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Original Article

Greenhouse gas emissions due to inhalation anaesthetics in the Netherlands, usage data and a survey of preferences among Dutch anaesthesiologists

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BACKGROUND Anaesthetic gases are an important source of greenhouse gas emissions from operating theatres and can attribute significantly to the carbon footprint of a nation's healthcare system.

OBJECTIVE To estimate the magnitude of the climate impact of inhaled anaesthetics in the Netherlands. Furthermore, the goal was to assess the preferences of Dutch anaesthesiologists for anaesthesia techniques, and to explore opportunities for reducing greenhouse gas emissions due to anaesthesia practice.

DESIGN A 2019 bottom-up purchase analysis of inhalation anaesthetics used in all of the Dutch hospitals was executed and an online survey was conducted among Dutch anaesthesiologists regarding their preferences for anaesthetic agents.

RESULTS Purchasing quantities of volatile anaesthetic agents were obtained from 61 of the 69 hospital organisations in the Netherlands (response rate 88.4%). A total of 12.2 kilotons CO_2 equivalent (0.07% of the Dutch healthcare system) was emitted due to inhalation anaesthetics in the Netherlands in 2019. The volume of the in 2019 purchased inhalation volatile anaesthetics was 9.178 l of sevoflurane (93.4%), 404 l of desflurane (4.1%) and 245 l of isoflurane (2.5%). The survey in which 182 anaesthesiologists participated demonstrated that propofol was the first drug of choice of 70% of respondents, desflurane was available in 16% of Dutch hospitals and 83% of anaesthesiologists answered never using desflurane. Nitrous oxide was not used by 63% of respondents, the remaining 27% reported using nitrous oxide only in less than 5% of their cases.

CONCLUSION The relatively low emission of greenhouse gases due to inhalation anaesthetics in Dutch healthcare compared to other countries can be explained by the limited use of nitrous oxide and desflurane by Dutch anaesthesiologists and their strong preference for intravenously administered propofol as an anaesthetic.

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KEY POINTS

- The emission of greenhouse gases due to anaesthesiology in the Netherlands is relatively small due to a limited use of desflurane and a preferential use of intravenous propofol.
- Despite the limited use of nitrous oxide by Dutch anaesthesiologists, it accounts for two-thirds of total Dutch healthcare system greenhouse gases emissions due to inhalation anaesthetics.
- Automated fresh gas flow and vapour capture technology when using inhalation anaesthetics should be mandatory in order to minimise their emission into the atmosphere.
- It is important that future generations of anaesthesiologists learn and maintain the technique of administering inhalation anaesthetics since it is undesirable to depend entirely on only one (intravenous) agent for general anaesthesia.

Introduction

Modern volatile inhalation anaesthetics (VAs) are inherently potent greenhouse gases (GHG).[1] They belong to the chlorofluocarbons (CFC) and hydrofluocarbons (HFC) that are short-lived climate pollutants (SLCP) with strong radiative forcing characteristics causing global warming. The Montreal Protocol (1987) and the Kigali amendment (2016) aim to phase out CFCs and HFCs because of their respective ozone depleting and GHG effects. Inhalation anaesthetics, being pharmaceuticals, have so far been exempted from these legally binding international agreements due to their medical necessity.[2]

The GHG effect of the globally emitted VAs in 2014 was estimated from atmospheric measurements and amounted to 3.1 million tons of CO_2 equivalents (CO_2eq) that year. In a period of 10 years (2004–2014) the atmospheric concentrations of desflurane and sevoflurane showed more than a doubling which can be explained by their popularity and the increase in the number of operations worldwide.[3] Using the same global warming potential over 100 years (GWP100), a bottom-up calculation based on the global number of bottles of sevoflurane, desflurane and isoflurane sold in 2019 came to 2.9 million tons of CO_2eq, a contribution of 0.01% of total global GHG emissions that year.[4] Due to the its high GWP100 of 2540 and relatively low potency, desflurane accounted for about 80% of the total greenhouse gas effect of modern inhaled anaesthetics, despite accounting for only 20% of the volume sold in 2019.[4]

