Review Article

The science of climate change and the effect of anaesthetic gas emissions

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Summary

The dedication of the international anaesthetic community to reducing the environmental impact of healthcare is important and to be celebrated. When this is underpinned by robust science, it has the potential to make a real difference. However, volatile anaesthetic agents have been widely promoted in the medical literature as damaging to the climate, leading to a drive to remove them from clinical practice. This is based on notional `CO_2-equivalent´ values created using the simple emission metric known as the global warming potential. Here, we assert that when proper consideration is given to the science of climate change, volatile anaesthetic gas emissions cannot be simply equated to real carbon dioxide emissions, and that their climate impact is vanishingly small. This paper gives anaesthetists a framework to make informed choices founded on climate science and calls for attention to be refocused on the urgent need to reduce the real carbon dioxide emissions associated with healthcare.

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Introduction

In 2010, Sulbaek Andersen et al. published a key paper on the potential effects of inhaled anaesthetic gases on the climate which stated: ``*On the basis of the derived 100 year GWPs the average climate impact per anaesthetic procedure… is the same as the emission of 22 kg carbon dioxide. We estimate that the global emissions of inhalation anaesthetics have a climate impact which is comparable with that from the carbon dioxide emissions from one coal-fired power plant or 1 million passenger cars*´´ [1]. This generated considerable interest and started the drive to remove volatile agents from clinical practice [2–4], despite a linked editorial by K. P. Shine, a leading climate scientist, expressing caution [5].

In this paper, we review the validity of the statement by Sulbaek Andersen et al. in the context of fundamental climate science and consider whether the drive to ban certain inhaled anaesthetic agents is scientifically justified. The pathway from global warming potential (GWP) to actual global warming and, ultimately, to climate impact is illustrated in Fig. 1. The complexity of this pathway cannot be overstated and each step along this pathway becomes increasingly relevant to what we need to know to take appropriate action. Our focus in this paper is on the volatile anaesthetic agents, but the role of nitrous oxide is also briefly discussed.

The greenhouse effect and greenhouse gases

To understand the potential role played by anaesthetic gases, it is necessary to start with the foundations of human-induced climate change – how greenhouse gases affect the

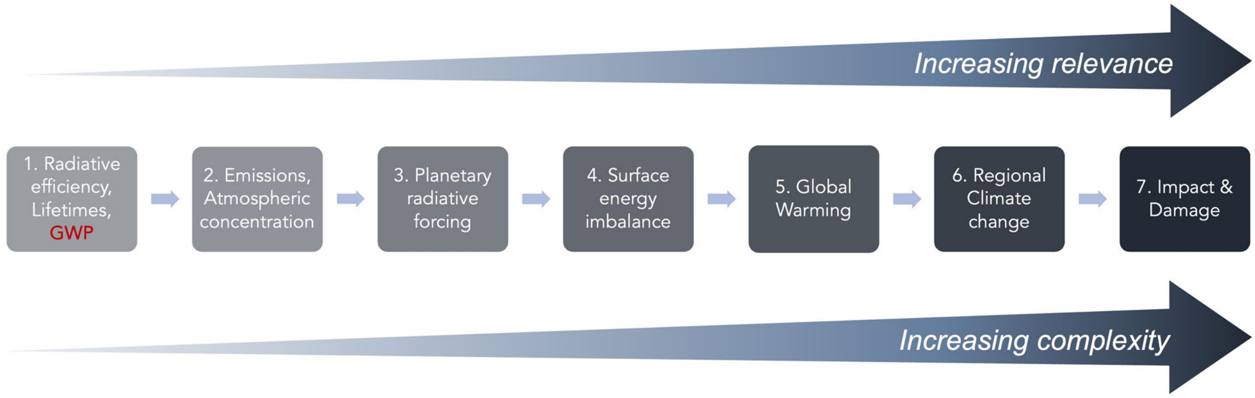

Figure 1 Schematic of the pathway from the infrared radiative properties of a greenhouse gas to climate change and its impacts, showing the increasingly complex nature of the climate science that needs to be applied to understand the real-world climate impact. GWP, global warming potential.

flow of infrared (thermal) energy from the Earth's surface and its atmosphere out to space, and conversely from the overlying atmosphere to the Earth's surface.

