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REVIEW

Waste not, want not: the anaesthesiologist and the environment

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Climate change has been described as the "defining issue of our time". The wide-ranging effects of climate change are well documented. These effects include a change in weather patterns with more frequent extreme weather events, loss of biodiversity, loss of food security, political instability and declining health. Sub-Saharan Africa is especially vulnerable to climate change, even though the region only accounts for a fraction of global greenhouse gas (GHG) emissions. The healthcare sector contributes significantly to climate change. Within healthcare, the provision of anaesthesia is associated with a disproportional contribution to GHG emissions, waste production and energy consumption. Anaesthesia providers were identified as crucial role players in improving sustainability within medicine. A growing body of literature emphasises the importance of sustainable anaesthesia practices. Recommendations are regularly updated based on expanding knowledge. However, the subject matter is broad and often falls outside the sphere of anaesthesiology, making it challenging and time-consuming to identify information relevant to clinical practice. Furthermore, recommendations might differ depending on a multitude of circumstances. This review aims to simplify and summarise contemporary literature and recommendations, and present these concisely.

Keywords: climate change, GHG emissions, waste production, energy consumption, anaesthesia

The defining issue of our time

Global climate change is a significant problem facing the modern world. The Royal Society and US National Academy of Sciences, in their recent publication, describe climate change as "one of the defining issues of our time".[1] Since the beginning of the 20th century, temperatures have increased on average by 1 °C throughout the world. This means that society is enduring the hottest period in the modern age.[2] International consensus states that human activity is the leading cause of rising global temperatures. The most notable human activity leading to global warming and climate change is the release of greenhouse gas (GHG) such as carbon dioxide (CO_2), methane (CH_4), halocarbons and nitrous oxide (N_2O).[1]

Sub-Saharan Africa is especially vulnerable to climate change, despite accounting for only a small fraction (< 4%) of GHG emissions.[3] Sub-Saharan Africa is warming more rapidly than the rest of the world. Sea level rise is also accelerated compared to the international average, and 33% of global droughts occur in this region.[4] The effect of climate change on food security is also disproportionally high, with the Intergovernmental Panel of Climate Change (IPCC) predicting the first climate-change-associated famine to occur in the region.[4] Impaired food security might have a ripple effect of increased urbanisation in a region with limited formal urban housing. Climate change can also increase conflict in an already unstable region characterised by poor governance.[3] Add to this the limited resources available to a poor and vulnerable populace, the effects of climate change pose a unique challenge to sub-Saharan Africa.

The healthcare sector: both culprit and victim

The healthcare sector contributes a substantial proportion of the total GHG emissions.[5,6] An analysis of 36 developed countries (including China and India) indicated that healthcare contributed 5.5% of each nation's total emissions. The burden of disease associated with GHG emissions and subsequent climate change can be expressed in disability-adjusted life years (DALY). Analysis of the burden of disease caused by GHG emissions in the US was estimated to be 470 000 DALY.[5,6] Other estimates of the health impact of GHG emissions by health sectors range from 23 000 DALY in Canada to 405 000 DALY in the US.[7] The healthcare sector is thus both a leading contributor and a victim of climate change.

Hospital services are the main contributor to GHG emissions within the healthcare sector, with operating theatres contributing disproportionately to the total hospital emissions.[5,7] Operating theatres produce medical waste (which requires incineration), run emergency services after hours, use anaesthetic vapours and medical gas at a high rate, require precise temperature control (by heating, ventilation and air conditioning [HVAC] units), require sterilisation of instruments, and consume single-use plastic at a high rate.[5,7]

The role of the anaesthesiologist

Anaesthesia delivery plays a significant role in GHG production in the theatre environment. Sources of GHG emissions in anaesthesia delivery include volatile agents, N_2O, general waste, medical waste, drug wastage, and electricity consumption by anaesthetic machines and -monitors.[5-9]

