Carbon footprinting of anaesthetic practice - the need to consider *work as done*

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To the editor -

We discussed with interest the work by Hu et al (2021) at our virtual journal club, based in the North West School of Anaesthesia, Manchester, UK. As anaesthetists we are greatly concerned with the environmental impacts associated with our practice. We were fascinated to learn about the various synthesis methods for volatile anaesthetic agents; something that we were not previously aware of. We are concerned both about the variation in emissions depending on how volatile agents are made, and that information on embodied emissions is not made available by drug manufacturers. We thank the authors for drawing this to our attention.

It has previously been suggested that using total intravenous anaesthesia (TIVA), thereby avoiding inhalational anaesthetic agents, is the 'greener' mode of delivering general anaesthesia (e.g. White and Shelton, 2020). However, Hu et al found that it is possible that anaesthesia with sevoflurane, the most commonly-used volatile anaesthetic agent in the UK, may have a carbon footprint equivalent to that of TIVA with the use of vapor capture technology (although this technology is not currently widely available). This finding is based on a model that assumes the use of a fresh gas flow of 0.5 L/min in the presence of oxygen as the carrier gas, and a single cycle of vapor capture with an efficiency of 70%. However, although we agree that many anaesthetists aspire to use a minimal fresh gas flows of around 0.5 L/min, it is rare that this is achieved in reality.

Between February and May 2021, supplies of propofol (the anaesthetic agent used in TIVA) were restricted in the UK due to the COVID-19 pandemic. We took the opportunity during this time to audit the fresh gas flows and anaesthetic agents used during general anaesthesia at Wythenshawe Hospital, Manchester, UK (a hospital that usually uses TIVA in a majority of cases). In this audit of 42 cases (table 1), which were sampled on an opportunistic basis, we employed 'spot checks' during the maintenance phase of anaesthesia (the time when fresh gas flow is usually at the lowest rate), and found a mean fresh gas flow of 1.18 L/minute used amongst the 29 cases in which volatile anaesthesia was used (similar to the UK 'scenario II' model in Hu et al's study). When possible, we also interrogated the anaesthetic

machines (Primus, Dräger, Lübeck, Germany) and recorded the duration of each case and the volume of inhalational anaesthetic agent used (all cases used sevoflurane; no other inhalational agents were used). Of note, anaesthetic rooms were not used at this time in order to minimize the number of locations in which airway procedures were undertaken in the context of the pandemic, so these figures account for the whole anaesthetic from induction to emergence.

By dividing the mean volume of sevoflurane used by the mean duration of general anaesthesia, we calculated that, on average, 18.74 mL (28.49 g) of sevoflurane was used per hour of general anaesthesia. Based on the figures quoted in Hu et al's paper (mass of sevoflurane utilized per hour at 1 minimum alveolar concentration (MAC) and a fresh gas flow of 1 L/min = 11.25 g), we conclude that amongst our sample, sevoflurane usage is equivalent to 1 MAC at 2.5 L/minute fresh gas flow, over twice as much as our 'spot check' figures would suggest, and higher than any of the scenarios modelled by Hu et al.

	Number of cases	Fresh gas flow (L/min)	Sevoflurane consumption (mL)*	Case duration (h)*	Sevoflurane use per hour (mL / g)
Inhalational anaesthesia (sevoflurane)	**29**	**1.18 [0.4-3.0]**	**33 [12-81]**	**1.76 [0.58-6.83]**	**18.74 / 28.49**
Total intravenous anaesthesia	**13**	**4.69 [1.0-6.0]**	**N/A**	**N/A**	**N/A**

Table 1: Summary findings of an audit of fresh gas flow rates and anaesthetic agent use during 42 cases of general anaesthesia at Wythenshawe Hospital between 17th March and 14th April 2021. Data are expressed as mean [range].
*Data on case duration and sevoflurane consumption were available for 21 of 29 inhaled general anaesthetics.

We hypothesize that the discrepancy in these figures is likely to be due to two factors. Firstly, there are times when higher volatile agent concentrations and fresh gas flow rates are intentionally used, for example to rapidly fill the breathing circuit with the desired concentration of anaesthetic agent at the start of a case. Secondly, the practice of anaesthesia is often laden with tasks at the start of a procedure (e.g. establishing additional vascular access, transferring the patient to the operating table), and this may distract anaesthetists from turning the fresh gas flow down at an earlier point.

The concepts of *work as imagined* and *work as done* have been recognized in the ergonomics literature for over 60 years (e.g. Ombredane and Faverge, 1955). As explained by Hollnagel (2017), *work as imagined* refers to "the various assumptions, explicit or implicit, that people have about how work *should* be done", whereas *work as done* refers to "(descriptions of) how something is *actually* done" (emphasis added). Comparing Hu et al's model with our own audit data, we wonder if Hu et al have somewhat optimistically based their models for inhaled anaesthesia on an environmentally-conscious version of *work as imagined*. Of note, TIVA administered by target-controlled infusion, as is the case in 90% of TIVA anaesthestics in the UK (Sury et al, 2014), safeguards against unintentional overuse of anaesthetic agent by automatically reducing the infusion rate as the anaesthetic progresses.

We commend Hu and colleagues for their diligent approach in calculating the carbon footprint of sevoflurane anaesthesia, and we agree that in certain specific circumstances this may approach that of TIVA. However, we are concerned that the 'best case scenarios' that they model may not reflect the realities of sevoflurane use in everyday clinical practice. Carbon footprinting is emerging as a valuable tool to help anaesthetists make better environmental decisions in clinical practice, but we believe that analyses should take steps to reflect *work as done*, rather than reflecting aspirational goals.

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Author Statement

Annie Pinder: Conceptualization, writing- original draft preparation, **Danielle Eusuf**: Conceptualization, writing- reviewing and editing, project administration, **Angela Gardner**: Conceptualization, writing- reviewing and editing, **Adam Kirk**: Conceptualization, investigation, writing- reviewing and editing, **Stephen Washington**: Conceptualization, writing- reviewing and editing, supervision **Karlie Whitehead**: Conceptualization, investigation, data curation, writing- reviewing and editing, **Cliff Shelton**: Conceptualization, writing- original draft preparation, supervision

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