Anaesthesia 2022, 77, 201–212 doi:10.1111/anae.15598

Guidelines

Principles of environmentally-sustainable anaesthesia: a global consensus statement from the World Federation of Societies of Anaesthesiologists

S. M. White,[1] C. L. Shelton,[2,3] A. W. Gelb,[4] C. Lawson,[5] F. McGain,[6,7] J. Muret[8] and J. D. Sherman,[9] representing the World Federation of Societies of Anaesthesiologists Global Working Group on Environmental Sustainability in Anaesthesia*

1 Consultant, Department of Anaesthesia, University Hospitals Sussex NHS Foundation Trust, Brighton, UK
2 Consultant, Department of Anaesthesia, Wythenshawe Hospital, Manchester University NHS Foundation Trust, Manchester, UK
3 Clinical Senior Lecturer, Lancaster Medical School, Faculty of Health and Medicine, Lancaster University, Lancaster, UK
4 Emeritus Professor, Department of Anesthesia and Peri-operative Care, University of California, San Francisco, CA, USA
5 Specialty Trainee, Departments of Anaesthesia and Intensive Care Medicine, Royal Victoria Infirmary, Newcastle upon Tyne, UK
6 Physician, Departments of Anaesthesia and Intensive Care, Western Health, Melbourne, Vic., Australia
7 Physician, Department of Critical Care, University of Melbourne, Melbourne, Vic., Australia
8 Physician, Departments of Anaesthesia and Intensive Care, Institut Curie PSL Research University, Paris, France
9 Associate Professor, Department of Anesthesiology, Yale School of Medicine, Department of Environmental Health Sciences (Epidemiology), Yale School of Public Health, New Haven, CT, USA

Summary

The Earth's mean surface temperature is already approximately 1.1°C higher than pre-industrial levels. Exceeding a mean 1.5°C rise by 2050 will make global adaptation to the consequences of climate change less possible. To protect public health, anaesthesia providers need to reduce the contribution their practice makes to global warming. We convened a Working Group of 45 anaesthesia providers with a recognised interest in sustainability, and used a three-stage modified Delphi consensus process to agree on principles of environmentally sustainable anaesthesia that are achievable worldwide. The Working Group agreed on the following three important underlying statements: patient safety should not be compromised by sustainable anaesthetic practices; high-, middle- and low-income countries should support each other appropriately in delivering sustainable healthcare (including anaesthesia); and healthcare systems should be mandated to reduce their contribution to global warming. We set out seven fundamental principles to guide anaesthesia providers in the move to environmentally sustainable practice, including: choice of medications and equipment; minimising waste and overuse of resources; and addressing environmental sustainability in anaesthetists' education, research, quality improvement and local healthcare leadership activities. These changes are achievable with minimal material resource and financial investment, and should undergo re-evaluation and updates as better evidence is published. This paper discusses each principle individually, and directs readers towards further important references.

Correspondence to: S. White
Email: stuart.white6@nhs.net
Accepted: 13 September 2021
Keywords: anaesthesia; carbon; climate change; consensus; environment; sustainability

*A full list of Working Group members can be found in Appendix S1.
Presented in part at the 17th World Congress of Anaesthesiologists, September 2021 (virtual).
Twitter: @DrCliffShelton; @AdrianGelb; @dr_cathy_lawson; @ForbesMcGain; @janemuret; @GreeningDoc; @wfsaorg

Consensus principles of environmentally sustainable anaesthesia

Anaesthesia providers should:

1. Minimise the environmental impact of their clinical practice.
2. Use environmentally preferable medications and equipment when clinically safe to do so.
3. Minimise the overuse/waste of medications, equipment, energy and water.
4. Incorporate environmental sustainability principles within formal anaesthesia education.
5. Embed environmental sustainability principles within anaesthesia research and quality improvement programmes.
6. Lead environmental sustainability activity within their healthcare organisations.
7. Collaborate with industry to improve environmental sustainability.

Why was this consensus statement developed?

Anaesthesia practice makes a measurable contribution to global warming. Recent professional guidance statements contain many useful recommendations for improving environmental performance in anaesthesia but were developed primarily by, and for, anaesthesia professionals in high-income countries [1–3].

This global consensus statement was developed using a formal Delphi process to ascertain whether these and other sustainability recommendations are desirable and achievable globally. Given the urgent need to cut global carbon emissions, our methodology was implemented deliberately to deliver this statement by the start of the 26th United Nations (UN) Climate Change Conference (COP26) held in Glasgow, UK, November 2021.

Methods

This project arose out of discussions between the seven Steering Committee members (see online Supporting Information Appendix S1) about the effects of the COVID-19 pandemic on environmental sustainability in anaesthesia and critical care. All those involved recognised the potential limitations of currently available guidance in this area and the need for global consensus to effect urgent change [4].

In the spring of 2021, the Steering Committee invited 38 anaesthesia providers with a recognised interest in sustainability (based on publication authorship or recognised professional leadership) to join a consensus-forming Working Group (online Supporting Information, Appendix S1). Representation was sought and achieved from all continents except Antarctica (Table 1).

A three-stage modified Delphi process (conducted in English) was used to reach consensus in this project [5, 6]. For the first Delphi stage, the 45 Working Group members were asked by direct email to contribute as many 'broad' principles of environmentally sustainable anaesthesia as they liked, that 'any anaesthetic service worldwide should aim to follow'. In total, 634 principles were received, which were categorised into 25 topic areas (e.g. 'education', 'procurement', 'leadership', etc), and reviewed by the Steering Committee. Each principle was allocated to a topic area, except for one principle that did not relate to any aspect of environmental sustainability in anaesthesia and was therefore excluded.

For the second Delphi stage, the remaining 633 principles were condensed by consensus within the Steering Committee into 55 statements, merging recurrent suggestions while maintaining the wording of the principles submitted. Three multiple choice statements were further formulated by the Steering Committee from conflicting but related principles about the use of desflurane and nitrous oxide, and the environmental obligations of healthcare systems.

