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Climate Change, Emissions of Volatile Anesthetics, and Policy Making: The Case of Desflurane

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Effective policy making in health care requires the quantitative analysis of interventions, including the environmental impacts of anesthetic gases like desflurane. Understanding the atmospheric properties of these gases and the physics of climate change are essential for assessing their environmental impact, and making informed policy decisions within health care systems.

This Open Mind article describes the results of a study based on mathematical models published in the Intergovernmental Panel on Climate Change's Fifth Assessment Report. Our work evaluates the environmental impact of both continuous and time-limited emissions, and transparently illustrates the potential outcomes of various climate policy interventions.

We present evidence from the climate science literature arguing that simplistic metrics like global warming potential (GWP) cannot accurately compare volatile anesthetics to CO₂, as this metric fails to properly differentiate between the climate effects of short-lived and long-lived climate pollutants.

Our findings show that continuing current desflurane emission rates for the next 100 years will not result in continuous increases of global average

temperature. Instead, a steady-state atmospheric concentration of desflurane is reached, resulting in a step increase in global mean surface temperature of 0.00015 °C. This step change is about a factor of 3000 smaller than the natural variability of global mean surface temperature due to solar and volcanic effects.¹ Moreover, this small increment of global warming is reversible: if use of desflurane is discontinued at some time in the future, the temperature step disappears within a few decades. These behaviors stand in stark contrast to constant-rate emissions of CO₂, which lead to continuously increasing temperatures, which then linger for centuries after the source of emission is removed.

CLIMATE POLICY CONTEXT

The prevailing view attributes approximately 3% of health care's greenhouse gas footprint to volatile anesthetics.² Over the past decade, these agents have garnered significant attention in the anesthesia literature because of their link to climate change. Concerns have been raised about the increasing atmospheric concentration of volatile anesthetic agents³ and their allegedly substantial contribution to global warming as potent greenhouse gases. This assertion is underpinned by comparing emissions of volatile anesthetics based on GWP, a measure of how much thermal energy a single, short-term release (or pulse emission) of a greenhouse gas would contribute to global warming, and by finding the mass of the equivalent pulse of CO₂ (CO₂-equivalent) that purportedly has a comparable effect.

When placed on a CO₂-equivalent scale, the volatile anesthetics present as exceptionally dangerous greenhouse gases. For desflurane, the GWP multiplier said to be relevant to a 100-year time period, GWP-100 is 2590.¹ In other words, a kilogram of desflurane is said to have the same climate effect as 2590 kg of CO₂. The multiplier said to be relevant for a 20-year time frame, GWP-20 is 7020.¹ Hence, one sees in the anesthesia literature statements like "[Use of] desflurane equates with driving 375 to 750 km per hour of anaesthetic use."²⁻⁵ As we will show below, CO₂ direct

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emissions, such as driving a car, are far more harmful to the environment than releasing the “equivalent” amount of desflurane.

Influenced by these assertions, many in the anesthesiology community have urged immediate climate action. Current guidelines recommend the avoidance of inhaled anesthetics, particularly desflurane, and consideration of total intravenous anesthesia (TIVA) or locoregional anesthesia as alternatives for reducing the environmental impact of anesthesia in the health care system.^{5–7} In response to these concerns, efforts to phase out volatile agents, led by the decommissioning of desflurane from the UK’s National Health System hospital portfolios, are currently underway.⁸ Furthermore, political decisions have led to the strong discouragement of desflurane use in the European Union, effective from 2026 under the revised F-gas regulation.⁹

We commend the international anesthesia scientific community’s dedication to reducing environmental impacts, as evidenced by the growing number of publications on this subject over the past decade. This commitment marks a significant step toward a more sustainable health care system and deserves recognition and support. Nonetheless, this article aims to reexamine the debate on volatile anesthetic agents. By using quantitative climate science tools, we demonstrate that their climate impact is considerably smaller than suggested by GWP metrics. In fact, GWP has attracted criticism from within the climate science community, including from the practitioners who introduced that concept in the first place. Instead, we advocate for informed decisions based on presently accepted climate science, emphasizing the need to reduce genuine CO₂ emissions associated with health care.

