Update in
Anaesthesia

The influence of perioperative services on global warming

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Abstract

Human health and well-being are inseparably linked to our natural environment. Global climate change and greenhouse gas emissions are harming our health in several ways. It is estimated that health care makes up for almost 5% of global CO_2 emissions. Paradoxically, the health sector impacts the environment and vice versa. Understanding the 'pathophysiology of climate change' is relevant for taking steps to decrease the environmental footprint of perioperative services in several ways, notwithstanding differences in health-care challenges between different countries. "Going green" involves practising an environmentally friendly and ecologically responsible lifestyle as well as taking steps to help preserve the earth and sustain natural resources. In this article, three scopes of anaesthesia practice as well as greening strategies in the operating department will be addressed: anaesthesia medication, operating room waste, and energy consumption. Elementary green changes at a local level may make a big difference in the mitigation of environmental impact of medical perioperative services at a global level. "Think global, act local" is an ancient wisdom that still stays true.

Key words: environmental footprint, anaesthesia, perioperative services, inhalational anaesthetics, tiva, operating room waste, operating room energy

INTRODUCTION

The negative impacts of climate change are seriously affecting human health worldwide, not only by extreme weather events and reduced biodiversity, but also by decreased air quality and reduced crop yield as well as compromised quality and supply of drinking water.[1] In 2006 the World Health Organization reported that 23% of global deaths could be attributed to modifiable environmental factors. The risks of increased morbidity and mortality due to cardiovascular, respiratory, renal and endocrine disease have been described. Change in climate impacts on the development and spread of infectious diseases. Our psychological well-being is adversely affected. Paediatric and elderly patients are not spared.[2]

Health care is an industry with a considerably large environmental footprint. This means that health care provision is accompanied by the usage of high amounts of energy and resources as well as production of pollutants, greenhouse gas emissions and waste production. Climate change confronts the health care sector with a paradox: treatment of patients benefits their health but may adversely affect the patients' and others' living conditions. In 2014, the health care sector's climate footprint reflected around 5% of the global carbon emissions. The majority of greenhouse gases is emitted by high-income countries, while the majority of the burden is suffered in lower and middle-income countries. This increases global inequality.[3,4]

The 21st United Nations Conference of the Parties (COP) climate agreement ('The Paris agreement') requires rapid emission reductions in all sectors of the global economy to limit global warming by 1.5 °C, compared to pre-industrial levels.[5] In 2017, a publication by The Lancet examined and explained the carbon footprint within the operating department.[6] Hospitals are one of the largest contributors to these greenhouse gas emissions with the operating department as disproportionate user of hospital resources as the largest polluter of all departments.[6,7]

The global impact of anaesthesia is uncertain. According to information of the Association of Anaesthetists ≈ 200 million anaesthetics are carried out worldwide annually through which it is expected that global impact of anaesthesia is not insignificant.[8] Discussion usually centres on the impact of volatile anaesthetics

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and anaesthetic gasses. Currently, the global inhalation anaesthesia market quantifies ≈ 12.5 million bottles (worth US$ 1.12 billion), a number calculated to rise to ≈ 14.9 bottles by 2025 (worth $ 1.34 billion). Sevoflurane is the market leader (70%), followed by desflurane (20%) and isoflurane (10%). Bottom-up estimated annual contribution of volatile anaesthetic agents represents ≈ 0,01% of global CO_2 production.[9] Nevertheless, the environmental footprint of anaesthesia is more than inhaled anaesthetic agents. Contributions made by equipment and drug manufacturing, building energy use, patient and staff transport as well as waste disposal cannot be disregarded.

Three strategies for perioperative services to reduce this carbon footprint will be illustrated here by the comparison of volatile versus intravenous anaesthesia, by waste management as well as by energy consumption in the operating department.

