2e emissions of volatile anesthetics were reduced by 90.3% from the baseline epoch (years 2015–2017) before educational interventions took place to 2023: CO_2e 1470 tons (mean 2015–2017), to 191 tons (2022) to 142 tons (2023). This change was brought about by the phasing out of desflurane and the use of propofol or sevoflurane and regional anesthesia where appropriate. The fastest and most sustainable changes were seen after internal top-down measures. The total cost of anesthetics also fell over the period under review (from €541,102/$594,238 in 2015 to €281,646/$309,303 in 2023).

CONCLUSIONS: Educational measures for anesthesiologists about the climate-damaging effects of volatile anesthetics—especially desflurane—can significantly reduce CO_2e emissions in anesthesia clinics. On the positive side, these measures have also reduced the annual costs for anesthetics. (Anesth Analg 2025;141:868–875)

KEY POINTS

- **Question:** To what extent can education on the carbon footprint of volatile anesthetics (desflurane, sevoflurane, and isoflurane) reduce the daily practice-related carbon emissions in anesthesiology departments?
- **Findings:** The carbon footprint of volatile anesthetics was reduced by ~90% over 5 years in 3 university anesthesiology departments simply through repeated lectures, publications, and adaptation of internal standard operating procedures on the climate impact of volatile anesthetics. This also resulted in significant cost savings.
- **Meaning:** Education is an effective, cost-efficient, and quick-to-implement measure to reduce the carbon footprint of daily anesthesiology practice.

From the [1]Department of Revenue Management, Charité-Universitätsmedizin Berlin, Berlin, Germany; [2]Department of Anesthesiology and Intensive Care Medicine, Campus Benjamin Franklin, Charité-Universitätsmedizin Berlin, Berlin, Germany; [3]Department of Anaesthesiology and Intensive Care Medicine, Campus Mitte and Campus Virchow Klinikum, Charité-Universitätsmedizin Berlin, Berlin, Germany; [4]Department of Anaesthesia, Zealand University Hospital, Nykobing F, Denmark; and [5]Department of Regional Health Research, University of Southern Denmark, Odense, Denmark.

Copyright © 2025 The Author(s). Published by Wolters Kluwer Health, Inc. on behalf of the International Anesthesia Research Society. This is an open-access article distributed under the terms of the Creative Commons Attribution-Non Commercial-No Derivatives License 4.0 (CCBY-NC-ND), where it is permissible to download and share the work provided it is properly cited. The work cannot be changed in any way or used commercially without permission from the journal.

DOI: 10.1213/ANE.0000000000007375

Accepted for publication November 13, 2024.

Conflicts of Interest, Funding: Please see DISCLOSURES at the end of this article.

Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's website (www.anesthesia-analgesia.org).

A. Schwiethal and S. Treskatsch contributed equally to this work.

Reprints will not be available from the authors.

Address correspondence to Assoc Prof Dr Susanne Koch, MD, Department of Anaesthesiology and Intensive Care Medicine, Charité – Universitätsmedizin Berlin, Campus Charité Mitte and Virchow-Klinikum, Augustenburger Platz 1, Berlin D-13353, Germany. Address e-mail to susanne.koch@charite.de.

The health care sector will increasingly have to deal with the consequences of climate change in the future.[1] The limit of 1.5 °C global warming was exceeded in 2024, and further global warming is already "in the pipeline."[2] Policy makers are aiming for net zero emissions while allowing fossil fuel extraction to continue to rise and coal, oil, and gas companies around the world to reap unchecked high profits. But the health care sector itself is also responsible for ~4.4% of total greenhouse gas emissions worldwide (Health Care Without Harm) and ~5.2% of greenhouse gas emissions in Germany.[3] In 2019, a climate protection agreement was signed between the Charité and the state of Berlin with the aim of reducing total greenhouse gas emissions at all 3 hospital sites of the Charité Universitätsmedizin Berlin (Campus Virchow Klinikum [CVK], Campus Benjamin Franklin [CBF], and Campus Charité Mitte [CCM]). Charité's CO2-equivalent (CO2e) emissions amounted to ~126.6 thousand tons per year.[4] By the end of 2021, CO2e emissions could be reduced to 104.8 thousand tons, primarily through the installation of a combined heat and power plant on Charité's CVK campus.[4]

To reduce the carbon footprint in anesthesiology departments, the next important issue after reducing energy consumption and switching to renewable energy is the daily use of volatile anesthetics.[5] These substances, classified as hydrofluorocarbons or chlorofluorocarbons (HFCs/CFCs), are almost completely released into the atmosphere after general anesthesia due to their low metabolization rate (<5%).[6] It is important to know that volatile anesthetics have a much higher global warming potential (GWP) compared to CO_2. In the case of desflurane, the GWP over a period of 100 years (GWP_{100}) is 2540 times higher (Supplemental Digital Content 1, Table S1, http://links.lww.com/AA/F169).[7] In contrast to CO_2, however, volatile anesthetics have a relatively short atmospheric lifetime of <10 years.[7] The short-term warming effect is therefore even greater than the commonly used GWP_{100}, as it only indicates a residual effect of their climate impact (Supplemental Digital Content 1, Table S1, http://links.lww.com/AA/F169).[8] Unfortunately, this knowledge is not yet part of standard training in anesthesia (at least in Germany), and many anesthetists are not yet aware of this.[9] For this reason, we have been trying to educate our colleagues in the Departments of Anesthesiology and Intensive Care Medicine at Charité since spring 2018.