Since the first publication in the late 1980s that investigated the global warming effect of inhaled anaesthetic drugs, little attention has been paid to the subject by the academic community until fairly recently.[10] The recent literature from the authors Sherman, Ryan, Andersen, Vollmer, and their respective teams, indicates the real global warming potential for all volatile anaesthetic agents in clinical use today.[11-14]

The metrics commonly used to determine the environmental impact of a gas are the global warming potential (GWP) and the ozone-depleting potential (ODP).[15] GWP is the metric described in the Kyoto Protocol to the United Nations Framework for Convention of Climate Change. This allows us to give non-CO_2 gases a CO_2-equivalence.[10,15,16] It is best described as the heat absorbed by any GHG in the atmosphere, as a multiple of the heat that the same mass of CO_2 would absorb. GWP for CO_2 is 1. It is thus a function of a gas' atmospheric lifetime and ability to absorb infrared radiation (radiative efficiency).[11,15] Different time horizons are used when expressing GWP. The internationally accepted standard is 100 years (GWP_{100}), but as most anaesthetic agents have a lifetime of fewer than 20 years, GWP_{20} might be a more suitable metric. ODP measures how much damage a chemical can cause to the ozone layer compared to a similar mass of trichlorofluoromethane (CFC-11). It is a function of a gas' atmospheric lifetime and the number and type of halogenations. Bromine-containing, and to a lesser degree chlorine-containing, substances are known to degrade ozone readily.[15]

Studies to investigate the global warming potential of volatile agents were conducted by Andersen et al.[11] and Ryan et al.[14] According to Andersen et al.,[11] halothane has a GWP_{100} of 50, compared to 510, 2 540 and 130 for isoflurane, desflurane and sevoflurane, respectively. These results differ from results by a comparative study by Ryan et al.[14] Andersen et al. attempted to explain the difference in results by highlighting differences in the methodology of the two studies and attempted to reproduce the results of Ryan et al., but failed to do so. Andersen et al. postulate that Ryan et al. used an inaccurate GWP_{100} as they included data