BASIC PHYSICS OF CLIMATE CHANGE

Our earth-atmosphere energy balance is a delicate equilibrium between incoming energy from the sun and outgoing energy from the earth. Rays from the sun that reach the earth's surface comprise nearly every part of the electromagnetic spectrum. Visible sunlight falls into the narrow range of the spectrum with short wavelengths between 0,3 and 0,7 micrometre (figure 1). The incoming energy that reaches earth's surface has an average intensity of 342 watt per square metre. About one-third is reflected by the earth's atmosphere and two-thirds is scattered as well as absorbed as infrared radiation by physical, chemical, and biological processes. Infrared radiation is radiant energy that is invisible but that is felt as heat. A greenhouse gas absorbs infrared radiation which is circulated in the atmosphere and eventually lost to space. Greenhouse gases also increase the rate at which the atmosphere can absorb short-wave radiation, but this has a much weaker effect on global temperatures. Without any greenhouse gases, average global temperature would be –18 °C and life as we know it would not exist. The primary natural greenhouse gases emitted are water vapour, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and ozone (O_3). Industry generated gases particularly fluorinated hydrocarbons contribute approximately 3%. Although CO_2 is the largest contributor to greenhouse gas, water vapour is the largest contributor to the greenhouse effect. Atmospheric gas concentrations are determined by the balance between sources (emissions of the gas from human activities and natural systems) and sinks (the removal of the gas from the atmosphere by conversion to a different chemical compound or absorption by bodies of water soil and vegetation). Most greenhouse gases take many years to leave the atmosphere. However, with human-induced emission of excess greenhouse gases, average surface temperatures are rising. The mixture of gases in the atmosphere influences the greenhouse effect, tipping the balance towards more energy absorption. It is common to express a climatological 'footprint' in CO_2 equivalents (CO_2 eq). CO_2 eq is a metric measure used to compare the emissions for any quantity and type of greenhouse gases. The relative impact of different greenhouse gases and their contribution to global warming depends on several chemical characteristics. Most important are a) efficiency of infrared absorption and b) biological degradability, comparable to atmospheric lifetime. A commonly used measure to allow comparisons of global warming impact of different gases is 'the 20 years global warming potential' (GWP_{20}). GWP_{20} is a measure of how much energy the emission of 1 kg of a certain gas will absorb in the atmosphere over 20 years, relative to the emission of 1 kg of CO_2; per definition, the GWP_{20} of CO_2 is