Here we present an evaluation of the effectiveness and sustainability of these courses in the anesthesiology departments of the Charité. We assessed the change in CO_2e emissions caused by volatile anesthetics in the period from 2015 (3 years before the start of the courses) to the end of 2023 for each clinical site of the Charité, depending on the timing and type of courses.

METHODS

We conducted a retrospective analysis at all 3 clinical campuses of the Charité (CVK, CBF, and CCM) to investigate the impact of external or internal (top-down or bottom-up) interventions focusing on the sustainability of anesthetics (desflurane, sevoflurane, isoflurane, and propofol) on daily practice and use of anesthetics by anesthetists at the 3 different campuses. We calculated the carbon footprint (CO2e) in connection with the amount of anesthetics used per quarter (Q1, Q2, Q3, and Q4) for the years 2015 to 2023 for each individual Charité campus and for all campuses together. The observation period begins in the first quarter of 2015 and ends in the fourth quarter of 2023. The intervention period began in September 2018 (fourth quarter of 2018), with the last intervention taking place in March 2023. This selection created a comparable baseline before the start of educational efforts within the Charité anesthesiology departments in 2018. Our data were extracted from the in-house pharmacy department and the business unit, which are datasets without patient identifiers. Therefore, our dataset did not contain any patient data.

Data Set

Interventions. We categorized interventions into external and internal events. External events included anesthesiological congresses and symposia in Berlin or scientific publications in the leading German anesthesiological journals by a member of our departments. Internal events either included teaching events in one of the clinics (bottom-up) or clearly stated sustainable decisions by the head of the department or the implementation of a standard operating procedure (SOP) with a focus on the sustainable use of anesthetics (top-down). We assume that external events would reach ~5% to 30% of anesthetists at all 3 clinical campuses of the Charité. Internal bottom-up events (teaching events) could reach approximately 50% to 80% of the anesthetist at the individual Charité campus where the teaching event took place. Internal top-down events are most likely to reach 100% of the members of the department, as they are mandatory for all members of the department. A list of all intervention events from September 2018 to March 2023 can be found in the Table. In particular, attention was drawn to the very high CO_2e footprint of desflurane compared to sevoflurane, isoflurane, or propofol. It was therefore recommended that the use of desflurane should be avoided. Sevoflurane and isoflurane should be administered in minimal- or low-flow techniques and, if possible, total intravenous

Table. List of Interventions Showing the Date, Location, and a Detailed Description of the Type and Content of Each Intervention

Date	Campus	Intervention group	Intervention description	Content of intervention
September 2018	All	External	Info desk at the German anesthesiological congress in Berlin	Climate change impact on health/carbon footprint of the health care sector/high carbon footprint of desflurane
December 2018	CBF	Internal top-down	Decision from the head of the department	Stop the use of desflurane
September 2019	CVK	Internal bottom-up	Lecture	Climate change impact on health/carbon footprint of the health care sector/high carbon footprint of desflurane
December 2019	CCM	Internal bottom-up	Lecture	Climate change impact on health/carbon footprint of the health care sector/high carbon footprint of desflurane
July 2020 and August 2020	All	External	Publication in German anesthesiological journals	Climate change impact on health/carbon footprint of the health care sector/high carbon footprint of desflurane/ recommendation to use low- and minimal-flow anesthesia or TIVA/ recommendation to avoid single-use material/ High energy needs of anesthesiological departments https://pubmed.ncbi.nlm.nih.gov/32346776/ and doi: 10.19224/ai2020.329 (German)
March 2021	All	External	Specialist training course in Berlin	Clinical anesthesiology/high carbon footprint of desflurane, recommendation to use of low- and minimal-flow anesthesia or TIVA
November 2021	CBF	Internal bottom-up	Setup a "Green-Team"	Green-Team within the anesthesiological department, change clinical practice toward a more sustainable way/ recommendation to use low- and minimal-flow anesthesia or TIVA/recommendation to avoid single-use material/high energy needs of anesthesiological departments
March 2022	All	External	Specialist training course in Berlin	Clinical anesthesiology/high carbon footprint of desflurane, recommendation to use of low- and minimal-flow anesthesia or TIVA
September 2022	CBF	Internal top-down	Standard operating procedure	Implementing a SOP for sustainability in anesthesiology: primary use of TIVA with propofol, use always low and minimal flow for sevoflurane anesthesia, no more use of desflurane
March 2023	All	External	Specialist training course in Berlin	Clinical anesthesiology/high carbon footprint of desflurane, recommendation to use of low- and minimal-flow anesthesia or TIVA

The interventions were divided into external and internal interventions. External interventions refer to anesthesiology training on the topic of sustainability in the region (Berlin). Internal interventions took place at individual sites and are further divided into "top-down" and "bottom-up" interventions, with "bottom-up" interventions being further training, lectures or publications of a nonbinding nature, while "top-down" interventions indicate binding guidelines from the respective hospital management.