Nitrous oxide (N_2O) is also a significant GHG (GWP100 of 298) but with a much longer atmospheric lifetime (114 years) than the aforementioned SLCP VAs.[5] Traditionally N_2O was abundantly used as an adjuvant in the administration of older VAs to create a more favourable clinical profile. Nowadays, this technique is less essential with the clinically superior modern VAs. However, N_2O is still widely used in healthcare as an analgesic in obstetrics and emergency medicine.[6] A breakdown of N_2O use in terms of clinical setting by Wong *et al.* showed that N_2O consumption during childbirth was a factor of 10 higher than during a single surgical procedure (534 l *vs.* 48 l) and that during a paediatric emergency room procedure 61 l were used.[7] Today N_2O from all sources is the third most important GHG for global warming and accounts for about 7% of all GHG emissions globally: some 57% comes from natural sources and approximately 43% from anthropogenic sources of which two-thirds is from agriculture.[8] Rough estimates regarding the share of N_2O emitted by healthcare range from 1% to 3% of the total annual amount of N_2O emitted globally.[9,10] Recent reports have shown that a significant proportion of N_2O purchased by hospitals is released unused into the atmosphere. Leaking pipeline manifolds are cited as the main culprit. In addition, there is a residual volume of 1% to 2% in N_2O cylinders after use which is released into the atmosphere before refilling.[11] Studies from individual hospitals in the UK and Australia have reported a N_2O wastage between 77% and 98% based on a discrepancy between purchase and usage data.[11–13]

Aside from energy consumption, anaesthetic gases are the most important source of GHG emissions from operating theatres.[14] In a carbon footprint assessment of the NHS in England, anaesthetic gases (including N_2O) accounted for 5% of the total GHG emissions of England's healthcare services.[15] In a carbon footprinting study of three Western academic hospitals it was shown that anaesthetic practice had a significant influence on the GHG emissions caused by VAs. The preferential use of desflurane resulted in tenfold higher emission of GHGs due to VAs compared with the hospital in which sevoflurane was the standard of care.[14] Life cycle assessments of anaesthetic drug use also show that the GHG emissions greatly vary with the choice of anaesthetic. When desflurane or N_2O are used for general anaesthesia this results in significantly higher GHG emissions compared to when sevoflurane is used.

When general anaesthesia is provided with the intravenous drug propofol the GHG emissions are almost negligible.[16,17] However, other detrimental effects of propofol use on the environment should not be overlooked. Propofol poses an ecological risk if it enters surface water. It is poorly biodegradable and has a high potential for bioconcentration in marine life. Also a large portion of the manufactured propofol is wasted due to regulations for the administration of propofol.[18,19] Furthermore, intravenous drug administration results in large amounts of plastic waste and this also poses a hazard to water supplies in water-scarce areas.[20]

The aim of this study was to assess the magnitude of the climate impact of inhaled anaesthetics in the Netherlands, to assess the preferences of Dutch anaesthesiologists for anaesthetic agents and finally, to explore opportunities for reducing healthcare GHG emissions due to anaesthetic practice.

A bottom-up purchase analysis of VAs in all Dutch hospitals was performed by asking hospital pharmacists for purchasing data on isoflurane, desflurane and sevoflurane in the year 2019. Data on the use of N_2O in the Dutch healthcare system were obtained from the National Institute for Public Health and the Environment (RIVM). In addition, an online survey was conducted in which Dutch anaesthesiologists and anaesthesiology residents were asked about their preferences for anaesthetic agents and the reasons for these preferences, focusing on side effects, pharmacological factors, environment, costs, and practical considerations. In addition, questions were asked regarding the use of GHG emission-saving methods in their daily practice.

Methods

For our survey, the Institutional Review Board of the Leiden University Medical Centre ruled that this research proposal (2022–2003) does not fall under the Medical Research Involving Human Subjects Act. This research does not meet the criteria because participants are not subjected to procedures or are required to follow rules of behaviour.

