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e-Learning Anaesthesia

Sustainability: **Intravenous and local anaesthetic agents**

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Dr Kathryn Greaves
Dr Juliette Fletcher

Contents

Module Learning Outcomes

- Carbon emissions - inhalational Vs intravenous Vs regional (CO_2e)
- Pharmaceutical water course contamination - implications and strategies to minimise
- Limitations of current evidence base and areas that future research should focus on
- Role and responsibility that industry has to play in sustainable healthcare

This module addresses our individual clinical practice and choices with respect to anaesthesia provision in the context of a move towards delivering a net zero NHS.[1] To truly provide sustainable practice we need to consider not just the environmental, but also the financial and social aspects of a course of action, the so-called triple bottom line.

In 2017 the Health and Social Care (HSC) sector in England was responsible for 4% of the total carbon footprint of the country.[2] The Sustainable Development Unit (SDU) of the NHS, now renamed ‘Greener NHS’, has reported a fall of 18.5% in the carbon footprint between 2007 and 2017 against a backdrop of a 27% increase in clinical activity.[2] Whilst this is encouraging and has helped to meet the interim Climate Change Act targets, this rate of reduction will be nowhere near enough to ensure that we are net zero (against a 1990 baseline) by 2050 and an excess of 10Mt of CO_2e per year over the target is forecast by 2030.[3]

There are many ways in which we, as anaesthetists, can make small changes to our daily practices that will help to shift the balance and accelerate these changes toward net zero. By way of shorthand, we use the term emissions to encompass all greenhouse gases.

Carbon emissions – inhalational vs intravenous vs regional (CO_2e)

Inhalational anaesthesia

The NHS Long Term Plan (2019)[4] identified the anaesthetic gases (sevoflurane, isoflurane, desflurane and nitrous oxide)[2,4,5,6] as a carbon hotspot within the HSC[2] and although they account for 1.7% of all carbon emissions this amounts to 5% of emissions from acute hospitals[2,4,5] equating to around 500,000 metric tonnes CO_2e annually (see Figure 1).

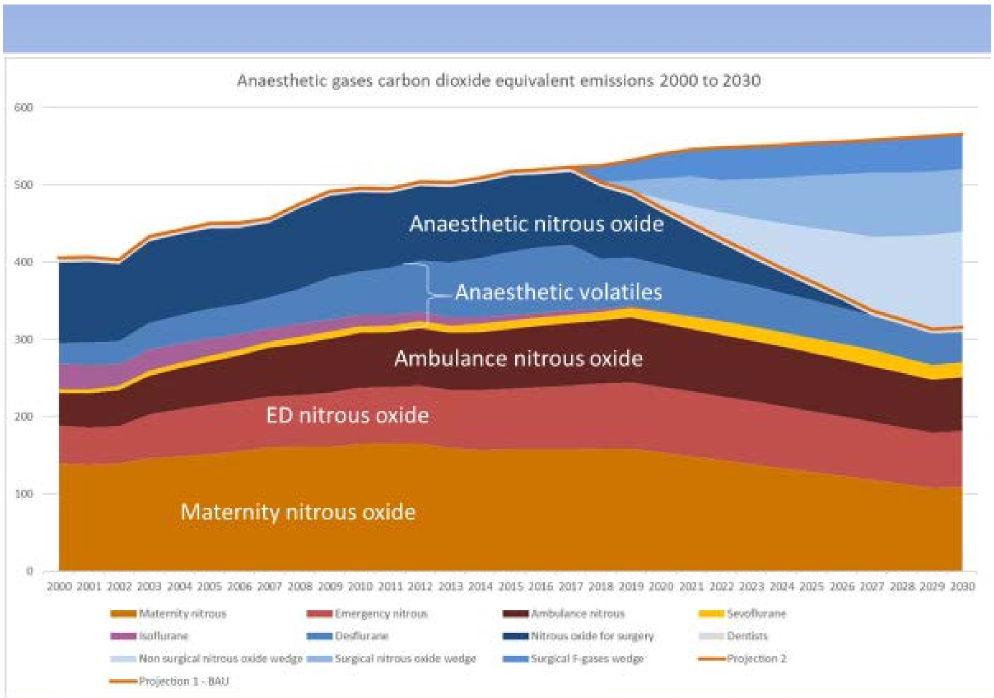
The fluorinated anaesthetic gases absorb infrared radiation at around 10µm. As absorption by naturally occurring greenhouse gases (GHG) does not occur at this wavelength, the agents exert an effect far out of proportion to their low atmospheric concentration. As they are vented to atmosphere unchanged, the more agent that is used and the longer the atmospheric life, the greater the effect. Thus, desflurane has a value twenty times that of sevoflurane (per mass equivalent) but as the MAC is 3 times higher, the global warming effect of a desflurane anaesthetic can be thought of as being approximately 60 times that of sevoflurane (per MAC hour).[7,8] For more details relating to this please see the e-modules within this series entitled '*Background science*' and '*Medical gases*'.