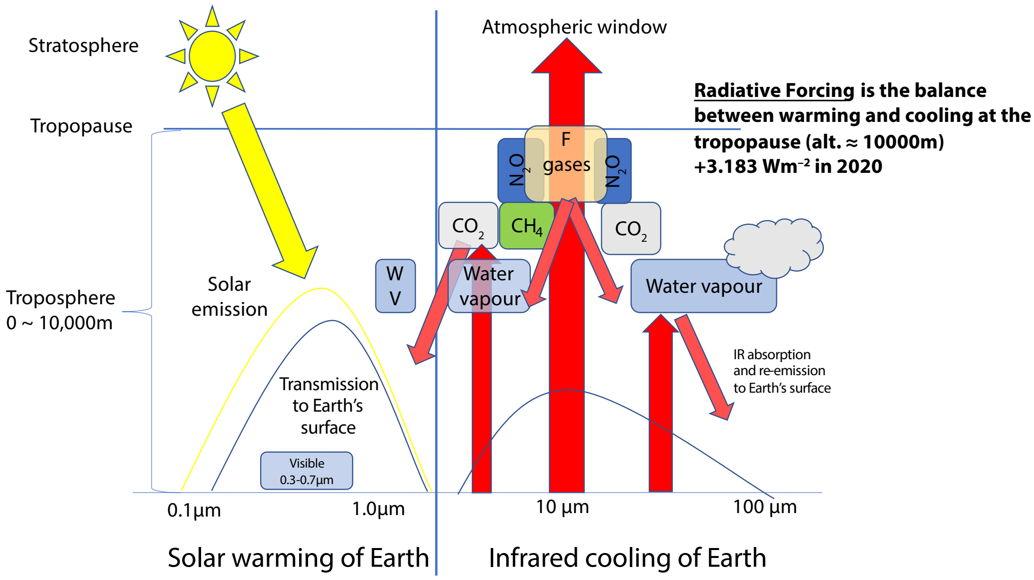

Figure 1. *Schematic representation of the 'pathophysiology' of the greenhouse gas effect relating to the use of inhaled anaesthetic agents (F gases). The temperature on Earth depends on the balance between radiation energy received and emitted by the planet. Energy from the Sun (electromagnetic radiation with a wavelength of 0,1–1 micrometre) reaches the Earth. Substances in the atmosphere and on the Earth's, surface can absorb radiation and convert this into heat (infrared radiation). Inhaled anaesthetic agents absorb infrared light (wavelength ± 10 micrometres) efficiently and contribute in this manner to heat trapping in the atmosphere, known as the greenhouse effect.*

equal to 1. Fluorocarbons have high GWP_{20} and last a long time in the atmosphere thus they have the potential to increase warming even though present in small amounts.

COMPARISON OF VOLATILES AND GASES VERSUS INTRAVENOUS ANAESTHESIA

Gases and volatile fluorocarbon agents used in anaesthesia absorb infrared radiation efficiently and have a relatively high atmospheric lifetime (table 1).[10] Sevoflurane has a GWP_{20} of 685. This means that the emission of 1 kg of sevoflurane captures the same amount of heat over a period of 20 years as 685 kg CO_2. Isoflurane and desflurane have a higher environmental impact with GWP_{20} values of 1800 for isoflurane and 6440 for desflurane. When nitrous oxide (N_2O) is used as an adjunctive agent in the anaesthetic gas mixture, the amount of fluorocarbon agents can be lowered, but N_2O itself is an important greenhouse gas with a GWP_{20} of 264. Furthermore, N_2O reacts with high energy oxygen atoms in the stratosphere to produce nitric oxide (NO), that triggers ozone-depleting reactions and makes the global ozone layer thinner. Ever since the Industrial Revolution began in the 1700's, concentrations of N_2O in the atmosphere have risen from 270 to 320 parts per billion (ppb, 1:10^9). Most of this increase is due to breakdown of nitrogen in synthetic fertilizers and sewage treatment plants; waste medical emissions of nitrous oxide account for only a small amount of all emissions of N_2O to the atmosphere. After delivery of inhaled anaesthetics to the patient, the elimination of most inhalational agents through biotransformation is negligible, except for halothane. Waste anaesthetic gases are taken up in the hospital scavenging system and subsequently expelled into the atmosphere. Once the inhalational agents are emitted, they have varying atmospheric lifetimes of 1.9 years for sevoflurane, 14.1 years for desflurane and 123 years for N_2O. A study group collected atmospheric samples of 4 halogenated anaesthetic agents at very remote sites during an expedition in the North Pacific and at an Antarctic station, as well as at the Swiss high-altitude station Jungfraujoch. At all sites, measurements showed a significant increase of anaesthetic agents in the atmosphere over the observed period from 2002 to 2014 (figure 2).[11] The researchers that conducted this top-down study calculated a global emission of halogenated anaesthetics of 3.1 ± 0.6 million-ton CO_2 eq for the four anaesthetic agents in 2014, with ≈ 80% stemming from desflurane; bottom-up studies estimated higher values. According to the recent activity report of these atmospheric scientists in 2021, the emissions of the abovementioned fluranes have not changed much in recent years, perhaps indicating that global demand has stabilized. Probable explanations might be market saturation, a more careful handling of the anaesthetics, or the move to alternative forms of anaesthesia. The scientists also state that a modelling study is underway to derive global emission based on atmospheric observations, to quantify emissions more accurately.[12]

