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The carbon footprint of general anaesthetics: A case study in the UK

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ABSTRACT

The UK National Health Service (NHS) aims to achieve net zero carbon emissions by 2050. One measure for reaching this target outlined in the NHS long-term plan (2019) is to reduce the carbon footprint of inhalational anaesthetic gases (IAGs). We modelled the synthesis of commonly used IAGs - sevoflurane, isoflurane, and desflurane - in comparison to intravenous propofol and estimated the carbon footprint generated throughout their lifetime, from manufacturing of raw materials to emissions of IAGs vented from operating theatres. We find that the carbon footprint of IAGs varies significantly depending on the method of chemical synthesis. Our results indicate that the carbon footprint of IAGs is minimised when using oxygen/air mix as the carrier gas at the lowest flow rate while applying a vapour capture technology (VCT). In this scenario, the carbon footprint of sevoflurane per minimum alveolar concentration hour is similar to that of propofol, which is a significant finding given that previous studies have favoured propofol as a means of carbon footprint reduction and only the active pharmaceutical ingredient of propofol was examined. Further, we show that the carbon footprint of sevoflurane used in the NHS during 2018, in the absence of VCTs, is not smaller than that of desflurane if sevoflurane is synthesised from tetrafluoroethylene. Therefore, to reduce the carbon footprint of IAGs, this study supports the continued reduction in the use of nitrous oxide and recommends a wider adoption of VCTs.

1. Introduction

Health care provision is a resource-intensive activity and requires considerable amounts of energy and consumables. As the detrimental impacts of climate change on human health have become more apparent, it is clear that the health care community also needs to critically examine the effect of its own activities on human and environmental health (Costello et al., 2009; Watts et al., 2015). A recent report by the Health Care Without Harm and Arup (Health care climate footprint report 2019) suggests that health care contributes 4.4% of global greenhouse gas emissions.. The report also estimated that the US health care accounts for 7.6% of national emissions, or 10% estimated by Eckelman and Sherman (2016), India's health care system accounts for 1.5% and the UK NHS accounts for 5.4%.

To achieve net zero carbon, the NHS long-term plan (2019) outlined that one approach is to reduce the carbon footprint of inhalational anaesthetic gases (IAGs). Sevoflurane, isoflurane and desflurane are the most commonly used IAGs. They are halogenated substituted ethers with global warming potential that is 130, 510 and 2540 times (Andersen et al., 2012) that of carbon dioxide over a 100-year time horizon (GWP_{100}), respectively. A case study conducted by the UK government's scientific research and development team (SageTech: leading sustainable anaesthesia, 2019) showed that the NHS England spends between £50–60 million on IAGs per year, with approximately 98% of these gases vented into the atmosphere. The NHS Sustainable Development Unit reported that the wasted anaesthetic gases represent 5% of the carbon footprint for the acute hospital sector (Carbon Footprint from Anaesthetic gas use, 2013). The use of IAGs with high GWP_{100} forms the largest single component of the carbon footprint of operating theatres (MacNeil et al., 2017; Thiel et al., 2018). 42% of the carbon emissions generated during surgical procedures are contributed by anaesthetic gases (Whiting et al., 2020), with desflurane identified as the most carbon intensive (Sherman et al., 2012). This is further compounded by the use of nitrous oxide (N_2O), which has a GWP_{100} of 265 (Myhre et al., 2013), as the default carrier gas in clinical practice.

Knowledge of the carbon footprint of desflurane amongst anaesthetists has changed anaesthetic practice in favour of sevoflurane (Limb, 2020). Meanwhile, a recent report by the NHS (For a greener NHS, 2020) highlighted that the development of vapour capture technology (VCT) has also increased the likelihood of widespread routine retrieval

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Table 1
Relative Characteristics of Anaesthetics.

	Sevoflurane	Isoflurane	Desflurane	N_2O	Propofol
MAC% (Sherman et al., 2012)	2.2%	1.2%	6.7%	105%	
Density (g/mL) (liquid form)	1.52	1.5	1.47	1.22	1.03
Molar mass (g/mol)	200	184.5	168	44	178.3
Metabolism (%)	4%	0.20%	0.02%	0.005%	100%
Bottle volume (ml)	250	250	240		
Tropospheric lifetime (y)	1.1	3.2	14	114	
GWP_{100} (Sulbaek Andersen et al., 2012)	130	510	2540	265	
Mass of agent used per hour with low flow (500 ml/min) anaesthesia at 1 MAC in an oxygen/air mix (g/hr) (Pierce and Taylor, 2020)	5.62	2.80	15.08		
Agent used per MAC-h (ml/hr) (Al-Rifai and Mulvey, 2016)					60

