The carbon footprint of anaesthesia

How the choice of volatile anaesthetic affects the CO_2 emissions of a department of anaesthesiology

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Summary

Background: The health sector contributes considerably to national greenhouse gas emissions. In that regard, anaesthesiology and its use of volatile anaesthetics (VAs) takes on a particular significance. VAs are potent greenhouse gases, with desflurane exhibiting 2540 times the Global Warming Potential of CO_2 whilst sevoflurane exceeds the effect of CO_2 by only 130 times. In early 2018 the Department of Anaesthesiology at the Kliniken Landkreis Karlsruhe placed limits on the use of desflurane. The primary objective of this study was to investigate the relevance of the intervention in relation to the department's overall carbon footprint.

Methods: Departmental emissions were calculated for 2017 and 2018 in CO_2 equivalents (CO_2e) for three areas: (1) emissions generated by the use of VAs calculated on the basis of actual utilisation and respective Global Warming Potentials, (2) emissions deriving from single-use disposable devices, packaging and containers for fluids and drugs, categorised according to material and waste classes, and (3) emissions from fuel consumption on employees' everyday commute to work.

Results: The emissions derived from single-use disposable devices, packaging and containers for fluids and drugs for 2017 and 2018 were 43.4 and 41.8 t of CO_2e respectively and totalled 48.5 and 48.6 t of CO_2e respectively from fuel consumption on employees' everyday commute to work. In 2017, the emissions from the use of VAs were 307.8 t of CO_2e or 77% of the department's total emissions. Following a reduction in desflurane use, this number dropped to 36 t or 28% of total emissions in 2018. The department's overall emissions decreased by 68% from 399.7 t to 126.4 t of CO_2e.

Conclusions: Germany's carbon footprint is 11 t per capita per annum and as such lies above the international average. Our calculations revealed very high work-related emissions for anaesthesiologists totalling 17.1 t of CO_2e per person and year. Decreased use of desflurane reduced these emissions to 5.4 t of CO_2e per person and year. Emissions per anaesthesiology case decreased from 38 to 12 kg of CO_2e. So long as efficient scavenging systems are not in place, the use of desflurane should therefore be questioned for ecological reasons. Further reductions in anaesthesia-related emissions should be addressed with utmost urgency.

Setting and aims

As a predominantly man-made phenomenon, climate change caused by the emission of greenhouse gases represents a fundamental threat to the ecological and social foundations of human existence. The 2018 IPPC report provides new insights into the effect that just 2 °C compared to 1.5 °C of global warming could have on humans and ecosystems. An increase in extreme weather events

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causing destruction of housing and critical infrastructure is one of the foreseeable consequences of climate change. In the context of 2 °C of global warming, rising sea levels alone could destroy the livelihoods of 10 million more people in costal zones when compared with 1.5 °C of global warming. Periods of extreme heat and a collapse of food production due to drought, torrential rain and flooding are expected to cause an increase in mortality. There can be no question that uncertainties remain as to the total extent of changes; these are in part due to differing model calculations and uncertainties over tipping points such as thawing of permafrost soils or melting of large ice masses in Greenland and the Antarctic. The probability of reaching such tipping points, however, increases once 1.5 °C of global warming is exceeded. According to general scientific consensus, a drastic reduction of greenhouse gases is required within the next two decades to avoid irreversible developments which could leave large areas of Earth uninhabitable [1,2].

The healthcare sector is particularly affected by climate change. Extreme heat, malnutrition in the face of crop failures, spread of diseases, increasing poverty as well as extreme weather events and the destruction of housing and critical infrastructure threaten the health and healthcare of a large number of people [3]. The number of deaths in Germany in 2018 from heatwaves caused by climate change alone has been estimated to be 1,200 [4], and over 150,000 worldwide [5]. At the same time, the healthcare sector is responsible for a significant amount of CO_2 emissions, particularly in developed countries; as such, it shares responsibility for causing climate change. The healthcare sector is estimated to directly and indirectly cause 5 to 10% of total CO_2 emissions of industrialized countries, with hospitals being responsible for the greater part [6–8].

