Almost all areas of human activity have the potential to influence climate. The administration of inhalation anaesthetics is one such activity. However, since the first dedicated study in 1989 of the possible role of halogenated anaesthetics, they have received only sporadic interest. Two recent papers, published in this issue of the British Journal of Anaesthesia and in Anesthesia and Analgesia earlier this year, have refocused attention on isoflurane, desflurane, and sevoflurane.

To be clear, such anaesthetics currently make only a very minor contribution to climate change. Using an estimate of the amount currently in the atmosphere (around a part per trillion), these three gases contribute only 0.02% of the climate effect that results from the increases in carbon dioxide due to human activity. Nevertheless, the issue is, all other considerations being equal, which of the anaesthetics is most ‘climate friendly’?

Although this question is easy to pose, it is not easy to answer—how do we compare the climate effect of gas A with gas B? I expect that there are similar issues when comparing the clinical effectiveness of different anaesthetics.

In assessing the climate effect of a gas, there are two distinct issues. The first is more straightforward and requires basic physical characteristics of a gas to be determined, via laboratory measurements and calculations. The key quantities are the atmospheric lifetime of the gas and the effectiveness of the gas at absorbing and emitting infrared radiation (the impact per unit concentration is characterized by a quantity called ‘radiative efficiency’) — this effect on infrared radiation results in a molecule contributing to the greenhouse effect. The two recent papers provide important updates for these quantities (albeit with some significant disagreement, especially for sevoflurane).

The second issue is much trickier. The aim is to place the climate effect of emissions of gases with differing lifetimes and radiative efficiencies on some common scale. So, for example, does a gas with a long lifetime but a low radiative efficiency have a larger or smaller effect on climate than a gas with a short lifetime and a high radiative efficiency? There is no unique answer to this question: it depends on the way the climate effect is quantified and it depends on a number of value-laden decisions.

Because carbon dioxide is the largest contributor to human-induced climate change, it is conventional to use climate metrics to place emissions of gases on a CO₂-equivalent scale. By using these metrics, a kilogram emission of a gas can be said to be somehow equivalent to the emission of X kilograms of CO₂.

The Kyoto Protocol to the United Nations Framework Convention on Climate Change, which committed nations to targets for their CO₂-equivalent emissions, is a multigas treaty. It covered emissions of greenhouse gases including CO₂, methane, nitrous oxide, and groups of fluorinated compounds. To make the Protocol operational, a metric was required so that non-CO₂ emissions could be given a CO₂ equivalence. The chosen metric was the global warming potential (GWP).

The GWP has been used in the recent studies on anaesthetics with clear results that, per kilogram emitted into the atmosphere, desflurane has the largest effect and isoflurane the least. According to Ryan and Nielsen, the effect of desflurane is significantly accentuated by the fact that more of it is required to deliver the same clinical effect. These authors go a step further by considering the carrier gas that is used. The significance here is that nitrous oxide is also a greenhouse gas. In the case of mixtures of...
isoﬂurane and sevoﬂurane with nitrous oxide, the climate effect can be dominated by the presence of nitrous oxide; hence, the choice of carrier gas can be as important as the choice of halogenated anaesthetic. (I have found it surprisingly diﬃcult to ﬁnd estimates for the contribution of medical uses of nitrous oxide to climate change. 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. One estimate for European emissions of nitrous oxide for anaesthesia is presently around 30 kt yr⁻¹. To get a very rough estimate for global emissions, this is scaled up by a factor of 3. If it is assumed that these emissions have been constant for a few decades, then the atmospheric concentration resulting from anaesthetic use would be around 0.5 parts per billion. The resulting radiative forcing would be around 0.001 W m⁻²; this is several times higher than the eﬀect of emissions of the halogenated anaesthetics and around 0.1% of the climate eﬀect due to CO₂ increases resulting from human activity.)

It is necessary, though, to stand back and consider the GWP a little further. To understand the basis of the GWP, consider a 1 kg release of a gas into the atmosphere. The concentration of that gas will decay over time, as chemical reactions remove it from the atmosphere. While the gas remains in the atmosphere, it will exert an eﬀect on the Earth’s energy balance, which is called ‘radiative forcing’ (which is the product of the change in gas concentration and the radiative eﬃciency). The GWP is constructed by calculating the time integral of this radiative forcing over some given time (called the ‘time horizon’), and then dividing this by the time integral of the radiative forcing due to a kilogram emission of CO₂. Hence, the CO₂-equivalent emission is calculated by multiplying the actual emission of a gas by its GWP value.