of exhaled anaesthetic agents and subsequent secondary re-delivery. Within this context the aims of this study are threefold. First, we will estimate the carbon footprint of sevoflurane, isoflurane, desflurane, and intravenous propofol, using life cycle inventory analysis which will be discussed in the next section. Previous studies (Sherman et al., 2012; MacNeil et al., 2017) showed that propofol is preferred against IAGs for environmental concerns, and desflurane has a higher carbon footprint per minimum alveolar concentration hour (MAC-h) than other IAGs (details of MAC-h will be discussed in the next section). We contribute to this literature by showing figures of IAGs estimated from two different synthesising methods which aims to avoid estimation bias resulted from a single method. For intravenous propofol, we looked beyond the current literature which studied the carbon footprint of the active pharmaceutical ingredient of propofol using a Life Cycle Assessment (LCA) approach (Sherman et al., 2012; Parvatker et al., 2019) to the real usable drug.

Furthermore, we will provide novel evidence of the potential impact of VCTs that cut the carbon footprint of IAGs per MAC-h in comparison to that of propofol. Finally, using the annual volumes of IAGs and propofol used within the UK NHS in 2018 (based on data collected from a sample of 193 NHS Trusts) we present the carbon footprint of general anaesthetics at the national level to inform policy. We find that the use of sevoflurane - depending on several variables in clinical setting - does not necessarily have a lower footprint than desflurane when scaled to the whole health care system, and that the use of intravenous anaesthetics like propofol is not necessarily a better option than gaseous anaesthetics when VCTs are available.

2. Methods

Widely used, Life Cycle Assessments (LCAs) are included in the 14,000 series of environmental management standards of the International Organisation for Standardisation (ISO). A key component of LCA and a stand-alone method in itself, life cycle inventory (LCI) analysis can be used to evaluate the carbon footprint throughout a product's life cycle (i.e. cradle-to-grave) from raw materials acquisition through production, use and disposal. In this study, we employed LCI to examine the direct and indirect carbon footprint generated during manufacturing and procuring general anaesthetics (e.g., energy, water, packaging, and transport) and other indirect carbon footprint from its upstream (i.e., from its raw materials) and downstream (i.e., from its use in health care facilities and wastes).

The functional unit in an LCI analysis provides a basis measurement to relate all estimates. In this study, 1 minimum alveolar concentration hour (MAC-h), or MAC-h equivalent for propofol, is used as the functional unit. MAC is the standard method of describing the potency of inhalational anaesthetics and is the alveolar concentration required to suppress a response to a standard surgical stimulus (skin incision). It is a common practice to use MAC-h as the measurement to compare the consumption or cost across anaesthetic agents at various fresh gas flow rates (Lobo and Lopez, 2020).

We assume that the average anaesthesia usage in the UK can be modelled by the parameters based on a functional unit of 1 MAC-h for maintaining anaesthesia in an average 70 kg adult patient for an hour. Under this assumption, we take the accepted values of 2.2%, 1.2% and 6.7% respectively for sevoflurane, isoflurane (most potent) and desflurane (least potent) as the basis of our modelling. However, intravenous anaesthesia does not have its equivalent of MAC and instead relies on the pharmacokinetics of propofol which is built into the programs of specially dedicated syringe drivers. In this study, we modelled the stable maintenance of anaesthesia and assumed a constant infusion rate of 60 ml/hr, which is equivalent to 0.01 g/hr as used in other studies (e.g., Sherman et al., 2012). Details of the characteristics and assumptions used are summarised in Table 1.