Abbreviations: CBF, Campus Benjamin Franklin; CCM, Campus Charité-Mitte; CVK, Campus Virchow Klinikum; TIVA, total intravenous anesthesia.

anesthesia (TIVA) with propofol or regional anesthesia should be preferred.

In January 2020, the Commission for Sustainability in Anesthesiology of the German Society for Anesthesiology and Intensive Care Medicine (DGAI) was established by one of the authors (S.K.). In the following month, various manuscripts on the topic were published, including a position paper focusing on sustainability in anesthesiology.[8,10,11] In 2021, 2 members of the Department of Anesthesiology launched a German-language podcast on the topic of sustainability in anesthesiology, and public media also picked up the Department of Anesthesiology`s efforts on the climate impact of anesthetic gases.[12–14] However, as these were informal events, they were not included in the list of interventions. Importantly, no anesthetic gas filters or recycling cartridges were installed at all Charité campuses by the end of 2023, nor were stickers with information on the carbon footprint of anesthetic gases affixed to the ventilators in the departments.

Anesthetic Consumption. The relevant measured variable was the consumption of the individual anesthetics (sevoflurane, desflurane, isoflurane, propofol) per Charité campus, whereby the quarterly purchase quantity for sevoflurane, isoflurane, desflurane, and propofol (concentrations: 0.5%, 1%, and 2%) (Supplemental Digital Content 1, Table S2, http://links.lww.com/AA/F169) and the associated costs per campus were requested from the in-house pharmacy. In the evaluation, it was assumed that the quantity purchased corresponds to the consumption quantity. Based on the chemical properties and concentrations of the individual preparations, the quantities of pure substance consumed were determined. The GWP (CO_2e) was then calculated on the basis of data from Sulbaek Andersen et al[7] and Özelsel et al[15] over the timeframe of 100 years (GWP_{100}), and over the timeframe of 5 years (GWP_5) to take into account, the chemical nature of volatile anesthetics, which already have the majority of their climate impact in the first 5 years after release. CO_2e emissions are presented for the timeframe of 5 years (GWP_5).

Costs. In addition to the consumption of anesthetics, the costs for the purchase of individual anesthetics were also included in the analysis. To account for a decrease in the number of operations in 2020 and

2021 due to the coronavirus disease-2019 (COVID-19) pandemic restrictions and a strike by health care staff at Charité lasting several weeks,[16] we also calculated the CO_2e emissions standardized to operation hours (CO_2e emissions kg/h of operation). The number and duration of operations were taken from the clinical database with the following attributes: operations under general anesthesia: incision-suture time >0/anesthesia time >0; operations with local or regional anesthesia: incision-suture time >0/anesthesia time = 0.

Statistical Analysis

Statistical analyses were performed with the SPSS software program, version 26 (copyright SPSS, Inc). The data are presented as counts or as calculated parameters. The temporal course of CO_2e emissions (GWP5) as a function of the quarterly consumption of the anesthetics used (desflurane, sevoflurane, isoflurane, and propofol) is shown as a run chart figure for each individual clinical campus of the Charité and for all campuses together.[17] External and internal events are included in the run chart graph. To get an overview, we compared the CO_2e values before and after the first external intervention. We draw a center line for the entire period, as well as a center line for the period before the interventions started (Q1/2015–Q3/2018) and a center line after the interventions started (Q4/2018–Q4/2023).

The differences in CO_2e emissions before and after intervention measures are shown as a box plot using Student *t* test or Mann-Whitney *U* test, if the normal distribution is missing. The effects of the individual internal events were determined on the basis of data from 4 quarters before and after the measure.

RESULTS

In the 3 years before the first intervention (2015, 2016, and 2017) the CO_2e emissions (GWP_5) from all Charité campuses caused by the use of volatile anesthetics summed up to >7500 tons/y (2015 = 7577 tons; 2016 = 8130 tons; and 2017 = 8169 tons) and fell continuously after the first external intervention in September 2018 to finally 1454 tons in 2023 (2018 = 6792 tons; 2019 = 4309 tons; 2020 = 3420 tons; 2021 = 2193 tons; and 2022 = 1957 tons). CO_2e emissions (GWP_{100}) fell from 1538 tons in 2017 to 142 tons in 2023 (Supplemental Digital Content 1, Table S3, http://links.lww.com/AA/F169).

Before the start of the interventions median of 2009 tons/quarter CO_2e was emitted at Charité, with large differences between the individual hospital sites (median CO_2e emissions: CVK = 1189 tons/quarter, CBF = 592 tons/quarter, CCM = 173 tons/quarter) (Figure 1). These differences are mainly related to the different use of anesthetics, also depending on the surgical departments, as well as the different number of operating theaters (CVK 32 operation theaters with 12 intervention places; CBF: 21 operation theaters with 3 intervention places, CCM: 15 operation theaters). After the interventions, CO_2e emissions at Charité in general, but also at each individual campus, have decreased significantly (Supplemental Digital Content 1, Table S4, http://links.lww.com/AA/F169).