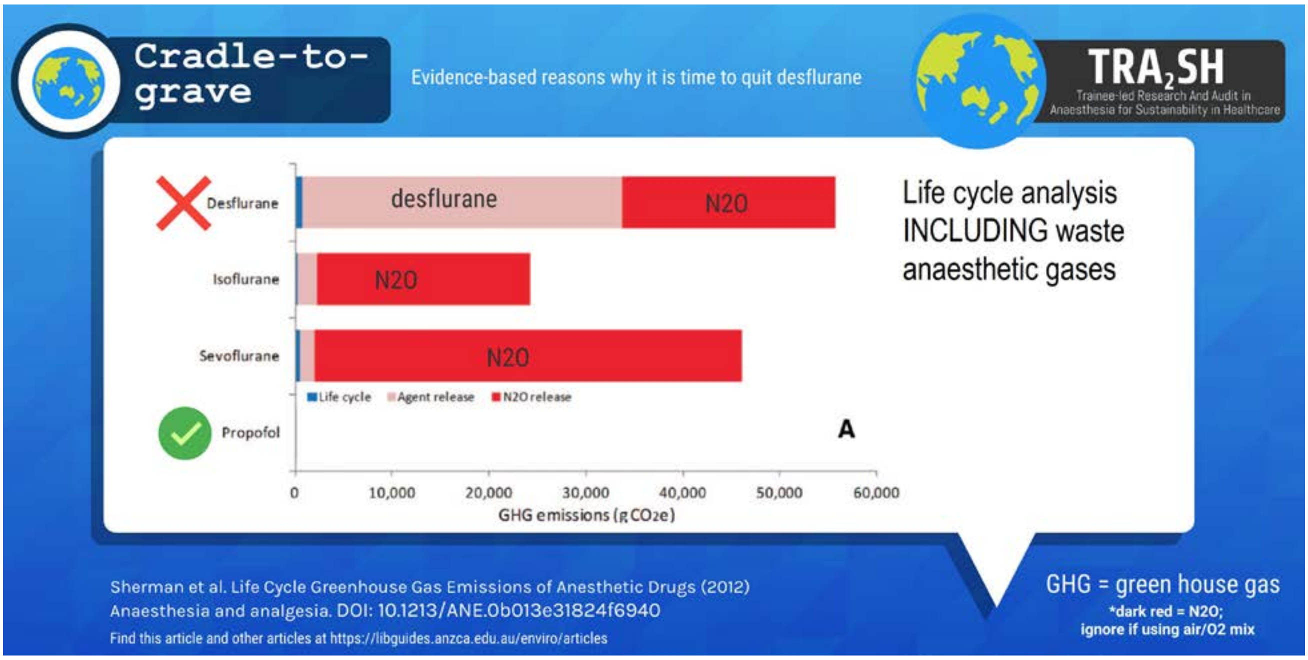

Figure 1: Life cycle GHG emissions for anaesthetics, including waste anaesthetic gas emissions[12,18]

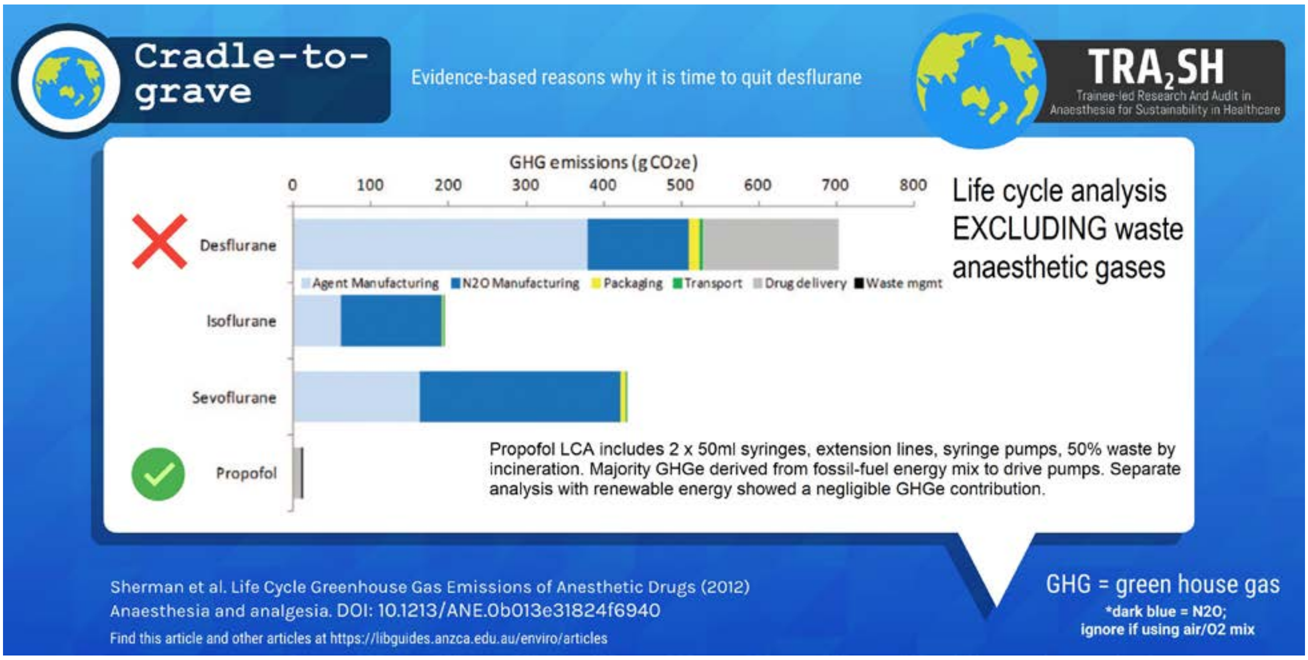

Figure 2: Life cycle GHG emissions of anaesthetics excluding waste anaesthetic gas emissions[12,18]

from another study that have been proven inaccurate by Calvert et al.[11,17] Although the exact values of the GWP of volatile agents differ in the literature, it is clear that all values calculated are very significant.