The Anaesthetic Impact Calculator smart phone app[9] calculates the CO_2e of inhaled anaesthesia and allows for comparison between the different agents. Using the validated mathematics behind the calculations, Table 1 was derived and compares the environmental impact of these inhalational anaesthetic agents 'per MAC hour'.[10] To quantify the CO_2e produced from your own practice using inhalational anaesthetic agents, as well as the impact that any changes in practice make to this, download the Anaesthetic Impact Calculator [9] and start inputting your data and tracking reductions. For more details on quality improvement projects pertaining to reductions in emissions relating to anaesthetic gases see the Royal College of Anaesthetists Quality Improvement Compendium, chapter 11 project 11.1 *"Focus on sustainability: reducing our carbon footprint through inhalational agents"*.[11]

	Sevoflurane	Isoflurane	Desflurane	N_2O
MAC	1.85	1.15	6.0	101
Tropospheric lifetime (y)	1.1	3.2	14	114
GWP_{100}	130	510	2540	298
Mass of agent used per hour with low flow anaesthesia (500ml FGF) and 1 MAC (g)	4.7	2.6	13.4	55 At 500ml/min
CO_2e of an hour's low flow anaesthesia at 1 MAC (kg CO_2e)	0.59	1.37	34	16.4 At 500ml/min
Comparative carbon emissions per MAC hour of agent (compared to sevoflurane)	1	2.3	57.6	n/a

Table 1: comparative characteristics of inhalational anaesthetic agents. Kindly provided by Dr JMT Pierce with figures from the Anaesthetic Impact Calculator.[9]

Nitrous oxide emissions in the NHS in England amount to 0.47MtCO_2e, over 5 times the emissions of the total inhalational anaesthetic agent use (0.08MtCO_2e) combined.[6] Anecdotally, the use of nitrous oxide in the operating room has fallen (per hour of anaesthesia) and is predicted to fall further still (Figure 1). Data from Greener NHS indicates that most nitrous oxide emissions come from Entonox® and it is therefore important to consider other locations where nitrous oxide is used for analgesia, including the emergency department, maternity and prehospital care. These are areas where there is a compelling argument to reduce nitrous oxide emissions further, but only where suitable alternative analgesics are available. See the e-module in this series entitled '*Medical gases'* for more details on this.



SDU Presentation to Association of Anaesthetists Glasgow 2019 with permission

Figure 1: With permission from the Sustainable Development Unit. This illustration plots the rise in CO_2e and then models the reductions in anaesthetic gas use in accordance with the NHS long term plan[4] (that 2% of the NHS carbon emissions reduction must come through transformation of anaesthetic practices). Over 80% of the CO_2e of inhaled anaesthetic and analgesic agents is due to nitrous oxide use throughout the healthcare system. Anaesthetic use of N_2O accounts for 25% of the total N_2O CO_2e and 75% is derived from the use of N_2O/O_2 mixes in maternity, emergency department and ambulance services.

