Green Surgery

Reducing the environmental impact of surgical care

brighton and sussex medical school

CENTRE for SUSTAINABLE HEALTHCARE inspire • empower • transform

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Foreword

The climate crisis is the major threat to health, says the World Health Organization. The harm is already here and increasingly visible to everybody with fires, floods, storms, and heatwaves, although these are only some of the ways that climate change harms health. Without concerted action the biggest harm will come from loss of land, water, and food, conflict, and forced migration. The world must do everything it can to reduce emissions of greenhouse gases, which means change at every level from the global to the personal, including in health systems and surgical practice.

Some people are surprised to learn that health systems are part of the problem as well as part of the solution, but, as this report makes clear, health systems are responsible for 4.4% of global emissions compared with 2.5% from aviation. If health systems were a country they would be the fifth largest emitter of greenhouse gases, and most health systems have rising emissions. Surgical practice is one of the biggest single causes of health system resource use, accounting for around 27% of NHS England financial spend and an estimated 5.7 million tonnes CO_2e per year.

An increasing number of health systems are committed to reaching net zero carbon emissions, and this will mean substantial changes not just in energy supply, buildings, transport, procurement, and much more but also in clinical practice. Who should lead those changes in clinical practice? The obvious answer is clinical teams, and that is the logic behind this report. Surgical teams should lead the changes in surgical practice, and this report brings together all those involved in surgical practice and the colleges and organisations that represent them.

The report assembles all the current evidence and is filled with recommendations, some of them easy to implement, others more difficult. Although the report has been produced primarily with the UK in mind, there is much that will be useful to surgical teams everywhere. Nobody knows how to achieve net zero in surgical practice, and the report makes clear that much more research and innovation will be needed. We need urgently to improve funding for getting all of healthcare, including surgical practice, to net zero, and we need to provide training and career paths for researchers.

Assembling this report has been a great deal of work, but even harder than writing the report is making it happen. The report includes a chapter on implementation, and leadership and education will both be crucial. The team will stay together to work on implementation, and the surgical colleges and its leaders will have a vital role.

Surgical practice like all of healthcare depends on teams, and this report brings together those from all parts of surgical practice. It is the first of what we hope will be a series of reports, bringing together people from all parts of the health system to work on issues like community services, prescribing, adaptation, and end of life care. The authors of the report have provided an excellent model of how to work together, assemble the evidence, and support implementation.

I thank the Health Foundation for funding this work, the team who have written the report, the many who have advised, and those who have overseen the process. This is work that will benefit all – patients, surgical teams, those running health systems, and ultimately the people of the world, for whom the potential harm from climate change will be reduced.

Dr Richard Smith CBE FMedSci
Chair, UK Health Alliance on Climate Change

Executive Summary

The Green Surgery report provides initiatives and recommendations to reduce the adverse impact of surgical care on the environment, based upon evidence synthesis and case studies. It also considers barriers and facilitators to implementation. Key contributors of emissions in the operating theatre include products (in particular single-use items), energy consumption, and anaesthetic gases (many of which are powerful greenhouse gases).

Circular economy principles may be used to mitigate the carbon footprint of products used for surgery, including reduction (e.g. streamlining single-use pre-prepared sets through removing unused items, and appropriate use of personal protective equipment) and switching from single-use to reusable equipment where appropriate. Where "reduce and reuse" are not possible, the lifespan of items can be extended through repair and remanufacture, and the recycling of waste.

In terms of energy use, staff in the operating theatre can switch off unused equipment, or turn equipment down where appropriate. In the design of operating theatres there are opportunities to install motion sensors for lighting, alongside use of shutdown checklists, using energy efficient lighting and appliances, and opting for clinically appropriate ventilation systems with lower energy consumption and appropriate set back modes; all with potential for retrofit. Hospitals can use (and ideally generate) renewable energy.

Anaesthetic gases are an important source of greenhouse gas emissions (in particular desflurane, which is being phased out across the NHS). Volatile anaesthetic emissions can be mitigated by switching to more environmentally preferable options, including using local, regional, and intravenous anaesthesia. Emissions associated with nitrous oxide can be reduced through decommissioning of centrally piped nitrous oxide and substitution with portable cylinders.

Outside of the operating theatre, we can optimise end-to-end surgical care pathways. Improving the quality of patient care goes hand in hand with sustainability, ensuring optimal use of resources and maximal patient benefit. This includes minimising unwarranted variation (over-use or under-use of surgical care) and using shared decision-making to ensure surgery is the right option for the individual patient. We can work with patients to optimise their health and wellbeing ahead of surgery, reducing risk of complications (also associated with emissions), with co-benefits to human and planetary health. There are opportunities to streamline patient pathways, including rationalising peri-operative investigations, and use of remote consultation supported by digital technologies. There are opportunities to increase the proportion of operations undertaken in ambulatory day-case settings, or outpatient clinics. More broadly, shifting resources towards public health to prevent individuals becoming surgical patients in the first place will reduce surgical emissions.

To implement these changes we call upon leaders (including national representative bodies, and at organisational and departmental level), educators, policy makers, and academics. Change will require engagement from all those in the surgical ecosystem, including senior and trainee surgeons, anaesthetists and anaesthetic trainees, nursing staff, operating department practitioners, and other allied health professionals, alongside colleagues in infection prevention and control, primary care, and public health practitioners. We must also work with our procurement teams, industry partners throughout the medical supply chain, and supporting services (including facilities and estates, instrument and linen reprocessing, and waste facilities), to optimise emissions associated with use of surgical products.

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We also thank all those who submitted case studies, the oversight committee for their contributions throughout the process and those who provided feedback during open consultation. Case studies featured in this report illustrate examples of real-world change, but outcomes data have not been verified and some financial and greenhouse gas emission figures are based on projections.

Appendix 1 provides an overview of the process for developing this report.

We are grateful to the Health Foundation for funding this project.