Anaesthetic gases are strong absorbers and emitters of infrared radiation, and they work alongside the principal, naturally occurring greenhouse gases of water vapour, carbon dioxide, ozone and methane. The commonly used anaesthetic gases absorb and emit infrared radiation at a part of the spectrum where there are very few other greenhouse gases with which to compete (known as an `atmospheric window´), and where infrared radiation from the Earth's surface could otherwise escape freely to space (i.e. transmission = 1). Consequently, their potential to trap infrared radiation (their radiative efficiency) is very high.

In contrast, human emissions of carbon dioxide are additive to the abundant carbon dioxide emissions from natural sources as part of the Earth's natural greenhouse effect. This means that the strongest absorption lines in the band of the spectrum where carbon dioxide absorbs infrared radiation are already saturated (i.e. transmission = 0), and it is the weaker absorption lines at the edges of the band that come into play in human-induced global warming. This explains why, relative to carbon dioxide, anaesthetic gases are more potent greenhouse gases in terms of radiative efficiency.

However, the greenhouse effect only works because tropospheric temperatures decrease with height. To trap more radiation in the planet, greenhouse gases need to be active in the middle/upper troposphere where they can absorb infrared emissions from the warmer layers below and re-emit to space at a colder temperature (i.e. the planet experiences a `net gain´ in energy). So, to be effective greenhouse gases, anaesthetic gases must be well mixed throughout the troposphere, as is the case for carbon dioxide and other major greenhouse gases. The time taken for a point emission of a gas to be mixed vertically and horizontally throughout the troposphere is at least 1 year, so only desflurane, which has a lifetime of 14.1 years [6], persists long enough to be regarded as radiatively effective [7]. The lifetimes of sevoflurane and isoflurane (1.4 and 3.5 years, respectively) are too short to have a full radiative effect [7].

Explaining global warming potential from a climate perspective

For the majority of greenhouse gases, atmospheric concentrations are the result of multiple emission sources. Climate protection protocols are therefore implemented by setting limits on emissions, and by expressing them in `equivalent´ terms using simple metrics, even though it is their atmospheric concentrations that ultimately matter. For example, the radiative efficiency and lifetime of a gas can be used to create the emission metric GWP, as described by Sulbaek Andersen et al. [8].

Global warming potential is defined simply as the ratio of the cumulative radiative forcing (the energy being added to the planet, based on radiative efficiency and lifetime) over a time horizon from the instantaneous release of 1 kg of a given gas, such as desflurane, relative to that of 1 kg of carbon dioxide. The typical GWP time horizon of 100 years (GWP_{100}) reflects the long lifetime of carbon dioxide and its cumulative radiative forcing, which is crucial for delivering its impact on the climate that we observe today and what will happen in the future. In other words, GWP_{100} attempts to mathematically capture what the entire addition of energy to the planet could be over 100 years after a single pulse emission of a particular gas as it decays and compare this with what a pulse of the same mass of carbon dioxide would add.

For desflurane, GWP_{100} is currently calculated as 2530 based on its radiative efficiency of 0.466 $Wm^{-2}ppb^{-1}$ (watts per square metre, per part per billion) [9], and this high value has prompted the anaesthetic community to label desflurane as a problematic greenhouse gas with the potential to contribute to global warming and lead to subsequent climate impacts. However, GWP does not consider the actual atmospheric abundance of a greenhouse gas, nor does it represent any of the physical complexity of the overall climate system illustrated in Fig. 1.

The GWP metric was created in 1990 to place emissions of different major greenhouse gases onto a common scale in order to aid international negotiations and inform multi-gas climate policies, such as the Kyoto Protocol. As Shine et al. noted [10], what GWP does not do (despite the name) is tell us about actual global warming. Nor can we infer a climate impact of that gas (Fig. 1). This is further emphasised by the Intergovernmental Panel on Climate Change (IPCC) [11, Box TS.2 in the Technical Summary], which states that "*all (emission) metrics have limitations and uncertainties, given that they simplify the complexity of the physical climate system and its response to past and future GHG emissions*"; it also notes that "*GWP is not well suited to estimate the cumulative effect on climate from sustained short-lived climate forcer emissions*". The IPCC defines short-lived climate forcers as pollutants with lifetimes of < 20 years; all volatile anaesthetic agents in current use fall into this category.