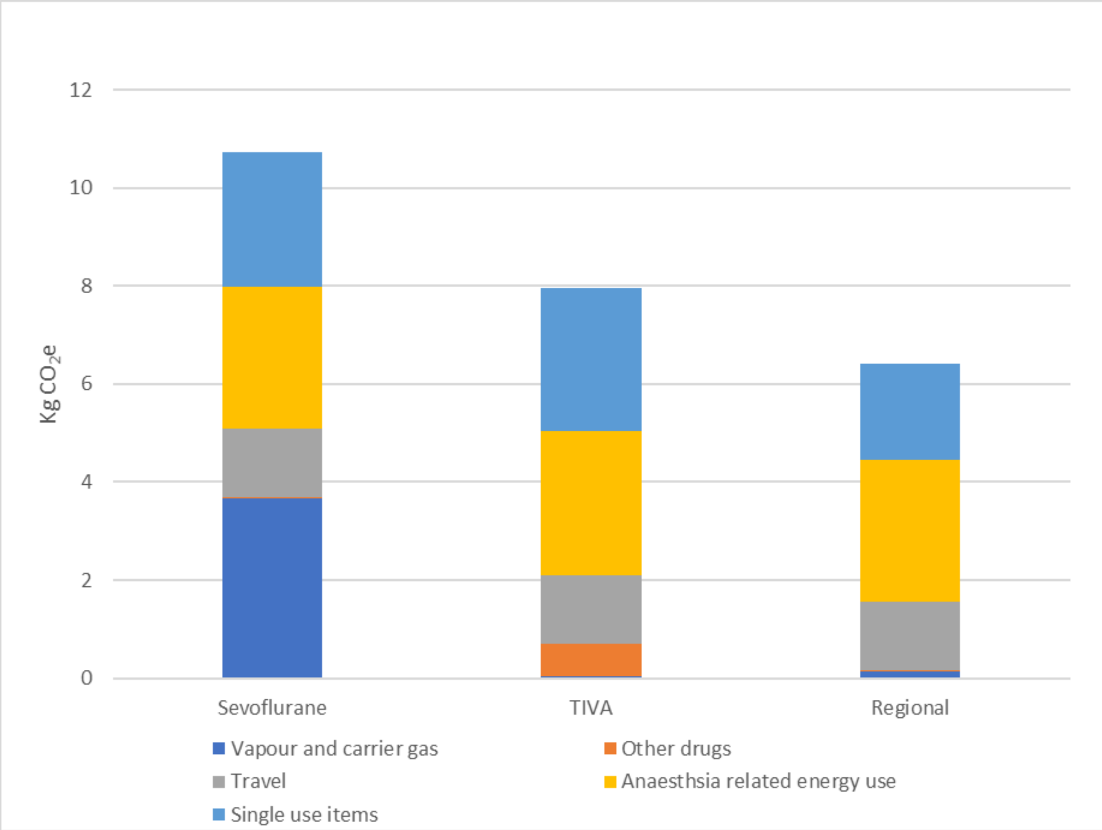
Intravenous and regional anaesthesia

Greenhouse gas emissions from propofol total intravenous anaesthesia (TIVA) are 4 orders of magnitude less than those from nitrous oxide and desflurane.[12] The use of TIVA and regional techniques removes or reduces the use of inhalational agents and thus their carbon emission contribution. Regional techniques, when used in combination with inhalational agents, also enable this due to a 'MAC' sparing effect, reducing the amount of inhalational agent required. TIVA completely abolishes the use of anaesthetic vapour.[12]

A common concern pertaining to the negative environmental impact of TIVA and regional anaesthesia over inhalational methods seems to be surrounding the increased use of single use plastics in the form of syringes in these anaesthetic techniques compared with inhalational. Disposable plastic components (e.g. syringes) used in these procedures are commonly made of polyvinyl chloride (PVC). 1kg of PVC produces 6 kgCO_2e throughout its life cycle, 3 kgCO_2e on manufacture and another 3 kgCO_2e on disposal through incineration. Packaging and residual drugs are also combusted. 1kg of paper produces 2.1 to 2.6kgCO_2e.[13]