Sherman et al.[12] conducted a thorough life cycle analysis (LCA) of the three most common volatile anaesthetics, N_2O and propofol (Figure 1 and Figure 2). They considered the resource use, manufacturing, transport, delivery and disposal into the environment. The authors included energy consumption, materials used and emissions at each of the above-mentioned life cycle phases.[12] They found that desflurane has an exceptionally high GHG effect. This effect is due to four factors unique to desflurane: its high minimum alveolar concentration (MAC), high GWP_{100}, the electricity consumption of desflurane vaporisers, and the fact that it does not undergo metabolism in vivo, thus leading to an increased fraction being vented into the atmosphere. Sevoflurane and isoflurane have comparably low GHG effects. Desflurane has 15 times the GHG effect of isoflurane and 20 times the GHG effect of sevoflurane when administered in an air/O_2 carrier gas and remains higher even if N_2O/O_2 is used.[12] An interesting observation is the effect of N_2O on the greenhouse effects of isoflurane and sevoflurane. When these agents are delivered using an air/O_2 carrier gas, isoflurane has the most significant effect mainly because of its high GWP_{100}. However, when the carrier gas is converted to N_2O/O_2, the GHG effect of sevoflurane is increased by 900% compared to only 65% for isoflurane. The immense effect of N_2O on sevoflurane's GHG effect is due to the increased flow requirements compared to isoflurane.[12] Halothane was not investigated.

Vollmer et al.[13] measured the atmospheric levels of volatile agents from 2004 to 2014. They found that sevoflurane, isoflurane and desflurane levels have increased.[13] Estimates from atmospheric levels indicate emissions of 880, 960 and 1 200 tons/year for isoflurane, desflurane and sevoflurane, respectively.[13] The equivalent CO_2 atmospheric release deduced from this data ranges from 2.5–3.7 million tons. Desflurane contributes the most, with an estimated 80%.[13] Halothane levels have decreased, but the data suggests that it is still being used at a rate of 120–280 tons/year.[13] Hu et al.[19] found that the synthesis method plays an essential role in volatiles' total GHG effect, particularly sevoflurane. They state that the synthesis of sevoflurane using tetrafluoroethylene results in significantly higher LCA GHG emissions.[19] The effects of N_2O are potentially more harmful than those of volatile anaesthetics. This is due to its very high MAC and GWP_{100} (298) and rapid alveolar uptake making low-flow anaesthesia challenging.[20]

Except for GWP, the ODP of anaesthetic agents should also be considered. The ODP for N_2O, halothane, isoflurane, sevoflurane and desflurane is 0.017, 1.56, 0.03, 0.00 and 0.00, respectively.[15]

It is clear from the body of evidence that sevoflurane (when sustainably synthesised) can be considered the most benign volatile agent, while desflurane is the least environmentally friendly option.[11-14] International organisations have called for the abandoning of desflurane due to its significant environmental impact.[18] Furthermore, N_2O usage should be well motivated due to its inherent detrimental environmental effects and its effect on volatile agents.[19]

It is essential to maintain perspective; considering the total global GHG emissions, the contribution of anaesthetic gases is relatively small although not insignificant. The estimated GHG effect (measured in GWP_{100}) resulting from global volatile anaesthetic usage is equivalent to one coal-fired power station or 1 million automobiles.[11,15]

Most studies attempting to evaluate the environmental impact of intravenous anaesthetics focus on propofol. Propofol has a low life cycle GHG effect (Figure 1 and Figure 2).[12,18] It is estimated that propofol's GHG effect is 0.01% that of desflurane.[12] Other studies have found the GHG effect equivalent to sevoflurane at low fresh gas flow.[19] The concern with propofol is its potential for bioaccumulation and toxicity to aquatic life forms. The liver extensively metabolises propofol, but the discarded fraction can