The 58 statements were formulated into a survey, administered anonymously on Earth Day (22 April) 2021 via an electronic platform (SurveyHero, enuvo GmbH, Zurich, Switzerland) to all 45 Working Group members. All statements were designed to elicit binary responses ('include in guidelines' or 'do not include in guidelines'). If a statement included more than one element (e.g. a statement concerning both nitrous oxide *and* desflurane), Working Group members were: instructed to vote for an

Table 1 Steering Committee and Working Group compositions, compared with global equivalent. Income classification according to World Bank 2020 data

	Steering Committee n = 7	Working Group n = 45	World
Continent, n			
Africa		7	
Asia		9	
Australasia	1	6	
Europe	4	15	
North America	2	6	
South America		2	
Gender identification, n			
Female	3	15	
Male	4	30	
Non-binary	0	0	
Declined	0	0	
Income			
Low		5%	13%
Lower-middle		20%	23%
Upper-middle		20%	26%
High	100%	65%	38%

'include' response only if they agreed with all elements. Working Group members were: invited to review the source principles and formulation process throughout; reminded that responses "*should be based in part on what you think are desirable and achievable principles of 'green' anaesthesia in your country/geographical region*"; and invited to submit any further (free text) comments at the end of the electronic survey.

All 45 Working Group members completed the survey, with between 42 and 44 members responding to any single statement. 'Consensus' was defined as the same response from >33 (75% [7]) Working Group members to binary statements, and the mode response to the three multiple choice statements. The Steering Committee then reviewed the accepted 'include' statements and classified them by consensus into seven themes ('fundamental', 'drugs/equipment', 'waste', 'education', 'research and quality improvement', 'leadership' and 'collaboration'). One principle of environmental sustainability in anaesthesia was formulated from each theme.

These principles formed the basis of the first draft of this paper, which was structured as a thematic narrative in the form of 'principle (theme), consensus statements, and discussion,' with direction towards further referenced reading. For the third Delphi stage, the draft paper, including the seven draft principles, was sent to the 45 Working Group members, inviting ratification and further comments, prompting minor alterations to the text after discussion among the Steering Committee, who then approved this final statement.

International adoption and dissemination

The World Federation of Societies of Anaesthesiologists (WFSA) designated the participants in this consensus process as 'the WFSA Global Working Group on Environmental Sustainability in Anaesthesia', reviewed the principles described in this manuscript and agreed to formally recognise and adopt them as a global consensus statement on the principles of environmentally sustainable anaesthesia. To aid international adoption and dissemination, the WFSA organised translation of the Summary from English into the five other official languages used by the UN (Arabic, Mandarin Chinese, French, Russian and Spanish) (online Supporting Information Appendix S2).

The consensus principles

Context

Climate change has been described as "*the biggest threat to global health in the 21st century*" [8]. Recent data indicate that mean global surface temperature is approximately 1.1°C higher than pre-industrial levels, and is continuing to rise at an unprecedented rate [9, 10]. Exceeding a mean 1.5°C rise will make global adaptation to the consequences of climate change less possible, worsening human health, food and water security, and political stability. Individual countries will vary in their capacity to adapt to the harms they experience, but every individual will be affected by these consequences [8, 11].

Urgent and substantial annual reductions in greenhouse gas emissions are required to meet the 1.5°C target. Global emissions will need to fall by approximately 7.5% annually between 2020 and 2030, a reduction – *every year* – equivalent to that estimated to have occurred transiently in 2020 due to the 'anthropopause' caused by COVID-19 [12]. Nationally Determined Contributions towards reducing global warming, proposed in the 2015 Paris Agreement, will be reviewed at COP26.

Globally, healthcare is responsible for nearly 5% of total global greenhouse gas emissions and similar fractions of harmful air pollutants [8, 13]. While global measures of emissions stemming from anaesthesia practice are lacking, inhalational anaesthetic agents contribute nearly 3% of National Health Service carbon emissions in England [14,

15]. Emissions from anaesthetic practice are presumed to be higher in high-income countries (HICs), compared with middle (MICs) and low-income countries (LICs) [16], yet the negative impacts of climate change are (and will continue to be) disproportionately borne by low and middle-income countries (LMICs). Furthermore, healthcare and anaesthesia contributions to global carbon emissions are likely to increase as developing national economies grow, and the global population continues to rise and age.

The contribution of anaesthetic practice to climate change is a global problem that requires global solutions. The Working Group recognised three fundamental underlying directives:

- Patient safety should not be compromised by sustainable anaesthetic practices.
- High, middle and low-income countries should support each other appropriately in delivering 'green' healthcare (including anaesthesia).
- Healthcare systems should be mandated to reduce their contribution to global warming.

The Working Group recognises that HICs need to reduce their own healthcare- and anaesthesia-related environmental emissions, but believes that, at the same time, they have a duty to support the development of sustainable anaesthesia practices in LMICs, and improve the delivery of safer healthcare everywhere. Of note, highly efficient working practices are often employed in LMICs to accommodate resource limitations, and HICs should be receptive to learning from LMICs about safe and effective resource conservation. The Working Group agreed that a good way to achieve this would be for hospitals and (inter)national bodies to develop and recommend meaningful, measurable standards for healthcare systems, which should aim to mandate (rather than simply encourage or direct) them to reduce their contribution to global warming. While anaesthesia providers (the term used throughout this paper to encompass the variety of international health professionals trained to deliver anaesthesia) may be able to influence 'top down' mandate in some countries, the Working Group recognise that 'grassroots' environmental sustainability strategies may be more successful in others.

The Working Group recommends the following seven principles that anaesthesia providers, their institutions and their professional organisations should adopt to provide environmentally sustainable anaesthesia practice. These principles, and the Delphi consensus statements from which they were derived, are presented below.

Anaesthesia providers should minimise the environmental impact of their clinical practice

The Working Group reached consensus that:

- Anaesthesia providers should lead by example on 'green' issues, both personally and professionally.
- Anaesthesia providers and their professional bodies should publicly advocate environmentally sustainable healthcare.
- Anaesthesia providers should collaborate within multidisciplinary sustainability teams to improve anaesthesia sustainability (e.g. with other specialties, industry, construction, environmentalists).
- As members of hospital sustainability committees, anaesthesia providers should both promote and procure measurable reductions in the wastage of drugs, single-use equipment and energy.
- There should be a lead individual for sustainability in each department of anaesthesia.