In recent years, there has been an extensive and complex debate in the climate literature around the relevance of simple emission metrics, such as GWP, for short-lived climate pollutants or forcers [12–14]. Methane has been the primary focus of these studies, but the arguments apply equally to desflurane: that emissions of long-lived (and hence cumulative) gases vs. short-lived climate pollutants translate into impacts on the planetary energy budget in fundamentally different ways. Drawing on this debate, Pierrehumbert concludes that "*there is no way to express emissions of short-lived gases in terms of an equivalent emission of long-lived gases without seriously misrepresenting some aspect of the climate response*" [15].

Despite these limitations and warnings, GWP has been taken up as a simple proxy for converting anaesthetic gas emissions to carbon dioxide equivalent (CO_2e) emissions and carbon footprints. Current statements on the environmental effects of anaesthetic gases [16] and the consequent actions to remove volatile agents from medical practice [2, 3] are based solely on their high GWP [17]. Even with the latest refinements [6], GWP (or indeed any emission metric) represents an over-simplification of the climate system and its potential response to greenhouse gas forcing. Based on climate science, we assert that this is a physically unsound approach for determining the potential climate impact of volatile anaesthetic gases, and that it is the atmospheric concentration and radiative forcing of individual greenhouse gases that matter, along with how the climate system may respond.

Radiative forcing by anaesthetic gases

Recognising the serious physical limitations of emission metrics, the climate science community prefers to use present-day estimates of radiative forcing at the top of the atmosphere to compare various greenhouse gases, rather than a mathematical projection from a hypothetical pulse emission (via GWP) [18].

Radiative forcing is the difference between the energy entering the planet and the energy leaving it which, for a stable climate, we would expect to be very close to zero. But anthropogenic greenhouse gas emissions have pushed the Earth out of equilibrium, so the climate is changing in an attempt to bring the planet back into energy balance. Radiative forcing is a fundamental measure of how far away we are from a stable climate.

The great advantage of radiative forcing is that it avoids the difficulty of how to account for short-lived climate forcers (which confounds GWP, and its derivative, CO_2e). It also takes account of present-day accumulations of greenhouse gases, as measured by atmospheric concentrations, which do not enter the GWP metric, but which are fundamental drivers of climate change.

It is worth highlighting that how an emission of a gas translates to an atmospheric concentration is very different for a long-lived greenhouse gas, such as carbon dioxide, compared with a short-lived climate forcer, such as a volatile anaesthetic agent. Carbon dioxide has been steadily accumulating in the atmosphere since the Industrial Revolution began, which is why the concentration has risen from 280 parts per million (ppm) by volume to over 420 ppm today. Even though global emissions of anaesthetic gases have increased substantially, albeit with significant uncertainties [19], their atmospheric concentrations have remained small (e.g. 0.37 parts per trillion for desflurane [9]), in part because their short lifetimes preclude any long-term accumulation.

Thus, if we know the radiative efficiency of a particular gas and its atmospheric concentration, then we can also know the current effect of that gas on the energy budget of the planet. Table 1 summarises the concentrations and the effective radiative forcing in 2019 as a result of anthropogenic emissions of major greenhouse gases since

Table 1 Global atmospheric concentrations, lifetimes, effective radiative forcing values for the three main anthropogenic greenhouse gases and the estimated global radiative forcing for the three main anaesthetic gases.

	Atmospheric concentration; parts per trillion	Atmospheric lifetime; years	(Effective) radiative forcing; Wm^{-2}
Carbon dioxide	420,000,000	100+	2.16
Methane	1,920,000	12.4	0.54
Nitrous oxide	336,000	123	0.21
Desflurane	0.37	14.1	0.00017
Sevoflurane	0.16	1.4	0.00003
Isoflurane	0.11	3.5	0.00006

Atmospheric concentrations for the three major gases are taken from US National Oceanic and Atmospheric Administration [30] and the effective radiative forcing from Figure 7.6 in the IPCC 6th Assessment Report [18]. For anaesthetic gases, the radiative forcing is calculated as their radiative efficiency ($Wm^{-2}ppb^{-1}$) multiplied by their atmospheric concentrations, based on the latest data [9].

1750, as reported in the IPCC 6th Assessment Report in 2021 [18]. Effective radiative forcing includes the adjustment by atmospheric temperatures, water vapour and clouds to the forcing agent. It is particularly relevant to abundant greenhouse gases which have already induced some degree of climate change. For carbon dioxide, the adjustments also include the physiological effects on vegetation.