As a blueprint, the questionnaire from a survey that was conducted on Australian and New Zealand anaesthetists was modified and translated into Dutch.[21] The adapted questionnaire was converted to a digital version using SurveyMonkey (https://surveymonkey.com) and for validation it was submitted to ten fellow anaesthesiologists in the LUMC for assessment of the readability and comprehensibility of the questions. As a result of this pilot, there was no need to adjust the questions in the survey. In total, the survey consisted of 17 questions that would take less than 5 min to complete (For survey questions see Appendix A. Supplemental Digital Content, http://links.lww.com/EJAIC/A104). Questions were formulated to capture anaesthetic techniques in order of preference. Apart from the three inhalation anaesthetics, respondents could also choose the intravenous anaesthetic drug propofol. Next, the rationale for these preferences was asked. Standard reasons for their preferences were chosen, and respondents could tick these, and in addition there was comment box for other reasons. These standard reasons were based on side effects, pharmacodynamic, pharmacokinetic and environmental properties of the agents, costs and practical considerations. In addition, questions were asked regarding the use of techniques for the efficient use of inhalation anaesthetics as these techniques can reduce the amount emitted into the atmosphere while still achieving the same effect on the patient. Such techniques included the use of low fresh gas flows (FGF) and the use of automated control of end-tidal inhalation anaesthetic concentration (EtControl).[22,23] The degree of willingness to adapt their anaesthesia technique for the benefit of the environment was surveyed as well as the demographic data of the participants (years of experience as an anaesthesiologist, type of hospital, and its geographic location).

A request for participation in the survey was addressed to all staff anaesthesiologists and anaesthesia residents in the Netherlands. Information regarding the study and a web link to the survey was published in the newsletter of the Dutch Society of Anaesthesiologists (NVA) and in the Dutch Journal of Anaesthesiology (NTvA). Furthermore, the survey was advertised via social media (LinkedIn). The survey was open for six months from 30 June to 30 December 2022. The input data were manually exported from ‘Survey Monkey’ to a Microsoft Excel sheet. Percentages and proportions were calculated for all quantitative results.

To obtain purchasing quantities of VAs in 2019 the anaesthesiology departments from all 69 hospital organisations in the Netherlands were first contacted by telephone to ask them for their cooperation for the study. Subsequently, an email was sent to the contacts in these departments explaining the purpose of the study with instructions regarding the retrieval of the requested information. This comprised the purchased numbers of bottles of isoflurane, desflurane and sevoflurane for their hospital organisation in the year 2019. These numbers had to be entered into an online counting form that was created with the online platform JotForm (https://jotform.com). If no response was received after four weeks, a reminder E-Mail was sent and if again no response was received after four weeks, the hospital pharmacist of the respective hospital was contacted directly asking for his cooperation and to provide the requested information. The online counting form was accessible for six months from July 2021 to January 2022. All data from the online counting forms were manually entered into a Microsoft Excel spreadsheet for calculating total volumes of all participating hospital organisations. From the supplied volumes, first the calculated amount of theoretically metabolised anaesthetic was subtracted. Then, using the specific gravity of the inhalation anaesthetic and its GPW100, the amount of emitted CO_2eq was calculated. Table 1 provides the details of the characteristics that were used for the calculation of the emissions of the VAs. No correction was made for the possible use of vapour capture technology (VCT) which allows inhaled anaesthetics to be captured after use as this technique was not yet available for the Dutch market in 2019.

The amount of N_2O that was sold in the Netherlands for healthcare purposes was collected from the Emission

Table 1 Characteristics of inhalation anaesthetics

	Sevoflurane	Desflurane	Isoflurane	Nitrous oxide
Density (g ml^{-1})	1.52	1.47	1.50	
Molar mass (g mol^{-1})	200	168	184.5	
Metabolism (%)	5	0.02	0.2	0.005
Bottle volume (ml)	250	240	250	
GWP100[a]	130	2540	510	298
Mass per bottle (gr)	380	353	375	
kg CO_2eq per bottle	**49**	**896**	**191**	

[a] GWP100, global warming potential calculated over 100 years.

Table 2 Distribution of years of training as a specialist trainee or years of experience as a consultant

	Training/experience (years)	No. of participants	% of total
Trainee specialists	1	1	3%
	2	11	34%
	3	7	22%
	4	5	16%
	5	8	25%
	Total	**32**	**100%**
Consultants	0–5	61	41%
	6–10	27	18%
	11–15	24	16%
	16–20	17	11%
	>20	19	13%
	Total	**148**[a]	**100%**

[a] Two consultants did not provide this information.