In the context of anaesthesiology, the use of volatile anaesthetics (VAs) is of particular significance. VAs are greenhouse gases which, have a significantly higher Global Warming Potential than CO_2 due to their physicochemical properties. These emissions can be calculated as CO_2 equivalents (CO_2e), making it possible to compare various different greenhouse gases with one another. Of the VAs, desflurane is especially problematic as it has more than 2,500 times the Global Warming Potential of CO_2, whilst sevoflurane exceeds the effect of CO_2 by only 130 times [9–11]. From 2018 on, the Department of Anaesthesiology, Intensive Care, Emergency Medicine and Pain Therapy at the Kliniken Landkreis Karlsruhe, Germany, placed limits on the use of desflurane for environmental reasons. Until then desflurane had been used on par with sevoflurane. Information regarding the greenhouse gas effects of VAs were circulated to all staff. Staff were permitted to request use of a desflurane vaporiser – all of which had been removed from anaesthetic machines – if they felt there were sufficient medical grounds to do so. The primary aim of this study was to determine the effect of this rearrangement on the carbon footprint of anaesthesia.

Methods

The Fürst-Stirum-Hospital Bruchsal and the Rechbergklink Bretten are county hospitals in the Karlsruhe district in Germany which together formally represent a single 515 bed hospital split across two sites, providing basic and standard levels of care. Both hospitals are academic teaching hospitals of the Ruprecht-Karls-University Heidelberg. Ten departments and two institutes treat more than 26,000 inpatients and 48,000 outpatients annually. 40 medical staff at the Department of Anaesthesiology, Intensive Care, Emergency Medicine and Pain Therapy provide anaesthesia services to the six surgical departments across the two sites. In 10 operating theatres and several decentralised areas the department provides anesthesia services to more than 11,000 patients of all ages per annum.

The aim of this study was to explore calculations of greenhouse gas emissions as CO_2e produced by anaesthesiologic services in the years 2017 and 2018 at both hospitals. Intensive Care, Emergency Medicine and Pain Therapy were not included in the calculations. The carbon footprint was calculated for three areas in which emissions could be directly influenced by the staff of the Department of Anaesthesiology. The primary goal was to show the effect that limiting desflurane use had on the carbon footprint.

1st area: emissions from volatile anaesthetics

The annual emissions in CO_2e generated by the use of volatile anaesthetics (VAs) was calculated on the basis of data on actual annual utilisation provided by the pharmacy.

The emissions in CO_2e were calculated on the basis of Global Warming Potentials (GWPs) for a period of 100 years. GWPs are a measure of the greenhouse potential of a chemical compound within a certain time horizon. They quantify the greenhouse effect of the mass of a compound compared to the effect of the same mass of CO_2. Per definition, CO_2 has a GWP of 1 [12]. Using GWPs100 with a reference period of 100 years is recommended in order to capture the entire effect of CO2 in the atmosphere [13]. Isoflurane, desflurane and sevoflurane persist in the atmosphere for 3.2, 14 and 1.1 years respectively [9], whilst nitrous oxide (N_2O) persists for 114 years [11]. The following GWPs100 were used for the calculations: isoflurane 510, sevoflurane 130, desflurane 2540 [9]. A correction factor of 5% was taken into account for sevoflurane which is metabolised to a small extent in the body and is therefore not emitted into the atmosphere in its entirety [14,15]. Neither isoflurane nor nitrous oxide were used as inhalational anaesthetics at either of the two sites.

2nd area: emissions deriving from single-use disposable devices, packaging and containers for fluids and drugs

Emissions deriving from single-use disposable devices, packaging and containers for fluids and drugs were recorded on the basis of 2017 and 2018 purchase orders placed with material logistics by the Department of Anaesthesiology including all single-use disposable products and drugs. All products of which a minimum of 10 per year had been ordered were included. Each article was weighed together with its own packaging but without cardboard shipping packaging. In the case of containers of fluids or drugs, the total weight was determined, and the weight of the contents subtracted. Products were categorised and evaluated according to their material and waste classes. Material categories chosen were plastic, paper/cardboard, metal, glass and batteries. In addition, further categories were introduced for products consisting of two materials: plastic + paper/cardboard and plastic + metal. In both hospitals, larger glass bottles (e.g. 100 ml antibiotic or saline bottles) are collected separately and recycled. All other products are collected as one by the contractor and incinerated. This includes sharps. Dangerous waste – such as blood products and infectious materials – is disposed of separately and was not included in the analysis; however, the quantity of such waste in both hospitals is negligibly small.