The short-term effects (1 year) of internal measures were significant for top-down interventions in every case and showed an impressive and rapid reduction, while bottom-up measures did not always lead to a clear and sustainable reduction in CO_2e emissions (Figures 1 and 2; Supplemental Digital Content 1, Table S4, http://links.lww.com/AA/F169). The overall reduction was mainly driven by the phase-out of desflurane. Today, desflurane is no longer used in any of the anesthesiology departments at Charité. The fastest and most sustainable reduction in CO_2e emissions occurred after internal top-down interventions (Figures 1C and 2), while external interventions or internal bottom-up interventions also resulted in a long-term reduction, but short-term setbacks could also occur (Figures 1B, 1D, and 2) and continuous measures were required to achieve a sustainable reduction.

Cumulative surgery hours were initially stable in the reporting period from 2015 to 2019, followed by a decline in 2020 and 2021 and a recovery in the total number of surgeries from 2022 on. As this could have biased our results, we have recalculated the CO2e emissions normalized to operating hours as a sensitivity analysis, where we did not find any major difference in the dynamics and the overall result (Supplemental Digital Content 1, Figure S1, http://links.lww.com/AA/F169).

It is important to note that from 2020 onwards there was an increase in operations performed under local or regional anesthesia (Supplemental Digital Content 1, Figure S1, http://links.lww.com/AA/F169), which was also part of the sustainable recommendations (Table).

The annual cost trend for the anesthetics described here was also decreasing (annual total costs 2015: €541,102/$594,238 to 2023: €281,646/$309,303), with the largest cost savings achieved by reducing and finally eliminating desflurane (Supplemental Digital Content 1, Figure S1, http://links.lww.com/AA/F169). We also adjusted the costs to anesthesia duration. We found again a clear decrease in the cost per hour of general anesthesia at all 3 clinical sites (Figure 3), and for all Charité campuses together from €2.34/$2.57 in 2015 to €1.05/$1.15 in 2023, with the increased purchase of propofol driving down costs.