Table 1 shows that the three major greenhouse gases contribute 2.91 Wm^{-2} to the net radiative forcing, which is currently estimated at 2.72 Wm^{-2} when allowing for negative forcing from aerosols [18]. It is this energy imbalance due to radiative forcing that then leads to global warming and the consequences that ensue (Fig. 1). In comparison, the concentrations of anaesthetic gases are very small (Table 1), even allowing for the paucity of global measurements [19]. Consequently, their radiative forcing is < 0.0003 Wm^{-2}, a percentage contribution of $< 0.01\%$ compared with the net radiative forcing that results from carbon dioxide. This value is minute and will be lost within the natural variability of the climate system. For context, the temporary reduction in emissions caused by the COVID-19 lockdown led to a net radiative effect of 0.2 Wm^{-2}, which was undetectable above the internal climate variability [18].

From radiative forcing to climate change and impact

In this section, we consider the various steps in the pathway shown in Fig. 1 that link radiative forcing to the response of the climate system, and ultimately to the regional and local climate impacts that will drive our mitigation and adaptation decisions. The science becomes increasingly complex as we move along the chain.

So far, we have considered the net radiative forcing at the top of the atmosphere that results from the action of greenhouse gases and other pollutants (Table 1). To go from that to global warming involves, first, consideration of energy flows through the atmosphere and the resulting energy budget at the surface of the planet (Fig. 2a), and second, how that translates into global warming (Fig. 2b).

The first thing to note is that the Earth's energy budget is complicated! There are numerous players, especially clouds and water vapour, both of which interact with infrared radiation and change the Earth's greenhouse, known as 'climate feedbacks'. A unique characteristic of the Earth's climate is that it can sustain water in its three states – solid, liquid and vapour – along with the latent heat exchange that takes place when water changes from one state to another. This is fundamental to the flow of energy around the climate system and for establishing the surface energy imbalance, which is what ultimately forces surface temperature to change.

Another important insight from Fig. 2a is that the various terms in the surface energy budget are many orders of magnitude larger than the radiative forcing from anaesthetic gases (Table 1). These terms, especially those associated with the water cycle, can change depending on weather and climate variations, effectively swamping any impact from volatile agents.

Increases in the global average surface temperature have been used as the most fundamental measure of climate change within international negotiations and as a metric for 'dangerous' climate change as defined in the United Nations Framework Convention on Climate Change Paris Agreement, which seeks to constrain global warming to 2°C or even 1.5°C [20]. However, the relationship between radiative forcing, surface energy imbalances and, ultimately, global warming is far from straightforward. Fig. 2b shows the latest global surface temperature record, expressed as the differences from the average for 1850–