Registration (https://www.emissieregistratie.nl/) which is the central location for all Dutch emission data under the auspices of the RIVM. It provides the formal historical and most recent emissions data for the Netherlands and is an independent and reliable data source in which emissions of about 375 substances and substance groups are registered. Ideally, the consumed amount of N_2O would have been obtained either directly from the supplier or through hospital purchasing figures. Both options were attempted in our study but did not provide reliable (incomplete) data. Unfortunately, the Emission Registration data gave no information regarding the breakdown into pure N_2O and Entonox.

Results

Bottom-up purchase analysis of inhalation anaesthetics

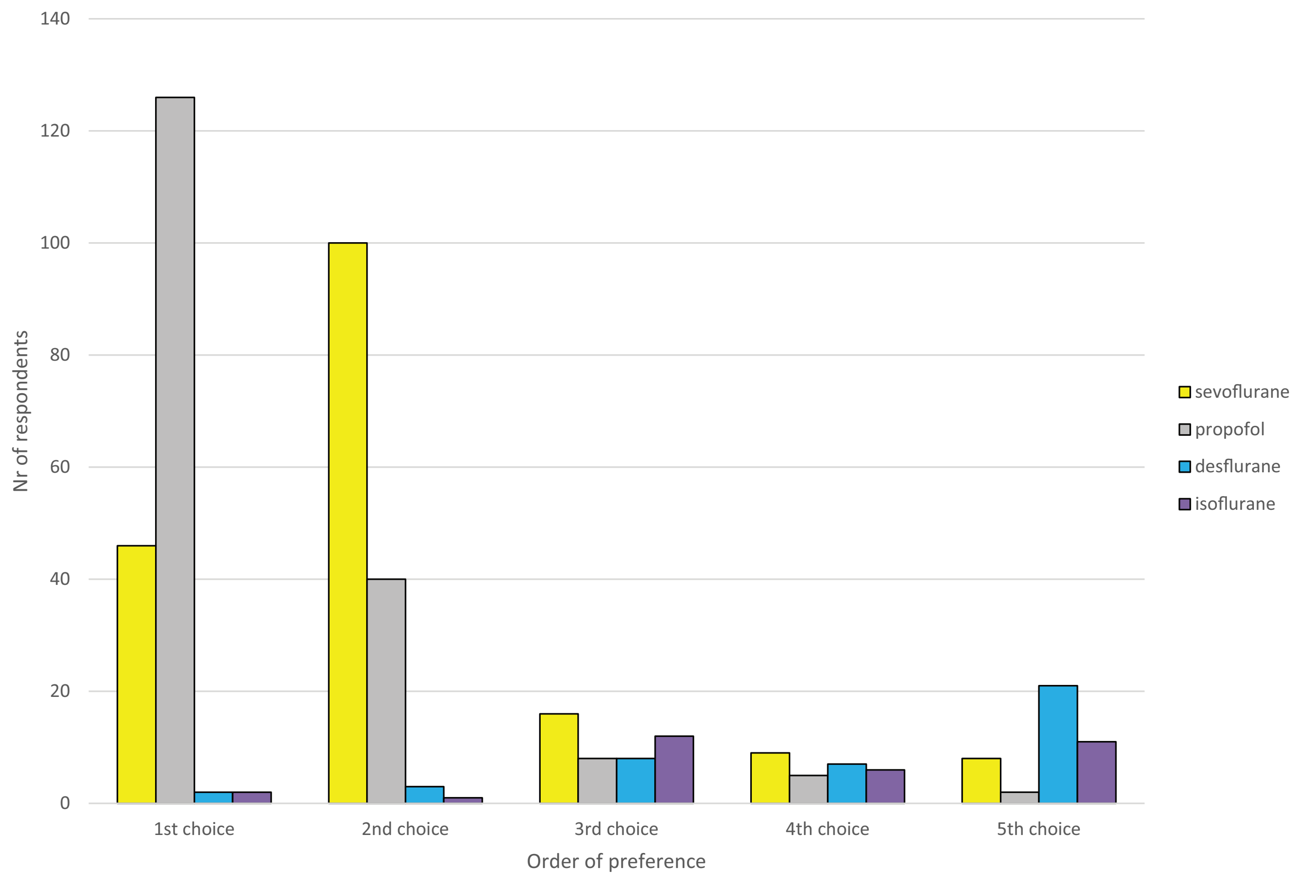
Purchasing quantities of VAs were obtained from 61 of the 69 hospital organisations in the Netherlands (response rate 88.4%). In 2019, the volumes of inhalation VAs purchased were 9178 l of sevoflurane (93.4%), 404 l of desflurane (4.1%) and 245 l of isoflurane (2.5%). Sevoflurane was used in all 61 hospitals (100%), desflurane in 16 (26%), and isoflurane in 3 (5%). Calculated emissions from these volumes were 1722 tons CO_2eq sevoflurane (50%), 1502 tons CO_2eq desflurane (41%) and 186 tons CO_2eq isoflurane (5%). Linear extrapolation of these figures from 88.4 to 100% results in a total of 3859 tons CO_2eq due to the emission of VAs in the Netherlands in 2019. According to the National Emission Registration the emission of N_2O stemming from the Dutch healthcare system in 2019 was 31.4 tons (8321 tons CO_2eq). Thus the total emission of inhalation anaesthetics in 2019 in the Netherlands came to 12.2 kilotons CO_2eq, which account for 0.07% of the 17 575 kilotons CO_2eq environmental impact of the complete Dutch healthcare sector as calculated for 2016.[24]