ARGUMENTS AGAINST USING GLOBAL WARMING POTENTIALS

The well-documented impact of greenhouse gases on Earth’s energy budget, including the interference of anesthetic gases, has been extensively discussed in the anesthesia literature.^{2,10,11} However, it is imperative to note that current assertions regarding the environmental impact of anesthetic gases and subsequent initiatives to eliminate volatile agents from medical practice are exclusively grounded in their elevated GWP values. As stated in the First Assessment Report of the Intergovernmental Panel on Climate Change, in which GWP was introduced:

It must be stressed that there is no universally accepted methodology for combining all the relevant factors into a single global warming potential for greenhouse gas emissions. In fact, there may be no single approach which will represent all the needs of

*policy makers. A simple approach has been adopted here to illustrate the difficulties inherent in the concept.*¹²

In a 2009 retrospective, Professor Keith Shine, the convening lead author of that chapter in the First Assessment Report, asked how “a simple approach” presented to “illustrate difficulties” was being used to select among policy options with profound economic and environmental consequences. This distinguished climate scientist went on to express doubt about how GWP is connected to climate change.¹³

Related doubts have been echoed over the years by many others in the climate science community:

*Because of the fundamentally different nature of the climate response to long- versus short-lived gases, there is no way to express emissions of short-lived gases [such as desflurane] in terms of an equivalent in emissions of long-lived gases [such as CO₂] without seriously misrepresenting some aspect of the climate response.*¹⁴

*There is no single scaling factor that can convert between CO₂ and [short-lived climate pollutant] emissions [...] Thus the application of GWPs does not give equivalence and hence the concept of “CO₂ equivalents” is misleading. The inability of the GWP methodology to transform emissions of different gases into one common scale that expresses climatic effects, implies that we are not able to estimate the climatic effect of a reduction target given in CO₂ equivalents.... The policy makers’ need for transparent and simple tools, such as the GWP concept has to be weighted against the inaccuracy in terms of equivalence and differences between the climate impacts. As the GWP concept is currently formulated and applied, it is associated with significant shortcomings. Given the centrality of the methodology in the current climate regime, it is important to communicate these shortcomings to policymakers*¹⁵

Further doubts about the validity of the GWP/CO₂-equivalent methodology have been expressed in a 17-page editorial in Climatic Change by O’Neill,¹⁶ and are reviewed in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).¹⁷

According to Article 2(1)(a) of the 2015 Paris Agreement of Parties to the United Nations Framework Convention on Climate Change, the internationally accepted standard for the measure of climate change is as follows: “The increase in the global average temperature.” In the modern practice of climate science, forecasts of the increase in the global average temperature for various policy options have nothing to do with GWP. Instead, physics-based methods such as general circulation models are used to predict the effect of various policy options on future earth temperatures.¹⁸ Consequently, we argue that

GWP is ill-suited as a proxy for accurately gauging the climate impact of volatile anesthetics contrary to the viewpoint of numerous publications in the anesthesiology literature.^{2,5–7}

CLIMATE IMPACT OF VOLATILE ANESTHETICS

A critical aspect of sound policy making lies in the quantitative analysis of policy interventions. The climate science community provides various analytical tools that forecast changes of the earth's climate. General circulation models are the most comprehensive means to forecast the effect on earth systems of changes in atmospheric composition and should be used where available.¹⁸ They represent the Earth's atmosphere, oceans, land surface, and ice by solving mathematical equations that describe physical processes such as air movement, heat transfer, and water cycles.

Models based on analytical equations are vetted by the IPCC¹⁷ and have been used in this work. Unlike more complex general circulation models, these equations can be coded on a spreadsheet. They offer a straightforward and transparent method for demonstrating the potential impacts of different climate policy interventions, making the results more accessible and easier to understand. Our assessments rely on formulations establishing the link between greenhouse gas emissions and incremental changes in the global mean surface temperature. Although the practice of utilizing temperature trajectories to compare outcomes of diverse policy options is not novel,¹⁹ it has not heretofore been applied to assess the climate impacts of anesthesia interventions.

Several factors influence the effectiveness of a greenhouse gas as an agent of climate change. The molecular structure of the gas determines its radiative efficiency, which refers to how effectively the gas can trap heat radiated from the Earth's surface. The overall impact of a gas on global warming is also determined by how much of the gas is present in the atmosphere. This depends on the rate at which the gas is emitted into the atmosphere (from natural or anthropogenic sources) and how quickly it is removed, either by being absorbed by land and water or by reacting with other molecules in the atmosphere.