Emissions from single-use devices were converted to CO_2 equivalents according to the method shown by MacNeill et al. in 2017. This method is based on conversion factors developed by the UK Department for Environment, Food and Rural Affairs which allow to calculate the carbon footprint of materials based on a lifecycle concept. Both emissions incurred upstream – that is during extraction of raw materials, transportation and material-specific production of materials – and downstream – i.e. in the context of waste disposal – are taken into account. Product-specific emissions during production, packaging or sterilisation are not included [16]. Because single-use devices are made from various different types of plastic (high-density and low-density polyethylene, polypropylene, PET and latex) [15] emission factors for average plastics were used (3,179 kg CO_2e per tonne (CO_2e/t) for production and 1,197 kg CO_2e/t for incineration). Conversion factors for mixed metals and paper/cardboard were 4,778 kg CO_2e/t and 1,017 kg CO_2e/t for production, and 31 kg CO_2e/t and -529 kg CO_2e/t for incineration. Glass production emits 895 kg CO_2e/t whilst incineration and recycling release 26 kg CO_2e/t and -366 kg CO_2e/t. For products consisting of plastic and metal or plastic and paper/cardboard a ratio of 90% plastic to 10% metal or paper/cardboard was assumed. The DEFRA conversion factors do not include values for batteries, so that batteries were excluded [16].

3rd area: emissions from fuel consumption on employees' everyday commute

Based on annual duty rotas and travel distance from home to the place of work, the work-associated distance travelled per annum was calculated for each departmental member of medical and nursing staff for 2017 and 2018. Distances off staff traveling by foot or bicycle were not included in the analysis. CO_2e were calculated based on the assumption that the distribution of diesel and petrol vehicles (44% and 56%) and the average fuel consumption (6.8 l diesel and 7.7 l petrol per 100 km) in the department conform to the German average distribution [17].

Results

At the two sites of the Department of Anaesthesiology 10,588 and 10,268 surgical procedures were recorded in 2017 and 2018 respectively. Training led to a decrease in desflurane use from 77.8 l in 2017 to just 4.3 l in the following year. Sevoflurane use rose from 82.5 to 105 l. The reduction of desflurane use by 73.4 l led to an increase in sevoflurane use of only 22.5 l; this is because the end-tidal concentration of sevoflurane required to achieve a sufficient minimal alveolar concentration (MAC) is lower.

In total, 549 different types of single-use disposable devices, packaging and containers for fluids and drugs were analysed. The use of such items showed only minor variations from 2017 to 2018, dropping from 10.9 t to 10.5 t (Tab. 1). Fuel consumption on employees' everyday commute also remained more or less constant. Staff used 8,079.6 l of diesel and 11,564.2 l of petrol in 2017, whilst consumption was 8,102.4 l of diesel and 11,596.8 l of petrol in 2018.

The primary aim of the study was to convert the emissions to CO_2 equivalents and show the effect of reduced desflurane use on total emissions (Fig. 1). As a result of the reduced use of desflurane, total CO_2 emissions across the examined areas of the department were reduced by more than 2/3, dropping to 32% of their previous year's level. In 2017 emissions from VAs were 307.8 t CO_2e, constituting 77% of total emissions, whilst in the following year they dropped to 36 t CO_2e or 28.5%, i.e. just shy of ¼ of total emissions. Increased use of sevoflurane by 22.5 l led to an