Anaesthesia is integral to the provision of healthcare but makes a significant and measurable contribution to environmental pollution. Several national health sector studies have demonstrated that the life-cycle of the healthcare supply chain (including the resource extraction, manufacture, packaging, distribution, use/reuse and disposal) accounts for approximately 70% of total healthcare emissions [8, 16]. Anaesthesia providers use significant quantities of medical supplies and pharmaceuticals [17, 18]. Waste anaesthestic gases alone have been found to account for 3% of all health sector greenhouse gas emissions in England (where the most rigorous national accounting has occurred, to date) [14]. Anaesthesia providers therefore have critical roles to play in reducing the environmental impact of their practice [19–21]. The Working Group agreed that anaesthesia providers should both lead on environmentally sustainable practice and collaborate with colleagues and other stakeholders on individual, departmental, regional, national and international levels [22].

Anaesthesia providers should use environmentally preferable medications and equipment when clinically safe to do so

The Working Group reached consensus that:

- Anaesthesia providers should always consider how they can safely reduce the amount of drugs, equipment, energy and water used in their practice, for environmental reasons.

- Anaesthesia drugs should be disposed of in an environmentally sustainable manner.
- For inhalational general anaesthesia, anaesthesia providers should use the (single) agent with the lowest global warming potential (GWP_{100}, i.e. halothane or sevoflurane before isoflurane, and isoflurane in preference to desflurane).
- Anaesthesia providers should use low oxygen/air flows during sedation and general anaesthesia, appropriate for the delivery system used.
- If used, anaesthesia nitrous oxide sources and piping should be routinely leak-checked
- All areas where inhalational anaesthesia is administered should be fitted with expired/waste agent scavenging and trapping/destruction equipment.
- In countries where they are available, desflurane and nitrous oxide should be used in specific agreed cases only (rather than not be used or be freely available for use).

The majority of publications on sustainability in anaesthesia have focused on the environmental impact of inhalational anaesthetic agents. Nitrous oxide, halogenated hydrocarbons and ethers are released directly into the atmosphere, where they contribute to global warming by radiative forcing, and in some cases also cause ozone depletion [15, 23, 24].

Unlike other greenhouse gases, inhalational anaesthetic agents are exempt from international regulation and reporting under the Kigali Amendment of the Montreal protocol, the Kyoto Protocol and the Paris Agreement, possibly due to their perceived medical necessity [25, 26]. This makes it difficult to precisely ascertain the global volume of each agent manufactured, distributed and released into the atmosphere annually, which in turn hampers efforts to prioritise the reduction of their use. Based on atmospheric sampling of volatile agents, however, their use appears to be increasing, particularly that of desflurane, which has the highest heat trapping properties of all the inhalational agents [27].

Two-thirds of the Working Group agreed that 'manufacturers should be legally required to publish international, annual data on the quantities of anaesthetic agents produced' (Table 2), although this did not reach the 75% threshold for consensus [7]). This redirects the burden of accounting for inhalational agent emissions onto individual providers and departments of anaesthesia (and possibly national societies), which should continuously evaluate the climate impact of the inhalational anaesthetic agents used to drive and track performance improvement [28].

In clinically relevant doses (global warming potential x mass delivered), desflurane and nitrous oxide have the greatest global warming impact of the inhaled agents, approximately 20 times more than isoflurane and 15 times more than sevoflurane over a 100-year period [29]. Indeed, desflurane and nitrous oxide are the greatest contributors to operating theatre greenhouse gas emissions prompting recent calls for their abandonment as anaesthetic agents [30].

'Greenhouse gas' emissions from inhalational anaesthetic agents can be reduced by: low-flow (e.g. <1 $l.min^{-1}$) anaesthesia in oxygen/air mixtures [15, 31]; using them less often [32]; and choosing inhalational agents with lower global warming impacts [33–35]. Technologies are currently being developed and refined to capture and destroy scavenged agents, thereby further reducing their atmospheric release [33].

Local, regional and intravenous general anaesthesia agents are associated with significantly fewer greenhouse gas emissions than inhalational general anaesthesia on a life-cycle basis (i.e. related to resource extraction, manufacture, packaging, distribution, use/reuse and disposal) [17, 36–41]. However, the evidence is still uncertain on other environmental impacts, for example water pollution arising from manufacturing and disposal of these drugs and their metabolites into water supplies [42, 43], as well as the global amount of each agent used.

Anaesthesia providers should minimise the overuse/ waste of medications and equipment, energy and water

The Working Group reached consensus that:

- When evaluating sustainable healthcare, the potential harms and benefits both for individual patients and for global health should be assessed.
- Anaesthesia providers should design and follow institutionally approved, regularly audited '5R' approaches to minimising anaesthetic waste (drugs, equipment, energy, water): 'reduce > reuse > recycle; rethink, research'.
- Anaesthesia providers should reformulate equipment packs to eliminate unnecessary items.
- Cleaning processes for reusable anaesthesia equipment should be environmentally sustainable.

Peri-operative care is a material-, energy- and water-intensive process. Operating theatres produce 25% of all hospital waste, of which 25% arises from anaesthesia care [44]. Approximately 25% of all operating room waste is readily recyclable, yet overall recycling rates remain very low [45].

There can be considerable carbon footprints attached to the life-cycle of equipment items used by anaesthesia providers. For single-use equipment, most of the carbon footprint is accrued during manufacture and distribution [18, 46, 47], reinforcing the importance of anaesthesia providers collaborating with industry to innovate sustainably in these areas, and guiding procurement decisions based on sustainability assessments [48]. On the contrary, for reusable equipment, the majority of the carbon footprint stems from cleaning and sterilising, reinforcing the importance of renewable sources of electricity [33, 49].

More directly, anaesthesia providers can influence the responsible use of equipment and its proper disposal. There are a number of opportunities for anaesthesia providers to innovate within the '5R' waste hierarchy of reduce > reuse > recycle (reprocess, rethink/research) [50]. Adopting a more minimalist approach, for example, by not routinely drawing up emergency drugs and by reducing unnecessary pre-operative investigations, enables anaesthesia providers to reduce the environmental impact of their clinical practice to a greater degree than by reusing equipment or especially by recycling materials. Reformulating equipment packs and stock levels at an institutional level further reduces waste and environmental emissions [51].