Despite its low intrinsic radiative efficiency, CO₂ is the most significant greenhouse gas associated with human activity: anthropogenic emissions presently total approximately 40 billion metric tons per year. As a fully oxidized form of carbon, CO₂ does not react readily with other molecules and dissolves slowly in seawater, meaning that the CO₂ emitted today will remain in the atmosphere for centuries.

Desflurane has properties opposite to those of CO₂. It has a much higher radiative efficiency—approximately 35,000 times greater than CO₂—but its

atmospheric lifetime is much shorter, approximately 14.1 years. Its emission rate is significantly lower, approximately 1000 metric tons per year,³ which is roughly 40 million times less than CO₂. Consequently, there is no straightforward multiplicative factor to compare the climate impacts of CO₂ and desflurane directly. To understand their individual contributions to global warming, it is essential to use physics-based models to evaluate their effects on global average temperature.

In our calculations, we adopt the unrealistic assumption that every surgical procedure worldwide—approximately 300 million procedures per year²⁰—is performed with desflurane. We further assume an average anesthesia duration of 120 minutes, with a mean fresh gas flow of 1.0 L·min⁻¹ and an average agent concentration of 5.5 Vol%. This results in approximately 30 mL of desflurane being used per procedure,²¹ all of which vents to the atmosphere. The density of desflurane is 1.465 g·mL⁻¹, so under these assumptions 1.32×10^{10} g = 13,200 metric tons of desflurane is released into the atmosphere each year. This is 13.7 times higher than the probable emission rate of 960 tons per year, the estimate based on the 2014 atmospheric concentration of desflurane.³ Additional data and detailed calculations are available in Supplemental Digital Content 1, <http://links.lww.com/AA/F171>.

CHARACTERISTICS OF SHORT-LIVED CLIMATE POLLUTANTS

There is no provision for time-dependent sources of greenhouse gas emissions in the GWP method. However, continuous or time-limited emissions (whether constant or varying) are important features of the real world. Using the multiyear emission model described in the Supplemental Digital Content 1, <http://links.lww.com/AA/F171>, which is a trivial extension of the IPCC equations, important insights into the earth's chemical and thermal systems emerge.

Figure 1 shows the impact of emitting 2 different greenhouse gases continuously over a century. Emitting 13,200 tons of desflurane annually (red curve) results in an initial linear increase in global temperature that soon flattens. This is due to desflurane's short atmospheric lifetime. In a few decades, desflurane achieves a steady-state concentration in the atmosphere in which there is dynamic equilibrium between emissions and natural sinks. To estimate the temperature change at this steady state given the estimated rate of contemporary emission of approximately 960 tons,³ we simply scale the result of emitting 13,200 tons per year, 0.002 °C, by 960/13,200, finding 0.00015 °C.

Figure 1 also shows the effect of emitting the “equivalent” amount of CO₂. We have multiplied

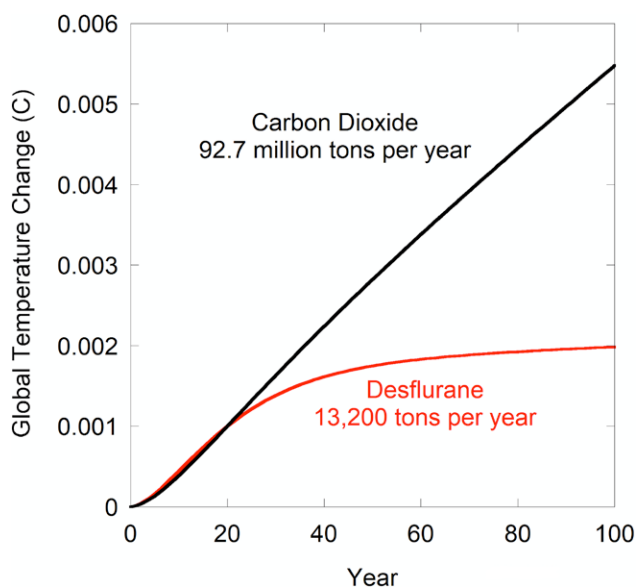


Figure 1. Global average temperature change resulting from continuous emissions of 2 greenhouse gases for 100 y. Red curve: hypothetical anesthesia emissions, assuming that all surgical procedures worldwide are done using desflurane: 13,200 tons of desflurane emitted each year. Black curve: direct CO₂ emissions, estimated using GWP-20 CO₂-equivalent: 92.7 million tons emitted each year. With direct CO₂ emissions, such as vehicle emissions, sustained for a century (black curve), the associated global average temperature continues to increase, whereas the red curve flattens after approximately 50 y. GWP indicates global warming potential.