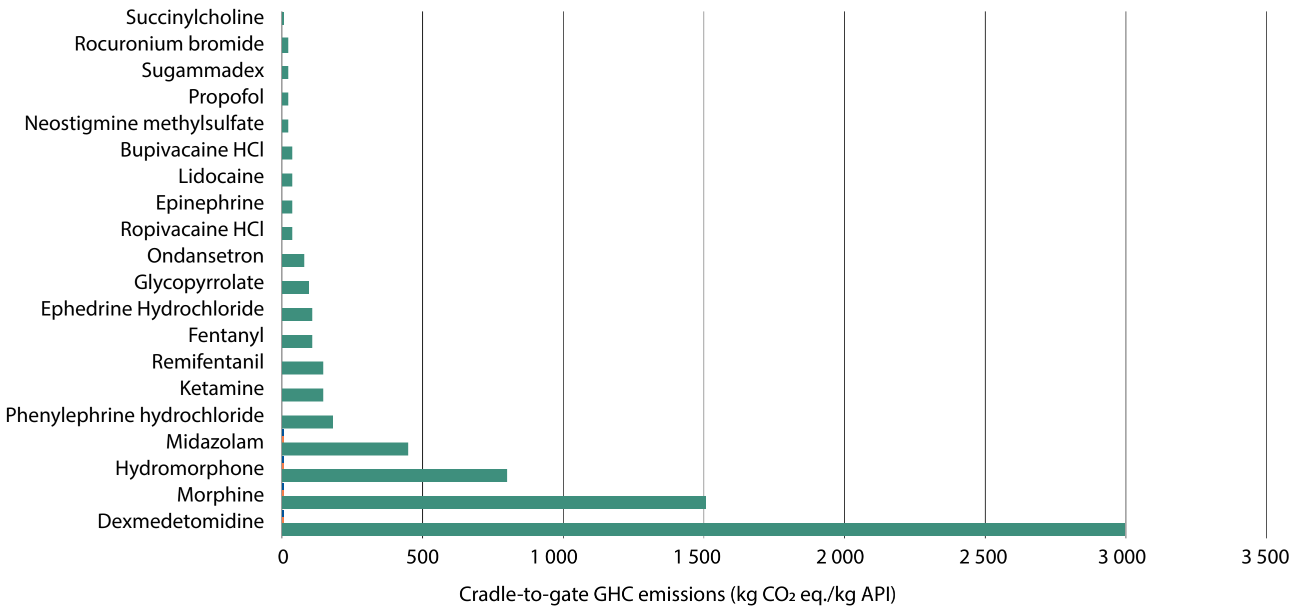

Figure 3: Cradle-to-gate GHG emissions per kg drug for 20 injectable drugs used in anaesthesia care (recreated from Parvatkar et al.[22])

contaminate water sources. The possibility of glucuronidated propofol undergoing deglucuronidation in the environment can not be excluded. If this proves to be the case, the environmental impact of propofol might be much higher than currently accepted.[21] Audits have shown that up to 50% of propofol is wasted, and due to the uncertainty of its biotoxicity, the current recommendation is to incinerate discarded propofol as medical waste.[12,21] With the potential biotoxicity in mind, propofol-based total intravenous anaesthesia has a fraction of the environmental impact of most volatile techniques.[12,22]

Unfortunately, limited information about the environmental impact of other commonly used drugs is available. This is due to the complicated process of accurately measuring cradle-to-grave emissions, confidential company patents, and the absence of GHG emission disclosure by pharmaceutical companies.[22] A US study[22] attempted to generate "cradle-to-gate" emissions for twenty common anaesthetic drugs and found that GHG emissions differ widely depending on the synthesis and the number of steps involved. Molecular complexity and molecular weight does not seem to influence GHG emissions.[22] Dexmedetomidine had the highest GWP_{100} and succinylcholine the lowest. It is clear from this study that it is not only volatile agents that might have a significant environmental footprint but also other drugs that are ubiquitous in modern anaesthesia.