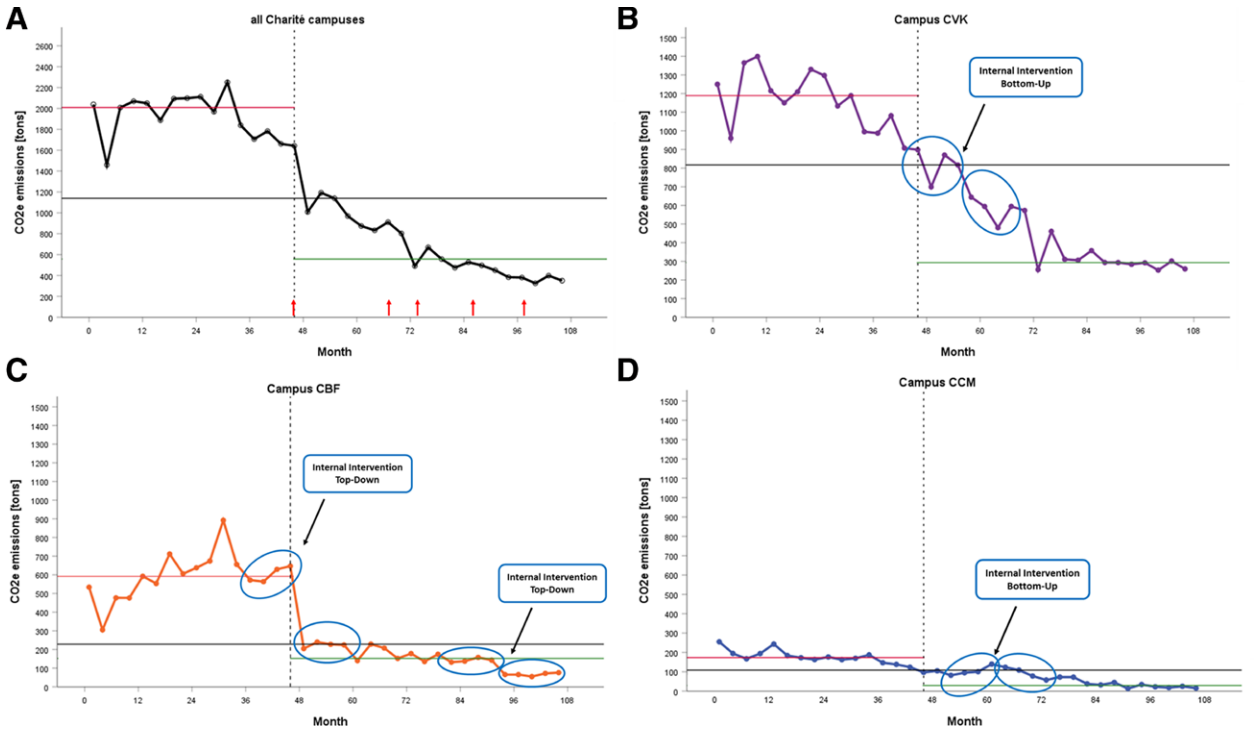

Figure 1. CO_2e emissions in tons from all anesthetic gases (desflurane, sevoflurane, and isoflurane) over 108 mo (from January 2015 until December 2023) at (A) all 3 anesthesiological departments of the Charité, (B) CVK, (C) CBF, and (D) CCM. The overall central line (black) indicates the median CO_2e emissions over the whole period, the red central line indicates the median CO_2e emissions before any intervention took place, and the green central line indicates the median CO_2e emissions after the start of interventions in September 2018 (month 46). Time points of external interventions are marked in (A) with little red arrows on the *y*-axis. Time points of internal "bottom-up" and "top-down" interventions at the individual anesthesiological departments are marked with black arrows and blue circles indicate the run of emissions before and after the intervention (B–D). There is a clear shift of the centerline after interventions started in month 46 (September 2018) to lower CO_2e emissions at all 3 anesthesiological departments of the Charité, and in the overall picture (A). The most rapid and sustained CO_2e reduction occurred after a top-down decision at the CBF Campus (C) in December 2018 (month 48). For the CO_2e, we used the timeframe of 5 y (GWP_5). CBF indicates Campus Benjamin Franklin; CCM, Campus Charité Mitte; CO_2e, CO_2 equivalents; CVK, Campus Virchow Klinikum; GWP_5, global warming potential over a period of 5 years.

DISCUSSION

The CO_2e footprint of volatile anesthetics could be significantly reduced (by ~87% to 90%) from 2018 to 2023 at Charité's 3 clinical campuses by repeatedly informing about the impact of volatile anesthetics on global warming. We found the most rapid (3–6 month) and sustained reduction after internal "top-down" measures were taken. In contrast, after external or internal "bottom-up" interventions, setbacks can occur within the next month. However, through repeated interventions, external or internal "bottom-up" measures can also achieve a sustainable and significant reduction of the CO_2e footprint of volatile anesthetics.

At the same time, a large reduction of costs due to the change in anesthetists' usage behavior could be demonstrated.

Within 6 years, training measures within the medical teams of the 3 Departments of Anesthesiology and Intensive Care Medicine at the Charité have saved a cumulative 6366 tons of CO_2e (GWP_{100}). This corresponds to the annual CO_2e footprint of ~600 people living in Germany.[18] In 2023, the conversion of anesthesia saved a total of 1396 tons of CO_2e, which corresponds to ~1.4% of Charité's total annual CO_2e emissions (104.8 thousand tons in 2021).

This significant reduction was achieved by the definitive abandonment of desflurane in line with an increased use of sevoflurane and TIVA with propofol) as well as a switch to more regional anesthesia techniques. According to the content of the training measures and an overall cost reduction, it can also be assumed that low-flow and minimal-flow techniques were implemented more consistently, although this cannot be clearly proven with our data.

As mentioned above, the most significant and sustainable CO_2e reduction was achieved after a top-down decision by the head of the anesthesiology clinic at the CBF campus. The head position was newly filled in November 2018 and right at the beginning, the new head of the department ordered a stop to desflurane. This finding clearly demonstrates the high level of responsibility that people in leadership positions have in the current climate crisis situation. Their decisions can lead to a

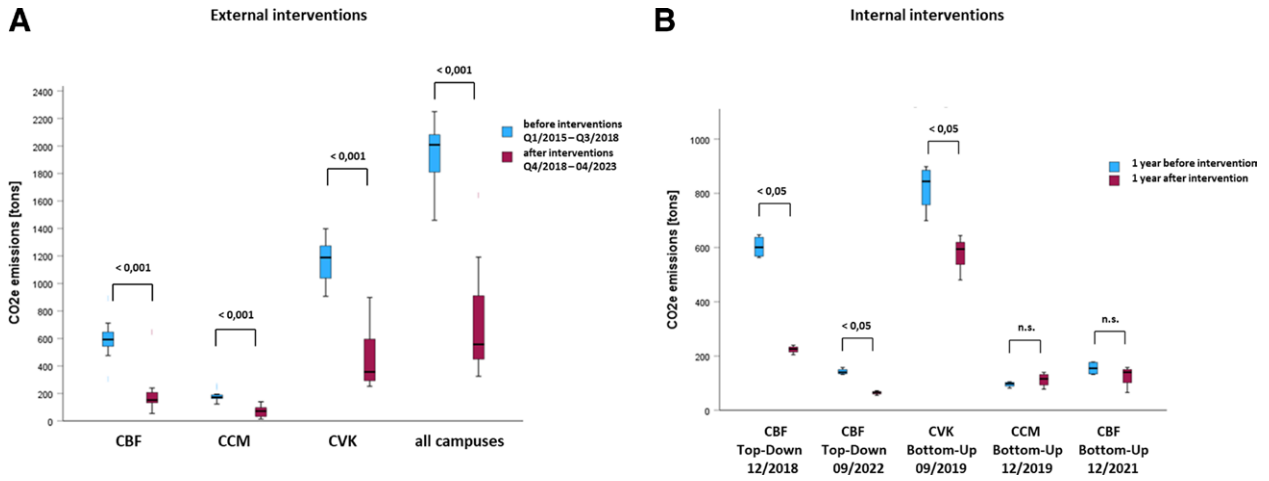

Figure 2. Change in CO_2e emissions in tons from all anesthetic gases (desflurane, sevoflurane, and isoflurane) before and after interventions took place. External interventions (A) compared the period before any intervention (Q1/2015–Q3/2018) and after the start of interventions in September 2018 until the end of our observation (Q4/2018–Q4/2023). Boxplots are medians (horizontal line) with interquartile range (edges of box) and 10th to 90th centiles (error bars). We found a significant reduction of CO_2e emissions at each individual clinical site (CVK, CBF, and CCM), as well as for the whole Charité (*t* test). Internal interventions (B) compare 1 year before the single internal intervention took place, until 1 year after the intervention. Internal top-down interventions also lead to a clear CO_2e reduction within 1 year, whereas the single bottom-up interventions showed an ambiguous picture (Mann-Whitney *U* test). CBF indicates Campus Benjamin Franklin; CCM, Campus Charité Mitte; CO_2e, CO_2 equivalents; CVK, Campus Virchow Klinikum.

significant reduction in CO_2e emissions in the very near future, while their refusal to do so will further fuel the climate crisis.