13,200 tons of desflurane (listed in the IPCC Tables as HCFE-236ea2) per year by 7020, the 20-year GWP multiplier,¹ finding 92.7 million tons of CO₂ per year. The associated temperature increase initially matches the warming rate due to desflurane, as implied by current anesthesia publications using GWP metrics. To put this in perspective, using the current propagated comparison with emissions of vehicles,²⁻⁵ this CO₂ emission would be equivalent to 500 billion miles traveled by vehicles with an average emission rate of 115 g CO₂ per km. According to OECD data, these total emissions are comparable to the yearly CO₂ emissions of the passenger car fleet of a country like Italy. However, with direct CO₂ emissions, such as vehicle emissions, sustained for a century (black curve), the associated global average temperature continues to increase. This is due to the very long atmospheric lifetime of CO₂.

Figure 2 shows another characteristic of short-lived climate pollutants. In this illustration, CO₂ (black curve) and desflurane (red curve) are both emitted at constant rates for 50 years, after which emissions cease. After cessation of emissions the accumulated global temperature increase attributed to CO₂ diminishes gradually over centuries while the temperature increase linked to desflurane is reversed within a matter of decades.

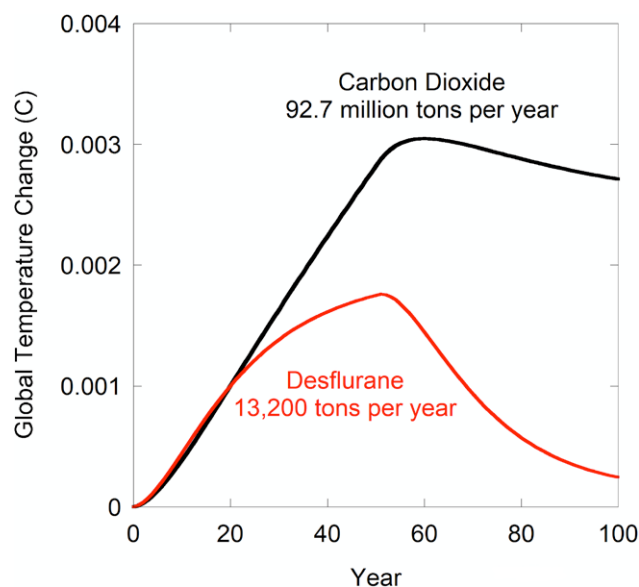


Figure 2. Global temperature change resulting from continuous emissions of 2 greenhouse gases for 50 y, after which emissions cease. Black curve: direct emissions of 92.7 million tons of CO₂. Red curve: 13,200 tons of desflurane. The temperature increase linked to desflurane is reversed within decades, whereas the effect of CO₂ emissions will persist for centuries.

CONCLUSIONS

Attempting to compare the global climate effects of desflurane and CO₂ using simplistic methods like GWP is fundamentally flawed. Unlike CO₂, which has cumulative effects persisting for centuries after emissions cease, the effects of short-lived climate pollutants like desflurane saturate, and then disappear within decades. Thus, relying on the popular GWP method for evaluating the environmental impact of desflurane is deeply misleading.

Our calculations, based on analytical models vetted and published by the IPCC,¹⁷ suggest that continuing to emit desflurane into the atmosphere at the present rate³ for the next 100 years would be responsible for additional warming of 0.00015 °C in the global mean surface temperature by the year 2124. Our findings support the contention of Slingo and Slingo¹¹ that the effect on climate of desflurane emissions will be lost within the natural variability of the climate system. Our approach makes qualitative statements quantitative. Undoubtedly, more accurate estimates can be obtained by using general circulation models.

Our primary objective is to quantify the environmental effects of desflurane on the global surface temperature of the Earth, an approach that, to our knowledge, has not been undertaken in previous studies. Our study demonstrates the negligible effects of current rates of desflurane usage.