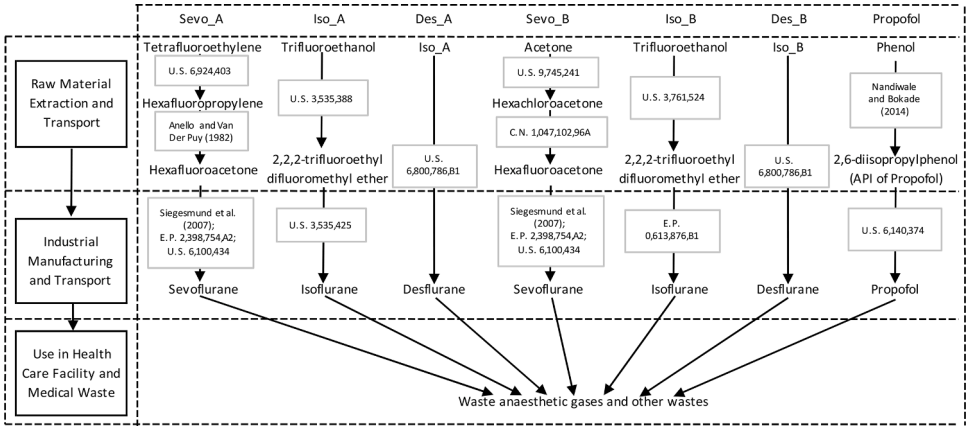

Fig. 1. Life-cycle inventory flow diagram for anaesthetics used per MAC-h. Anello and Van der Puy, 1982, Nandiwale and Bokade, 2014, Siegemund et al., 2000.

Table 2
Scenarios for IAG consumption per MAC-h.

	Fresh gas flow (L/min)	% Gas flow O_2/N_2O	% MAC-h from agent/N_2O	N_2O used per MAC-h (g) †	Drugs	Agent used per MAC-h (g) (Pierce and Taylor, 2020)
Scenario I						
(1)	1	40/60	37/63	66.06	Sevoflurane (UK)	4.16
(2)	1				Isoflurane	2.07
(3)	1				Desflurane	11.16
(4)	2			132.11	Sevoflurane (US)	8.32
Scenario II						
(5)	1	100/0	100/0	0	Sevoflurane (UK)	11.25
(6)	1				Isoflurane	5.60
(7)	1				Desflurane	30.16
(8)	2				Sevoflurane (US)	22.49
Scenario III						
(9)	0.5				Sevoflurane (UK)	5.62
(10)	0.5	100/0	100/0	0	Isoflurane	2.80
(11)	0.5				Desflurane	15.08

We use an online open source python platform Lcopt (Joyce, 2017), which uses Ecoinvent 3.3 as its inventory database, to perform the LCI analysis. However, direct information on synthesising the general anaesthetic agents is not publicly available. To avoid bias, we modelled two different synthesising methods based on information contained in respective patents. While one method, which we refer to as "Method-A", applies relatively older manufacturing processes, the other, which we refer to as "Method-B", uses newer processes that are self-proclaimed to be more sustainable. The life cycle inventory flow diagram is summarised in Fig. 1.

In particular, Method-A uses tetrafluoroethylene to synthesise sevoflurane (Almemark and Tjus, 2018), while Method-B uses hexachloroacetone that is made from acetone. For isoflurane, both methods use trifluoroethanol to synthesise 2,2,2-trifluoroethyl difluoromethyl ether which is then used to obtain isoflurane, while patents assembled in Method-B self-proclaimed to improve production efficiency and reduce costs and environmental disposal problems. The processes described in Method-B are similar to the ones modelled by SciFinder in Sherman et al. (2012). Since desflurane is derived from isoflurane and the process is rather straightforward, we followed U.S. 6800,786,B1 only in this study. The associated patents and references for each major step are presented in Fig. 1, where Method-A is denoted by "_A" while Method-B by "_B", respectively.

For propofol, the liquid used in operating theatres is modelled using U.S. Patent 6140,374. To the best of our knowledge, this is the first study to model the synthesis of the propofol liquid in an LCI framework. Other studies such as Sherman et al. (2012) and Parvatker et al. (2019) only provide an LCA study on 2,6-diisopropylphenol which is the active pharmaceutical ingredient (API) of propofol. This API usually accounts for 1–2% of the propofol liquid.

The references and patents presented in Fig. 1 provide information on chemical intermediates and process energy and/or water used. A summary of the data for each process can be found in the Appendix. It is then linked to the existing data in the LCI database. When exact matches are unavailable in the database, proxies that best matched the (production) characteristics of the target were used and noted. For assumptions and proxy data used to match with the Ecoinvent inventory database, see online supplementary materials.

For transport, since most fast-moving and low-value medical consumables are procured and distributed centrally by the NHS Supply Chain in the UK (Boiko et al., 2020), we assume that each NHS Trust obtained the anaesthetic agents from the same logistic centre using the same type of vehicles. Therefore, the carbon footprint generated from transportation are assumed to be the same across drugs, meaning they are out of scope. Similarly, as the LCI analysis is based on per (MAC) hour the energy consumptions of using general anaesthetics in operating theatres, such as lighting, sensors, and displays, are also considered to be identical for all agents. Hence, they are out of scope.