A similar study by the Department of Anesthesiology at the University Hospital of Wisconsin examined the impact of training on reducing the carbon footprint of

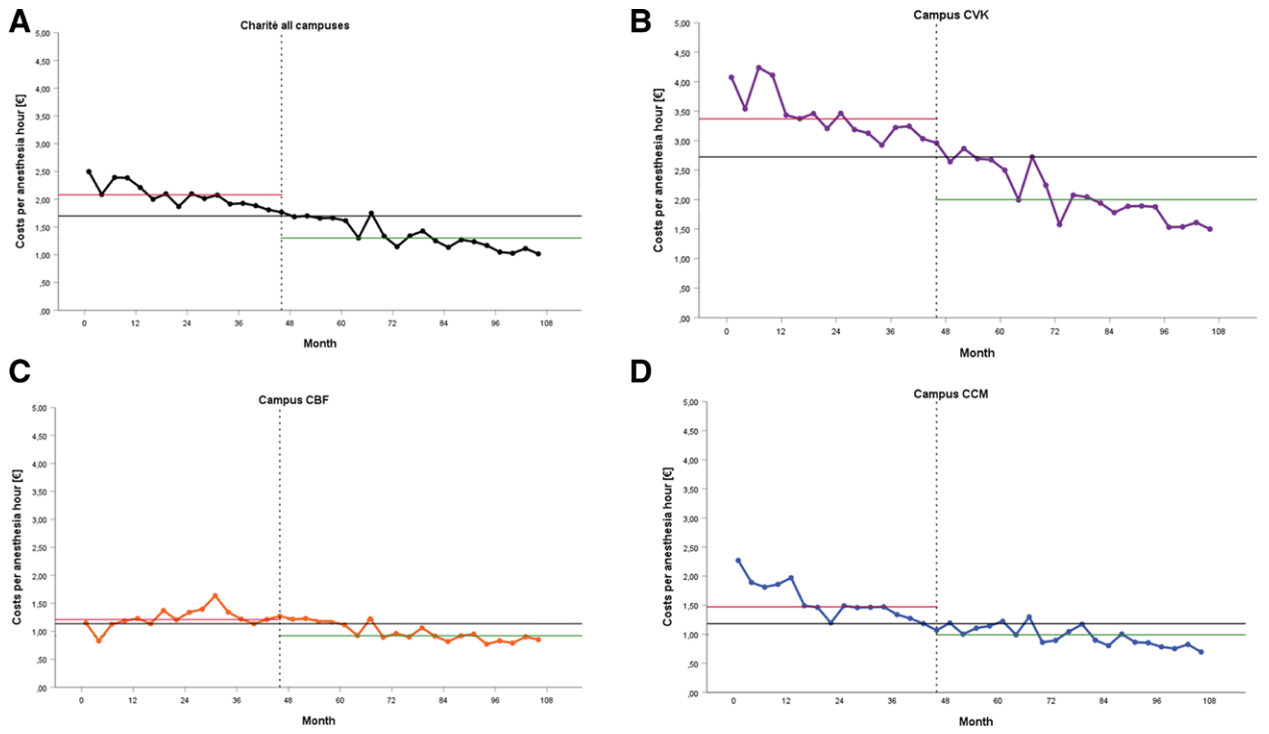

Figure 3. Development of the costs per anesthesia hour (in €) quarterly analyzed over 108 mo (from January 2015 until December 2023) at CBF (A), CCM (B), CVK (C), and all 3 anesthesiological departments of the Charité (D). Overall centerline (black horizontal line) indicates the median costs over the whole period of 108 mo, the red horizontal line indicates the median costs per anesthesia hour before interventions started (month 0 until 46), and the green horizontal line indicates the median costs per anesthesia hour after interventions started (month 47 until 108). There is a clear shift of the centerline after interventions started in month 46 (September 2018) to lower costs per anesthesia hour in all 3 anesthesiological departments of the Charité. CBF indicates Campus Benjamin Franklin; CCM, Campus Charité Mitte; CVK, Campus Virchow Klinikum.

volatile anesthetics over a 3-year period.[19] They found a comparable overall reduction in the CO_2e footprint of 64%, combined with significant cost savings. In view of rising CO_2e prices in the future, a change in usage behavior could lead to even greater cost savings in the coming years.

Both studies show that a significant and financially advantageous reduction in CO_2e emissions in terms of sustainability in anesthesia can be achieved through training measures alone.