Discussing the clinical advantages of desflurane is beyond the scope of this paper. The decision on the clinical benefits of using desflurane remains

with the clinician. However, this study provides a clear, quantifiable understanding of desflurane's impact on global surface temperature, enabling clinicians to make more informed decisions. Since the Hippocratic Oath states, "I will abstain from all intentional wrongdoing and harm," the essential question for clinicians is as follows: What causes more harm? Withholding desflurane from patients, denying from them the advantages of this volatile anesthetic, or accepting its environmental impact? With this study, clinicians now have the data needed to answer that question. ■

DISCLOSURES

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REFERENCES

- Intergovernmental Panel on Climate Change (IPCC). In: Masson-Delmotte V, Zhai P, Pirani A, et al, eds. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. doi:10.1017/9781009157896.
- Sulbaek Andersen MP, Nielsen OJ, Sherman JD. Assessing the potential climate impact of anaesthetic gases. *Lancet Planet Health*. 2023;7:e622–e629.
- Vollmer MK, Rhee TS, Rigby M, et al. Modern inhalation anesthetics: potent greenhouse gases in the global atmosphere. *Geophys Res Lett*. 2015;42:1606–1611.
- Ryan SM, Nielsen CJ. Global warming potential of inhaled anesthetics: application to clinical use. *Anesth Analg*. 2010;111:92–98.
- McGain F, Muret J, Lawson C, Sherman JD. Environmental sustainability in anaesthesia and critical care. *Br J Anaesth*. 2020;125:680–692.
- Buhre W, De Robertis E, Gonzalez-Pizarro P. The Glasgow declaration on sustainability in anaesthesiology and intensive care. *Eur J Anaesthesiol*. 2023;40:461–464.
- Gonzalez-Pizarro P, Brazzi L, Koch S, et al; the Sustainability National Representatives. European Society of Anaesthesiology and Intensive Care consensus document on sustainability: 4 scopes to achieve a more sustainable practice. *Eur J Anaesthesiol*. 2024;41:260–277. doi:10.1097/EJA.0000000000001942.
- Watts N, Moonesinghe R, Foreman C. Putting anaesthetic emissions to bed: commitment on desflurane. Accessed January 21, 2024. <https://www.england.nhs.uk/blog/putting-anaesthetic-emissions-to-bed/>.
- EUR-Lex. Regulation (EU) 2024/573 of the European Parliament and of the Council of 7 February 2024 on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014. Accessed May 5, 2024. <https://eur-lex.europa.eu/eli/reg/2024/573/oj>.
- Campbell M, Pierce JMT. Atmospheric science, anaesthesia, and the environment. *BJA Educ*. 2015;15:173–179.
- Slingo JM, Slingo ME. The science of climate change and the effect of anaesthetic gas emissions. *Anaesthesia*. 2024;79:252–260.
- Shine K, Derwent RG, Wuebbles DJ, Morcrette JJ. Radiative forcing of climate. In: Houghton JT, Jenkins GJ, Ephraums JJ, eds. *Climate Change: The IPCC Scientific Assessment*. Cambridge University Press, 1990:41–68.
- Shine KP. The global warming potential-the need for an interdisciplinary retrieval. *Clim Change*. 2009;96:467–472.
- Pierrehumbert RT. Short-lived climate pollution. *Annu Rev Earth Planet Sci*. 2014;42:341–379.
- Fuglestad JS, Berntsen TK, Godal O, Skodvin T. Climate implications of GWP-based reductions in greenhouse gas emissions. *Geophys Res Lett*. 2000;27:409–412.
- O'Neill BC. The jury is still out on global warming potentials. *Clim Change*. 2000;44:427.
- Myhre G, Shindell D, Bréon FM, et al. Anthropogenic and natural radiative forcing with supplementary material. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press; 2013.
- Weart S. The development of general circulation models of climate. *Stud Hist Philos Sci Part B: Stud Hist Philos Mod Phys*. 2010;41:208–217.
- Shindell D, Kuylenstierna JCI, Vignati E, et al. Simultaneously mitigating near-term climate change and improving human health and food security. *Science*. 2012;335:183–189.
- Meara JG, Leather AJM, Hagander L, et al. Global Surgery 2030: evidence and solutions for achieving health, welfare, and economic development. *Lancet*. 2015;386:569.
- Biro P. Calculation of volatile anaesthetics consumption from agent concentration and fresh gas flow. *Acta Anaesthesiol Scand*. 2014;58:968–972.