Survey of Dutch anaesthesiologists

The survey was completed by 182 respondents, 150 consultants (82%) and 32 specialist trainees (18%). Mean number of years of experience of the consultants was 10.2 ± 8.0 years. The exact distribution of years of training and experience of the participants are shown in Table 2. Of the respondents, 66 (36%) were employed at a university hospital, 69 (38%) at a large tertiary centre hospital, 41 (23%) at a small peripheral hospital and 6 (3%) at a private hospital. On the question ''In my daily practice, the drugs I use for general anaesthesia are as follows, in order of preference'' most respondents selected propofol as their drug of choice (70%) followed by sevoflurane (25%), desflurane (1%) and isoflurane (1%). As the second choice, sevoflurane was selected by 56% and propofol by 22% of the respondents (Fig. 1). The reasons for choosing a particular anaesthetic (questions 3–7) are shown in Table 3. Propofol was most often chosen for low incidence of side-effects such as postoperative nausea and vomiting (PONV) by 94%, followed by environmental reasons (71%) and fast awakening and discharge times (64%). Sevoflurane was chosen for haemodynamic stability (48%), low chance of awareness (43%) and short awakening and discharge times (36%). Desflurane was not used by 83% of the respondents and isoflurane was not used by 91% of the respondents. Nitrous oxide was not used by 63% of the respondents, 10% gave as reason for using N_2O the 'haemodynamic stability'. Almost 30% of respondents indicated under ''others'' that they used N_2O for induction of anaesthesia in children (as an adjuvant to sevoflurane) and also as an analgesic for painful moments during procedures. The estimated percentage of procedures where N_2O was used was indicated by 70 anaesthesiologists and was on average $4.6 \pm 4.9\%$.

Use of FGF <1 l min^{-1} was chosen by 138/182 (76%) and 1–2 l min^{-1} by 37/182 (20%), only 2 respondents indicated to use FGF >2 l min^{-1}. Reasons for not using FGF <2 l min^{-1} were 'potentially unsafe' 4/182 (2%) and 'Against user's advice (the formation of compound A) ' 5/182 (3%). On whether EtControl was used 132/182 (73%) answered 'true', 21/182 (12%) answered 'false' and 29/182 (16%) indicated that this technique was not available. When asked 'If patient safety is not compromised, I am willing to adapt my anaesthesia technique for the sake of the environment'. 90.7% agreed, 3.8% was neutral and 5.5% disagreed.

FIGURE 1 Ranking of preference for anaesthetic agent use.



Discussion

Our study shows that healthcare emissions of VAs and N_2O in the Netherlands are responsible for 0.07% of the carbon footprint of the entire Dutch healthcare sector.[24] The total of 12.2 kilotons of CO_2eq emitted is comparable to the annual emissions of about 6700 passenger cars (116 $gCO_2\ km^{-1}$, 15 000 km $year^{-1}$). The primary explanation for these relatively low emissions compared to other countries is the limited use of N_2O and desflurane by Dutch anaesthesiologists and a strong preference for intravenously administered propofol as an anaesthetic.[15] Desflurane, the VA with the highest GWP, was only available in 16% of Dutch hospitals and 83% of anaesthesiologists surveyed never used desflurane. Nitrous oxide was not used by 63% of respondents, the remaining 37% reported using N_2O in less than 5% of their cases. The intravenous anaesthetic propofol was chosen as the first drug of choice by 70% of survey respondents, with a low incidence of side-effects such as post-operative nausea and vomiting PONV, environmental reasons and short awakening and discharge times as the main reasons. Emission mitigation measures of inhalation anaesthetics such as FGF $<1\ l\ min^{-1}$ and EtControl were already used by 76% and 73% of respondents, respectively.