One point of contention is simple—what time horizon should be chosen? The Kyoto Protocol chose 100 yr, but there is no compelling reason for this choice. As shown below, the value of GWP depends quite markedly on the choice; in general, short-time horizons tend to make the short-lived gases look more climate eﬀective, whereas long-time horizons put more emphasis on the long-lived gases.⁴⁻⁷

In their studies of the eﬀects of inhaled anaesthetics, Sulbaek Anderson and colleagues² article in this journal, chose 100 yr, whereas Ryan and Nielsen³ chose the 20 yr time horizon (although their supplemental information presents GWP values using 100 yr). Their justification ‘that the relatively short atmospheric lifetimes of the . . . anaesthetics . . . warrant the use of 20 years . . .’ does not seem compelling, especially when they go on to say that for nitrous oxide ‘its impact is better addressed with the 100 year (time horizon)’. The problem, as I see it, is that one cannot pick and choose the time horizon arbitrarily based on a desire to emphasize (or indeed de-emphasize) the impact of a particular set of gases; once a particular metric is chosen to compare diﬀerent emissions, then consistent parameters in that metric should be used for all gases. Since the Kyoto Protocol chose to use 100 yr, I believe that for consistency’s sake, 100 yr is the preferred choice.

But there is another point of contention: why choose the GWP as the metric in the ﬁrst place? Is there anything uniquely useful in comparing the time-integrated radiative forcing due to an emission? The answer is almost certainly no; even for an atmospheric scientist, the relevance of ‘time-integrated radiative forcing’ for comparing gases is not obvious. The GWP seems to have become enshrined in international legislation because it was the only metric on oﬀer to policymakers at the time of the Kyoto Protocol negotiations, rather than because of any argument that it was somehow the right choice.⁶ Despite this, in many senses, the GWP concept has been a success, as it has allowed a transparent, consistent, and easily applied methodology to implement climate change policy.

One might argue that something more tangible, such as surface temperature change, might form the basis of a better metric, but there is also a growing understanding that the appropriate choice of metric depends on the precise formulation of the climate policy that it is aiming to serve.⁷⁻⁹ We recently developed an alternative to the GWP, the global temperature change potential (GTP)⁷ which compares the eﬀect of an emission of a gas on the surface temperature some years after the emission has occurred. This is not the place to detail the formulation of the GTP or to suggest that it is a better metric than the GWP; nevertheless, it is instructive to investigate the impact of using it on the perceived climate eﬀect of the inhaled anaesthetics.

Table 1 shows a comparison of the GWP and GTP (for time horizons of 20 and 100 yr) for isoflurane, desflurane, and sevoﬂurane. The calculation uses lifetimes and radiative eﬃciencies given in the paper by Sulbaek Anderson and colleagues² and available methods for calculating the GWP⁴ and GTP⁷ (the GTP values depend, to some extent, on particular choices for some uncertain characteristics of the climate system). Values for nitrous oxide⁴⁷ are also given. Isoﬂurane, desflurane, and sevoﬂurane are relatively short lived (lifetimes range from around 2 to 9 yr)¹ which is much shorter than the lifetimes of CO₂ and nitrous oxide (typically centuries).⁷ This means that the GWPs and GTPs are a strong function of the choice of time horizon, with the 20 yr values being several times larger than the 100 yr value.

<table>
<thead>
<tr>
<th></th>
<th>GWP 20 yr</th>
<th>GWP 100 yr</th>
<th>GTP 20 yr</th>
<th>GTP 100 yr</th>
</tr>
</thead>
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<tr>
<td>Nitrous oxide</td>
<td>290</td>
<td>300</td>
<td>300</td>
<td>320</td>
</tr>
<tr>
<td>Isoﬂurane</td>
<td>1800</td>
<td>510</td>
<td>790</td>
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<td>Desflurane</td>
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<td>1620</td>
<td>3650</td>
<td>550</td>
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<tr>
<td>Sevoﬂurane</td>
<td>720</td>
<td>210</td>
<td>260</td>
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</table>
Several messages emerge from Table 1. First, there is no unique CO₂ equivalence for the emission of a kilogram of a given anaesthetic; it depends significantly on both the choice of metric (GWP vs GTP) and time horizon (20 vs 100 yr). Given the current legislative framework for the Kyoto Protocol, I believe there is a logic to using the 100 yr GWP as the standard; however, Table 1 shows clearly that any quantitative assessments of CO₂ equivalence will be materially affected by metric choice.

Secondly, for the short-lived gases, the GWP is higher than the GTP, particularly for the 100 yr time horizon. Finally, among the halogenated anaesthetics, on a per kilogram basis, the ranking of these gases remains robust for all metric choices; desflurane is the more potent climate gas, mainly because it has a longer lifetime than the other two. However, the relative importance of nitrous oxide varies from being the least important, by some distance, for the 20 yr GWP, to being the second most important for the 100 yr GTP.

The current climate effect of anaesthetics is small and it could be argued that clinical decisions about the effectiveness of different compounds should take priority. Nevertheless, there is a need to monitor the climate impact, especially if there were to be a significant growth in emissions. There is also a need to characterize the effect of other anaesthetics, either in use, or proposed for use. Finally, of the gases considered here, desflurane has the largest climate effect. Where there are no compelling reasons for using it, and for using nitrous oxide as a carrier gas, the climate effects of anaesthetic use would be lessened if they were not used.

Conflict of interest
None declared.

References
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