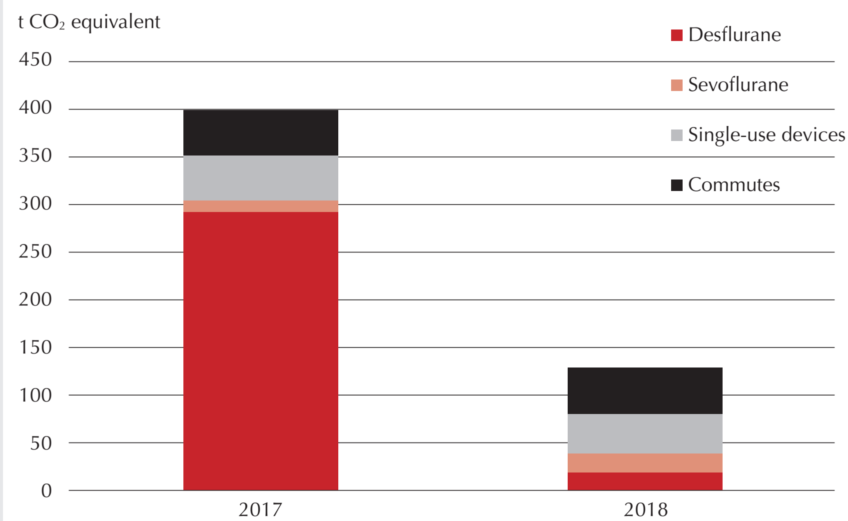
Table 1
Weight of and emissions from single-use disposable devices, packaging and containers for fluids and drugs in 2017 and 2018 by class of material.

Class of material	Weight (in kg)		Emissions (in kg CO_2 equivalent)	
	2017	2018	2017	2018
Plastic	9,015.7	8,657.0	39,573.7	37,980.5
Paper/Cardboard	159.5	137.8	78.6	67.3
Metal	46.4	30.0	223.1	144.1
Glass	1,230.2	1,258.7	1,604.0	1,716.5
Plastic + Paper/Cardboard	135.4	137.7	539.9	549.1
Plastic + Metal	319.3	299.1	1,411.1	1,321.8
Sum	**10,906.5**	**10,520.3**	**43,430.4**	**41,779.3**

increase in sevoflurane related emissions of 4.5 t CO_2e whilst limiting use of desflurane cut emissions by 276.1 t CO_2e; the net effect of reduced desflurane use was a reduction of emissions by 271.6 t CO_2e. Emissions from use of single-use devices were 43.4 and 41.8 t CO_2e in 2017 and 2018 respectively (Tab. 1). Table 2 shows which items had the greatest impact on the carbon footprint. Fuel consumption caused by commutes stayed almost constant at 48.5 and 48.6 t CO_2e.

Total departmental emissions were thus reduced by 273.4 t CO_2 equivalent through reduced use of desflurane. This equates to a 67.4% reduction per anaesthesia case, from 38 kg CO_2e in 2017 to 12 kg CO_2e in 2018. The emissions in CO_2e per anaesthesiologist full-time post were 17.1 t in 2017 and 5.4 t in 2018.

Figure 1



Emissions of anaesthesiology in 2017 and 2018 in tonnes CO_2 equivalent.

Table 2

Product categories covering single-use disposable devices, packaging and containers for fluids and drugs responsible for emissions exceeding 1 t CO_2 equivalent per annum.

Product categories	Emissions in kg CO_2 equivalent	
	2017	2018
Infusion bottles (plastic)	7,646.0	7,814.7
Ventilation systems	4,571.9	4,240.5
Patient blankets	3,423.7	3,389.3
Gloves	2,749.0	2,860.0
Syringes	3,015.4	2,821.9
Infusion and perfusor systems	2,640.3	2,572.6
Filters	1,567.1	1,570.8
Anaesthesia sets	1,439.5	1,558.8
Suction systems	1,610.3	1,553.3
Sterile gowns	1,381.3	1,402.4
Laryngeal masks	1,483.7	1,296.0
Ventilation masks	1,428.9	1,262.0
Infusion bottles (glass)	977.7	1,108.7

Discussion

The intervention – that is the transition away from desflurane – led to a 68% reduction in total departmental emissions, equating a reduction of 273.4 t CO_2 equivalent. On average, each German citizen is responsible for 11 t of CO_2 emissions per annum, which is notably more than the European average [18]. Our study showed that prior to the intervention each medical member of staff caused 17.1 t CO_2e p.a. through professional activity in anaesthesiology alone, not including private emissions such as those from dwelling, eating and recreational travel. Despite the savings achieved, emissions from professional activities were still 5.4 t CO_2e in 2018.