Table 3 **Reasons for choosing a particular anaesthetic (questions 3–7)**

	Sevoflurane	Desflurane	Isoflurane	Propofol
I do not use this agent	3 (2)	151 (83)	165 (91)	0 (0)
Low costs	23 (13)	0 (0)	7 (4)	28 (15)
Only available anaesthetic	21 (12)	0 (0)	1 (1)	2 (1)
Environmental reasons	7 (4)	2 (1)	2 (1)	129 (71)
Fast awakening/discharge	66 (36)	21 (12)	2 (1)	116 (64)
Low chance of awareness	78 (43)	1 (1)	6 (3)	15 (8)
Haemodynamic stability	88 (48)	3 (2)	6 (3)	14 (8)
Low incidence of side effects (PONV[a])	5 (3)	0 (0)	0 (0)	171 (94)

Data are *n* (%). [a] PONV, post-operative nausea and vomiting.

The purchased volume of desflurane in the Netherlands in 2019 was 4.1% of the total amount of VAs, but as a result of its high GWP100, desflurane's calculated emissions accounted for 41% of total inhaled VAs emissions. Globally, desflurane's market share in 2019 was 5 times higher (20%) than in our study, accounting for 77% of the total CO_2eq emitted due to VAs in that year.[4] Atmospheric measurements also show that 80% of the emissions of VAs in the world stem from desflurane use.[3] There is a wide variation in the use of desflurane in different countries. Reported emission rates of desflurane from Austria and Ireland (31% and 40%) match those of our study.[25–27] However, in Germany and Australia, 77% and 88% of emissions are caused by desflurane, respectively.[21,28] Although the popularity and use of desflurane has declined in the Netherlands since 2020 due to its environmental impact, this is not the only reason for its limited use reported in our study. Since the introduction of sevoflurane and desflurane in the 1990s, sevoflurane has enjoyed much greater preference among Dutch anaesthesiologists. This was partly because sevoflurane was marketed very aggressively during the introduction period and partly because it did not require the purchase of an expensive vapouriser like the one for desflurane. Furthermore, sevoflurane is suitable for inhalation inductions of children, which is not the case for desflurane.

Comparing our data one-to-one with those of Australia and New Zealand,[21] the first thing to note is the difference in the preference for desflurane use. Our survey showed that only 1% of Dutch anaesthesiologists had desflurane as their first choice while in the study by McGain *et al.* 12% indicated this.[21] Based on the consumption numbers from that study, the effect of this is that 88% of emissions were caused by desflurane use in Australia in 2017. In addition, the volume of inhalation anaesthetics consumed in Australia was 53 250 l *vs.* 9827 l in the Netherlands, thus greater by a factor of 5, while the population of Australia is only 1.5 times bigger. Assuming that the number of operations in both countries is proportionally equal, it might be inferred that intravenous anaesthesia with propofol is chosen much more often in the Netherlands, which was confirmed by the fact that 70% of the respondents in our study indicated anaesthesia with propofol as their first choice. So, because of the preference of Dutch anaesthesiologists for intravenous anaesthesia with propofol and very limited use of desflurane, the calculated emission of volatile anaesthetics in 2019 in the Netherlands (3.9 kilotons CO_2eq) was 16% of that in Australia (63.7 kilotons CO_2eq) in 2017.