During a general anaesthesia maintained by desflurane, a vaporiser is required to keep the drug at the recommended temperature to ensure controlled titration. We assume that the heating element has a power rating of approximately 0.25 kW (Sherman et al., 2012), and in Ecoinvent 3.3 we set the electricity parameter at the European standard high voltage (> 24 kV). During the administration of propofol, we apply the standard practice which uses the 50 mL syringe to deliver the drug. The carbon footprint generated from manufacturing the syringes are calculated from a dataset collected from a Chinese manufacturing factory. In addition, the power rating of this syringe pump is assumed to be 15 W (Pierce et al., 2014).

As this is a carbon footprint study, other environmental impacts, such as ecotoxicity of propofol in wastewater, are not considered. The wasted plastics and sharps associated with using propofol have no matching records in the Ecoinvent life cycle inventory database. Nonetheless, the carbon footprint of the waste treatment processes is marginal as suggested in Sherman et al. (2012). Wastes that are associated with using propofol are not included in the carbon footprint calculation. With regard to the IAGs, all unmetabolised gases are exhaled by the patients and enter the atmosphere through the anaesthetic gas scavenging system in the absence of gas-capturing technology. Hence, they are included in the carbon footprint calculation. However, basic disposables, such as tubes, circuits, and CO_2 absorbents, were considered equivalent for all inhalational agents. Hence, they are out of scope.

Further, we investigated the effect of a vapour capture technology (VCT) that is capable of recycle and reuse anaesthetic gases (e.g., Deltasorb® and SageTech®). For simplicity, we assume that each IAG can only be recycled once during its life cycle. To estimate the life cycle carbon footprint of IAG per MAC-h in the presence of a gas-capturing technology, a two-stage model is employed. In the first stage, the anaesthetist uses a manufactured anaesthetic gas for the anaesthesia administration for an hour. During the procedure, the wasted gas is captured by the technology, and the recycling ratio is assumed at 70% (a preliminary trial result provided by SageTech®). In the second stage, the anaesthetist uses the recycled drug along with the manufactured drug to complete another one hour procedure. Hence, dividing the total carbon footprint generated through these two stages by two gives the carbon footprint of the IAG per hour in the scenario where a gas-capturing technology is applied.

Data on anaesthetic usage were acquired from NHS Trusts across the UK to estimate the carbon footprint of IAGs at the national level. An NHS Trust is an organisational unit within the NHS which provides hospital services, community services and/or other aspects of patient care and generally serves either a geographical area or a specialised function (e.g., ambulance services). Health services in England, Wales, Scotland, and Northern Ireland, are divided into 254 such trusts. Data was

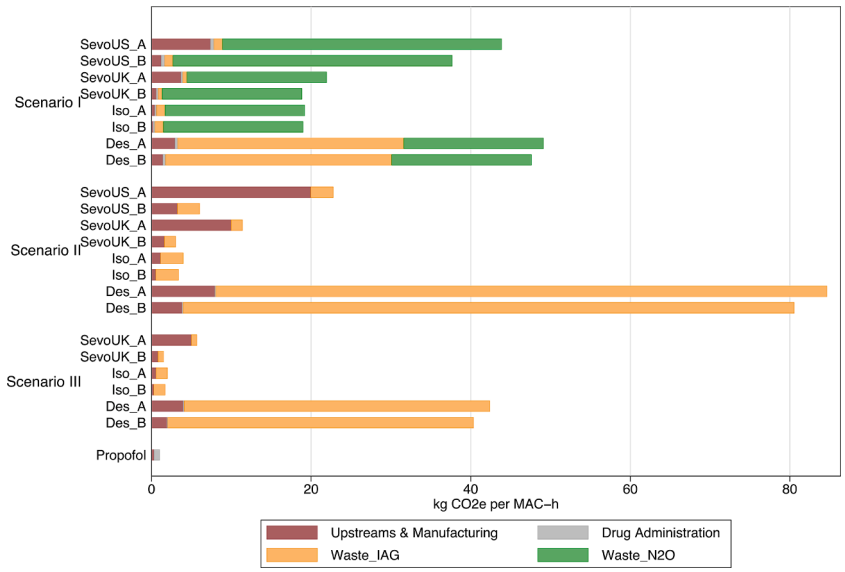

Fig. 2. Carbon Footprint of IAGs per MAC-h by Clinical Scenarios.

