Comparison of the Climate Impact of Inhaled Anaesthetic Gases in Real Terms

Poster No. EE89

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I. INTRODUCTION

- The use of certain halogenated inhaled anaesthetics has been the subject of several publications advocating for their removal from medical practice so that healthcare providers can address environmental concerns.[1,2]
- Theoretical extrapolations and calculations, such as the Global Warming Potential (GWP) values over a 100-year time horizon, have formed the backbone to this messaging and the conclusions of many of these publications.[3,4]
- However, GWP does not provide adequate accounting for climate change impacts, which will occur within the stated time horizons or after the respective cutoff points.[5,6]
- As short-lived climate forcing (SLCF) gases, desflurane, sevoflurane, and isoflurane will be negligible in comparison to carbon dioxide, especially in terms of carbon dioxide equivalence (CO_2eq).[6-8]
- Short atmospheric lifespans relative to carbon dioxide (<20 years vs >100 years) will mean their ability to impact environmental change on the same level is not realistic.[6,9-11]
- Choosing to reduce desflurane, sevoflurane, or isoflurane in an effort to reduce warming will conversely lead to an increase in the irreversible warming of the Earth if carbon dioxide emissions continue unabated.[6,7,12,13]

II. OBJECTIVES

- This study aims to recontextualize existing climate impact calculations for certain inhaled anaesthetic gases.
- The expected emission volumes will be calculated to compare with the existing atmospheric concentrations of said gases in the Earth's atmosphere.
- The respective and realistic impact on the environment based on the more immediately relevant terms of radiative efficiency and forcing will be derived as a result.
- An estimation of the longer-term impact of a pulse of each gas over time is also provided as an extension of the analysis offered by the model's base scenarios for comparison.

III. METHODS

- The model is an Excel-based assessment of widely used gases in inhaled anaesthesia detailing two scenarios comparing the impacts of isoflurane, sevoflurane, desflurane, and nitrous oxide, respectively.
- Results are scaled from calculating the radiative forcing of a typical hour of maintenance anaesthesia, accounting for variations in practice where changes to vaporizer settings (volume concentration %) and fresh gas flow (L/min) are set versus published/expert data.
- This impact is then considered as a fraction of the total Earth's atmospheric concentration for each gas, which is separately calculated as part of the model.
- Understanding the contribution percentage of each pulse emission to the known atmospheric concentration of the total body of accumulating gas means we can know the atmospheric concentration of the pulse itself.
- The two scenarios for results we then consider for expected typical practical scenarios:
  - Scenario 1: Calculations and outcomes derived from a clinical theoretical publication, plus inputs from widely cited literature.[14-16]
  - Scenario 2: Outcomes derived from expert opinion, the latest observable data reported by the Intergovernmental Panel on Climate Change (IPCC), and published literature.[17,18]
- The key inputs and parameters for each gas per scenario are detailed in Tables 1 and 2.