Using a worked example and comparing an inhalational anaesthetic with the same procedure performed under TIVA or a regional block we can illustrate the savings, in terms of carbon, that can be made through changes in anaesthetic technique (see

Figure 2). These are not the only benefits to performing procedures in this manner.[14] Patient outcomes and experience may be enhanced if TIVA or regional techniques are successfully employed and there may also be financial savings for the hospital in reduced length of stay, increased day case surgery, reduced postoperative nausea and vomiting and pain, demonstrating that these techniques are sustainable across all three elements of the triple bottom line.



$KgCO_2e$	Sevoflurane	TIVA	Regional
Vapour and carrier gas	3.66	0.03	0.15
Other drugs	0.03	0.66	0.005
Travel	1.4	1.4	1.4
Anaesthesia related energy use	2.89	2.94	2.89
Single use items	2.74	2.94	1.97
Total	10.72	7.97	6.415

Figure 2: Comparison of different anaesthetics for a total knee replacement in an 80kg male for a duration of 2 hours. Kindly provided by Dr JMT Pierce.[15]

Regional anaesthesia

Considering simply the mass alone of single use items and active pharmaceutical ingredients (API), required to achieve safe regional anaesthesia, it would seem that of the three forms of anaesthesia, regional is the most sustainable. However, until there is a good science basis for this statement, we urge a word of caution. We need engagement from industry to determine accurate life cycle assessments for the entirety of contents within a pharmaceutical product and not just limited to the API to gain a clearer understanding of the true difference in impact between these modalities of anaesthesia. One must also remember that the carbon emissions alone do not tell the full negative environmental impact of one anaesthetic technique over another.

Pharmaceutical contamination of watercourses

The process of converting raw materials to active pharmaceutical ingredients, and ultimately to waste products and metabolites risks not only the atmospheric burden but watercourse contamination too.

The term pharmaceuticals relate to compounds manufactured for use as medicines, intended for either human or animal consumption. These compounds are specifically developed to produce a biological effect, their very reason for existence becoming the cause of ecological problems if they are leached into the environment.[16] As pharmaceutical usage has increased over recent decades, so too have the potential polluting effects medicines can have on the environment. These effects will damage wildlife and their natural habitats, and as biologically active compounds enter our drinking water and the food chain, humans may also suffer side effects of their presence. The long-term consequences of watercourse contamination have only been considered in recent studies, and much work needs to be done so that we can prevent environmental damage in the future.

A watercourse is defined as a channel through which water flows, including streams, rivers and estuaries.[17] Pharmaceuticals and their metabolites can reach watercourses through direct and indirect routes (see Table 2 below). Direct routes include sewerage systems, effluents (liquid sewage discharged into the river or sea) from sewage treatment plants, industrial discharges and through livestock and fish farming.[18]

Direct	Indirect
Sewerage systems	Incorrect medicine disposal
Sewage effluents	Reuse of wastewater
Industrial discharges	Fertiliser contamination
Livestock farming	
Fish farming	
Pharmaceutical production	

Table 2: Sources of pharmaceutical watercourse contamination

The majority of direct pharmaceutical watercourse contamination in the UK occurs through domestic and hospital sewage disposal, as human medicines are mostly excreted as metabolites or unchanged in urine and faeces.[19] Indirect contamination is more difficult to monitor, and combines the incorrect disposal of medicines, (being flushed down the toilet or sink,) the recycling of wastewater, and the application of sludge produced in sewage treatment plants onto crops by farmers.[18] This last method of contamination allows pharmaceuticals to enter the soil and crops, thus appearing in the human food chain.