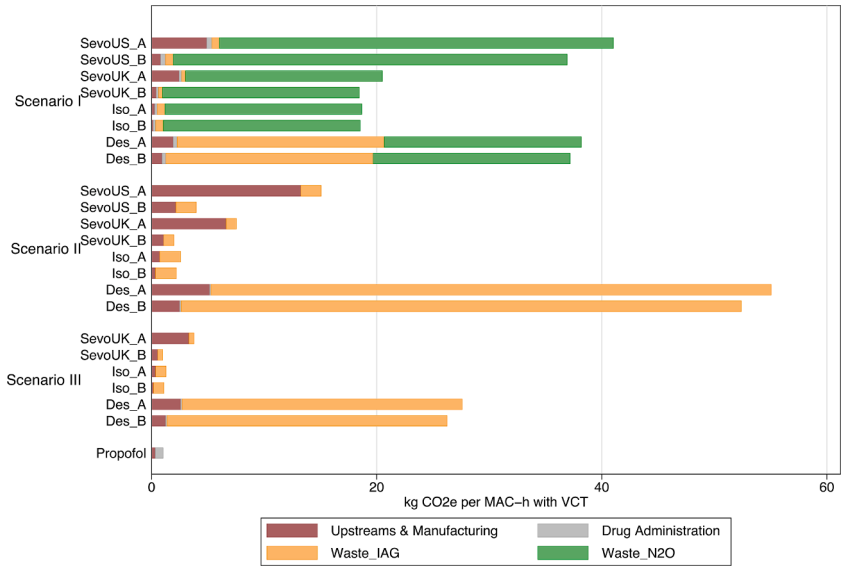

Fig. 3. Carbon Footprint of IAGs per MAC-h by Clinical Scenarios in the presence of VCT.

requested under the Freedom of information Act 2000 from each trust. Ethical approval was obtained from the University of Exeter (reference: Dec19/D/226). 193 out of 254 (76%) trusts had provided information for 2018 as some trusts responded that the administrative cost of collecting the data is prohibitive given the format of their records or the data has been lost after changing the computer system.

To integrate this primary activity data with the carbon footprint estimates, annual volumes of used IAGs are converted into annual MAC-h operated according to the figures presented in Table 2. Note that the minimum gas flow rate of sevoflurane is regulated by the U.S. Food and Drug Administration to 2 L/min in the US, while there is no regulation imposed in the UK which usually ranges between 0.5 L/min and 1 L/min. Hence, we show our results for both UK and US scenarios. Three clinical scenarios are modelled, a general scenario where nitrous oxide is used as the carrier gas which accounts for 60% of the gas flow and 63% of the MAC, and two scenarios where nitrous oxide is not used but differ in gas flow rates.

3. Results

3.1. The carbon footprint of anaesthetics per functional unit

Fig. 2 presents the results of the carbon footprint of each general anaesthetic agent per MAC-h estimated by the LCI analysis. The carbon footprint of IAGs is mainly contributed by the synthesis method, the emissions of unmetabolised gases, and the nitrous oxide used as the carrier gas. In line with Sherman et al. (2012), we find that desflurane has the highest carbon footprint in all scenarios, though sevoflurane comes close in Scenario I. Propofol has the lowest carbon footprint by a large margin in most scenarios (1.01 kg CO_2e per MAC-h, where half of the footprint is from the electricity that used to manufacturing the syringes).

Method-B, which applies more modern and efficient (e.g., in terms of energy, water and resource use) manufacturing processes (denoted by B in Fig. 2), generates less carbon footprint than Method-A (denoted by A) for all three anaesthetic gases. Manufacturers who use a method that avoids the intermediate tetrafluoroethylene can significantly reduce the