The Green Surgery Report is endorsed by the following organisations:

Abbreviations

AGSS	Anaesthetic Gas Scavenging System
AHP	Allied Health Professional
CFU	Colony Forming Unit
CJD	Creutzfeldt-Jakob Disease
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide equivalents
COP	UN Climate Change Conference of Parties
COVID-19	Coronavirus Disease 19
CT	Computerised Tomography
ECG	Electrocardiogram
ERP	Enhanced Recovery Protocol
FGF	Fresh Gas Flow
FiO_2	Fraction of Inspired Oxygen
G&S	Group and Save Test
GHG	Greenhouse Gas
GIRFT	Get It Right First Time
GMC	General Medical Council
GP	General Practitioner
GWP	Global Warming Potential
HEPA	High Efficiency Particulate Air Filter
HTM	Health Technical Memoranda
HVAC	Heating, Ventilation, and Air Conditioning
IPC	Infection Prevention and Control
IPCC	Intergovernmental Panel on Climate Change
LAF	Laminar Airflow
LCA	Life Cycle Assessment
LED	Light Emitting Diode
MAC	Mean Alveolar Concentration
MRI	Magnetic Resonance Imaging
N_2O	Nitrous Oxide
NHS	National Health Service
NICE	National Institute for Health and Care Excellence
ODP	Operating Department Practitioner
PIR	Passive Infrared Sensor
PM	Particulate Matter
PPE	Personal Protective Equipment
PPN	Procurement Policy Note
PSP	Priority Setting Partnership
QI	Quality Improvement
QR Code	Quick Response Code
SSD	Sterile Services Department
SusQI	Sustainable Quality Improvement
T_CAF	Temperature Controlled Air Flow
TIVA	Total Intravenous Anaesthesia
TMA	Turbulent Mixed Airflow
TURBT	Trans Urethral Resection of Bladder Tumour
UCV	Ultra Clean Ventilation
UK	United Kingdom
UN	United Nations
USA	United States of America
vCJD	Variant Creutzfeldt-Jakob Disease
WAG	Waste Anaesthetic Gas
WHO	World Health Organization

1. Introduction

Section key points

- Climate change is the greatest threat to human health in the 21st century.
- Healthcare provision contributes to ~4.4% of total global greenhouse gas emissions.
- Surgical care is a major area of resource consumption, with the carbon footprint of surgical care in the UK in 2019 estimated at 5.7 million tonnes CO_2e.
- Carbon hotspots in the operating theatre include anaesthetic gases, energy, and products (particularly single-use).
- There are known labour rights abuses within the supply chain of products used in surgical care.
- Sustainable surgery involves providing high-quality, high-value surgical care in a way that is environmentally, socially, and financially sustainable.
- The NHS, alongside the healthcare systems of 27 other countries have committed to Net Zero Carbon targets; the majority of UK healthcare staff and the public support this ambition.

1.1 Interplay between human health and planetary health

Following the industrial revolution of the late eighteenth century, a new geological era began (the 'Anthropocene'), in which human activities became the primary driver of environmental change.[2] **Planetary boundaries** describe environmental thresholds within which humanity can safely survive and thrive, of which four have already been crossed; climate change, land-system change, loss of biosphere integrity, and altered biogeochemical cycles (others considered in the 'safe' zone are stratospheric ozone depletion, ocean acidification, and freshwater use, whilst atmospheric aerosol loading and novel entities have not yet been quantified).[3] An additional planetary boundary relating to 'green water' has recently been defined (relating to terrestrial precipitation, evaporation, and soil moisture), and has already been crossed.[4] **Climate change** can be defined as long-term changes in mean average weather conditions, or their increased variability,[5] and is considered a 'core' planetary boundary due to its importance to stability of other environmental systems.[3]

The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) concluded that **human activity is the unequivocal cause of rapid global warming of the atmosphere, land, and oceans**.[6] This is driven largely by anthropogenic (originating in human activity) emissions of gases which absorb infrared radiation (greenhouse gases, GHGs), including carbon dioxide (CO_2), methane, nitrous oxide, and halogenated gases.[6] The rate of climate change is unprecedented and accelerating, with atmospheric CO_2 (forecast global average 419.2 parts per million in 2023) at its highest ever concentration in two million years.[7]

The landmark Paris Agreement set a legally binding international treaty to limit global warming to 2 °C, preferably 1.5 °C (compared with pre-industrial levels). It was signed by 196 parties at the 21st United Nations (UN) Climate Change Conference (COP21) in 2015.[8] The majority of countries (representing 90% of world Gross Domestic Product) have committed to reaching **net zero emissions** by the middle of this century,[9] defined as the state in which anthropogenic GHG emissions are balanced by anthropogenic removal of such emissions.[5]

Box 1: A note on Carbon Footprints and Life Cycle Assessment (LCA)

Around three-quarters of anthropogenic GHG emissions are made up of carbon dioxide,[10] and CO_2 is therefore used as a reference gas. Non-CO_2 GHGs can be assigned a global warming potential (GWP), based on the amount of radiative forcing (heating effect) associated with one tonne of a given gas relative to one tonne of CO_2, over a set time-period,[5] typically 100 years. In this report, a '**carbon footprint**' is defined as the estimation and summation of direct and indirect GHG emissions associated with a given product or process, including non-carbon GHGs which are converted to carbon dioxide equivalents (CO_2e) based on their global warming potential.

The term 'carbon' is sometimes used as shorthand to encompass other GHGs; for example, 'net zero carbon', 'carbon cost', or 'reduce carbon' may relate specifically to CO_2, but often implies inclusion of other GHGs (as in this report).

In this report, a **life cycle assessment** (LCA) is defined as the evaluation of the cumulative environmental impact of a product or process across a range of environmental impact categories, including but going beyond only the carbon footprint. Through applying a consistent methodology to different units of analysis (e.g. different products serving the same clinical function), this allows us to quantify and compare environmental impacts.

Impact of climate change on human health

Planetary health is intricately linked with human health, and climate change has been proposed as the greatest threat to human health in the 21st century.[11] Climate change threatens public health through:

Direct impact of extreme weather events

- For example, heatwaves, flooding, drought and storms.[12]
- Modelling indicates global warming of 4.1 °C could lead to 83 million cumulative excess global deaths between the year 2020 and 2100, whilst limiting warming to 2.4 °C could avert nearly 90% (74 million) of those deaths.[13] This model assumes a mortality cost of carbon at one excess death per 4,434 metric tons of CO_2.[13]

Indirect impacts of global warming

- For example, those associated with poor air quality, food and water insecurity, and transmission of climate-sensitive infectious disease.[14]
- Air pollution is the largest environmental cause of morbidity and premature death, with 3.3 million deaths attributable to anthropogenic air pollution in 2019.[12] We note that whilst a small proportion of air pollution relates to climate change itself (such as temperature inversions, desert dust movement),[15] the majority of air pollution is caused by the extraction and burning of fossil fuels (which also drives climate change).[16]

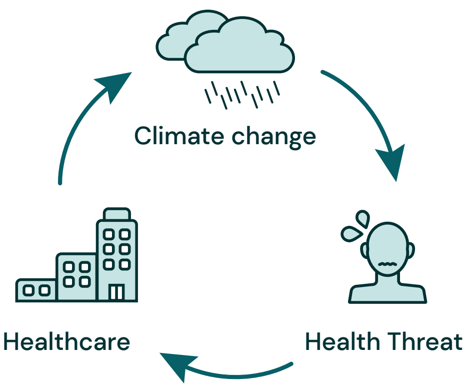
Vulnerable individuals are at greatest risk of climate-related health impacts including those with existing health conditions, older people, and children.[12] Health impacts of climate change also risk **widening inequalities** (and the associated health gap) and follow a social gradient, with those at highest levels of socioeconomic deprivation most likely to suffer from food and water insecurity, whilst also being least able to adapt their homes or move, and to suffer disproportionately from uninsured losses.[14] In contrast, the poorest half of the world population contributes only a small fraction of global GHGs (estimated at 7%), demonstrating **climate injustice**.[17]