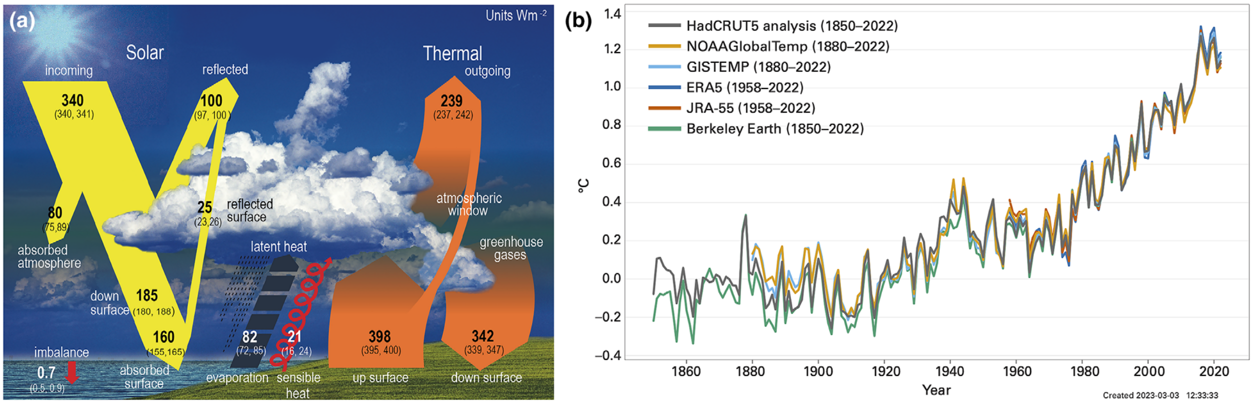

Figure 2 Energy flows and global warming. (a) Schematic representation of the global mean energy budget of the Earth. Numbers indicate best estimates for the magnitudes of the globally averaged energy balance components in Wm^{-2} together with their uncertainty ranges in parentheses (5–95% confidence range), representing climate conditions at the beginning of the 21st century. Compare the magnitudes of these components with the radiative forcing by anaesthetic gases in Table 1. Adapted from [18]. (b) Various analyses of global surface temperature history from instrumental data for 1850–2022, compared with the 1850–1900 average. Note that the global mean temperature in 2022 was 1.15 [1.02–1.28]°C above the 1850–1900 average. The years 2015–2022 were the eight warmest years in the 173-year instrumental record. Adapted from [31].

1900. It is only in the latter half of the 20th century that a long-term warming trend can be detected above the natural variability of the climate system, despite the growth of anthropogenic carbon dioxide emissions and the steady accumulation of atmospheric carbon dioxide since the Industrial Revolution.

The reason for this is that the oceans take up over 90% of the surface energy imbalance from greenhouse gas forcing. Since the thermal capacity of the oceans is huge, it takes decades for ocean surface temperatures, and hence global mean surface temperature, to rise and be detectable above the natural variability of the climate system. The scale of this natural variability is demonstrated in Fig. 2b; there are substantial fluctuations of several tenths of a degree, year by year and decade by decade, despite sustained and increasing greenhouse gas radiative forcing.

Clearly, in the context of the energy exchanges within the climate system, thermal inertia of the oceans and scale of natural variability, the tiny perturbations from anaesthetic gases presented in Table 1 are likely to have a vanishingly small effect on the trajectory of global warming. This is true even if emissions, and hence atmospheric concentrations, were to continue to increase.

Regional and local climate change

So far, we have considered globally averaged quantities. However, even global mean surface temperature is far from a clear indicator of what is currently happening, and might happen, to our climate. The body temperature of a patient does not give us a diagnosis, and just like the human body, the climate system is complex and interactive.

The climate system consists of five major components: atmosphere; oceans; land; biosphere; and cryosphere (ice and snow), all of which interact within and between each other, across a myriad of space and timescales (online Supporting Information Fig. S1a). The circulations of the atmosphere and oceans are critical for redistributing heat and other vital components, acting as key determinants of how the climate will change locally and globally (online Supporting Information Fig. S1b,c). In the atmosphere, weather systems move energy rapidly around the world in hours, days and months, mixing warm and cold air masses, constantly forming and dissipating clouds and creating rainfall. In the oceans, the currents and the great overturning circulations (such as the Atlantic Thermohaline Circulation) move energy much more slowly, from months to millennia, often sequestering heat at depth. The heat exchanges in weather systems and ocean circulations are huge; consequently, any short-lived effects from anaesthetic gas emissions will surely be lost within the natural variability of the system and make no contribution to long-term climate change.

Climate change and the impacts that it brings are a consequence of these complex processes acting within and between the various components of the Earth system. From extreme flooding to damaging droughts and heatwaves, and from severe storms to rising sea levels, these are the impacts that will cost us dearly.

Predicting climate impacts

So how do climate scientists make sense of all this complexity, and how do they make the predictions that tell us what future climate impacts will be? The answer is through modelling the climate system from first principles using fundamental physical laws, such as Newton's Laws of Motion, radiative transfer theory and moist thermodynamics. These fundamental physical equations are solved using sophisticated numerical techniques on a supercomputer, by dividing the Earth's atmosphere and oceans into millions of volumes, each with its own physical characteristics (online Supporting Information Fig. S2a). Integrating these equations forward in time produces a time-evolving simulation of the weather and climate over the coming days, years and decades (online Supporting Information Fig. S2b). None of this complexity is accounted for in emission metrics like GWP.

Climate modelling represents one of the most complex applications of supercomputing, running to well over a million lines of code. Predictions by these climate models are the bedrock of the IPCC process. Without them, we would not know why our climate is changing and how it will change in the future. Global warming is just one of the emergent properties of these complex simulations. But they tell us so much more: from what mitigation actions are needed to avoid dangerous climate change, and how we should adapt to make ourselves resilient to changing weather and climate patterns, rising sea levels and extreme events.