With respect to our goal of investigating the potential for reducing healthcare GHG emissions from Dutch anaesthesia practices, 76% of respondents were found to be using FGF$<$1 l min^{-1} and 73% were using EtControl. Similar numbers were also reported in the French and Australian/New Zealand surveys.[21,29,30] In a recent worldwide survey among anaesthesiologists however only 49% of the respondents used a FGF$<$1 l min^{-1}.[31] Managing FGF is a safe and effective way to reduce the waste of inhalation anaesthetics and the environmental pollution due to their GHG effect.[22] With a minimum FGF of 0.5 l /min^{-1} (minimal flow), the desired clinical effect can be achieved in patients. Using more than minimal flow results in waste of inhalation anaesthetics. Since there is a linear relationship between the volume of fresh gas used and the volume of inhalation anaesthetics used, reducing FGF is an effective mitigation strategy.[17,32] Traditionally FGF was set manually, but nowadays ventilators can be equipped with an EtControl function with which the FGF is optimally adjusted according to the requested concentration of VA. In a comparative study of VA consumption with EtControl and manual control, the mean consumption of sevoflurane was 14 ml h^{-1} *vs.* 30 ml h^{-1} (−53%) and of desflurane 27 ml h^{-1} *vs.* 45 ml h^{-1} (−40%).[23] Our survey deliberately did not ask about the use of VCT as this technique for capturing VAs from the anaesthesia machine outlet was not then available on the Dutch market in 2019. The use of VCT can reduce the amount of VAs emitted into the atmosphere and VAs can potentially be recovered and reused, which can provide financial savings in addition to environmental gains.[33] This technique has recently become available to the market, but there are mixed results regarding its effectiveness in daily practice. In a clinical study performed on 13 patients 62% to 86% of the delivered desflurane was adsorbed with FGFs ranging from 0.5 to 3 l min^{-1}.[34] In a recent clinical trial in 80 patients, the median amount of desflurane recaptured was only 52%.[35] In 70 bariatric patients utilising minimal flow and EtControl only 45% of the administered sevoflurane was captured with VCT.[36] The hypothesis presented for this low VA capture was that a significant amount of sevoflurane and desflurane was still present in the body after extubation, and thus could not be captured. This seems an unlikely explanation since a computer simulation study showed that theoretically at least 73% of the administered VA could be recovered and only very small amounts of VAs are exhaled in the first hour after surgery.[37] The exact effectiveness of VCT will require further study, but the capture and recycling of VAs offers prospects for reducing environmental pollution. In fact, the modelled use of sevoflurane with low FGF and VCT has a similar carbon footprint to intravenous anaesthesia with propofol.[17]

The use of N_2O greatly affects the total amount of GHGs emitted by anaesthesia practice worldwide due to its high GWP100 and low potency.[38] Data from Ireland and Austria show that N_2O can be responsible for >80% of emissions from inhalation anaesthetics.[26,27] Our calculation of 68% for the Dutch situation matches this order of magnitude. This large fraction occurring despite the fact that the use of N_2O in the Dutch healthcare system has fallen drastically in the past decades. In 2019, it was only

5% of the amount of N_2O emitted in 1990 (RIVM data). This recent decline in N_2O use for anaesthesia purposes has also been observed by others.[39–41] It is consistent with our survey results showing that anaesthesiologists rarely use N_2O now. Nitrous oxide was initially widely used as an adjuvant to VAs to improve the clinical profile of these agents, but with the arrival of desflurane and sevoflurane in the 1990 s, that need has been eliminated. Furthermore, the use of more efficient respirators and the introduction of the intravenous agent propofol during the same period reduced N_2O emissions by anaesthesiologists. Still the impact of N_2O on the total amount of emitted GHGs in our study is responsible for two thirds of total emissions and reducing their emissions should be a priority in mitigating climate impact of inhalation anaesthetics. Even though the clinical use of N_2O by Dutch anaesthesiologists has drastically fallen it is still readily applicable as an analgesic in obstetrics and emergency care. For this application there are not always equally effective alternative pain control methods available. In such cases, it is possible for 71–81% of the administered N_2O to be collected and to be catalytically destroyed at the bedside.[42] Minimising wastage of N_2O by routinely checking for leaks in pipeline systems or even decommissioning N_2O manifolds should be encouraged given the significant reported leak of N_2O into the atmosphere.[6] The Royal College of Anaesthetists has issued a consensus statement on the removal of pipeline N_2O in the United Kingdom and Republic of Ireland recommending that given the fact that N_2O is no longer an essential drug in modern anaesthetic practice, N_2O manifolds should be decommissioned as soon as possible and if necessary replaced by point-of-care cylinders.[43] Furthermore legislation should ensure that gas residues in N_2O cylinders are destroyed rather than vented into the atmosphere before refilling.[6]