Health and equity were more prominent topics in the 2021 UN Climate Change Conference of Parties (COP26) than in previous COP meetings. This led to more than 70 countries committing to strengthen the climate resilience and lower the emissions of their health systems.[18] The World Health Organization (WHO) released a special report ahead of the conference, calling upon government and policy makers to rapidly bring about transformative change to protect both planetary and human health.[14] An open letter entitled 'Healthy Climate Prescription' signed by 600 organisations representing 46 million nurses, doctors and healthcare professionals globally called upon world leaders to **"avert the impending health catastrophe by limiting global warming to 1.5°C, and to make human health and equity central to all climate change mitigation and adaptation actions"**.[19] An editorial published in over 220 health journals delivered a similar message.[20]

Environmental impact of healthcare

Whilst climate change threatens human health,[11] healthcare provision paradoxically contributes to the problem (Figure 1).

Figure 1: Interplay between human and planetary health



Health Care without Harm estimated that the **healthcare sector is responsible for 4.4% of global net emissions**, and that if the healthcare sector were a country it would be the fifth largest emitter.[21] The National Health Service (NHS) in England generates an estimated 25 million tonnes CO_2e per year,[22] responsible for around 4% of national GHG emissions.[23] This includes three 'scopes' of greenhouse gas emissions (Table 1).

Table 1: NHS England Greenhouse Gas (GHG) contributions[22]

Scope	Definition	Example	Responsible for % of NHS England GHG emissions
Scope 1	GHGs directly emitted from (and controlled by) an organisation	• Anaesthetic gases • Hydrofluorocarbons or chlorofluorocarbon propellants from metered dose inhalers	5%
		• Direct emissions from combustion of petrol or diesel from NHS owned and leased vehicles	4% (alongside other business travel– categorised as scope three emissions)
		• Combustion of fossil fuels onsite (such as within gas boilers)	10%
Scope 2	GHGs indirectly emitted due to energy purchased	• Purchased energy in the form of electricity, steam, heating or cooling	
Scope 3	All other GHGs	• Supply chain, including: • Pharamaceuticals and chemicals • Medical equipment • Non-medical equipment	62%
		• Patient, visitor and staff travel	10%
		• Water and waste disposal	5%
		• Commissioned services	4%

GHG emissions associated with the supply chain for healthcare made the largest contribution to the NHS carbon footprint (almost two-thirds), of which pharmaceuticals and chemicals (20% of total) and medical equipment (10% of total) were the biggest contributors.[22] 'Medical equipment' includes products used directly for delivery of healthcare such as surgical instruments, syringes for administering medications, and medical gloves.

The environmental impact of healthcare delivery extends beyond global warming, for example nitrous oxide and halogenated anaesthetic gases such as isoflurane contribute to **ozone depletion**, reducing the shielding effect of the atmosphere from ultraviolet radiation and increasing risk of skin cancer in affected regions.[24] The healthcare sector contributes to **air pollution**, and has been estimated to generate 2.8% of global particulate matter (PM_{10}) emissions, and 3.4%-3.6% of the air pollutants nitrogen oxides and sulphur dioxide.[25] In England in 2017 it was estimated that 3.5% of all road travel was related to the NHS (9.5 billion road miles), and generated 330 t of $PM_{2.5}$ and 7,285 t of nitrogen oxide.[26] The provision of healthcare also has a large **water footprint** (estimated at 2.23 billion m^3 in England),[26] contributing to water scarcity.[25]

Ecotoxicity refers to adverse effects of anthropogenic chemical, physical, or biological agents on ecosystems. Use and disposal of pharmaceuticals is associated with increased concentrations of bioactive pharmaceutical compounds in water systems and soil, including antibiotics, analgesics and anti-inflammatory drugs.[27] Pharmaceutical residues may be absorbed by other species such as fish, reptiles, and birds, at a rate faster than elimination, leading to bioaccumulation.[27] Healthcare is increasingly reliant upon **single-use plastics**, with the global medical plastics market responsible for 2% of total plastics production by value, and growing by 6.1% per year.[28] This contributes to global warming through burning of fossil fuels in manufacturing processes,[29] and contributes to accumulation of plastic fragments in our biosphere. There is also evidence of high levels of **microplastics** in the operating theatre, which may be due to the high levels of plastic materials in use.[30] The consequences of such exposure to the health of staff or patients are not yet fully known, and there is emerging evidence that some microplastics and their additives can induce cytotoxicity, hypersensitivity, immunotoxicity, and endocrine disruption.[31]

In light of increased awareness of both the impact of planetary health on human health and the environmental impact of the healthcare sector itself, there is a growing movement towards mitigating the environmental impact of healthcare provision. The United Kingdom (UK) has been a leading proponent of sustainable healthcare. The Well-being of Future Generations Act was passed in Wales in 2015, requiring public bodies to consider the UN Sustainable Development Goals and climate change.[32] In 2019, Scotland became the **first national healthcare system to commit to meeting net zero carbon emissions** (as part of wider Scottish Government targets).[33] **The Greener NHS in England** (formed in 2020) was the first national healthcare organisation to publish a full strategy to decarbonise the healthcare system, setting targets for meeting net zero carbon emissions within the direct control of the NHS by 2040, and to extend this to those in the supply chain by 2045.[23] All these policies were built upon the foundation of the NHS Sustainable Development Unit Carbon Reduction Plan, first formulated in 2009.[34] **The UK became the first country to integrate this into legislation**, amending the Health and Care Act in 2022 to specify compliance with the Climate Change Act, and the Environment Act.[35]

27 countries have now joined the UK in making Net Zero commitments for their healthcare systems, and another 73 countries have pledged to develop low carbon, sustainable health systems.[18] Healthcare systems will also need to adapt to meet increased demands caused by direct and indirect health impacts of climate change, and to ensure that healthcare facilities can withstand extreme weather events such as flooding and heatwaves, alongside (where relevant)

rising sea levels. For example heatwaves in 2022 led to widespread elective surgery cancellations in the UK.[36] Improving preparedness for climate change may help reduce the impact on surgical care provision.