Anecdotally, in many parts of the world, single-use devices have mostly replaced reusable equipment in anaesthesia practice. Explanations for this include concerns about infection control, practitioner preference, cost saving and marketing efforts [46]; however, although single-use devices may theoretically reduce (but not prevent) infection transmission, evidence for this is largely absent. For example, infection benefits have not been shown for single-use laryngoscopes or single-use surgical jackets [52, 53]. Typically, on a life-cycle basis, single-use equipment is more expensive and has a larger carbon footprint than reusable devices in most countries [46, 53]; although this depends on the number of times they are reused, the cleaning and sterilisation methods used and the source of electricity. The 'single-use vs. reuse' debate requires a nuanced understanding, balancing the needs of the individual patient with those of the anaesthesia provider [44], the hospital (financially) [18, 46] and the population as part of wider environmental health considerations [53]. There is also considerable scope for further exploration into improving the energy efficiency of device manufacture, transport and disposal, single-use device reprocessing and reusable device sterilisation [49, 54].

A much higher proportion of non-hazardous anaesthetic waste (mainly packaging) is potentially recyclable compared with the proportion that is currently recycled [55]. There are several barriers to effective recycling: infection control concerns; the absence of theatre waste streaming or nearby recycling facilities; economic disincentives; and production pressure. However, these are surmountable with leadership and education from interested anaesthesia providers [56]. At best, however, recycling only recovers a fraction of the materials used and the emissions embedded within them. Although essential for sustainable resource management, reducing and reusing resources have a much higher impact than recycling in reducing emissions.

'Reprocessing' (also known as 'remanufacturing') refers to the refurbishing, cleaning, sterilisation and repackaging of single-use devices for reuse in a regulated manner. Although reprocessing has been shown to be safe and has the potential to reduce costs and environmental impacts, not all countries have appropriate legislative approval [49].

Rethinking and research aim to decrease the life-cycle environmental impact of medications and equipment, for example exploring the costs/benefits of using renewable energy during manufacture and transport, reducing mixed materials and multilayer packaging that hamper their recovery, developing biodegradable plastics and packaging and importantly reorganising patient care pathways to align with 'low carbon care' [33]. Even in the presence of COVID-19, it is possible to envisage ways to safely reduce and reuse personal protective equipment [4], for example.

Anaesthesia providers should incorporate environmental sustainability principles within formal anaesthesia education

The Working Group reached consensus that:

- Continuing professional development in anaesthesia should include personal and institutional education about environmental sustainability.
- Anaesthesia training should include education on environmental sustainability.

In some countries, environmental sustainability is gaining recognition as an essential component of healthcare training. In the UK, for example, the principles of sustainable healthcare have been incorporated into the undergraduate curriculum for medicine [57], as well as the 2021 postgraduate curriculum for anaesthetic training (peri-operative – key capability K [58, 59]). The Association for Anaesthetists' Environment and Sustainability Committee

provides continuing professional education for members, for example at conferences and in members' publications, and supports annual fellowships in sustainability for anaesthesia trainees [60]. Interest is growing in developing similar initiatives in undergraduate and postgraduate training elsewhere [61, 62]. Professionally, several societies have made statements about the importance of sustainability in anaesthetic practice, emphasising the need for education on sustainable anaesthesia in training schemes worldwide [1–3, 63].

Currently, a barrier to providing sustainable healthcare education to trainees in anaesthesia is a perceived lack of knowledge about atmospheric science and environmental sustainability among the experienced practitioners who act as educators [60], despite the availability of educational materials in the published literature [23, 33, 64]. This underlines the added importance of incorporating environmental sustainability into continuing professional development resources (e.g. conferences, educational papers and courses) [59, 65], which could form part of anaesthesia providers' appraisal and recertification processes.

To these ends, the Working Group agreed that both anaesthesia training and continuing professional development should include education on environmental sustainability.

There was agreement, but not consensus (i.e. 50–74% agreement) on the statements 'anaesthesia training should prioritise the teaching of environmentally sustainable anaesthetic techniques (e.g. regional/total intravenous anaesthesia)' and 'anaesthetists should help educate their local communities about the health benefits of environmental sustainability' (Table 2). This suggests that further work is needed to develop the best educational practices (e.g. whether preferentially teaching specific anaesthesia techniques is more beneficial than simple information provision about sustainable healthcare [1]), and how anaesthesia providers might best add value to sustainability education beyond the peri-operative setting [59, 66].

Anaesthesia providers should embed environmental sustainability principles within anaesthesia research and quality improvement programmes

The Working Group reached consensus that:

- Anaesthesia providers should always consider the financial, social and environmental implications of anaesthesia interventions in research and quality improvement projects.
- Professional organisations should promote sustainable anaesthesia through professional recognition, and the award of research grants and fellowships.
- Professional journals and conferences should routinely present peer-reviewed research and quality improvement projects on anaesthesia sustainability.
- Environmental sustainability should be embedded within hospital audit and quality improvement programmes.

Broad professional appreciation of the contribution of anaesthetic practice to climate change is relatively recent, and consequently based on a small but growing body of evidence, published mostly since 2005. Both research and knowledge gaps were reflected in the additional 56 invited general content comments submitted by 25 Working Group members. The most prevalent of these (23, 41%) concerned uncertainties in the evidence to do with the statements for which there was agreement but no consensus (i.e. 50–74% agreement, 16/55 members (29%), Table 2). In particular, there was uncertainty about how the type of anaesthesia (regional/total intravenous/inhalational) affects environmental sustainability; whether individual anaesthesia professionals should try to influence professional/industry/colleague/patient choices [67]; how the type of breathing circuit used influences environmental sustainability; whether reusable equipment is safer for patients and more environmentally sustainable than single-use devices; and if environmentally sustainable anaesthesia reduces healthcare costs. In fact, evidence already exists that addresses many of these perceived uncertainties [17, 18, 28–32, 37–39, 43, 49, 63, 68], emphasising the need for more education and more rapid and wider communication of research findings throughout the profession. Further research is needed; given the urgency of the subject matter, a focused approach to directing ongoing research through a formal international research priority setting exercise would benefit the profession [37, 69].

Quality improvement projects can enable the integration of sustainability principles into anaesthesia practice, in alignment with the 'triple bottom line' of environmental (planet), social (people) and financial (profit) accountability. 'Greenhouse gas' emission and resource consumption metrics, for example, can be linked to financial costs and clinical outcomes [53, 70]. Sharing implementation methodologies and the results of such improvement projects is vital for disseminating and achieving the greatest environmental benefits, and should become a routine component of professional meetings and awards [54, 71, 72].