According to the IPPC's budget approach, future worldwide emissions must be limited to approximately 420 Gt CO_2e if global warming is to be limited to 1.5 °C (figures from 2018). Taking into consideration current worldwide annual emissions of approx. 42 Gt CO_2e, that total could be reached in less than 10 years assuming steady or even rising emissions [19]. Exceeding the 1.5 °C limit may tip unstable systems (with thawing of permafrost soils or melting of Antarctic ice masses), causing a runaway effect, drastically increasing the ecological effects of climate change. Sea levels may rise by a number of metres whilst large swathes of previously inhabited and farmed land may fall to desertification [1,2]. The German federal government has committed itself to the 2050 climate plan which provides that CO_2 emissions in Germany should drop by 55% by 2030 [20]. Europe as a whole is to be climate neutral by 2050, i.e. should no longer emit greenhouse gasses, or otherwise offset emitted greenhouse gasses, e.g. through use of absorption technologies [21]. As Germany has failed to reach its milestones for 2020, a radical chance of course is required throughout all societal sectors if the goals for 2030 and later are to be met. The healthcare sector and within it the specialist field of anaesthesiology – which in turn is often one of the largest departments within a hospital – cannot be excepted.

In our department, the first step towards reducing CO_2 emissions was to almost completely forego use of desflurane, which is by far the most detrimental VA. The aim of this study was to show the effect of this change as a reduction in CO_2 equivalent emissions. Our analysis shows that the intervention alone was responsible for a 2/3 year on year reduction in CO_2 equivalent emissions from anaesthesiologic activities. As a result of ecological considerations we have now discontinued desflurane use.

Earlier studies discussed the use of low-flow versus minimal-flow anaesthesia as a significant measure towards reduction of VA consumption. After reaching steady state, minimal-flow anaesthesia can reduce VA consumption by approx. 50% when compared with low-flow anaesthesia [11]. Whilst, if only for economic reasons, this measure will have been implemented almost universally in Germany, in the past in the USA there have – for regulatory and theoretical reasons – been significant reservations against low-flow anaesthesia [22]. Hospitals in the USA have also had little financial incentive to reduce VA consumption; patients are billed separately for drugs used, so that hospitals do not cover the costs themselves. In addition to using low-flow and minimal-flow anaesthesia and switching to less damaging VAs – as presented in our study – foregoing use of N_2O is a relevant step in avoiding greenhouse gas emissions. N_2O is a potent greenhouse gas which persists in the atmosphere for a substantial length of time [9]. The addition of N_2O increases the Global Warming Potential of sevoflurane by 83% during steady state [11]. Increasing use of total intravenous anaesthesia is also an option for reducing greenhouse gas emissions [23,24]. In addition, the negative effect of VAs on the environment could be mitigated by not emitting those VAs into the environment but rather capturing them using suitable technical means and destroying [25] or recycling [26] them. The requisite technical processes have already been developed and in the next few years ought to become the accepted standard in anaesthesiology departments which still wish to use VAs. With worldwide emissions from use of VAs estimated at 4 million tonnes CO_2e [10], implementing such technologies would appear to be urgent. Furthermore, recycling or at the very least rendering VAs innocuous may become an economically attractive option. If in future the price on carbon rises to 55 €/t – as is currently planned for 2025 – desflurane prices will, depending on purchase cost, rise by approx. 75% by virtue of emissions taxes alone. These additional costs could be avoided by implementing appropriate measures.

Requirements in infection control and process optimization have led to the increasinge use of disposable rather than reusable products in operating theatres. Single-use devices often cause significantly more CO_2 emissions than do reusable products. As such it has, for example, been shown that the use of single-use laryngoscope blades [27], and even of single-use drapes and gowns [28–30] is both ecologically and economically disadvantageous for hospitals. This compares with assumed advantages in the context of infection control and process optimisation in logistics and sterilisation. It has to be assumed that dedication and investigations will be required at a local level if the most environmentally sustainable approach is to be found for each hospital. However, there must be doubts over whether the increasing use of single-use products can be the direction in which we should be heading. It would also appear to be necessary to back up infection control guidelines which can only be fulfilled using single-use products with hard evidence. Table 2 provides an indication of which product groups require the most urgent attention in this respect.