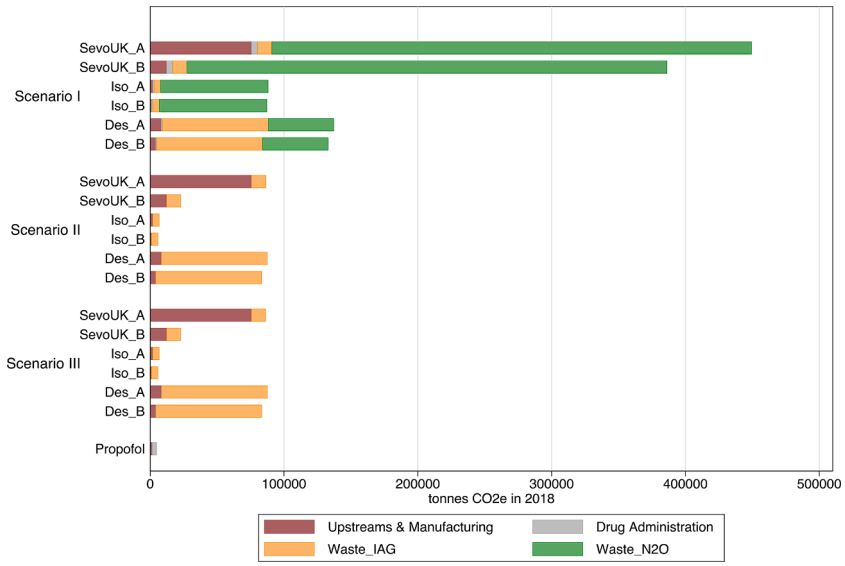

Fig. 4. Carbon Footprint of Anaesthetics Used in the UK, 2018.

carbon footprint of sevoflurane by 84%, but the differences are relatively small for either isoflurane or desflurane across synthesising methods.

Fig. 2 also shows that the carbon footprint of either isoflurane or sevoflurane drops in the absence of nitrous oxide. However, eliminating nitrous oxide without decreasing the gas flow rate increases the use of sevoflurane. As shown in Scenario II, for the sevoflurane manufactured from Method-A and administrated at the lowest US gas flow rate (2 L/min), the carbon footprint of sevoflurane per MAC-h is as large as 20 kg CO_2e. It is four-fold greater than the ones manufactured from the same method but administrated at the lowest UK gas flow rate (0.5 L/min). As the GWP for desflurane is so high, reducing the use of nitrous oxide in the anaesthesia maintained by desflurane increases its carbon footprint.

3.2. Vapour capture technology

Fig. 3 presents the results of the carbon footprint of IAGs per MAC-h for the same scenarios presented in Fig. 2 but with the application of a vapour-capturing technology (VCT) that has a 70% recycling rate. The figures indicate that the effect of VCT is the strongest on desflurane given its high global warming potential while the effect on sevoflurane and isoflurane is relatively small. In Scenario I, where nitrous oxide is used as the carrier gas, applying a VCT reduces the carbon footprint of desflurane per MAC-h down below that of sevoflurane (for Method-A) or at a similar level (for Method-B). If nitrous oxide is not used and sevoflurane is administrated with the lowest gas flow rate at 0.5 L/min, i.e., Scenario III, sevoflurane that are made from Method-B emits 0.996 kg CO_2e per MAC-h which is similar to that of propofol which emits 1.013 kg CO_2e per MAC-h. Hence, with the help of a VCT that can recycle 70% of the anaesthetic gas once in its life cycle sevoflurane could become less carbon intensive than propofol. Notice that this is most likely to be an underestimation as, in practice, technologies may recycle the gases for more than once.

3.3. The carbon footprint of general anaesthetics used in the UK

Using the anaesthetic 2018 usage data from the NHS, Fig. 4 shows the carbon footprint of the anaesthetics used in the UK. Since we are using the UK usage data, Fig. 4 excludes the US scenarios for sevoflurane. Because 56,140 L of sevoflurane are used in 2018 compared to 21,279 L of desflurane, the carbon footprint of sevoflurane is as big as desflurane in the absence of nitrous oxide (Scenarios II and III) if sevoflurane is manufactured from Method-A. If nitrous oxide is used, the carbon footprint of sevoflurane is almost four-fold greater than that of desflurane for both synthesising methods as shown in Scenario I. For isoflurane, only 6384 L were used in 2018. Hence, its carbon footprint is much smaller than that of sevoflurane and desflurane in all scenarios. Since a nationwide implementation of VCT had not yet been rolled out in 2018, in the absence of VCT the carbon footprint of propofol is the smallest.

4. Discussion

To the best of our knowledge, this is the first study presenting the estimated carbon footprint of general anaesthetic agents per MAC-h with two different synthesising methods. In line with the literature, we find that both sevoflurane and isoflurane have a smaller life-cycle carbon footprint per MAC-h than desflurane in all scenarios. The results indicate that the difference is more significant for sevoflurane in relation to isoflurane and desflurane. Using tetrafluoroethylene as the raw material to synthesise 1 MAC-h of sevoflurane increases the life cycle carbon footprint of its manufacturing and procurement process by five-fold in comparison to the method of gas-phase catalytic fluorination of hexachloroacetone. We also find that the optimal clinical practice to reduce the carbon footprint of anaesthetic gases is to use an oxygen/air mix while the gas flow rate is kept at its minimum. Using anaesthetic usage data collected from the NHS, we showed that the carbon footprint of sevoflurane used in the UK is not smaller than that of desflurane in most scenarios unless nitrous oxide is not used as the carrier gas and sevoflurane is not manufactured by tetrafluoroethylene. We believe these pieces of evidence are crucial to identify the effective policy that can reduce the overall carbon footprint of anaesthetic gases.