Anaesthesia providers should lead environmental sustainability activity within their healthcare organisations

The Working Group reached consensus that:

- Anaesthesia providers should recommend sustainable redesign in any proposed rebuilding/renovation of operating theatres.
- Hospitals and other organisations should facilitate the delivery of sustainable anaesthesia
- Hospitals and (inter)national bodies should recommend meaningful, measurable standards for reducing anaesthesia carbon emissions.
- 'Closing down theatre' protocols should be followed after each operating list, to reduce avoidable energy wastage.
- Anaesthetic rooms/operating theatres should be ergonomically designed to optimise sustainable anaesthesia (e.g. waste streaming facilities).

Healthcare facilities are large consumers of natural resources, and peri-operative care particularly so [68]. The mean energy usage of operating theatres (by surface area) is between three and six times that of the mean in the remaining hospital building. Mitigating emissions intensity and inefficient hospital energy use are recognised as key components of strategies to reduce carbon emissions [68].

Participating in leadership roles within healthcare organisations enables anaesthesia providers to positively influence environmentally sustainable activities, particularly related to policy, operation, redesign, procurement and culture.

Embedding sustainability within hospital policies facilitates the delivery of the social and environmental benefits that improve healthcare safety, quality and patient and staff satisfaction in a cost-efficient manner, in accordance with the 'triple bottom line' [32, 33, 54, 73].

Policies need to be actionable. Reducing energy consumption in theatres, for example, might involve policies that guide personnel to turn down heating, ventilation and air conditioning system exchange rates in unoccupied operating theatres, which can be achieved without impeding infection control [33, 54].

The design of new facilities, and the refurbishment of existing ones, afford opportunities to improve patient and staff experience, energy efficiency, as well as other sustainability objectives (e.g. enabling 'greener' transport options, waste streaming, etc [33]). Promoting the delivery of sustainable anaesthesia should focus particularly on changing provider behaviour, as this is the main determinant of healthcare resource use [54, 74].

Anaesthesia providers should collaborate with industry to improve environmental sustainability

The Working Group reached consensus that:

- Anaesthesia providers should collaborate with manufacturers to improve the sustainability of anaesthesia drugs, single-use equipment, packaging and energy use.
- Manufacturers should publish open-source data about the environmental sustainability of their anaesthesia drugs and equipment.
- A 'traffic light' colour-coding system should be developed to indicate the environmental impacts of drugs, equipment and devices, guiding sustainable procurement.
- Contracts with manufacturers should include total cost of ownership clauses, that is incorporating both the financial and environmental (return, repair, recycling, donation) costs of purchase.
- Contracts with manufacturers should be tendered only after careful consideration of their products' sustainability credentials.

Decarbonisation of supply chains is crucial for achieving sustainable healthcare and circular economies (i.e. keeping materials in use and making more efficient use of natural resources) [8, 13, 14, 16, 49, 54, 74–76].

Anaesthesia providers are well positioned to influence industry production and design, as well as patterns of clinical consumption of drugs and equipment. They can (and already do) use their influence as leaders to advocate for and bring about change. Industry responds to the demands of its market and is keen to improve its environmental credentials when this is financially viable. Anaesthesia providers need to collaborate with industry, both by procuring products that have been provided in a transparent, certified sustainable manner (particularly, medications and equipment) and by helping industry develop better ways of doing this, with consideration for the 'triple bottom line'.

Lack of agreement

There were few statements (5/55 (9%), Table 2) for which neither consensus nor agreement (i.e. <50%) was reached. Members' comments indicated that these were items that they thought were of limited relevance to anaesthesia providers (e.g. hospital provision of environmentally sustainable food and linen/cutlery/crockery), or were not achievable globally, or were not desirable (e.g. virtual meetings and conferences) even though these have a measurable and/or plausible impact on environmental sustainability.

Table 2 Statements for which there was agreement but no consensus (i.e. 50–74% of the Working Group supported inclusion in the guidelines), and statements for which there was no agreement (i.e. < 50% of the Working Group supported inclusion in the guidelines)

Statement	Consensus Committee agreement
Agreement, no consensus, n = 15	
Anaesthetists should reduce both their personal and their professional contributions to global warming.	74%
Well-maintained circle breathing circuits should always be preferred to semi-open or open breathing circuits.	74%
Anaesthetists should collaborate with colleagues on sustainability issues via online networks (local, regional, national, international).	72%
Anaesthetists should develop measurement tools to determine their own and their department's annual carbon footprint (CO_2e).	68%
Environmentally sustainable anaesthesia delivers national cost and health benefits for patients and the environment.	68%
When feasible, anaesthetists should prioritise giving regional anaesthesia over total intravenous anaesthesia, and total intravenous anaesthesia over inhalational anaesthesia, for environmental reasons.	68%
Hospitals and professional societies should not invest in environmentally harmful companies.	67%
Manufacturers should be legally required to publish international, annual data on anaesthetic agent production.	67%
Anaesthetists should help streamline surgical patients' care pathways (e.g. through teleconferencing) to optimise environmental sustainability.	64%
Anaesthesia training should prioritise the teaching of environmentally sustainable anaesthetic techniques (e.g. regional/total intravenous anaesthesia).	64%
Anaesthetists should favour reusable equipment over single-use/disposable devices.	63%
Anaesthetists should consider reusing time-expired equipment, or returning/reprocessing/recycling/donating it via accredited pathways.	63%
Anaesthetists should help educate their local communities about the health benefits of environmental sustainability.	56%
The environmental impact of anaesthesia is affected by the modality used (e.g. regional, intravenous, inhalational).	56%
Anaesthetists should formulate environmentally sustainable anaesthetic care plans with patients.	56%
Anaesthetists should encourage colleagues and patients to use low-carbon options (e.g. walking, cycling) when travelling to hospital.	51%
No agreement, n = 5	
Anaesthetists should lobby for only reusable non-surgical equipment (linen, cutlery, crockery etc) to be available in operating theatre suites.	46%
Anaesthetists should use pre-filled syringes, if available.	43%
Anaesthetists should attend meetings and conferences online rather than in person, if possible.	40%
Anaesthetists should lobby for staff and inpatients to have access to locally sourced, sustainable, plant-based food (disposed of as necessary in an environmentally sustainable manner).	39%
All areas where inhalational anaesthesia is administered should be fitted with fume cupboards for vaporiser filling.	36%
Excluded	
Anaesthetists should ensure that all equipment is technically up-to-date and running optimally.	