Crucially, it is from these simulations that we have learned that it is the ongoing accumulation of carbon dioxide in the atmosphere which will determine the level of future warming and its related climate impacts (online Supporting Information Fig. S3), even allowing for the wide range of possible emission trajectories for other well-mixed greenhouse gases, such as methane and hydrofluorocarbons. The relationship between cumulative carbon dioxide emissions and decadal scale warming trends is almost linear. It highlights that future warming will be determined by how successful we are in controlling our direct carbon dioxide emissions.

Returning to GWP and carbon dioxide equivalence

Global warming potential has been taken up as an easy proxy for the climate impact of an anaesthetic gas and for converting emissions of that gas to CO_2e emissions to suggest behavioural options. On the basis of GWP, anaesthetic gases appear to be very ´damaging´. However, this conclusion is scientifically unsound: their lifetimes are short; their emissions, accumulation and resulting atmospheric concentrations are minute; and their actual radiative forcing is vanishingly small.

Anaesthetic gas emissions cannot be equated to direct carbon dioxide emissions from, say, a car journey, as is often done. Direct carbon dioxide emissions accumulate in the atmosphere over decades, continually adding to the radiative forcing of the planet, and continuing to cause climate change while those of anaesthetic gases will not. It is of vital importance that healthcare policy makers understand this difference. Indeed, as Fuglestvedt noted in 2003, ´´*the terms in which GWPs express equivalence may not be well understood by policy makers in their application of GWP. Given the name, it is natural to assume that GWPs express equivalence in terms of the contribution of different gases to increasing temperatures*´´ [21]. However, ´´*there is no equivalence beyond equal integrated radiative forcing over the chosen time horizon*´´ [21].

A key reason that CO_2e values are misleading is that long- and short-lived gases affect atmospheric concentrations, and thus the planet's energy budget, in fundamentally different ways. Continued emissions of carbon dioxide add cumulatively to the atmospheric stock, and thus, temperatures will increase indefinitely for as long as emissions are maintained, then remain close to this level for many decades once emissions cease [22]. In contrast, for a short-lived gas, the radiative forcing responds to the current emission rate; the climate response depends primarily on current emissions, with ´*little memory of the past*´ [15]. Thus, the warming behaviour is more transient. The year-on-year temperature change resulting from a short-lived climate pollutant emission differs markedly on whether this is a ´´*newly established source or an existing flow of emissions being maintained – for which the [pronounced] initial temperature increase is already experienced*´´ [23].

What this means is that expressing anaesthetic gas emissions as CO_2e using GWP misrepresents their impact on global temperature. It is true that eventual mitigation of short-lived climate pollutants (such as methane) can make a useful contribution to climate protection once stringent carbon dioxide controls are in place [15], but only those short-lived climate pollutants contributing substantial radiative forcing offer significant opportunities for abatement. The minute radiative forcing of the volatile agents means that they are not the ´quick win´ suggested by some.

How could anaesthetists know their climate impact?

So, what should be the recommended process for understanding and comparing the climate effects of marginal non-carbon dioxide emissions for those working in healthcare? Framing the discussion around radiative forcing provides a physically robust measure of the potential contribution of anaesthetic gases and we have highlighted that it is ultimately their concentrations, not emissions, that matter.

One way forward is to monitor the atmospheric concentrations of anaesthetic gases so that their radiative forcing can be regularly calculated and compared with those of other greenhouse gases, as in Table 1. Measurements of anaesthetic gas concentrations are now routinely reported in the United Nations Environment Programme/World Meteorological Organization ozone assessments, which are conducted every 4 years [9]. Mole fractions are measured close to the surface by global monitoring networks, especially the Global Atmospheric Watch programme of the World Meteorological Organization [24]. The surface data can be used to approximate a mole fraction representative of the global tropospheric abundance. These assessments would provide an early warning that radiative forcing is increasing to consequential levels and emissions are therefore becoming too high. Nevertheless, any warming that may result from the volatile agents is short-lived, reversible and therefore deferable [15]; a monitoring system is thus sufficient.

A comment on nitrous oxide

Nitrous oxide is both a powerful greenhouse gas and an ozone-depleting substance. Its GWP_{100} of 273 [9], long lifetime of 123 years and abundance in the atmosphere (see Table 1), make it an important player in climate change. While we are able to state with confidence that the contribution of volatile anaesthetic agents to net radiative forcing is minute because their atmospheric concentrations are known, and because there are no other sources, the contribution of medical nitrous oxide emissions is less clear-cut.