1.2 The environmental impact of surgical care

An estimated **313 million surgical procedures were performed worldwide in 2012**, representing a one-third increase in volume over eight years.[37] This upward trend has been disrupted in recent years by cancellations and delays to planned elective surgical care relating to the COVID-19 pandemic.[38]

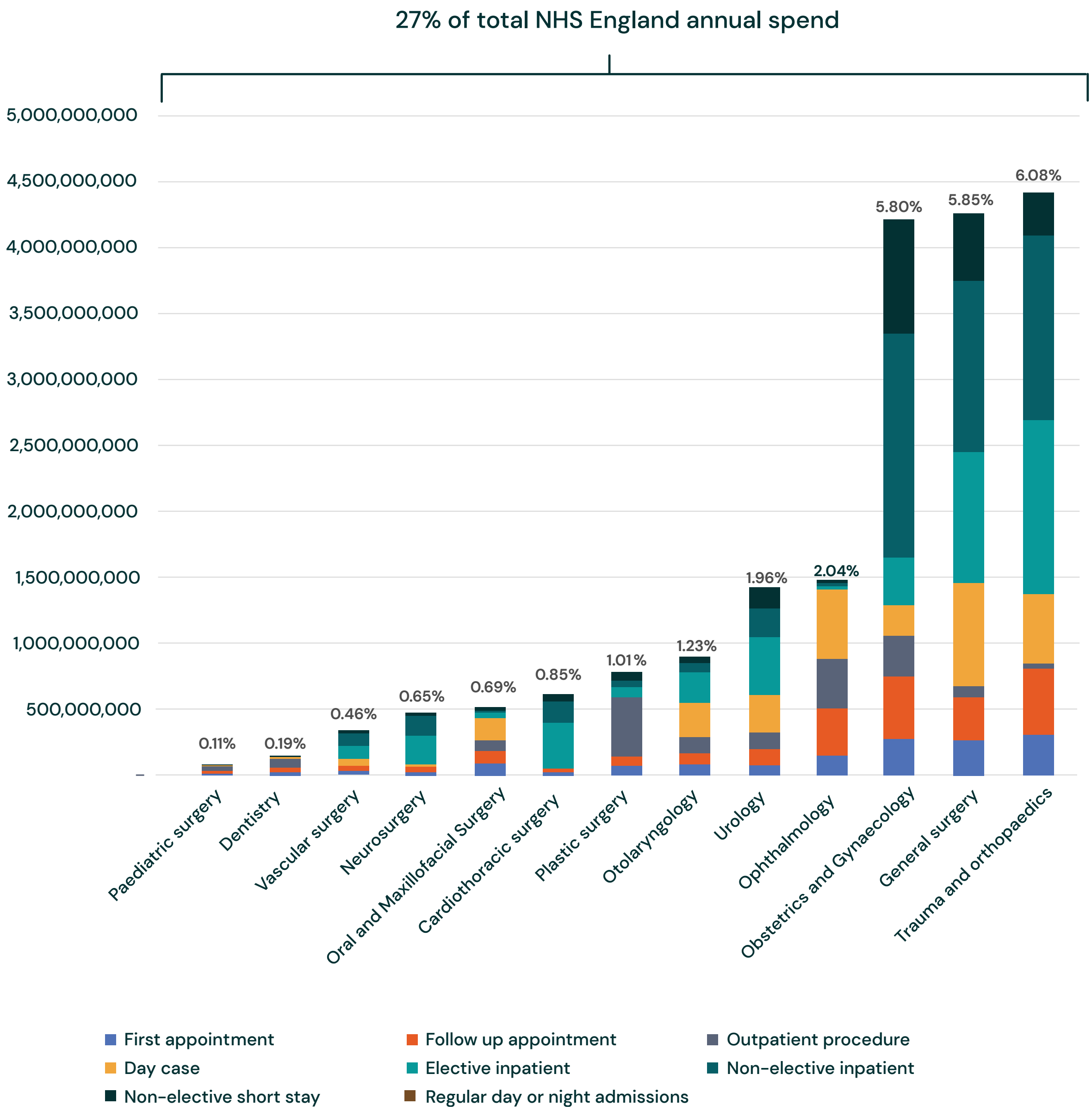
Surgical volume is dependent on how surgical 'procedures' are defined, for example between 2009 and 2014 an estimated 1.5 to 7.9 million procedures (at a cost of £5.6 to £10.9 billion) were performed each year in the UK, with lower figures derived using a 'restrictive' categorisation of a procedure (only major procedures), and higher for an 'inclusive' categorisation (including minor surgery, interventional radiology procedures and diagnostic endoscopies).[39] The total cost of surgical procedures (using the higher figure, but excluding upstream outpatient appointments and investigations, or downstream follow-up and management of complications) was previously estimated to account for **9.4% of the total NHS budget**.[39]

The scope of surgical care extends beyond operations and encompasses surgical patient pathways. Based on NHS England financial spend in 2019/2020,[40] (analysis in Appendix 2), we estimate that surgical care including outpatient appointments, procedures, and inpatient admissions cost £19.5 billion; this amounts to 27% of the £72.6 billion NHS England total spend on acute, community, ambulance and mental health providers in the financial year. Applying this proportionately to the 16.3 million tonnes of CO_2e associated with these areas in 2019,[22] we estimate that the carbon footprint of surgical care in England totalled 4.8 million tonnes of CO_2e in 2019. Assuming the same carbon intensity of surgery per person in the population across other UK nations, we estimate that in 2019 the carbon footprint of surgical care in Northern Ireland was 162 kilotonnes CO_2e, in Scotland was 468 kilotonnes CO_2e and in Wales was 270 kilotonnes CO_2e. The summated estimate of the **carbon footprint of surgical care in the UK in 2019 is therefore 5.7 million tonnes of CO_2e**. To offset this would require planting of over half a million hectares of forest, an area more than triple the size of London.

Figure 2 breaks down the NHS England annual spend by surgical specialty in the 2019/20 financial year. The three specialties with highest financial spend were trauma and orthopaedics (6.1% NHS England annual spend), general surgery (5.9%), and obstetrics and gynaecology (5.8%). Across all surgical specialties, when broken down by type of financial spend:

- 7% related to 9.7 million first outpatient appointments
- 11% to 17.4 million follow-up appointments
- 7% to 9.8 million outpatient procedures
- 16% to 3 million day-case procedures
- 22% to 821,000 elective inpatient admissions
- 26% to 1.1 million non-elective long stay inpatient admissions
- 11% to 2 million non-elective short stay inpatient admissions

Figure 2: Annual spend on surgical care in NHS England, 2019/20



Based on NHS England national cost collection, financial year 2019/2020.[40] Percentage above bars indicates proportion of total NHS England annual spend on acute, community, ambulance and mental health providers

The operating theatre

The operating theatre is a resource-intensive area of a hospital, using large quantities of single-use products (which typically generate around one-fifth of total hospital waste),[41] and is three to six times more energy intensive than the rest of the hospital.[42] A study examining operating suites in Canada, the United States of America (USA), and the UK estimated that a **typical operation** had a carbon footprint of 146-232 kg CO_2e,[42] comparable to emissions associated with driving **400-650 miles** in an average petrol car.[43] The same study found that a typical operating department in a large UK hospital generated over 5,000 tonnes CO_2e per year,[42] equivalent to driving an average petrol car 580 times around the Earth.[43]

The principal components that make up the carbon footprint of an operating theatre are:

- Anaesthetic gases
- Reusable and single-use products
- Energy associated with the maintenance of the theatre environment (heating, ventilation, air-conditioning, lighting) and other electronic equipment
- Water
- Pharmaceuticals
- Patient and staff travel
- Capital goods
- Hospital infrastructure

The relative contributions of each of these components will vary in different settings and with different operations. Reviews report the biggest contributors to the carbon footprint (**carbon hotspots**) of operations to be **anaesthetic gases, energy usage**, and **products** used in surgery.[44,45]

1.3 Labour rights abuses in surgical products

In addition to the environmental impact of surgery, reports over the last fifteen years document cases of **labour rights abuse** in the manufacture of products used in healthcare, including surgical care in the NHS. This includes:

- **Sweatshop** and **child labour** in the manufacture of both disposable and reusable steel surgical instruments and laryngoscope blades in Pakistan (Figure 3)[46-48]
- Forced migrant labour in the manufacture of gloves in Malaysia[49] and Thailand[49,50]
- State-sponsored Uyghur and North Korean forced labour in the manufacture of masks and gowns in China[51,52]
- Labour rights violations in the manufacture of surgical masks in Mexico,[53] nurse uniforms in India,[54] and surgical drapes in Thailand[55]
- Likely labour rights harms in the manufacture of electrosurgical equipment, given known issues in electronics supply chain[56]

A lack of transparency in supply chains makes it difficult to accurately qualify labour risk in products used in surgical care, but risk is high for high volume low-complexity products, usually sourced at low price from countries known to have weak legislation, policy, and track record in protecting workers.[57-59] Purchasers always consider value for money, but it is often the case that little consideration is given to the conditions in which the products are made, the impacts on the people who make them, or the environmental implications for manufacturing countries.[59] Practices of procuring **cheap disposable healthcare products drive GHG emissions and environmental degradation** at sites of material extraction and manufacture, as well as significantly raising the **risk of labour rights harm**.[59-61]

Over the last decade, increasing regulatory efforts have been made at advancing the ethical procurement of healthcare products globally, ranging from the implementation of suppliers' codes of conduct to import bans. Developments in the UK include the Modern Slavery Act 2015[62] and the Health Care Act 2022[63,64] which require purchasers to obtain assurances regarding labour standards in the products they procure.

These legislative and regulatory initiatives have led to some demonstrable improvements, but serious labour rights harms persist[48,50] because the uptake, enforcement, and monitoring of socially sustainable procurement processes has not been widespread.[59] One reason for this is the complexity and **limited transparency** in multi-tier surgical value chains, which often limits procurers' ability to monitor standards and verify whether suppliers are meeting due diligence requirements.[48,57,65] Evidence also suggests that only a small fraction of contract breaches result in sanctions.[58]

Advancing a socially sustainable model for surgical products requires:

- **Labour rights protection embedded** in purchasing decisions[49]
- Supply chain transparency[66]
- Collaborative buyer-supplier-manufacturer relationships[67]
- A clear system of rewards and sanctions[57]

These strategies are also essential for supporting the transition towards greener products used in surgical care.

Figure 3: Manufacture of steel surgical instruments in Sialkot, Pakistan

Photo credit: Martin Kunz

1.4 Principles of sustainable healthcare and the triple bottom line

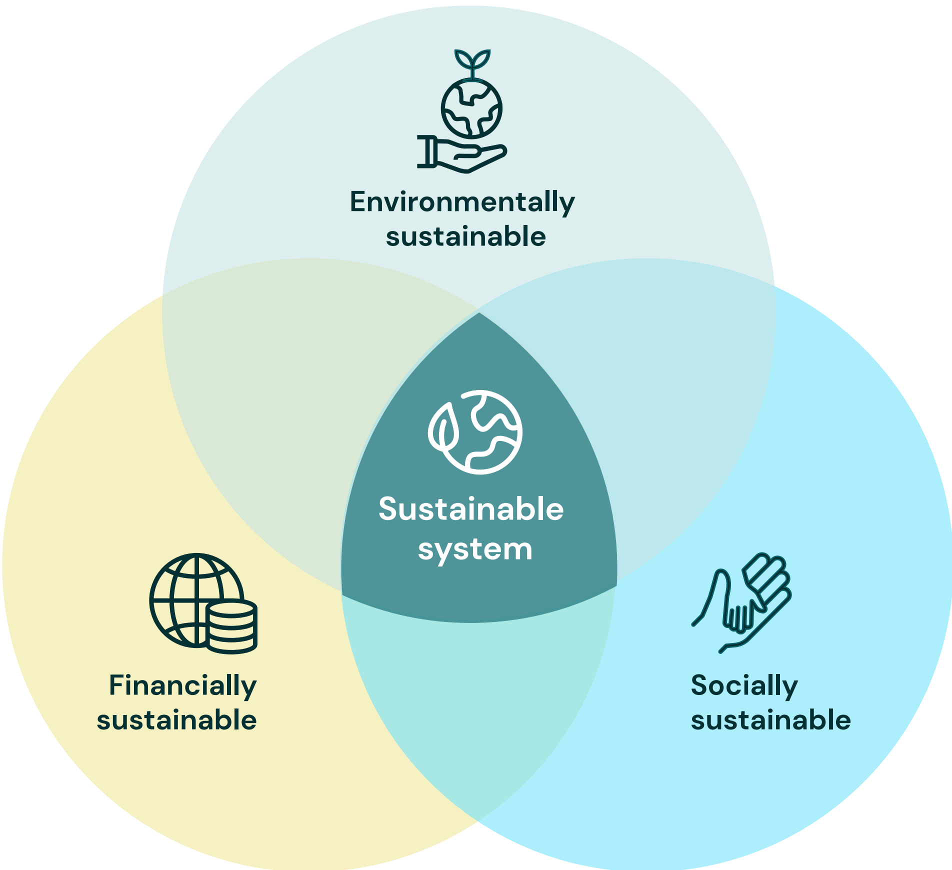
The UN 2030 Agenda for Sustainable Development aims to provide a 'shared blueprint for peace and prosperity for people and the planet, now and into the future'.[68] With this aim, 17 **UN Sustainable Development Goals** have been set, illustrating the complex interdependence between improving health and wellbeing, reducing inequality, environmental sustainability, and economic prosperity.[68]

'**Doughnut economics**' is another conceptual framework used to guide sustainable use of resources,[69] which encourages humanity to operate in the safe and just space between meeting basic social needs (in line with the UN Sustainable Development Goals),[68] whilst not exceeding the maximum ecological ceiling (which can be defined by the planetary boundaries previously discussed).[3]

Another core concept used to frame sustainable healthcare is the '**triple bottom line**', which encompasses the environmental, social, and financial costs of human activities[70] (alternatively referred to as the three Ps of people, planet, profit). This considers systems to be sustainable only where the three considerations intersect (Figure 4).[70]

We recognise that the triple bottom line framework has some limitations, including in evaluation (for example to provide valid measures for each pillar of sustainability), in practical application (for example where priorities to provide safe and high quality clinical care may conflict with other goals), and in strategic prioritisation (for example where investment in whole system change is more important than short term fixes).