As new vapour capture technology (VCT) becomes available, we provide novel evidence on the effectiveness of this technology to reduce the carbon footprint of anaesthetic gases. In the scenario of a general anaesthesia maintained in an oxygen/air mix at 0.5 L/min gas flow rate, a technology with a 70% gas recycling rate reduces the carbon footprint of sevoflurane per MAC-h to a level that is as low as propofol if sevoflurane is manufactured by the method of gas-phase catalytic fluorination of hexachloroacetone. In the scenario of a N_2O/oxygen mix, the carbon footprint of desflurane per MAC-h is as large as that of sevoflurane in the presence of a VCT with 70% recycling rate. These findings

are significant as it shows the capacity of a VCT to reduce the carbon footprint of general anaesthesia. However, it is important to note that if the manufacturer of propofol uses renewable energy the carbon footprint of propofol estimated here can be cut by half. This would leave propofol the least carbon intensive drug even in the presence of the VCT.

Furthermore, it had been argued that the best approach to cut the carbon footprint of general anaesthetics is to use total intravenous anaesthesia propofol instead of inhalational agents (e.g., Sherman et al. 2012). However, while propofol has a limited impact on the environment with regard to carbon footprint, 1% of the drug is excreted unchanged in patient's urine and enters the biosphere. Larger quantities enter sewerage if waste drug is improperly discharged into sinks. Propofol is considered toxic to aquatic organisms, has a high bioaccumulation potential and soil mobility with no evidence of biodegradability in water. It is currently given a Persistence, Bioaccumulation and Toxicity Score of 6/10 (Mankes 2012). The remaining 99% of propofol is metabolised via glucuronidation and sulfation. Details of the persistence of propofol in the biosphere has not been published. Future work is needed to identify the downstream impacts of intravenous anaesthetics before recommendations of their use over inhalational anaesthetics can be made. Also note that, in some scenarios, there is not much difference between the carbon footprint of propofol and sevoflurane or isoflurane, especially in the presence of a VCT. Additionally, the use of volatile anaesthetics for surgery reserves propofol for situations of high demand for its sedative use in intensive care.

With regard to study limitations, the estimated carbon footprint of anaesthetic agents was calculated using proxies when exact matches for the materials needed were unavailable in the LCI database. As such, the results of the analysis must be interpreted with caution. However, we do provide a framework for future analysis as industrial data on manufacturing inputs becomes available. In addition, full information on the manufacturing side of each anaesthetic agent, such as energy consumption, was not publicly available. This could vary by factory or the drug produced. Researchers are encouraged to conduct surveys with the manufacturers and provide more insight.

5. Conclusion

The Lancet Commission on Climate and Health has called for the health care community to take a leadership role in advocating for emissions reductions and to critically examine its own activities with respect to their effects on human and environmental health (Watts et al., 2018). In early 2020, the new NHS campaign, "For a Greener NHS", plans to tackle the climate emergency and reach 'net zero' emissions. In response, we conducted the first study to estimate the carbon footprint of general anaesthetic agents, considering different manufacturing pathways in various clinical scenarios, in a view to reduce their carbon footprint. We measured the carbon footprint of anaesthetic gases in three different clinical scenarios, estimated the effect of vapour capture technology, and showed the current carbon footprint of general anaesthetics used within the UK. This study encourages health care providers to work closely with industry to identify sustainable pathways and develop vapour capture technologies.

CRediT authorship contribution statement

Xiaocheng Hu: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review & editing, Visualization, Project administration. **JM Tom Pierce:** Supervision, Validation, Writing - review & editing. **Tim Taylor:** Supervision, Writing - review & editing, Funding acquisition. **Karyn Morrissey:** Conceptualization, Supervision, Writing - review & editing, Project administration, Funding acquisition.

Declaration of Competing Interest

Xiaocheng Hu, Tim Taylor and Karyn Morrissey acknowledge funding from the Innovate UK to the University of Exeter and SageTech Medical Equipment Ltd. This study was conducted independently and without the intervention of SageTech Medical Equipment Ltd. JM Tom Pierce declares no competing interests.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.resconrec.2021.105411.

Appendix

Table i

Table i
Data on Each Process to Synthesise Sevoflurane under Method-A (Sevo_A).