Limitations

There were methodological limitations in the development of these principles. There were probably differences in knowledge about, and resources for, environmental sustainability within the Working Group, leading to variability in statement acceptance. Statements were based on opinions, rather than strong evidence from meta-analyses of randomised controlled trials (which are frequently not appropriate or feasible in this field of study). Consequently, we could not ascribe recommendations within a GRADE (Grading of Recommendations, Assessment, Development and Evaluations) framework for each of the principles.

Although the Steering Committee has considerable expertise in environmental sustainability, and its members formed part of the Working Group, its main function was to organise and conduct the study. Expert contributors could not be identified in several geographical locations; as a result, global representation was proportionately greater from higher income countries than lower/middle-income countries (Table 1). However, content contributions from all members of the Working Group were assessed anonymously and given equal weight throughout the consensus process.

This Delphi analytical process was undertaken manually, which may be less accurate than software-based techniques [76]. It was conducted in English, which is a second language for 27 out of the 45 Working Group members (60%). However, no member sought clarifications about any communication.

Finally, although medical consensus guidelines cater to the needs of most patients and healthcare professionals in most circumstances, anaesthesia providers always need to balance environmental and patient benefits with local or regional environmental factors, (e.g. water shortages or different energy sources (coal vs. renewables.)

Conclusions and future work

The Working Group suggests that the above seven consensus principles form the basis of sustainable anaesthesia practice. The Working Group's expert opinion is that these recommendations are achievable globally, with minimal material resources and financial investment. A number of resources already exist on how to implement the recommendations made in this paper [4–6, 33, 54, 68, 74], which anaesthesia providers should discuss regularly at institutional and national meetings. This work is iterative, with opinion forming much of the basis for the recommendations, informed by published evidence. We suggest that these principles undergo re-evaluation and updates as better evidence is published, and we strongly encourage institutions to sponsor anaesthesia providers in undertaking the necessary research as a matter of urgency.

Acknowledgements

The authors acknowledge the kind contributions of M. Kirov, C. Lu, F. Martin, D. Prato and P. Yazbeck. AG is the president of the World Federation of Societies of Anaesthesiologists and a consultant for Masimo, Inc. and Haisco Pharmaceuticals; FM has received competitive grants from ANZCA and ANZ College of Intensive Care Medicine for environmental sustainability research and is a member of Doctors for the Environment Australia; CS is a co-opted member of the Association of Anaesthetists Environment and Sustainability Committee, and Executive Editor of *Anaesthesia Reports*; CL is the former Association of Anaesthetists and Centre for Sustainable Healthcare National Fellow for Environmentally Sustainable Anaesthesia. JS is co-chair of the American Society of Anesthesiologists Subcommittee on Environmental Health. No other competing interests declared.

References

1. American Society of Anesthesiologists. Greening the operating room and perioperative arena: environmental sustainability for anesthesia practice. 2020. https://www.asahq.org/about-asa/governance-and-committees/asa-committees/committee-on-equipment-and-facilities/environmental-sustainability/greening-the-operating-room (accessed 01/07/2021).
2. Australia and New Zealand College of Anaesthetists. Statement on environmental sustainability in anaesthesia and pain medicine practice. PS64. 2019. https://www.anzca.edu.au/resources/professional-documents/standards-(1)/ps64-statement-on-environmental-sustainability-in.aspx (accessed 01/07/2021).
3. European Society of Anaesthesiology and Intensive Care Sustainability Committee. Sustainability toolkit: how to reduce our carbon footprint in the OR, in the hospital, on the planet? 2020. https://www.esaic.org/uploads/2020/03/display-mobile1.pdf (accessed 01/07/2021).
4. McGain F, Muret J, Lawson C, Sherman JD. Effects of the COVID-19 pandemic on environmental sustainability in anaesthesia. *British Journal of Anaesthesia* 2021; **126**: e119–22.
5. Trevelyan EG, Robinson N. Delphi methodology in health research: how to do it? *European Journal of Integrative Medicine* 2015; **7**: 423–8.
6. White SM, Altermatt F, Barry J, et al. International Fragility Fracture Network consensus statement on the principles of anaesthesia for patients with hip fracture. *Anaesthesia* 2018; **73**: 863–74.
7. Diamond IR, Grant RC, Feldman BM, et al. Defining consensus: a systematic review recommends methodologic criteria for reporting of Delphi studies. *Journal of Clinical Epidemiology* 2014; **67**: 401–9.
8. Watts N, Amann M, Arnell N, et al. The 2018 report of the Lancet Countdown on health and climate change: shaping the health of nations for centuries to come. *Lancet* 2018; **392**: 2479–514.
9. World Meteorological Organization. The state of the global climate 2020. https://public.wmo.int/en/our-mandate/climate/wmo-statement-state-of-global-climate (accessed 01/07/2021).
10. United Nations Framework Convention on Climate Change. Adoption of the Paris Agreement. 2015. http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf (accessed 01/07/2019).
11. Masson-Delmotte V, Zhai P Pörtner HO, et al. Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. 2018. https://www.ipcc.ch/sr15/ (accessed 01/07/2021).
12. Institute for Energy Research. Global carbon dioxide emissions fell 7 percent in 2020. https://www.instituteforenergyresearch.