Based on the issues with volatile anaesthetics discussed above, total intravenous anaesthesia (TIVA) may be considered as an alternative to avoid the use of volatile agents. The widely used intravenous anaesthetic propofol is extensively glucuronidated by the liver; approximately 88% of the given dose is excreted as inactive metabolites and 1% is excreted unchanged in urine. It is not possible to exactly describe the ecotoxicity of propofol, though it is very toxic to aquatic life and has a high potential for bioaccumulation and persistence. Around 33 to 50% of the drug is usually discarded rather than administered; non-metabolized propofol can be dangerous when ending up via hospital wastewater

Table 1. *Chemical and climatological properties of volatile anaesthetic agents and N_2O in relation to CO_2. Anaesthesia practice is by far the dominant source of these inhalational agents in the atmosphere; estimates of their contribution to global greenhouse gas emissions range from 0,01% to 0,1%. In a clinical context, inhaled anaesthetics can make up more than half of perioperative services carbon emissions.*[7, 8, 10, 15, 19, 20]

	Carbon dioxide	Sevoflurane	Isoflurane	Desflurane	Nitrous oxide
	CO_2	$(CF_3)_2CHOCH_2F$	$CHF_2OCHClCF_3$	$CHF_2OCHFCF_3$	N_2O
Atmospheric concentration (1750)	280 ppm	–	–	–	270 ppb
Atmospheric concentration (2014)	400 ppm	0,23 ppt	0,12 ppt	0,32 ppt	320 ppb
Atmospheric lifetime (years)	–	1,9	3,5	14,1	123
Peak infrared absorption (µm)	4.5, 7.8, 14-16	8	8.5	8.1	4.5, 7.8, 12.5-17
Global Warming Potential (GWP_{20})	1	685	1800	6440	264
Estimated global ton-use (2014)	–	1200	880	960	–
kg CO_2eq/ MAC hour (FGF 1 L/min) without N_2O		3 - 11	3 - 4	81 - 85	–
kg CO_2eq/ MAC hour (FGF 1 L/min) 60% N_2O : 40% O_2		19 - 22	19 - 24	48 - 56	–
Vehicle km for the same carbon footprint (1 MAC h; FGF 1 l/min; car emitting 200g CO_2 per km)	–	6,5	14	320	95

Ppm/ ppb/ ppt: parts per million (10^6), billion (10^9), trillion (10^{12}); GWP_{20}: '20 years global warming potential'; CO_2 eq: CO_2 equivalents; FGF: Fresh Gas Flow.