Output		
Sevo_A	1	kg
Input		
Tetrafluoroethylene	2.5	kg
N-dimethylformamide	15.36	kg
Ethylene oxide	4.9	kg
Polymerisation	4.9	kg
Sulfur	0.02	kg
Iodine	3.8	kg
Potassium hydroxide	7.6	kg
Hydrogen	0.47	kg
Formaldehyde	0.3	kg
Aluminium	1.2	kg
Chloride gas	2.3	kg
Hydrogen fluoride	7.0	kg
Potassium carbonate	0.8	kg
Water	9.7	kg
Energy	75.35	Mj
Package (Carton board box)	0.70	kg

Table ii

Table ii
Data on Each Process to Synthesise Isoflurane under Method-A (Iso_A).

Output		
Iso_A	1	kg
Input		
Trifluoroacetic acid	4.79	kg
Potassium hydroxide	3.71	kg
Dimethyl sulfate	7.07	kg
Chlorine gas	3.80	kg
Phosphorus pentachloride	0.06	kg
Hydrogen fluoride	0.00	kg
Hydrochloric acid	22.04	kg
Water	4.31	kg
Package (Carton board box)	0.70	kg

Table iii

Table iii
Data on Each Process to Synthesise Desflurane under Method-A (Des_A).

Output		
Des_A	1	kg
Input		
Trifluoroacetic acid	6.32	kg
Potassium hydroxide	4.90	kg
Dimethyl sulfate	9.33	kg
Chlorine gas	5.02	kg
Phosphorus pentachloride	0.11	kg
Hydrogen fluoride	0.20	kg
Hydrochloric acid	29.09	kg
Sodium hydroxide (50%)	0.14	kg
Water	10.8	kg
Package (Carton board box)	0.67	kg

Table iv

Table iv
Data on Each Process to Synthesise Sevoflurane under Method-B (Sevo_B).

Output		
Sevo_B	1	kg
Input		
Iron	0.6	kg
Nitric acid	2.34	kg
Hydrogen fluoride	29.04	kg
Aluminium oxide	0.82	kg
Copper	0.01	kg
Acetone	0.5	kg
Chlorine gas	7.6	kg
Activated carbon	0.04	kg
Hydrogen	0.47	kg
Formaldehyde	0.3	kg
Aluminium	1.2	kg
Potassium carbonate	0.8	kg
Ethylene oxide	4.9	kg
Polymerisation	4.9	kg
Water	9.7	kg
Energy	0.17	Mj
Package (Carton board box)	0.70	kg

Table v

Table v
Data on Each Process to Synthesise Isoflurane under Method-B (Iso_B).

Output		
Iso_B	1	kg
Input		
Trifluoroacetic acid	2.88	kg
N-Methyl-2-pyrrolidone	1.04	kg
Chlorodifluoromethane	2.24	kg
Sodium hydroxide (50%)	4.77	kg
Chlorine gas	0.68	kg
Electricity	2.5	kwh
Water	3.20	kg
Energy	2.13	Mj
Hydrogenation	2.88	kg
Package (Carton board box)	0.70	kg

Table vi

Table vi
Data on Each Process to Synthesise Desflurane under Method-B (Des_B).

Output		
Des_B	1	kg
Input		
Trifluoroacetic acid	3.80	kg
N-Methyl-2-pyrrolidone	1.37	kg

Table vi (*continued*)

Chlorodifluoromethane	2.96	kg
Sodium hydroxide (50%)	6.43	kg
Chlorine gas	0.90	kg
Antimony pentachloride	0.03	kg
Hydrogen fluoride	0.20	kg
Electricity	3.3	kwh
Water	9.4	kg
Energy	2.8	Mj
Hydrogenation	3.8	kg
Package (Carton board box)	0.67	kg

Table vii

Table vii
Data on Each Process to Synthesise Propofol (liquid).

Output		
Propofol (liquid)	1	kg
Input		
Phenol	0.02	kg
Isopropyl alcohol	0.08	kg
Soybean oil	0.1	kg
Eggs	0.996	kg
Benzyl alcohol	0.0015	kg
Glycerol	0.0225	kg
Ethanol extraction	0.996	kg
50 mL Syringe:		
Polypropylene	0.4712	kg
Plunger rubber (synthetic)	0.1355	kg
Polyethylene (low density)	0.0016	kg
Electricity	10.2820	kwh
Water	0.85	kg
Energy	0.0266	Mj
Package (Carton board box)	1.2968	kg

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