Figure 4: Triple bottom line of sustainability



In line with these concepts, 'sustainable healthcare' is defined in this report as the provision of healthcare in a manner which meets health and wellbeing needs without direct or indirect negative impact on the health (or potential to provide healthcare) of populations separated by socioeconomic status, geography, or time. This report focuses on the environmental element of sustainable healthcare, with the definition extending to respect non-human life, and the term 'sustainability' and 'sustainable' are used hereon in to refer to environmental sustainability.

Section recommendations

Recommendation	Short term	Long term	Stakeholders
R1.1 Raise awareness of links between human and planetary health, and sources of greenhouse gas emissions in surgery	Have conversations with colleagues, patients[a,b] Share Green Surgery report with colleagues[a]	Develop educational resources[c]	Healthcare professionals[a] Patients[b] Educators[c]
R1.2 When designing healthcare interventions, consider impact on environmental, financial, and social sustainability whilst maintaining or improving patient and population outcomes	Consider sustainability within audit, quality improvement, and research projects[a]	Consider sustainability at all stages of surgical care delivery, including upstream supply chain and supporting services[a,d,e,f]	Healthcare professionals[a] Healthcare provider management teams[d] Supporting services[e] Industry[f]

Note: Letters in superscript after each short and long-term recommendation correspond with letters after each stakeholder group, indicating the group(s) with primary responsibility. This applies to all subsequent Section Recommendations in the Report.

2. Reducing need for surgical care

Section key points

- Prevention may reduce GHG emissions associated with the provision of surgical care, for example surgical conditions linked with obesity, dietary factors (including red and processed meat consumption), sedentary lifestyles, trauma, and exposure to cigarette smoke, alcohol, ultraviolet light, air pollution and human papilloma virus.
- Delivering the right care to the right patient, at the right time and place, and reducing unwarranted variation in surgical care can ensure that carbon emissions associated with surgery are optimised.
- Using shared decision-making and ‘choosing wisely’ principles may help empower patients to work alongside clinicians to ensure a given intervention is right for them.

2.1 Public health and prevention of surgical disorders

Prevention is one of the pillars of sustainable healthcare,[71] and **prevention of surgical disorders** will reduce carbon emissions associated with such care provision.

Prevention of disease (or disease progression) can reduce carbon emissions through:

- Preventing disease occurrence, to reduce overall requirement for healthcare
- Preventing progression of diagnosed disease, or its complications, which may reduce frequency and intensity of healthcare intervention

Smoking, poor diet, physical inactivity, and harmful alcohol use are leading risk factors for ill health and premature mortality in the UK[72] and globally.[73] Many of these risk factors are more prevalent in low- and middle- income countries, and among individuals living in socio-economic deprivation.[74] Some of the conditions caused by these **modifiable risk factors** may ultimately require surgery, and are at least in part preventable, for example:

Obesity

- Risk factor for osteoarthritis (and subsequent need for knee and hip replacement),[75] symptomatic gallstones (necessitating gallbladder removal),[76] and abdominal or inguinal hernia development (which may require repair).[77] These comprise some of the most common surgical procedures in the UK.[78] Obesity is also associated with increases in gastro-oesophageal reflux disease (which may be managed surgically), metabolic disorders such as diabetes, and respiratory diseases (obstructive sleep apnoea), in turn leading to rising numbers of bariatric procedures and complications after surgery. Obesity is also the second biggest modifiable risk factor for cancer in the UK, including uterine and oesophageal cancer.[79]

Diet

- Foods associated with gastrointestinal diseases which may require surgical management include red and processed meat (associated with increased risk of colorectal cancer),[80] foods high in fat, refined sugar and fructose (associated with increased risk of gallstone formation),[81] and saturated fats (associated with atherosclerotic disease).[82] Conversely, high fibre foods and whole fruit are associated with reduced risk of diverticulitis.[83]

Sedentary lifestyle

- Physical activity is associated with reduced risk of cancers including breast, colon, prostate cancer,[84] and cardiovascular disease.[85]

Smoking

- Causally associated with 25% of all cancers and responsible for one-third of cancer deaths, including those which may involve surgical management, such as cancers of the upper aerodigestive tract, oesophagus, lung, urinary tract, pancreas, stomach and liver.[86] Smoking is also a major risk factor for cardiovascular disease which may require surgical intervention (e.g. coronary artery bypass surgery, abdominal aortic aneurysm repair, peripheral vascular bypass, lower limb amputation).[87]

Alcohol

- 4% of global cancer diagnoses in 2020 were attributable to alcohol consumption, including cancers of the liver, breast, upper aerodigestive tract, oesophagus, colon and rectum.[88]

Trauma

- Tackling interpersonal violence, and initiatives to reduce road traffic accidents, knife and gun crime will reduce surgical trauma.

Ultraviolet light

- Exposure to natural or artificial (tanning bed) ultraviolet light is the major risk factor for melanomatous and non-melanomatous skin cancer. In the USA, 1 in 4 people have used a sunbed, and there has been a 25 fold increase in rates of skin cancer over the last 100 years.[89] Educational strategies to minimise ultraviolet exposure have been shown to be effective, most notably in Australia.[90]

Air pollution

- Air pollution affects a range of organ systems, including conditions which may require surgery, and may increase risk of appendicitis, cardiovascular disease, cataracts, Crohn's disease, and osteoporosis, as well as bladder, colorectal, gastric, kidney, and lung cancer.[91]

Human papillomavirus

- Human papillomaviruses are associated with one-third of infectious-agent related cancers, including cancer of the oropharynx, oesophagus, anogenital region, cervix, and breast.[92] Vaccination reduces this risk.

Health professionals can play a role in advocating for health-promoting policies on the **wider determinants of health**, which include individual lifestyle factors, social and community networks, living and working conditions (including education, housing, and unemployment) alongside general socio-economic, cultural and environmental conditions.[93] These factors are drivers of health inequalities. Public health interventions can be introduced at population level (for example regulation or legislation or population level information campaigns), or by targeting individuals (e.g. weight management services) and communities at highest risk (informed by health needs assessments).

Alongside preventing disease, individual level behaviour changes are often also beneficial for carbon reduction, representing **co-benefits**, meaning there are benefits to both human and planetary health.[94] For example, shifting from fossil fuel-based transport to walking and cycling encourages physical activity which reduces risk of obesity, heart disease and other chronic conditions, whilst also reducing emissions. Healthy diets are also recognised to have significantly lower environmental impacts.[95] In particular, reducing red and processed meat consumption lowers risk of colorectal cancer,[80] whilst also resulting in a reduced dietary carbon footprint.[96]

Screening programmes for earlier detection of disease may lead to less or lower intensity treatment, and so have the potential to reduce healthcare-related carbon emissions, including emissions related to elective surgery (such as earlier diagnosis of bowel or breast cancer) or emergency surgery (for example in aortic aneurysm management). However, screening programmes also mean that a number of healthy people undergo investigations, with some healthy people who do not have a disease going on to receive further investigation and/or treatment.[97] To date there are no comprehensive analyses of the impact of screening programmes on healthcare-related carbon emissions.