Modern anaesthetic machines combined with circle breathing circuits equipped with CO_2-absorbers have allowed anaesthesiologists to employ low-flow anaesthesia. Welch[23] defines low-flows as less than 2 l/min and basal flow as 0.25–0.5 l/min. The advantages of low-flow anaesthesia regarding environmental impact are simple: the lower the fresh gas flow during anaesthesia, the less volatile and gas is consumed.[23] Volatile usage can be reduced by up to 80% when using low-flow techniques.[15] Carbon dioxide absorbent is depleted at a higher rate when low-flow anaesthesia is used, but this is unlikely to offset the advantages of its volatile sparing effects.[12] The concern with low-flow anaesthesia is the formation of various compounds within the carbon dioxide absorber, most notably NH_4 and compound A. This can be minimised by increasing flows for a few minutes every few hours.[23] However, Zhong et al.[24] recommend not using low-flow anaesthesia when conducting a total intravenous technique with a carbon dioxide absorber. The authors suggested a fresh gas flow rate of 4–6 l/min to minimise the financial cost of anaesthesia. Unfortunately, this did not significantly affect the life cycle GWP.[24] However, the argument can be made that reducing the financial cost allows for the use of funds in other areas where sustainability can be improved.

Waste further adds to the environmental impact of hospitals. Anaesthesia contributes a quarter of theatre waste, and up to a third of total hospital waste.[7,8] Medical waste can be classified as either general waste suitable for landfills or biomedical waste that must be incinerated or autoclaved before disposal. Medical waste disposal is not only more expensive than general waste disposal but is also more damaging to the environment.[7]

Estimates suggest that 70% of general waste is inappropriately discarded as medical waste, even though international consensus suggests that medical waste should not exceed 15% of total hospital waste. Implementing a waste segregation system can reduce medical waste by 80%.[7]

Comparing LCAs of reusable vs single-use items showed compelling results. One of the main determinants is the energy source used when cleaning/sterilising reusable items.[8] For example, studies conducted in Australia have found that single-use items have a smaller footprint, but the reverse is true in Europe. The reason for this is the difference in energy sources used by the regions.[8] Another determinant is the type of product. For example, the reusable version for some products has a lower footprint in some countries (such as laryngeal mask airways [LMAs] in the US), while the single-use version is more environmentally friendly in others (face masks, laryngoscopes and breathing circuits in Australia).[8]

A significant amount (60–70%) of general waste is recyclable.[7] Recycling is substantially more affordable and more environmentally sustainable than disposal. Even though the benefits of recycling are clear and the willingness of anaesthesiologists to recycle has been demonstrated, only a third of first-world (Canadian) anaesthesiologists recycle. Reported barriers include poor hospital leadership and lacking education/information.[7,8] Information regarding recycling practices in southern Africa is lacking, and research in this area should be encouraged.

Internationally accepted processes of reducing waste are centred around the core strategy: avoid, reduce, reuse, recycle and reprocess.[6-9] An in-depth discussion of each component is beyond the scope of this article. Local hospitals, health departments, industry, communities and the medical fraternity should conduct audits and LCA and build waste management programmes around this core strategy.

Conclusion

When considering the role that anaesthesiologists play in pollution and climate change, we are seemingly faced with two opposing priorities. On the one hand, patient care weighs heavily; on the other, our increasingly tenuous global climate condition can no longer be ignored. Our practice should be patient-centred, but with consideration given to the effect of these practices on society as a whole. It has been shown in the last decade that sustained efforts can lead to marked reductions in GHG emissions, medical waste and water- and energy consumption, without placing patients at risk. Therefore, patient safety need not be sacrificed on the altar of sustainability – the two should co-exist.

Conflict of interest

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