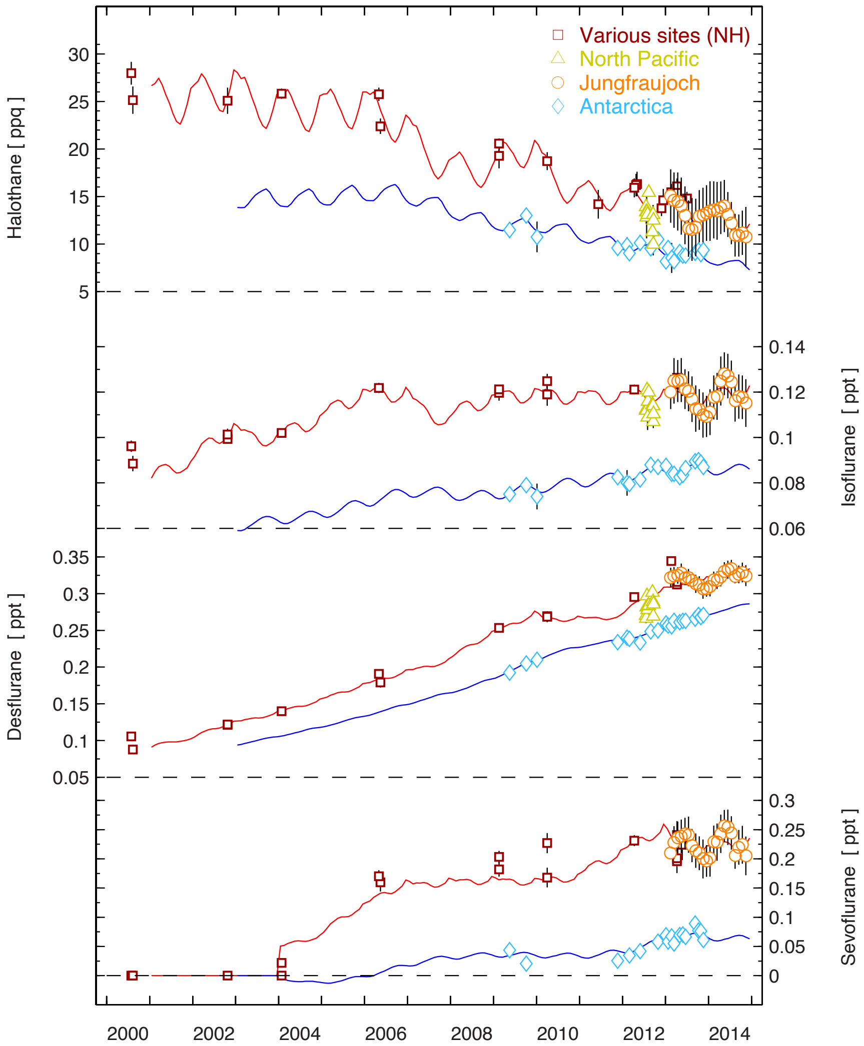

Figure 2. *Concentration of 4 halogenated anaesthetic agents in the atmosphere at various locations. Halothane is declining, despite multi-decadal emissions, mainly because its relatively short lifetime. In contrast, isoflurane, sevoflurane and desflurane have grown significantly in the atmosphere over the observed time period (2000–2014).*

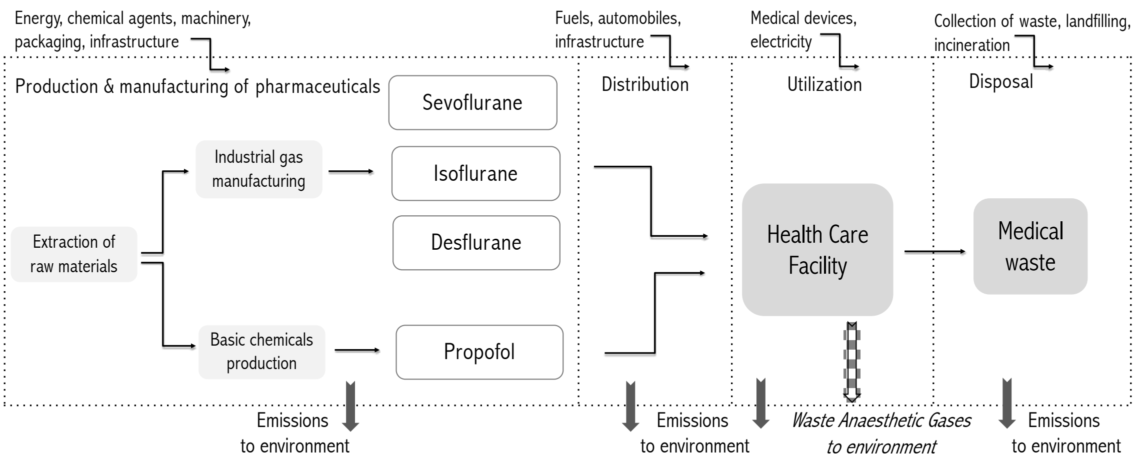

Figure 3. *A Life Cycle Assessment (LCA) of anaesthetics is used to assess environmental impacts associated with these products over their life cycle stages: from extraction of raw materials through to production and manufacturing, transport, use and disposal. This scope is termed 'cradle-to-grave' approach.*