org/climate-change/global-carbon-dioxide-emissions-fell-7-percent-in-2020/ (accessed 01/07/2021).
13. Pichler P-P, Jaccard IS, Weisz U, Weisz H. International comparison of health care carbon footprints. *Environmental Research Letters* 2019; **14**: 064004.
14. Tennison I, Roschnik S, Ashby B, et al. Health care's response to climate change: a carbon footprint assessment of the NHS in England. *Lancet Planet Health* 2021; **5**: e84–92.
15. Campbell M, Pierce JMT. Atmospheric science, anaesthesia and the environment. *British Journal of Anaesthesia Education* 2015; **15**: 173–9.
16. Healthcare Without Harm. 2019 Health care's climate footprint. https://noharm-global.org/sites/default/files/documents-files/5961/HealthCaresClimateFootprint_092319.pdf (accessed 01/07/2021).
17. Sherman J, Le C, Lamers V, Eckelman M. Life cycle greenhouse gas emissions of anesthetic drugs. *Anesthesia and Analgesia* 2012; **14**: 1086–90.
18. Sherman JD, Raibley LA 4th, Eckelman MJ. Life cycle assessment and costing methods for device procurement: comparing reusable and single-use disposable laryngoscopes. *Anesthesia and Analgesia* 2018; **127**: 434–43.
19. McGain F, Kayak E, Burch H. A sustainable future in health: ensuring as health professionals our own house is in order and leading by example. *Medical Journal of Australia* 2020; **213**: 381.
20. McGain F, Ma SC, Burrell RH, et al. Why be sustainable? The Australian and New Zealand College of Anaesthetists Professional Document PS64: Statement on Environmental Sustainability in Anaesthesia and Pain Medicine Practice and its accompanying background paper. *Anaesthesia and Intensive Care* 2019; **47**: 413–22.
21. Muret J, Kelway C, Abback P, et al. Members of the SFAR's Sustainability Group French Society of Anaesthesia; Intensive Care. Why should anaesthesiologists and intensivists care about climate change? *Anaesthesia Critical Care and Pain Medicine* 2019; **38**: 565–7.
22. Royal College of Anaesthetists. Sustainability strategy 2019-2022. 2019. https://www.rcoa.ac.uk/system/files/SustainabilityStrategy2019-2022.pdf (accessed 01/07/2021).
23. Shine KP. Climate effect of inhaled anaesthetics. *British Journal of Anaesthesia* 2010; **105**: 731–3.
24. Muret J, Fernandes TD, Gerlach H, et al. Environmental impacts of nitrous oxide: no laughing matter!. *British Journal of Anaesthesia* 2019; **123**: e481–2.
25. Charlesworth M, Swinton F. Anaesthetic gases, climate change, and sustainable practice. *Lancet Planetary Health* 2017; **1**: e216–7.
26. Sherman JD, Ryan S. Ecological responsibility in anesthesia practice. *International Anesthesiology Clinics* 2010; **48**: 139–51.
27. Vollmer MK, Rhee TS, Rigby M, et al. Modern inhalational anaesthetics: potent greenhouse gases in the global atmosphere. *Geophysical Research Letters* 2015; **42**: 1606–11.
28. Lindén-Søndersø A, Nielsen N, Bentzer P. Klimateffekterna från anestesin kan minska [Climate footprint of halogenated inhalation anesthetics]. *Lakartidningen* 2019; **116**: FR9L. (Swedish).
29. Sulbaek Andersen MP, Sander SP, Nielsen OJ, Wagner DS, Sanford TJ Jr, Wallington TJ. Inhalation anaesthetics and climate change. *British Journal of Anaesthesia* 2010; **105**: 760–6.
30. Shelton CL, Sutton R, White SM. Desflurane in modern anaesthetic practice: walking on thin ice(caps)? *British Journal of Anaesthesia* 2020; **125**: 852–6.
31. Feldman JM. Managing fresh gas flow to reduce environmental contamination. *Anesthesia and Analgesia* 2012; **114**: 1093–101.
32. White SM, Shelton CL. Abandoning inhalational anaesthesia. *Anaesthesia* 2020; **75**: 451–4.
33. McGain F, Muret J, Lawson C, Sherman JD. Environmental sustainability within anaesthesia and critical care. *British Journal of Anaesthesia* 2020; **125**: 680–92.
34. Hu X, Pierce JMT, Taylor T, Morissey K. The carbon footprint of general anaesthetics: a case study in the UK. *Resources, Conservation and Recycling Advances* 2021; **167**: 105411.
35. Ozelsel T, Sondekoppam RV, Koch S. The carbon footprint of general anesthetics: a case study in the UK. *Resources, Conservation and Recycling Advances* 2021; **12**: 200053.
36. McAlister S, Ou Y, Neff E, et al. The environmental footprint of morphine: a life-cycle assessment from opium poppy farming to the packaged drug. *British Medical Journal Open* 2016; **6**: e013302.
37. Parvatker AG, Tunceroglu H, Sherman JD, et al. Cradle-to-gate greenhouse gas emissions for twenty anesthetic active pharmaceutical ingredients based on process scale-up and process design calculations. *ACS Sustainable Chemistry and Engineering* 2019; **7**: 6580–91.
38. Kuvadia M, Cummis CE, Liguori G, Wu CL. 'Green-gional' anesthesia: the non-polluting benefits of regional anesthesia to decrease greenhouse gases and attenuate climate change. *Regional Anesthesia and Pain Medicine* 2020; **45**: 744–5.
39. Özelsel TJP, Ip VHY, Sondekoppam RV. "Green-gional" anesthesia: a lot greener than you think. *Regional Anesthesia and Pain Medicine* 2021; **46**: 553–4.
40. Stockholm County Council. Janusinfo. Pharmaceuticals and environment. https://www.janusinfo.se/environment (accessed 01/07/2021).
41. Kostrubiak M, Vatovec CM, Dupigny-Giroux LA, Rizzo DM, Paganelli WC, Tsai MH. Water pollution and environmental concerns in Anesthesiology. *Journal of Medical Systems* 2020; **44**: 169.
42. Organisation for Economic Co-operation and Development. Pharmaceutical residues in freshwater. Hazards and Policy Responses. 2019. https://www.oecd.org/environment/resources/Pharmaceuticals-residues-in-freshwater-policy-highlights-preliminary-version.pdf (accessed 15/07/2021).
43. Miller TH, Bury NR, Owen SF, MacRae JI, Barron LP. A review of the pharmaceutical exposome in aquatic fauna. *Environmental Pollution* 2018; **239**: 129–46.
44. McGain F, Hendel SA, Story DA. An audit of potentially recyclable waste from anaesthetic practice. *Anaesthesia and Intensive Care* 2009; **37**: 820–3.
45. McGain F, White S, Mossenson S, Kayak E, Story D. A survey of anesthesiologists' views of operating room recycling. *Anesthesia and Analgesia* 2012; **114**: 1049–54.
46. Eckelman M, Mosher M, Gonzalez A, Sherman J. Comparative life-cycle assessment of disposable and reusable laryngeal mask airways. *Anesthesia and Analgesia* 2012; **114**: 1067–72.
47. Sanchez SA, Eckelman MJ, Sherman JD. Environmental and economic comparison of reusable and disposable blood pressure cuffs in multiple clinical settings. *Resources, Conservation and Recycling* 2020; **155**: 104643.
48. McGain F, Story D, Lim T, McAlister S. Financial and environmental costs of reusable and single-use anaesthetic equipment. *British Journal of Anaesthesia* 2017; **118**: 862–9.
49. MacNeill AJ, Hopf H, Khanuja A, et al. Transforming the medical device industry: road map to a circular economy. *Health Affairs* 2020; **39**: 2088–97.
50. Hutchins DC, White SM. Coming round to recycling. *British Medical Journal* 2009; **338**: b609.
51. Thiel CL, Eckelman MJ, Guido R, et al. Environmental impacts of surgical procedures: life-cycle assessment of hysterectomy in the US. *Environmental Science and Technology* 2015; **49**: 1779–86.
52. Sherman JD, Hopf HW. Balancing infection control and environmental protection as a matter of patient safety: the case