Although research in this area is limited, drug groups most commonly causing concern for their potentially harmful effects on wildlife include the following, with those commonly used during anaesthetic and critical care practices highlighted (in bold):

- **Antibiotics**
- Antidepressants
- **Anti-epileptics**
- Anti-parasitics
- **NSAIDs**
- **Analgesics**
- **Beta-blockers**
- Statins
- **Steroids**
- Oral contraceptives
- Hormone replacement therapies
- Drugs used in the treatment of cancer.[20]

Many of these drugs have also been found in lakes and reservoirs, as well as in seawater.[17]

Implications of watercourse contamination

Drugs that are lipophilic and designed to cross cell membranes have the potential to accumulate in species that they were never intended to reach, such as aquatic animals.[16] The most notable example of this has been the feminisation of male fish in English rivers, a mutation shown to be directly proportional to the amount of oestrogen containing sewage effluent found in the water.[21] This has serious implications for the future sustainability of various fish species, as the affected fish have lower rates of reproductive success.

Phase 1 drug metabolism reactions such as oxidation and hydrolysis result in metabolites that are more water-soluble and sometimes more active than the parent drug. Propofol undergoes glucuronidation and sulphonation to produce water-soluble compounds that are then renally excreted.[22] A very small fraction of propofol is renally excreted unchanged.[23] Perhaps more concerning is the amount of propofol entering the sewerage system through incorrect disposal down the sink. No pharmaceutical waste should be disposed of into the sewers in this way, but propofol has been identified in hospital effluents, and is known to be toxic to aquatic life.[24] Further research will be necessary to determine the implications of the presence of propofol on the aquatic environment. Until these effects are fully understood, action that can be taken easily and immediately is the encouragement of safe waste drug disposal and avoidance of expelling it down the sink.

Veterinary medicine has also been responsible for pollution of watercourses, with anti-parasitic drugs used in sheep dip washing off animals when they enter streams and rivers.[20] These pharmaceuticals kill the larvae of certain fly populations, removing the food source for birds further up the food chain.

Perhaps the most concerning reported public health phenomenon in recent years has been the development of antibiotic resistance, a developing crisis as bacteria change to become less responsive to antibiotics.[25] Global mortality from drug-resistant bacterial infections has recently been estimated at up to half a million people per year.[26] Unnecessary prescribing of antibiotics when they are not clinically indicated, and inappropriate consumption of them in countries where they are available to purchase without a prescription have both contributed to antibiotic resistance, and the World Health Organisation have called for a change in global behaviour in an attempt to prevent this crisis from worsening.[25] Antibiotics have also been implicated in their use in animal feeding operations and fish farming, where they are routinely given to treat disease and promote growth of animals. This has led to dissemination of antibiotic resistant genes into the wider environment.

Hospital effluents have been identified as concentrated sources of antibiotic resistant pathogens such as E. coli containing extended-spectrum beta lactamases (ESBL), and vancomycin resistant enterococcus (VRE).[27] Antibiotic resistant genes can accumulate in nitrogen-rich waste, and while sewage treatment plants utilise numerous methods to reduce the transmission of harmful compounds into the environment, they cannot remove antibiotic resistant genes altogether. The solid portion of sewage is particularly difficult to rid of these contaminants, and if these bio-solids are then used as fertiliser for crops, a new avenue of contamination will exist for antibiotic resistance to develop.

Strategies to minimise watercourse contamination

Recommendations for future practice to minimise pharmaceuticals contaminating watercourses have been summarised by the CHEM-Trust Report,[20] and include the following points:

- Rationalising the use of medicines, and discontinuing any that are no longer indicated
- Ensuring the correct disposal of unwanted medications, for example utilising pharmacy take back schemes
- Improving the functioning of sewage treatment plants to remove pharmaceutical contaminants
- Encouraging the development of more environmentally friendly medicines
- Reducing the use of veterinary medicines in livestock and fish farming

In addition to these points, anaesthetists should all be educated in the correct disposal of unused drugs, to minimise the flushing of potentially harmful medicines into the sink, causing contamination of the aquatic environment. The Association of Anaesthetists has produced a guideline to help clinicians ensure the appropriate disposal destination for waste products within anaesthesia.[28]