Figure 1. Flowchart of the methodology

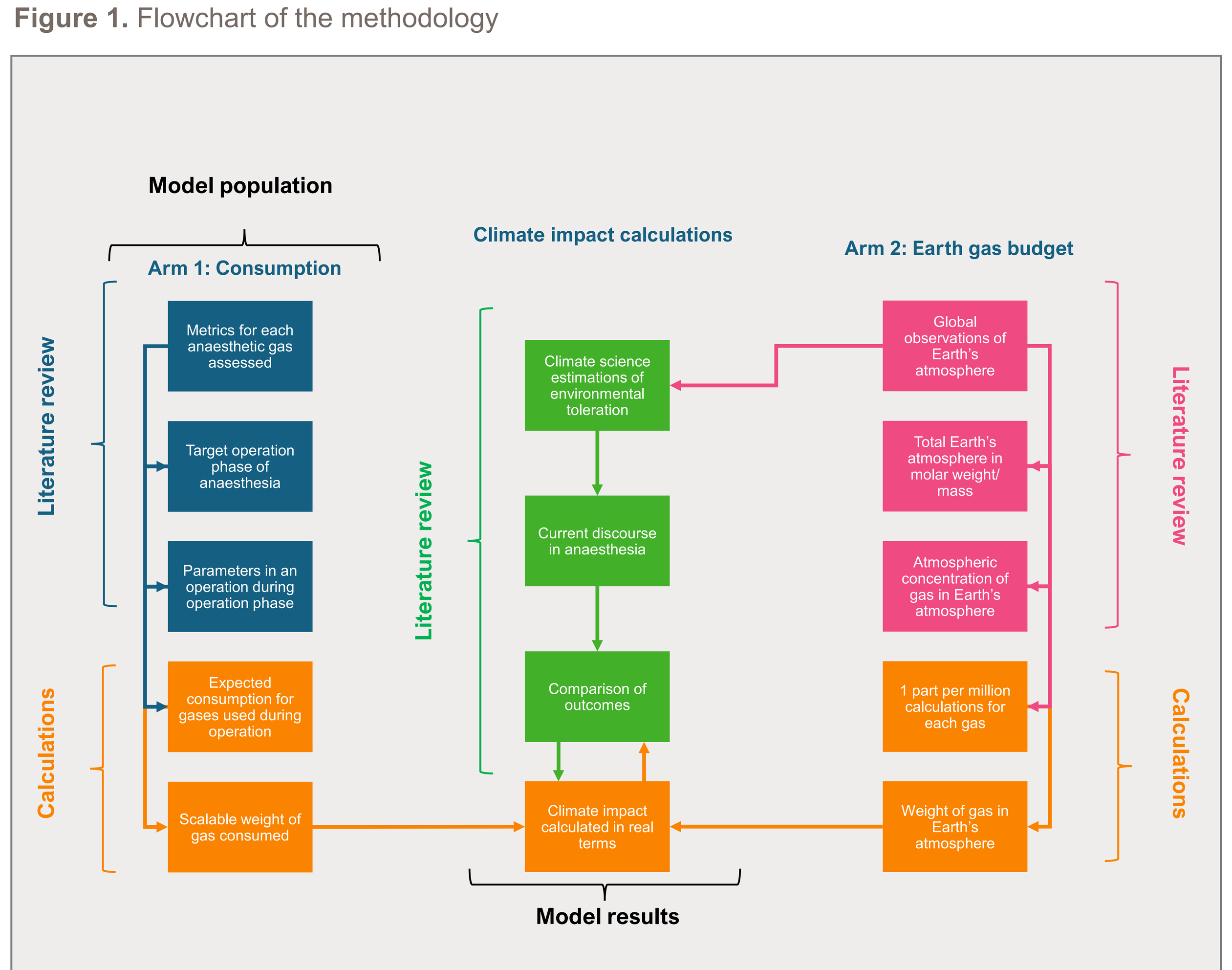


Table 1. Key inputs for consumption per hour and forcing calculations.

	Scenario 1			Scenario 2		
Key element	Des	Sevo	Iso	Des	Sevo	Iso
Volume concentration (%)[15]	5.46	1.31	2.03	6.00	1.71	1.15
Fresh gas flow rate (L/minute)[15]	1.050	3.060	3.000	4.000[a]	4.000[a]	4.000[a]
Molecular weight (g/mol)[19-21]	168.04	200.05	184.49	168.04	200.05	184.49
Density (g/mL)[22]	1.465	1.52	1.5	1.465	1.52	1.5
Fixed coefficient[23]	3,534	3,666	3,618	3,534	3,666	3,618
Volume consumed per hour (mL/hour)	16.36	13.12	18.63	68.48	22.39	14.07
	Scenario 1[14-16]			Scenario 2[17,18]		
Key element	Des	Sevo	Iso	Des	Sevo	Iso
Stated radiative efficiencies ($W\ m^{-2}\ ppb^{-1}$)	0.420	0.370	0.450	0.426	0.299	0.466
Atmospheric concentration (ppt^{-1})	0.30	0.13	0.097	0.11	0.16	0.37
Atmospheric lifetime (e-folding, years)	10.8	2.2	3.5	13.7	1.41	3.48

Table 2. Key input for Earth atmospheric mass calculations.