of laryngoscope handles. *Anesthesia and Analgesia* 2018; **127**: 576–9.
53. Thiel CL, Sherman JD, Hopf HW. Use of disposable perioperative jackets and surgical site infections. *Journal of the American Medical Association Surgery* 2020; **155**: 453–4.
54. Sherman JD, Thiel C, MacNeill A, et al. The Green Print: advancement of environmental sustainability in healthcare. *Resources, Conservation and Recycling* 2020; **161**: 104882.
55. McGain F, Jarosz KM, Nguyen MN, Bates S, O'Shea CJ. Auditing operating room recycling: a management case report. *Anesthesia and Analgesia Case Reports* 2015; **5**: 47–50.
56. McGain F, Clark M, Williams T, Wardlaw T. Recycling plastics from the operating suite. *Anaesthesia and Intensive Care* 2008; **36**: 913–4.
57. General Medical Council. Outcomes for graduates. 2020. https://www.gmc-uk.org/education/standards-guidance-and-curricula/standards-and-outcomes/outcomes-for-graduates/outcomes-for-graduates (accessed 01/07/2021).
58. Royal College of Anaesthetists. 2021 curriculum learning syllabus: stage 1. 2021. https://rcoa.ac.uk/documents/2021-curriculum-learning-syllabus-stage-1/introduction (accessed 01/07/2021).
59. NHS Health Education England. e-Learning for Healthcare. Environmentally sustainable anaesthetic practice. 2020. https://www.rcoa.ac.uk/events-professional-development/education-professional-development/e-learning-anaesthesia (accessed 01/07/2021).
60. Association of Anaesthetists. Environment and Sustainability Committee. https://anaesthetists.org/Home/Resources-publications/Environment/Our-environmental-work/Environment-and-sustainability-committee (accessed 01/07/2021).
61. Petre MA, Bahrey L, Levine M, van Rensburg A, Crawford M, Matava CT. Anesthesia environmental sustainability programs-a survey of Canadian department chiefs and residency program directors. *Canadian Journal of Anaesthesia* 2020; **67**: 1190–200.
62. Planetary Health Report Card. 2020–2021 Summary Report: an International Medical School Initiative. 2021. https://phreportcard.org/wp-content/uploads/2021/04/2021-phrc-summary-report-final.pdf (accessed 21/08/2021).
63. Pierce T, Lawson C. A call to arms. *Royal College of Anaesthetists Bulletin* 2020; **119**: 34–5.
64. Sulbaek Andersen MP, Nielsen OJ, Wallington TJ, Karpichev B, Sander SP. Medical intelligence article: assessing the impact on globa1081-5.l climate from general anesthetic gases. *Anesthesia and Analgesia* 2012; **114**: 1081–5.
65. Société Française d'Anesthésie et de Réanimation. Developpement durable. https://sfar.org/espace-professionel-anesthesiste-reanimateur/developpement-durable/ (accessed 01/07/2021).
66. Shelton CL, McBain SC, Mortimer F, White SM. A new role for anaesthetists in environmentally sustainable healthcare. *Anaesthesia* 2019; **74**: 1091–4.
67. Royal College of Anaesthetists. Your anaesthetic and the environment. https://www.rcoa.ac.uk/patient-information/about-anaesthesia-perioperative-care/your-anaesthetic-environment (accessed 01/07/2021).
68. MacNeill AJ, Lilywhite R, Brown CJ. The impact of surgery on global climate: a carbon footprinting study of operating theatres in three health systems. *Lancet Planetary Health* 2017; **1**: e381–8.
69. James Lind Alliance. Greener operations: sustainable perioperative practice priority setting partnership. https://www.jla.nihr.ac.uk/priority-setting-partnerships/greener-operations-sustainable-perioperative-practice/ (accessed 01/07/2021).
70. Multicenter Perioperative Outcomes Group. ASPIRE measures. Sustainability SUS-01: low fresh gas flow. https://spec.mpog.org/Spec/Public/32 (accessed 01/07/2021).
71. Mortimer F, Isherwood J, Wilkinson A, Vaux E. Sustainability in quality improvement: redefining value. *Future Healthcare Journal* 2018; **5**: 88–93.
72. Mortimer F, Isherwood J, Pearce M, Kenward C, Vaux E. Sustainability in quality improvement: measuring impact. *Future Healthcare Journal* 2018; **5**: 94–7.
73. McGain F, Naylor C. Environmental sustainability in hospitals - a systematic review and research agenda. *Journal of Health Services Research and Policy* 2014; **19**: 245–52.
74. Centre for Sustainable Healthcare. Sustainability in quality improvement. https://www.susqi.org/ (accessed 01/07/2021).
75. Care without Carbon. The road to sustainability in US health care. https://ysph.yale.edu/climate/phes/sustainability-health-care-symposium/ (accessed 01/07/2021).
76. Daú G, Scavarda A, Scavarda LF, Portugal VJT. The healthcare sustainable supply chain 4.0: the circular economy transition conceptual framework with the corporate social responsibility mirror. *Sustainability* 2019; **11**: 3259.
77. Haynes CA, Shelton K. Delphi method in a digital age: practical considerations for online Delphi studies. In: Wang V, Reio TG, eds. *Handbook of Research on Innovative Techniques, Trends, and Analysis for Optimized Research Methods*. Hershey: IGI Global; 2017.

Supporting Information

Additional supporting information may be found online via the journal website.

Appendix S1. List of Working Group members.

Appendix S2. Summary of environmentally sustainable anaesthesia, translated into Arabic, Mandarin Chinese, French, Russian and Spanish.