The atmospheric nitrous oxide concentration is a result of multiple different emissions, from both natural sources and anthropogenic emissions (see Global Nitrous Oxide Budget [25]; online Supporting Information Fig. S4). The contribution to the latter from healthcare is not easy to quantify. Shine notes that ``*because nitrous oxide is a long-lived greenhouse gas, a thorough estimate would require not only knowledge of current emissions but also the history of its emissions*´´ [5]. He estimates that the atmospheric concentration resulting from anaesthetic use could be around 0.5 ppb, with a resulting radiative forcing of around 0.001 Wm^{-2}; this is several times higher than the effect of emissions of the volatile anaesthetics, but still less than 0.1% of the climate effect due to carbon dioxide increases resulting from human activity [5]. Similar estimates of nitrous oxide emissions in anaesthesia have been reported elsewhere [26].

Since the lifetime of nitrous oxide is very similar to that of carbon dioxide, it is possible in this case to convert nitrous oxide emissions to equivalent carbon dioxide emissions based on its GWP_{100} (unlike the volatile short-lived agents); in other words, the climate effect of 1 kg of nitrous oxide is equivalent to emitting 273 kg of carbon dioxide. So, auditing the use of nitrous oxide across the health sector would be a valid approach to estimating its contribution to healthcare carbon footprints. Again, decisions about its use would need to consider its clinical benefits vs. its impact (albeit very small) on the climate system.

Conclusions

The serious limitations of emission metrics in guiding sectoral mitigation strategies have been emphasised repeatedly in the climate science literature and the healthcare community now needs to take note. The use of GWP and CO_2e emissions has placed an inappropriate emphasis on volatile anaesthetic agents within health sector carbon footprints [27], when the focus should be on reducing the real sources of carbon dioxide and other major greenhouse gases. While changing a vaporiser feels achievable and tangible, the scientific reality is inconsequential when we consider all the steps from GWP to climate impact.

In contrast, the carbon dioxide that we mistakenly believe we have `saved´ is very much out there, changing the climate for generations to come. As Pierrehumbert emphasises, early implementation of short-lived climate pollutants mitigation that substitutes to any significant extent for carbon dioxide mitigation will lead to a climate that is irreversibly warmer and it is ``*our emissions of CO_2 in the coming century that will determine the character of the Anthropocene*´´ [15].

This is of particular importance when considering the relative impacts of total intravenous anaesthesia vs. volatile anaesthesia. Life-cycle analyses, using GWP and CO_2e, have stated that propofol has the least overall impact on greenhouse gas emissions even when taking into account the disposable plastics for intravenous administration [28]. This calculation, using CO_2e, is misleading. Any transient radiative forcing from a volatile anaesthetic will be lost in the complexity of the climate system, whereas any carbon dioxide emitted from the substantial quantities of plastic production and incineration will contribute to a climate that continues to warm indefinitely [29].

The choice of anaesthetic technique should therefore be patient-focused. Nevertheless, anaesthetists should continue to use appropriately low fresh gas flows, reduce the use of nitrous oxide when clinically appropriate, reduce waste and work to increase overall population health. It is carbon dioxide emissions that will define our future, not the use of volatile anaesthetic agents. The integration of climate and wider environmental science into healthcare decisions has the capacity to result in policy changes that are founded on robust science. This would direct the highly regarded energy and enthusiasm of the anaesthetic community towards practices that will make a real difference to sustainable healthcare.

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Supporting Information

Additional supporting information may be found online via the journal website.

Figure S1. Complexity of the climate system. Full details are on the figure.

Figure S2. Schematic of a climate model showing how the atmosphere and oceans are divided up into volumes, each with its physical properties and a snapshot from a global simulation showing the clouds and weather systems produced by a state-of-the-art climate model.

Figure S3. Near-linear relationship between cumulative carbon dioxide emissions and the increase in global surface temperature. Full details are on the figure.

Figure S4. Global nitrous oxide budget between 1980 and 2016, based on an inventory that incorporates both natural and anthropogenic sources and accounts for the interaction between nitrogen additions and the biochemical processes that control nitrous oxide emissions. Full details are on the figure.