	Scenario 1	Scenario 2
Key element	Nitrous oxide	Nitrous oxide
Volume concentration (%)[24]	104	104
Fresh gas flow rate (L/minute)	2.370 (average of the other gases)[15]	4.000[a]
Molecular weight (g/mol)[25]	44	44
Density (g/mL)[25]	1.220	1.220
Fixed coefficient[23]	2,942.64	2,942.64
Volume consumed per hour (mL/hour)	221.13	373.22
Stated radiative efficiencies ($W\ m^{-2}\ ppb^{-1}$)[18]	0.00320	0.00320
Atmospheric concentration (ppt^{-1})[18]	336,000.00	336,000.00
Atmospheric lifetime (e-folding, years)[18]	109	109

- The volume of inhaled anaesthetic consumed in a typical hour of maintenance anaesthesia is calculated using the following equation[23]:

$$x = \frac{(C*F*T*W)}{K[D*MV]}$$

  - X is the volume (mL/time) that will be consumed.
  - C is the concentration setting in % on the vaporizer; F is the fresh gas flow rate in litres/minute; T is the time in minutes for the operation; W is the molecular weight of the gas.
  - The constant (K) is multiplying D for the density of the gas; MV is the fixed molar volume (2,412)[23].
  - This study sets Time to be one hour (60 minutes) in each case.
- The global volume of inhaled anaesthetic gases in the Earth's atmosphere is calculated by ascertaining the atmospheric weight of each gas' concentration in 1 part per million (dividing the Earth's mass of dry air by the molecular weight of air) and comparing it with the stated atmospheric concentration in parts per trillion.
- This is calculated using the key values in Table 3.

Table 3. Key inputs for Earth atmospheric mass calculations.

Key element	Value	Source/comment
Total dry air mass (kg)	5.14 x 10^{18}	Trenberth at al, 2005[26]
Molar mass/molecular weight dry air (g/mol)	28.97	Gatley et al, 2008[27]
Conversion to moles (moles)	177.29	Calculation of 1 mole of dry air atmosphere (divide total dry air mass in kg by molar mass/ molecular weight of dry air [g/mol] represented in thousands)

	Scenario 1			Scenario 2		
Key element	Des	Sevo	Iso	Des	Sevo	Iso
% incremental out of total weight in the atmosphere (ppt^{-1}, % x 10^{-6})	0.27	0.43	0.67	0.91	0.60	0.59
Atmospheric concentration (ppb^{-1} x 10^{-12})	0.80	0.56	0.65	3.37	0.96	0.65

- Across both scenarios, the radiative forcing per hour was negligible and made no sense in comparison with carbon dioxide emissions.
- To further demonstrate this, an estimation based on the number of hours of surgeries per day in the United Arab Emirates (UAE) was constructed in line with published data and some assumptions.
- The estimation in place multiplies the expected forcing per hour by the number of hours, with the following split:
  - Desflurane (14%); sevoflurane (38.5%); isoflurane (47.5%).
  - These values were chosen by the authors to represent a split of the hours, assuming all else is equal, as reflected in the typical case in Scenario 1 and accounting for physician choice.[15]
  - This share split is fictitious as the choice of gas in the market is heavily dependent on procurement by tendering in any one year.

Table 4. Key values.

Key element	Value	Source/comment
Number of surgeries	704,717	(UAE; Weiser et al, 2016; Projection to 2025, Expert author opinion)[28]
Average number of hours per surgery	2.0	(UAE; Expert author opinion)
Number of hours in operation daily in 2025 (hours, daily)	4,001	(360 days in operation on average, Expert author opinion)

IV. RESULTS

- Considering outcomes, in Scenario 1, a typical hour in maintenance anaesthesia is calculated to yield the following radiative forcing: isoflurane (515.62 x 10^{-12} W m^{-2}), sevoflurane (320.25 x 10^{-12} W m^{-2}), and desflurane (202.76 x 10^{-12} Wm^{-2}).
- Under inputs from expert opinion and the latest data in Scenario 2, we calculated the following yields per hour: isoflurane (522.95 x 10^{-12} W m^{-2}), sevoflurane (441.59 x 10^{-12} W m^{-2}), and desflurane (878.99 x 10^{-12} W m^{-2}).
- In comparison with carbon dioxide, inhaled anaesthetics provide incrementally negligible contributions to climate change; notably, impacts such as +/-0.20 W m^{-2} remain negligible.[7]
- Nitrous oxide, having a longer atmospheric lifetime and being used during a greater number of procedures due to the impact of dentistry, for the purposes of this paper, is only calculated in terms of radiative forcing per hour.
  - Scenario 1: Nitrous oxide (0.11 x 10^{-12} W m^{-2})
  - Scenario 2: Nitrous oxide (0.19 x 10^{-12} W m^{-2})

Table 5. Key results on inhaled anaesthetic consumption.