streams into the water system. Propofol must be incinerated at > 1000°C for over 2 seconds to fully remove the drug. Comparison of different anaesthetics needs to be conducted using life cycle assessment (LCA), an internationally standardized method, that is used by climate scientists. In this context, a 'cradle-to-grave' analysis can be performed between different anaesthetic agents and clinical products (figure 3).[13] A 'cradle-to-grave' assessment quantifies environmental impacts at each stage of a product's life cycle, from the extraction of natural resources to various steps in the process of manufacturing, packaging, transportation, use of the product and ultimately, disposal. Each step in the process contributes to a certain environmental burden. All steps of the analysis for one product together are expressed into equivalents of CO_2 emissions. Apart from that, other outcome measures of LCA's include among others eutrophication, ozone depletion and fine particulate matter. Comparative life cycle assessment of anaesthetic agents would enable anaesthesiologists to choose alternatives with lower environmental impact, although life cycle inventories are still lacking data of commonly injectable drugs. Life cycle assessment was studied to examine the climate change impacts of maintaining 1 hour of general anaesthesia using sevoflurane, isoflurane, desflurane or propofol. Desflurane must be administered in a higher concentration (MAC_{40} = 6,6%) than sevoflurane (MAC_{40} = 1,8%) and isoflurane (MAC_{40} = 1,17%). In terms of waste anaesthetic gas and other life cycle stages, desflurane accounts for the largest carbon footprint among the anaesthetics considered. Unlike the physical properties of sevoflurane and isoflurane, maintenance of anaesthesia with desflurane necessitates a vaporizer with an electrically powered heating element to keep the agent at the recommended temperature of 39°C. New technologies to recapture and destruct or reuse waste anaesthetic gases are being developed, to prevent environmental contamination. However, recent evidence shows that the devices currently marketed grossly underperform.[14] Maintaining anaesthesia with propofol also requires electricity to drive the syringe pump. Furthermore, for propofol anaesthesia, additional disposable plastic syringes, infusion lines and three-way valves are needed and wasted propofol is incinerated in accordance with regulations; however, manufacturing and waste are minor contributions to environmental impacts of propofol. The quantified greenhouse gas impact of 1 hour of anaesthesia with propofol (MAC-equivalent) amounts approximately 0.01–1.01 kg CO_2 eq. compared with inhalational agents, without the application of vapour-capturing technology, the greenhouse gas impact of propofol anaesthesia amounts to a magnitude of nearly 4 orders lower.[15,16,17] The impacts of inhalational agents varied according to method of synthesis, fresh gas flow rate and carrier gas admixture with nitrous oxide (60% N_2O: 40% O_2) or without nitrous oxide (table 1). Another study presented the life cycle impact of a single surgical procedure on several aspects such as material, waste, energy, and anaesthetic agents. Clinical data were collected from 62 cases of hysterectomy and for the use of volatile versus intravenous anaesthetics it was concluded that the life cycle greenhouse gas emission of propofol anaesthesia, was drastically lower in comparison with sevoflurane or desflurane anaesthesia.[18] Concerted efforts by the anaesthesia department of a group of hospitals in British Columbia (Canada) to minimize the consumption of inhalation agents, have led to the joint purchase of low-flow anaesthesia machines combined with the choice to use volatile anaesthetics with the lowest GWP_{20} values. The researchers assessed the volume of volatile anaesthetics used during a period from 2012–2016. They measured the carbon dioxide equivalent and the quantity of the volatile anaesthetic that had been used. The emission of inhaled anaesthetic agents amounted to 13,4 million kg CO_2 eq in 2012 and declined to 4,5 million kg CO_2 eq in 2016; the difference represented a reduction of 66% in greenhouse gas emissions for their anaesthesiology departments.[19]