We acknowledge many unknowns in the relationship between prevention and sustainable healthcare, for example, how and to what extent prevention of disease or progression of disease for individuals may impact healthcare related carbon emissions over the life course of a given individual.

CASE STUDY: Identifying patients at high risk of fractures

Setting	Christie NHS Foundation Trust	
Patients	Patients on acute oncology ward	
Intervention	Use of FRAX assessment tool to evaluate fracture risk of patients, and provide preventative treatment (Adcal)	
Outcome		Prevention of hip fracture and subsequent surgery, prevention of interruptions to oncology treatment
		↓ 316 kg CO_2e / 100 patients (assuming 1 fracture prevented)
		↓ £3,500 / 100 patients (assuming 1 fracture prevented)

Patients with an oncology diagnosis are likely to be at higher risk of fragility fracture for several reasons. There is a lack of local and national guidance on bone protection in adult oncology patients.

In 2022, Tom Hicklin, Claire Higham, and Mohitraje Mankumare conducted a project to assess the impact of identifying and intervening on patients at high risk of fracture in an acute oncology ward at the Christie NHS Foundation Trust. The team used the FRAX Fracture Assessment tool (https://frax.shef.ac.uk/FRAX/tool.aspx?country=1) to estimate ten-year risk of hip fracture in an unselected group of oncology in-patients. They determined the workforce, environmental, and medication implications, and compared the environmental and financial cost of screening and subsequent treatment, with that of managing and treating a hip fracture.

The team modelled prevention using a calcium and vitamin D3 supplement, and estimated that for 100 patients treated, they could prevent 1 fracture per year, with projected annual carbon savings of 316 $kgCO_2e$ and cost savings of £3,500.

Source: Centre for Sustainable Healthcare[98]

2.2 Reducing unwarranted variation

There is evidence of **unwarranted variation** in healthcare, including medical expenditure, use of pharmaceuticals, use of investigations, location of surgery, and rates of surgery.

In a study from the USA, healthcare spending on hospitalised patients over the age of 65 was found to vary 1.4 fold between the highest and lowest quartile, with variation greater between clinicians than between hospitals, and no evidence of reduced 30-day mortality or readmission associated with higher spending.[99] Data from the European Union show large variations in the proportion of the population undergoing radiological investigation each year (e.g. 5% in Romania vs 35% in Austria),[100] and in the proportion of adults taking prescribed medication (e.g. 23% in Romania vs 62% in Croatia).[101] There is also evidence of over-use of medication in low and middle-income countries.[102]

Data on rates of surgical intervention evidence both over-use (surgery in cases where benefits do not outweigh risks) and under-use (where patients who would benefit do not receive surgery). For example, comparing matched populations, twice as many hip replacements are performed in some regions of the UK compared to others.[103]

Substantial variation in surgical practice across the UK exists for a range of indicators, such as in the number of patients operated on per theatre session, how many pre- and postoperative appointments patients have, or whether procedures are performed as a day-case surgery or inpatient stay. Twice as many patients are admitted overnight for standard conditions in the lowest quartile of hospitals in England compared to the highest quartile.[104] There is also evidence of variation between private and public hospitals; a study in Australia found increased rates of obstetric intervention and neonatal morbidity in low-risk women in private hospitals.[105]

The reasons underlying unwarranted variation are complex and multifactorial, and may include the 'inverse care law', whereby those most in need and suffering health inequalities are least likely to access healthcare.[106] Sustainable healthcare includes equitable access to (and provision of) healthcare. Tackling health inequalities and personalised care models taking into account diversity can optimise resource utilisation associated with surgical care. **Sustainable healthcare involves ensuring the right patients access the right care at the right time, in the right place, and that the associated carbon or other environmental burden of this care provision is necessary rather than avoidable**.

NHS England's **Getting It Right First Time** (GIRFT) program has worked with providers to understand unwarranted variation through analysing local data from the *Model Health System*, a dashboard that allows benchmarking of hospitals across the NHS, and clinically-led discussion with hospital teams to promote best practice across the system. This work is supported by a range of guidance and tools published by GIRFT; one of these tools which focuses on optimising day surgery rates contributed to a 20% shorter stay in orthopaedic settings and a 25% reduction in revision joint replacements.[107] Increased use of GIRFT day-case surgical pathways instead of inpatient surgery could help reduce healthcare-related carbon emissions. For example, if all hospitals not already in the upper quartile were able to achieve the upper quartile day-case rate for transurethral resection of bladder tumour (TURBT) in England, over 217 tonnes CO_2e could be saved per year (equivalent to powering 198 homes for 1 year).[108] This illustrates that carbon savings often go hand in hand with high quality patient care.

The newly launched GIRFT surgical hubs accreditation scheme includes two sustainability criteria within the core criteria: (1) having "an understanding of the Trust Green Plan and how this will affect the hub"; and (2) having "an awareness of and a plan to move towards The Green Theatre Checklist".[109] The latter refers to the **Intercollegiate Green Theatre Checklist**, designed to facilitate surgical teams to bring about change (featured in Section 7).[110]

We acknowledge that the environmental impact of minimising unwarranted variation will depend on whether there is net under-use or over-use, which will vary by surgical condition, and requires further research. Ultimately such strategies should aim to reduce the environmental impact of the entire range of key health outcomes at the population level.

2.3 Cosmetic surgery

Cosmetic surgery has become commonplace in the UK, with over 31,000 surgical procedures performed in 2022,[111] and has caused debate about the 'disorder' that such surgery is treating. Patients undergoing cosmetic surgery are more likely to have anxiety or depression,[112] and one in ten have a psychiatric diagnosis of body dysmorphic disorder (which may not be recognised by surgeons).[113-115] However, most patients who have had cosmetic surgery report improved psychological wellbeing,[112] but may be stigmatised and viewed by others as less attractive.[116]

In a survey of 2,000 British people, one in three participants had undergone or considered facial cosmetic surgery, rising to three quarters of those aged 18-24.[117] Amongst these younger populations the top three factors influencing the decision to undergo facial cosmetic surgery were peers (45%), social media influencers (45%), or filters on social media picture apps such as *Snapchat* (41%).[117] This raises questions on whether public health approaches targeted at improving social media literacy, mental health, and redefining cultural norms are a better approach to tackle the widespread and growing desire for cosmetic surgery.