Use of Anesthetics

A survey of German anesthetists in 2020 revealed that in ~50% of cases (multiple answers possible), the choice of anesthetic to be administered was based on local standard practice and the availability of the anesthetic at the workplace. Only in ~35% of cases were patient-related indications and in ~33% operation-related indications were decisive for the choice of the anesthetic.[20] It can therefore be assumed that a change in anesthesia practice is possible in most cases without endangering the patient.

In the survey, in particular younger colleagues expressed a desire for more comprehensive training in regional anesthesia procedures.[20]

In this respect, the increase in regional anesthesia procedures from 2021 in our study is interesting. In contrast to a simple change of anesthetic agent (sevoflurane or propofol instead of desflurane), the more frequent use of regional anesthesia techniques requires equipment (including sonography equipment) and training measures in advance that enable younger colleagues to use these techniques. Based on the data available in the current study, it can be assumed that more regional anesthesia procedures have been taught at the Charité in recent years and that these will be used more frequently in the future, depending on patient preference or surgical indication. The expanded expertise of anesthetists is an advantage for patients and for the climate.

In another worldwide survey of anesthetists, it was found that 83% prefer anesthesia with sevoflurane and only 6% to 12% administer desflurane in their daily routine.[21] In developing countries (mostly) in Africa and the Middle East, isoflurane is the second most commonly used volatile anesthetic.[21] As only 45% of respondents reported knowing the differences in the carbon footprint of anesthetics, this suggests that the decision to primarily administer sevoflurane or isoflurane is not only based on climate concerns but also on the difference in cost or simply local standard practice.

Another way to reduce the CO_2e footprint of anesthetic gases could be achieved by separating and recycling the anesthetic agents. In the first life cycle assessment (LCA) comparing the CO_2e footprint of volatile anesthetics including the use of anesthetic gas recycling solutions with TIVA, it was shown that for desflurane even under minimal-flow conditions (0.5 L/min) no sufficient reduction of the CO_2e footprint could be achieved (only ~ 32.5%).[22] In another study analyzing the captured amount of desflurane in a clinical setting, only ~25% of the desflurane administered for general anesthesia could be captured.[23,24] However, it also appears that in the future the use of anesthetic gas recycling filters could be beneficial for the use of sevoflurane.[22]

Limitations

We have not included the cost of the necessary materials to safely administer TIVA or regional anesthesia in our calculation, so the actual costs are likely to be higher with increased use of TIVA and regional anesthesia procedures. In addition, costs were not adjusted in our results for the general increase in costs from 2015 to 2023. Therefore, it can be assumed that there would have been an increase in costs if purchasing conditions had remained unchanged. Nevertheless, here presented real costs of the sole anesthetic decreased overall indicating an economic benefit of our sustainability efforts. In future, higher quantities of sevoflurane and propofol could also lead to a better purchase price being negotiated.

The decline in the number of operations due to the COVID-19 pandemic and the prolonged strike by health care staff has had an impact on our data. However, after adjusting the CO_2e emissions to the operating hour, a significant decrease in CO_2e emissions independently remains.

CONCLUSIONS

We were able to show that the CO_2e footprint related to the use of anesthetics could be reduced within a few months or 1 to 2 years just by educating and training anesthetists. Just by changing our daily practice combined with a clear directive announcement, we have reduced the CO_2e footprint at the Charité by a few hundred to thousand tons per year.

We are living in times of climate change and the 1.5 °C limit has been exceeded in the year 2024 leading to increased numbers of climate related catastrophes in the near future.[2,25,26] Leading climate scientists have urgently recommended that greenhouse gases with a short atmospheric lifetime of <20 years in particular should be significantly reduced in the near future.[26] Compared to CO_2 or N_2O, volatile anesthetics have a very short atmospheric lifetime of <10 years. As anesthetists, we now have a unique opportunity to contribute to the reduction of global warming in the coming years by simply adapting our daily anesthetic practice. ■

ACKNOWLEDGMENTS

We would like to thank all anesthesiology colleagues at the individual Charité Campus, especially senior physicians Dr

Bernadette Kleikamp, Caroline Finger, Max Pötzsch, Philipp Brandhorst, Anika Müller, Edda Klotz, Susanne Schleicher, Susanne Heim, Astrid Fahlenkamp, and Charlotte Samwer.

DISCLOSURES

Conflicts of Interest: The authors declare numerous funding support and lecture fees related and unrelated to this work, which are included in Supplemental Digital Content 2, http://links.lww.com/AA/F170. **Funding:** This work was supported by facilities of the Charité – Universitätsmedizin Berlin. **This manuscript was handled by:** Olubukola Nafiu, MD, FRCA, MS.