OPERATING ROOM WASTE

Medical waste is the most visible form of healthcare environmental impact. Hospitals in the Netherlands produce approximately 76 million kg of waste per year, of which 20–30% is generated by operating rooms. Hospital waste consists of a mixed stream of regulated medical waste, paper, glass, various types of plastic and chemicals, such as pharmaceuticals. Disposal of (regulated) hospital waste via high temperature incineration generates 2,1 to 3 kg CO_2 per kg waste and for optimization of waste handling it has been demonstrated that up till one third of this waste could be recycled.[16] In life cycle thinking, recycling is not the first step to make because of the extra energy and resources that go into a new product. Currently, sustainable waste strategies are aiming at reducing waste production by alternative strategies such as critical appraisal of the use of sterile trays and protocols for setting out or unwrapping operating materials. According to the waste management hierarchy tool this is expressed as six priorities: 'rethink, refuse, reduce, reuse, recycle, recover'. Reduction of waste saves more carbon than reuse and recycling. 'Reuse', means preparing materials for reuse in its original form and will result in reduction of disposable instruments and equipment in favor of sterilizable reusable alternatives. Several life cycle analyses demonstrate that reusable alternatives for laryngoscopes, surgical instruments and trays tend to be almost 50% cheaper (total cost of ownership) than the use of disposables, but that the reduction of the carbon footprint of reusables is highly dependent on the use of the type of energy used for disinfection and sterilization. The climate impact will decrease if renewable-based electricity or natural gas-based electricity is used. Compared with Australia, where mostly brown coal energy is used, carbon savings in the United States can be up to 48% with reusables and in Europe this adds up to 84%.[18] Whereas choice of anaesthetic gas is an important determinant of variation in operating room emissions, the surgical technique largely influences the amount of waste. In the abovementioned study, vaginal, abdominal, laparoscopic, and robotic hysterectomy were compared.[16] The authors concluded that laparoscopic and robotic approaches to hysterectomy were nearly three times more climate-intensive than abdominal (2.8 times) or vaginal hysterectomy (2.9 times) and led to 50% more operating room waste. The finding that advanced surgical procedures and approaches appear to be considerably more environmentally polluting than traditional approaches is worrisome because surgical techniques will become less invasive over time.

ENERGY

Most of the operating room (OR) energy impact is caused by heating, ventilation, and air-conditioning (HVAC) in the OR. These HVAC systems demand up to 99% of total energy use in the operating room and contribute to 16–80% of the total carbon footprint of surgery, aside from electricity expenditure such as for OR lighting and electricity to run equipment. Operating rooms are three to six times more energy intense per square metre than the hospital as a whole. The HVAC systems of hospitals are large consumers of energy in the operating department and often activated 24/7 to circulate the air up to 30 times an hour, rather than differentiated activity due to functions or schedules. Concerning bacterial concentration in the operation plenum areas, a study was performed with 6–30 air changes per hour, and it turned out that with 6 air changes per hour the same level of air quality was achieved.[20] It was also found that, when the operation rooms are at rest (e.g., nights, weekends), lowering or switching off the air handling systems from 30 to 6 air changes per hour could save up to 70% in annual energy cost. After restarting the system, the protected area complied with the airborne particle regulations within 20 minutes and a stable temperature difference was achieved within 23 minutes.[21] Amsterdam University Medical Centers started a pilot to place the HVAC system in stand-by mode in 15 of their 20 clinical operating rooms out of regular operating schedule. This energy reduction yielded 8,000 kWh a week (400,000 kWh annually). In comparison, an average Dutch household uses 4,000 kWh per year. This increasing energy efficiency not only results in a smaller carbon footprint (estimated 240,000 kg CO_2 per year) but also significant cost reduction for the hospital. Altogether, there is an enormous opportunity for adopting smarter energy strategies in the operating department, such as HVAC setbacks, occupancy/vacancy sensors, LED lighting as well as awareness campaigns for health care professionals.