Our results show that Dutch anaesthesiologists prefer to undertake their anaesthesia for the most part with intravenous propofol, and can do so without the use of desflurane. In contrast, worldwide only 23% of anaesthesiologists indicate that they prefer intravenous anaesthesia and 64% prefer inhalation anaesthesia.[31] As a result of efforts to make the healthcare sector more sustainable, several countries have reduced desflurane use in recent years. In Scotland, for example, the use of desflurane was completely phased out by 2023, and Australia and New Zealand have seen sharp reductions in its use. However, in Japan and Taiwan, desflurane is the most commonly used VA.[44] A risk-benefit analysis of desflurane *vs.* sevoflurane regarding clinical, financial and environmental characteristics shows that there are no reasons to prefer desflurane as an anaesthetic agent.[45,46,47] The European Union has issued a proposal with the intention of prohibiting the use of desflurane from January 2026. Given the importance of universally phasing down HFCs, this is a logical choice given the availability of the low-GWP alternative sevoflurane. However, care must be taken to ensure that sevoflurane remains available to anaesthesiologists. Although intravenous propofol is a good alternative to sevoflurane for many indications, inducing anaesthesia in children with a facemask is a unique feature of sevoflurane. Also, Dutch anaesthesiologists indicated choosing sevoflurane for its haemodynamic stability and low risk of awareness. Apart from the clinical differences between propofol and sevoflurane, the administration technique of VAs is completely different from that of intravenous agents. Anaesthesiologists have mastered this technique since the early days of ether, and it is important that the future generation of anaesthesiologists learn and maintain their skill with this technique. Furthermore, completely phasing out VAs in the interest of global warming would mean complete reliance on a single agent (propofol) to administer general anaesthesia. During the COVID-19 pandemic, the global shortage of propofol led to a flight to sevoflurane and isoflurane, even patients in the ICU were kept under anaesthesia with these VAs.[48]

Phasing out HFCs is of great importance given the relatively large impact these agents have as a result of their large GWPs. These agents are mainly used in as refrigerants, propellants, foams etc. Given the exuberant global presence of these agents and their relatively short atmospheric lifetime, immediate phasedown can have a major impact on the ultimate global temperature rise.[49,50] The phasing down of these HFCs is expected to avoid emissions of 8.8 gigatons CO_2eq per year by 2050, potentially providing up to 6–10% of the needed mitigation to stay below 2°C average global temperature rise.[50] The share of global HFC emissions from VAs is estimated to be of 9.8 million tons CO_2eq in 2050 in a growth scenario (2% increase of emissions per year) of the aforementioned 8.8 gigatons CO_2eq which is 0.08%.[3] This relatively low impact of VAs does not mean that anaesthesiologists need not worry about the release of their agents, but can be seen as an argument for allowing the continued use of sevoflurane in particular. In order to minimise the environmental impact, the use of sevoflurane will have to be regulated by, for example, making EtControl and VCT mandatory if this agent is chosen for general anaesthesia.

Limitations of our study are that we were not able to obtain N_2O procurement data from Dutch hospitals as this was apparently too complicated to obtain. Instead, we used data from the national Emission Registration, which may have led to underreporting given that these data are based on voluntary declarations from the largest N_2O suppliers in healthcare. We would have liked to obtain purchase data of propofol, however, the problem is that propofol is used not only for general anaesthesia, but also for ICU sedation and procedural sedation, among others. The population of our survey might be skewed by the relatively large number of young respondents. It is possible that our results are influenced by this and that more propofol and N_2O are used by this group. However, our procurement data show a similar pattern.

Conclusion

Our study shows the normal practice of Dutch anaesthesiologists results in relatively limited greenhouse gas emissions from inhalation anaesthetics. A preference for intravenous propofol and very little desflurane or N_2O use result in a carbon footprint that is equal to the annual emissions of about 6700 passenger cars. However, there is definitely room for improvement. Implementation of strategies to reduce clinical use and wastage of N_2O, complete elimination of desflurane for general anaesthesia, and mandatory use of EtControl and VCT when using sevoflurane can make the apparently unavoidable GHG emissions from anaesthetic care acceptable for future generations.

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