REFERENCES

1. Koch S, Klitzman R. Reliance on fossil fuels: ethical implications for intensivists. *Intensive Care Med*. 2023;49:330–333.
2. Hansen JE, Sato M, Simons L, et al. Global warming in the pipeline. *Oxford Open Climate Change*. 2023;3:1–33.
3. Matthies-Wiesler F, Gabrysch S, Peters A, et al. The Lancet Countdown on Health and Climate Change—Policy Brief für Deutschland. Accessed July 29, 2024. https://klimagesund.de/wp-content/uploads/2021/05/Policy-Brief-2019.pdf.
4. Berlin, Senatsverwaltung für Umwelt, Verkehr, Klimaschutz und Umwelt. Klimaschutzvereinbarung zwischen dem Land Berlin, Verkehr und Klimaschutz und der Chairté—Universitätsmedizin Berlin . Accessed July 29, 2024. https://www.charite.de/service/pressemitteilung/artikel/detail/land_berlin_und_charite_unterzeichnen_klimaschutzvereinbarung/.
5. MacNeill AJ, Lillywhite R, Brown CJ. The impact of surgery on global climate: a carbon footprinting study of operating theatres in three health systems. *Lancet Planet Health*. 2017;1:e381–e388.
6. Vollmer MK, Rhee TS, Rigby M, et al. Modern inhalation anesthetics: Potent greenhouse gases in the global atmosphere. *Geophys Res Lett*. 2015;42:1606–1611.
7. Sulbaek Andersen MP, Nielsen OJ, Wallington TJ, Karpichev B, Sander SP. Medical intelligence article: assessing the impact on global climate from general anesthetic gases. *Anesth Analg*. 2012;114:1081–1085.
8. Koch S, Toussaint S, Özelsel T. Das "global warming potential" inhalativer Anästhetika—Stoppt Desfluran. *Anästhesiol Intensivmed Notfallmed Schmerzther*. 2020;55:144–146. (in German).
9. Sherman J, Le C, Lamers V, Eckelma M. Life cycle greenhouse gas emissions of anesthetic drugs. *Anesth Analg*. 2012;114:1086–1090.
10. Koch S, Pecher S. New challenges for anesthesia due to the climate change. *Anaesthesist*. 2020;69:453–462.
11. Schuster M, Richter H, Pecher S, Koch S, Coburn M. Ecological sustainability in anaesthesiology and intensive care medicine. A DGAI and BDA position paper with specific recommendations. *Anasth Intensivmed*. 2020;61:329–339.
12. Lehmann F, Samwer C. Podcast hyperkapnie. Accessed January 5, 2024. https://hyperkapnie.com/. (in German)
13. Six-Sasmaz C, Michna J. *Klimaschutz im Krankenhaus—Neue Rezepte für eine nachhaltige Medizin*. ZDF. Accessed January 5, 2024. https://www.zdf.de/gesellschaft/plan-b/plan-b-klimaschutz-im-krankenhaus-100.html. (in German)
14. Haas M. Your surgery could harm yourself and the planet. Here's what some doctors are doing about it. In: Environment & Space | Health. Accessed January 5, 2024. https://upworthyscience.com/anesthesia-side-effects/.
15. Özelsel T, Sondekoppam RV, Buro K. The future is now—it's time to rethink the application of the global warming potential to anesthesia. *Can J Anesth*. 2019;66:1291.
16. Deutsches Ärzteblatt. Streik bei Charité und Vivantes wird ausgeweitet. Accessed January 5, 2024. https://www.aerzteblatt.de/nachrichten/127206/Streik-bei-Charite-und-Vivantes-wird-ausgeweitet. (in German)
17. Wolfe HA, Taylor A, Subramanyam R. Statistics in quality improvement: measurement and statistical process control. *Paediatr Anaesth*. 2021;31:539–547.
18. BMUV. Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz, Kohlenstoffdioxid-Fußabdruck pro Kopf in Deutschland. Accessed December 7, 2024. https://www.bmuv.de/media/kohlenstoffdioxid-fussabdruck-pro-kopf-in-deutschland. (in German)
19. Zuegge KL, Bunsen SK, Volz LM, et al. Provider education and vaporizer labeling lead to reduced anesthetic agent purchasing with cost savings and reduced greenhouse gas emissions. *Anesth Analg*. 2019;128:e97–e99.
20. Koch S, Samwer C, Rossaint R, et al; DGAI/BDA Commission on Sustainability in Anaesthesiology. Survey regarding routine use of anaesthetic techniques and knowledge of their environmental impact in Germany 2020. *Eur J Anaesthesiol*. 2022;39:282–284.
21. Gonzalez-Pizarro P, Koch S, Muret J, et al. Environmental sustainability in the operating room: a worldwide survey among anaesthesiologists. *EJAIC*. 2023;41:260.
22. Hu XC, Pierce JMT, Taylor T, Morrissey K. The carbon footprint of general anaesthetics: a case study in the UK. *Resour Conserv Recycl*. 2021;167:1.
23. Hinterberg J, Beffart T, Gabriel A, et al. Efficiency of inhaled anaesthetic recapture in clinical practice. *Br J Anaesth*. 2022;129:e79–e81.
24. IPCC, 2023. Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. In: Core Writing Team, Lee H, Romero J, eds. IPCC, 2023:35–115. doi: 10.59327/IPCC/AR6-9789291691647.
25. Copernicus - Europe's eyes on earth, Copernicus: 2024 virtually certain to be the warmest year and first year above 1.5°C, 2024 [cited 2024, 18.12.2024]. https://climate.copernicus.eu/copernicus-2024-virtually-certain-be-warmest-year-and-first-year-above-15degc
26. Ripple WJ, Wolf C, Newsome TM, et al. World scientists' warning of a climate emergency 2021. *Bioscience*. 2021;71:894–898.