CONCLUSION AND RECOMMENDATIONS

Healthcare industry generates a large carbon footprint, with special attention to operating departments. As leaders in this environment and because awareness is the first step to meaningful change, it behoves anaesthesiologists as responsible clinicians to play our part in minimizing the impact of operating theatres on climate change. Major investments to reduce the carbon footprint in the operating department are essential. Three effective greening strategies (low-hanging fruit) were described in this update: the environmental effect of inhaled anaesthetic agents, production of operating room waste and energy consumption in the operating department. The scopes described in this article offer an opportunity to reduce environmental emissions in anaesthesiology practice in a simple way by 'quick wins'.

Since waste anaesthetic gases are vented directly from the hospital, they are considered direct emissions and are reported as GHG emissions (scope 1), which are direct emissions from owned or controlled sources.[22] The European Parliament has published a proposal for a regulation on fluorinated greenhouse gases and to ban or at least severely restrict the use of desflurane starting January 2026. The American Society of Anesthesiologists (ASA) has proclaimed the 'Inhaled Anaesthetic 2020 Challenge'. This initiative was started to encourage anaesthesiologists to reduce their annual facility inhaled anaesthetic volume by 50%; the same efforts to decarbonise anaesthesia were repeated in 2022.[23] Basically, this ASA sustainability initiative aims at reducing inhaled anaesthetic waste gases in the atmosphere by avoidance of high impact inhaled anaesthetics (such as desflurane and nitrous oxide). Severely restricting the use of one anaesthetic agent should not distract the anaesthesia team from sustainable interventions, such as:

- to flatten nitrous oxide emissions whenever possible and use oxygen/air as the carrier gas; if it is needed to administer volatile anaesthetic agents, then sevoflurane is preferred over desflurane;
- to minimize fresh-gas flow (FGF) during maintenance, but at the same time allow sufficient flow to provide oxygen to meet the metabolic requirements of the patients; newer types of low-flow anaesthesia machines can closely regulate 'end-tidal' anaesthetic gas concentrations;[24]
- to develop technology to capture and recycle or destroy the wasted potent inhaled anaesthetics that we will continue to use;
- to administer epidural or intravenous analgesia during labour in the clinical setting instead of nitrous oxide inhalation;
- to prioritize TIVA or locoregional anaesthetic technique instead of volatile agent-based anaesthesia whenever possible.[25,26]

Anaesthesiology staff should be empowered and educated, primarily by their professional bodies, to choose anaesthetic techniques prudently so as to ensure the safety of the patient.

25% of all OR waste has been attributed to anaesthesia-related materials.[27] With regard to waste materials, the waste hierarchy principle can be applied for ranking an order of preference to reduce and manage waste. In the first place this principle gives top priority to prevent production of waste. ASA's Task Force on Environmental Sustainability has published 'Greening the operating room and perioperative arena' (2014) in which sustainability issues are addressed for all anaesthesia practice areas, including waste stream and recycling.[28]

Considering some of the most energy-intensive systems in the operating department reveal potential targets for small behaviour changes that may have large collective effects, such as to switch off the HVAC systems, control temperatures in the OR and to turn off equipment and lights after day-to-day work.[29] In addition it will increase savings in costs and/ or expenses.

As exemplified, anaesthetists and nurse anaesthetists encounter more than volatile gases, waste of drugs, equipment and disposables as well as energy consumption in their work. Empowering staff to be aware of the influences of perioperative services on global warming will lead to rationalising and making adjustments in their working environment. Awareness is the first step to meaningful change.

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The waste hierarchy tool is originally designed in 1979 by Ad Lansink, a politician in the Dutch Parliament ('Lansink's Ladder'). The waste management hierarchy indicates an order of preference for action to reduce and manage waste from most favorable to least favorable actions. https://www.recycling.com/downloads/waste-hierarchy-lansinks-ladder/

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