	Scenario 1			Scenario 2		
Key element	Des	Sevo	Iso	Des	Sevo	Iso
Radiative forcing per hour maintenance anaesthesia (x 10^{-12} W m^{-2})	0.36	0.21	0.27	1.57	0.29	0.27
Hours in use per day (number of hours as per assumed practice split)	560	1,539	1,902	560	1,539	1,902
Total radiative forcing (x 10^{-12} W m^{-2})	202.76	320.25	515.62	878.99	441.59	522.95

Figure 2. Key outcomes regarding the expected pulse emission over time for desflurane, sevoflurane, and isoflurane based on matched values from a) Vollmer et al. 2015[16] and b) World Meteorological Organization (WMO).[18] Values matched with consistent fresh gas flow at 4 L/min and expected volume concentration % as per textbook 1 MAC.[24] Some lasting impact is expected from every emission; however, the relative impact in real terms will be very minor.

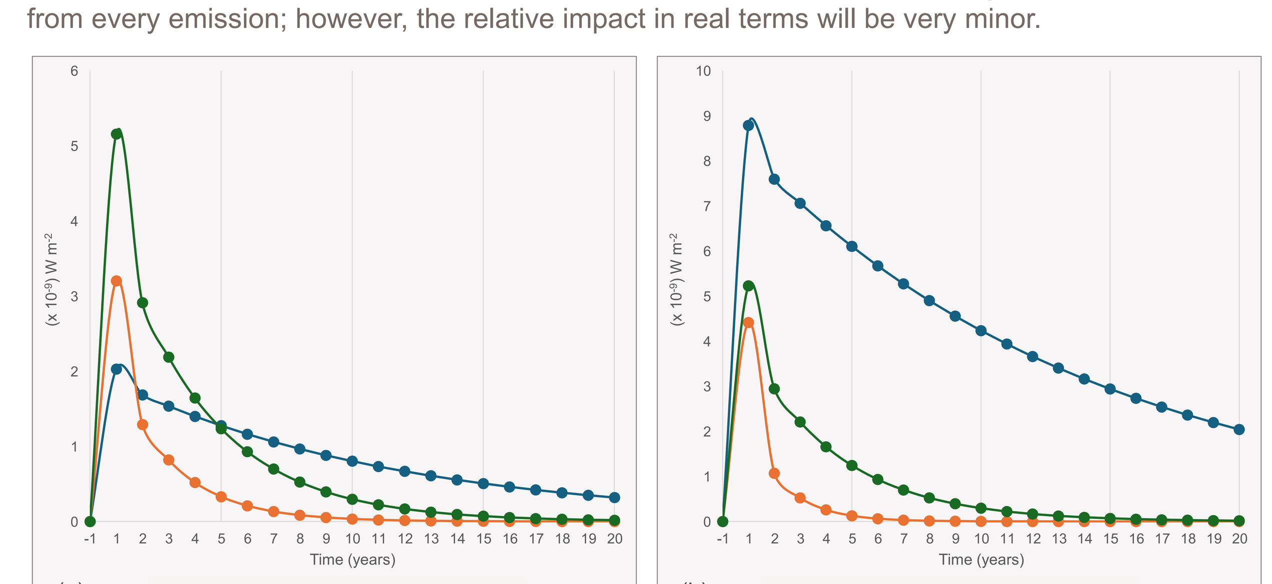
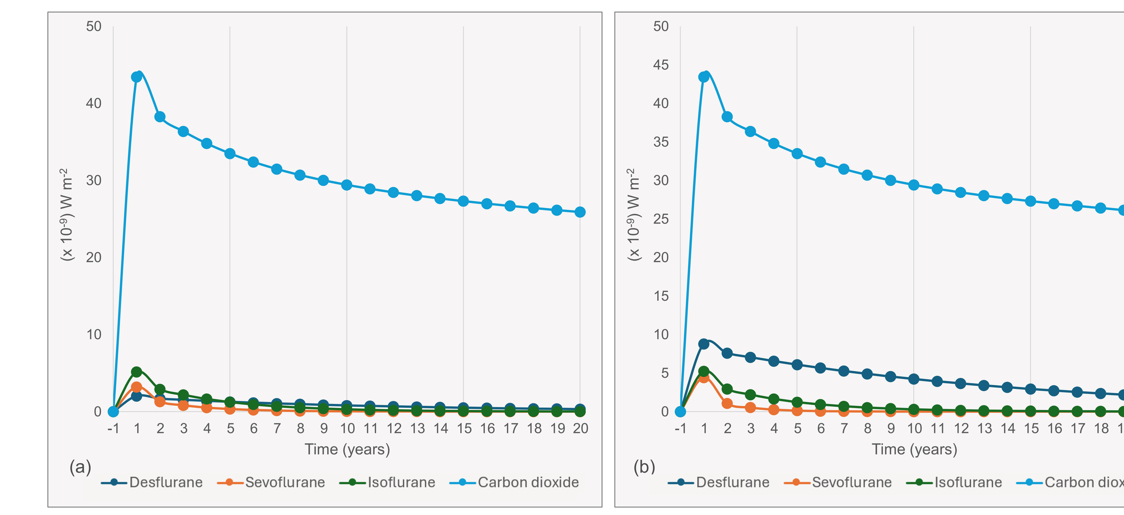