The Environment Agency is the Government body responsible for the protection of the environment in England, and the quality of water and water discharges into rivers, lakes and the sea, providing information to their European counterparts.[29]

In order to address the evolving crisis regarding antimicrobial resistance, the EU issued the One Health Action Plan against Antimicrobial Resistance in 2017.[30] Their report acknowledges the importance of environmental contamination by antibiotics and emphasises the need for further research to ascertain the level of threat certain pollutants pose to both wildlife and humans through watercourse contamination.

There are opportunities for almost every healthcare professional as well as members of the public to take responsibility for some of these strategies to minimise watercourse contamination. Recognising the part that we all play in both the environmental contamination by pharmaceuticals, and the drive for sustainability in healthcare is essential if we are to minimise the damage caused by our daily practice.

Limitations of current evidence base and areas for future research

Evidence is key in determining the negative impact that anaesthesia is having on the environment, and consequently how we can improve our working practices to limit such an impact. Whilst much has been done to date, there are still gaps in our knowledge pertaining to this area with further work being necessary.[8] The NHS Net Zero Expert Panel[31] has been created by NHS England in 2020, with the aim to create instructions on how we can achieve net zero carbon emissions and deliver the sustainable elements of the NHS long term plan.[4]

The accepted methodology to evaluate the environmental impact of a drug or device is a Life Cycle Analysis (LCA). An LCA incorporates the impact of the development, evaluation, manufacture, packaging, transport, storage, administration and waste management of drugs and devices and often touch upon more than just carbon emissions, including water and air pollution to allow for fairer comparisons between techniques to be made.[13] The limitations of LCAs are discussed in more detail in the e-module within this series entitled '*Procurement and Carbon costing*', however it is worth outlining some details here.

Considering the LCA of anaesthetic drugs, including gases, the main focus has been on comparing carbon emissions, which reveals part, but not all the environmental impact of our agents. By focusing on carbon emissions alone we may be disregarding other equally, if not more important environmental impacts of our agents, such as water and soil contamination and pollution, air pollution (aside from carbon) and the negative impacts to economies.[7,8] It is only when taking all of these impacts into account that we can have a more balanced approach in choosing the right drug and anaesthetic technique for each patient that we are caring for.

Perhaps one of the biggest limitations in the LCA work into anaesthetic drugs that we have is lack of engagement from pharmaceutical companies. This has meant that the LCA work pertaining to drug production and manufacture from raw materials to parent compound is based on derivations from first principles, as drug manufacturing 'recipes' remain a closely guarded secret, with carbon emissions being very well-educated calculations and estimates rather than actual emissions data. Greater transparency is necessary as often only the API is focused on within these life cycle analyses and the manufacturers do not account for the other excipients in the drug's ‘recipe’. Collaboration with the pharmaceutical industry using this life cycle method will create more accurate LCAs of anaesthetic drugs and may allow anaesthetists to make more informed decisions.[7,13]

In the context of waste drugs further research is needed to understand the environmental impacts they might have other than greenhouse gas emissions. With some measure of unprocessed drugs, and their metabolites likely to make their way into the aquatic and agricultural environment, it is important for future research to investigate what course these agents take within ecosystems, whether they are harmful, and actions that we can take to mitigate these detrimental effects.[7]