A significant proportion of CO_2 emissions in our study was caused by employees' commute to and from work. Reducing these emissions requires new mobility concepts. Measures are not limited to public infrastructure, however – both hospitals as employers and employees themselves must play a role. Accessibility of public transport, attractive intermodal commuter ticket schemes, car sharing, availability of charging points and free charging of electric cars are starting points which have been introduced in some industrial companies. In contrast, many German hospitals do not even provide bicycle shelters.

Limitations of our investigation

The calculations of CO_2 emissions in this study are subject to a number of methodological limitations. This study only covered anaesthesiologic activities, but not intensive care, emergency medicine and pain therapy. The areas included in and excluded from our analysis may be critically discussed. For example, CO_2 emissions caused by employees' commute were included, but other CO_2 emissions attributable to the personal sphere, such as food supply at the workplace, clothing etc. were not. Calculating CO_2 emissions from volatile anaesthetics using the GWP100 approach is common scientific practice so as to be able to compare the effects of VAs with direct CO_2 emissions. However, other approaches are possible – especially with regard to the 100-year time horizon, which influences the results significantly. The use of a 100-year time frame does, however, seem justified in light of the long-lasting effects of greenhouse gases in the atmosphere, and is thus recommended in pertinent literature [9,10,13]. What doesn't become apparent, however, is that the main greenhouse gas effect of VAs is seen during their atmospheric lifetime, so within a 10 to 30-year timeframe – which is also the time period of action remaining to limit global warming [31]. For pragmatic reasons calculations of CO_2 equivalents for single-use disposable devices, packaging and containers for fluids and drugs were performed using a simplified model incorporating the weight and an evaluation of six different types of material and 2 different modes of disposal in accordance with British DEFRA guidelines [16]. This model does not, however, permit for a complete lifecycle analysis of individual products. Product-specific emissions incurred during production, packaging and sterilization were not included in the calculations. It was not possible to calculate precise CO_2 equivalents for production, logistics and disposal of every individual product, because such data are not available and there is no requirement for manufacturers to make them available. When compared with a full lifecycle assessment of a disposable laryngoscope blade [27] the error in our calculations using DEFRA conversion factors may be up to 66% for plastic and 23% for metal single-use products. This emphasises the need to oblige manufacturers to provide data on product and production-specific emissions. Such obligations may be introduced in future because such data will be necessary to set realistic prices on carbon. In addition to quality, price and availability, such data should then become an important criterium when selecting products. The same is true for CO_2 equivalent emissions caused by the production of drugs. Again, data is lacking and, thus, could not be included in the calculations. Lastly, even the model used to calculate CO_2 equivalents of employees' commutes is based on pragmatic simplifications, as actual fuel consumption was not measured and average values were applied instead.

The major limitation of our study, however, is to be found in the fact that energy consumed in the running of the operating theatre – and especially heating, ventilation and air conditioning – was not evaluated. Earlier studies have shown this factor to make up between 17 and 84% of total emissions from operating theatres [15]. On the one hand, data on energy consumed were not available to us. On the other hand, delimiting energy consumed by the surgical department would have been exceedingly difficult. At the same time, the focus of our analysis was intentionally placed on emissions which could be influenced and were caused by the Department of Anaesthesiology.

Conclusion

In conclusion, this study was able to show that in the case considered the CO_2 emissions of the Department of Anaesthesiology were reduced by two thirds simply through altering the choice of volatile anaesthetic. Even so, total emissions of climate-damaging CO_2 from professional activities of anaesthesiologists remain alarming. If German climate sector are not to be meaningless, every aspect of society will need to radically reconsider both personal and professional practices. The healthcare sector cannot excuse itself from this obligation. The ongoing search for options to reduce the greenhouse gas emissions of anaesthesiologists and in co-operation with our surgical partners must be prioritised.

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