Figure 3. Key outcomes regarding the expected pulse emission over time for desflurane, sevoflurane, and isoflurane compared with carbon dioxide, based on matched values from a) Vollmer et al. 2015[16] and b) World Meteorological Organization.[18]



- Using a reference value for carbon dioxide, for example, powering the city state of Dubai for one hour,[29] we can put that within a similar scale to view the calculated impact of the inhaled anaesthetics from this study.
- Figure 3a represents the Vollmer et al. 2015 matched values, while Figure 3b shows the textbook reference, WMO, and consistent **fresh gas flow** versus the same carbon dioxide reference.[16,18, 24]
- Carbon dioxide emissions will exist long past the lifetime of the anaesthetics and cumulate to a greater degree of warming the environment.

V. DISCUSSION

- Recent publications have begun to highlight that a greater focus on radiative forcing and other more appropriate calculations are better ways to reflect the true impact of a gas on the environment and that it can be derived using published data.[7,8]
- Using a reference emission[16] (960 metric tonnes per year), over the course of 100 years, the change in the global mean surface temperature would amount to 0.00015°C. When following the same logic with annualized values for desflurane in this study:
  - Scenario 1: 0.002°C multiplied by 4.83 metric tonnes/13,200 metric tonnes[8] = 0.000000732°C
  - Scenario 2: 0.002°C multiplied by 20.23 metric tonnes/13,200 metric tonnes[8] = 0.000003064°C
- Additionally, by using low-flow rates in anaesthesia, it can be an acceptable way to control wastage in environmental and cost terms.[7,30]

VI. CONCLUSION

- We present a novel method that can aid hospital administrators, physicians, and policy makers refocus needed efforts to mitigate their climate impact by appraising the actual impact, in real terms, of inhaled anaesthetics.
- Moving discourse towards realistic impacts, centres discussions on the best/safest combination of drugs for the patient, returning decision-making to the physician.
- Benefits of using inhaled anaesthetic gases should be at the forefront of the decision-making, and not the negligible environmental impact.

VII. LIMITATIONS

- The model will not account for variations in wash-in, wash-out, induction, and drug administrations throughout (or in part) based on individual working practices.
- It will ONLY seek to estimate a typical operation hour (e.g., during maintenance anaesthesia) and the climate impact this is likely to have from a fictitious but relevant split of potential hours of use in a given day.
- The model is not designed to fully simulate the Earth's climate budget or truly showcase a full accounting for impact on the climate, as it is not complex enough to cover all the factors necessary to do so.
- Factors, such as, but not limited to:
  - Climate impact adjustments from other factors; representations of the travel of molecules; the time lags between emission and impact; different topographies; temperatures; changes year on year; and different gas atmospheric lifetimes.
- This model will not assess gas concentration using a scientific method such as gas column monitoring, nor account for time or distribution variables from emission to effective altitude for recording of pulse efficiencies.

VIII. ACKNOWLEDGEMENTS

- The medical writing support was provided by CIMS Medica Pvt Ltd. The authors are fully responsible for all content and editorial decisions, were involved at all stages of poster development, and have approved the final version.

IX. DECLARATION

- This Study was funded by Baxter AG Scientific Office, Dubai, United Arab Emirates.

[a]Expert author opinion. Abbreviations: Des, desflurane; Sevo, sevoflurane; Iso, isoflurane.

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