The role of industry in sustainable healthcare

Looking into the future, it is clear that techniques to reduce carbon emissions alone will not be sufficient to avert a climate catastrophe in coming years. Projections by Greener NHS have outlined that significant innovation, as well as 100% uptake of current sustainability initiatives (both governmental and clinical) will still leave a huge shortfall to our net zero carbon emissions 2050 climate change target.[2] Innovation will be necessary to bridge this gap, with schemes such as the introduction of an environmental ratings system for anaesthetic drugs already being postulated.[32] Examples of environmental protective strategies already utilised in anaesthesia include techniques to capture, extract and reuse anaesthetic gases [8,33,34,35] 'cracking' of nitrous oxide, use of reusable equipment over single use where appropriate, reduction of waste and wasteful processes and procedures, along with appropriate waste segregation. All these techniques are summarised in the recent BJA article "Environmental sustainability in anaesthesia and critical care".[8] The search for an ideal, sustainable anaesthetic agent with minimal environmental impact is still ongoing. Further information can also be found in the following e-modules within this series – '*Sustainable healthcare*', '*Procurement and carbon costing*', '*Medical gases*', '*Processes, pathways, and journeys*', '*Energy use and water consumption*', '*Waste- what happens to it*' and '*The anaesthetist as an educator*'.

A sustainable healthcare system has been defined as one that is able to deliver "high quality care and improve public health without exhausting natural resources or causing severe ecological damage".[1] The NHS is one of the largest public sector contributors to climate change, with carbon dioxide emissions in excess of 20million tonnes each year.[36] In an effort to improve environmental sustainability the NHS Carbon Reduction Strategy was set out in 2009. This outlines the measures that will need to be taken for the NHS to meet the targets from the Climate Change Act (2008). As previously stated, the overall target is for the UK to demonstrate a reduction in its carbon emissions to net zero, in relation to the 1990 values, by the year 2050.[37]

To assist the NHS in meeting this target, in 2008 two organisations came into existence, the Centre for Sustainable Healthcare, and the Sustainable Development Unit (now known as Greener NHS). The Centre for Sustainable Healthcare is a charitable organisation working with healthcare professionals, patients, and members of the public to promote the connections between maintaining good health and caring for the environment.[38] They have outlined 4 principles of sustainable clinical practice, which are:

- Prevention
- Patient empowerment and self-care
- Lean systems
- Low carbon alternatives

These principles have been reiterated by Public Health England, who collaborated with the NHS and social care providers in 2014 to address the issues of sustainable healthcare. Their three aims focus upon creating and maintaining a healthy environment, building resilience within the population to achieve health, and preventing or managing health problems where possible.[39] Greener NHS is an organisation working with the NHS and Public Health England to promote the three elements of sustainability – environmental, social and financial.[1] They work with the Government assessing the sustainable development requirements of public healthcare in England and supporting processes to reach the zero carbon emission goal by 2050.

On a global scale, the World Health Organisation (WHO) recognised the changing demands of healthcare in 2012, introducing the Health 2020 policy to address these needs.[40] Ensuring the sustainability of all European health care systems was one of its central policies. Within this report they stress that "collaboration between environmental and health sectors is crucial to protect human health from the risks of a hazardous or contaminated environment".[40] The achievement of these targets will rely upon investment from every possible sector, ranging from the government to healthcare professionals and patients themselves.

As anaesthetists we are uniquely situated in the healthcare service battle against climate change. We are the largest specialty amongst hospital doctors, and our collective actions can therefore be used to exert leverage within our organisations and beyond. We are frequently individual practitioners with the freedom to choose how we deliver the best care to our patients from a wide range of techniques. However, collectively our influence can stretch far beyond the encouragement of TIVA and regional options, and the avoidance of desflurane and nitrous oxide. Through working with our industry partners, we are able to change the supply chain and procurement, opting for more sustainable options wherever possible. This has already been demonstrated through surveying anaesthetists on whether they utilise plastic hook rings on anaesthetic facemasks, and subsequently discontinuing their use.[41] We all have a responsibility to take action, lowering carbon emissions and reducing drug wastage. Ensuring we remain updated with new developments and making more environmentally considerate choices will be the first step in our journey towards providing greener anaesthesia for our patients.

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Royal College of Anaesthetists
Churchill House, 35 Red Lion Square, London WC1R 4SG
020 7092 1500 | e-LA@rcoa.ac.uk | rcoa.ac.uk/e-learning-anaesthesia

@RCoANews
RoyalCollegeofAnaesthetists

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