2.4 Shared decision-making may reduce rates of surgery

It is important that clinicians work with patients to consider whether an operation is the best option for them through **shared decision-making**. **'Choosing Wisely'** is an international initiative for shared decision-making, aiming to reduce unnecessary investigations, treatments, and procedures,[118] where patients are presented with information including the natural history of their condition, conservative management, personalised risk of complications, and given opportunity to reflect before deciding the best approach for them (abbreviated to **'BRAN' - the Benefits, Risks, Alternatives and what if Nothing were done**).[119] 'Realistic Medicine' is another such initiative, seeking to empower patients and clinicians to have frank conversations about risks of healthcare procedures.[120] Trials of shared decision-making have found an average of one in five elective procedures were unwanted by the patient.[121]

Frailty and age are important factors to consider when evaluating personalised risk of complications. Two-thirds of people over 65 have multi-morbidity,[122] and this age group represents almost half of patients having an operation requiring an anaesthetist.[123] A review found that frailty was associated with a four-fold increase in post-operative complications,[124] and a study of elective noncardiac surgical patients found 15% of patients decided against a planned operation following review by a geriatrician.[125] That reluctance may be well-founded; a review found 14% of patients self-reported regret from undergoing surgery.[126] A study of 5.9 million patients undergoing major surgery in the US found an incidence of complications of 12.5%.[127] Surgery may also necessitate intensive care and the risk of this should be openly communicated. For example 25% of UK intensive care admissions follow elective surgery, and a further 18% follow emergency or urgent surgery.[128]

Shared decision-making may be particularly important in the management of cancer, whether localised, advanced or metastatic. Such patients are vulnerable and deserve an honest appraisal of survival and treatment, and associated short- and long-term morbidity. Studies have found decision-regret by patients treated for localised prostate cancer,[129] or for advanced head and neck cancer.[130]

In emergency care, non-surgical management may be considered where clinically appropriate. For some conditions, such as small abscesses (<1.5cm in maximal diameter), or uncomplicated appendicitis, the carbon footprint of medical treatment may be lower than operating. The decision will always be principally determined by clinical factors, but there may be instances where there are win-wins for patient outcomes and environmental impact. This will be context specific: if conservative management leads to a longer hospital stay, or increased risk of morbidity (including recurrence, readmission and/or subsequent surgery) then environmental harm may be greater. It is also important to note that while surgery is initially resource intensive, it may have a lower environmental impact in some chronic conditions. For example, one study found that after nine years the carbon footprint of surgery for gastro-oesophageal reflux disease was lower than that for medical treatment.[131]

Section recommendations

Recommendation	Short term	Long term	Stakeholders
R2.1 Support initiatives to prevent the need for surgical interventions (e.g. targeted towards reducing obesity, consumption of red and processed meat, smoking, and alcohol)	Identify modifiable risk factors during every patient encounter, have conversations and point patients in direction of further support and resources[a,b]	Develop public health initiatives targeted at high-risk populations[c] Shift resource allocation towards disease prevention, and initiatives that support equitable access of high-quality healthcare[d] Develop wider initiatives encouraging green patient transport[e]	Primary care clinicians[a] Members of surgical and anaesthetic team[b] Public health practitioners[c] Policy makers[d] Healthcare provider management teams[e]

R2.2 Reduce unwarranted variation in surgical care	Support initiatives which collect local data on variation and try to reduce it (e.g. Getting it Right First Time)[b]	Improve understanding of unwarranted variation in surgical care,[f,c] and develop initiatives to minimise this[c,g]	Members of surgical and anaesthetic team[b] Academics[f] Public health practitioners[c] Surgical leaders[g]
R2.3 Ensure that a given intervention is the best option for an individual patient	Use shared decision-making and 'choosing wisely principles' in every patient encounter, ensuring intervention is the right option for the individual patient[b]	Support research on personalised medicine, to better understand likelihood of success and impact of a given intervention for an individual[d]	Members of surgical and anaesthetic team[b] Academics[d]

3. Surgical care pathways

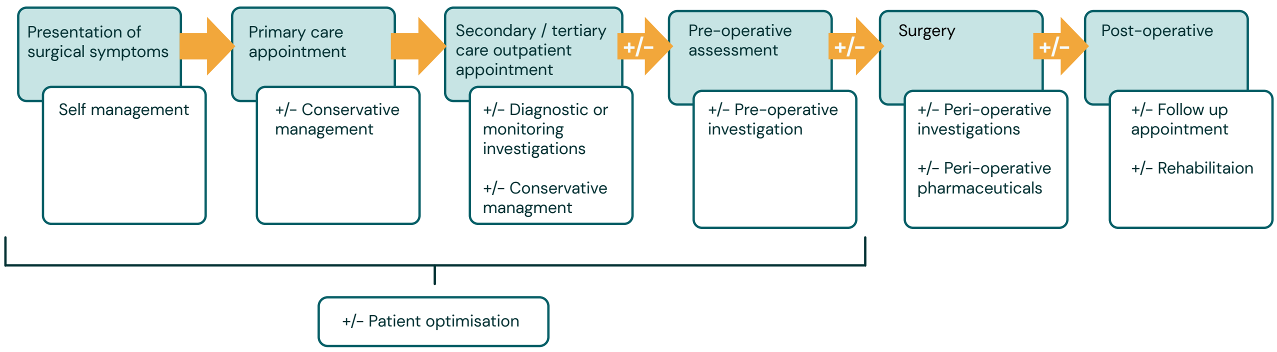
Section key points

- The environmental impact of surgical patient care can be reduced by interventions throughout the surgical care pathway.
- Streamlining patient pathways includes reducing low-value steps and unnecessary consultations (including creating 'one-stop' clinics), and rationalising and eliminating unnecessary pre-operative investigations.
- Use of telehealth, digital patient management systems and centralised lean electronic medical records can reduce carbon impacts.
- Pre-operative optimisation can reduce complication rates, including smoking cessation, alcohol moderation, exercise, nutrition, and weight optimisation.
- Operations should be performed in a timely manner, and in ambulatory day-case or outpatient settings where clinically appropriate.
- In-hospital stay can be minimised, for example through enhanced recovery protocols and early discharge planning and virtual wards.
- Post-operative tests and imaging should not be performed where unnecessary.

3.1 Streamlining surgical patient care pathways

The environmental impact of surgical patient care extends beyond the operating theatre, and must be considered throughout the entire surgical care pathway (Figure 5). There are opportunities to mitigate these effects by applying the **reduction principle** to eliminate aspects of the peri-operative journey that do not add value to patient care, which is also likely to result in financial savings. An estimated 20% of total healthcare expenditures is deemed wasteful due to over-treatment, lack of coordination, and administrative complexity.[132]

Figure 5: Surgical patient pathway



A lean management tool to assist analysis is **value stream mapping**, which can be used to identify steps that do not add value in a given surgical patient pathway, bottlenecks, and unnecessary passing of patient data between individuals (risking errors). Applied in healthcare, this often improves service quality, patient satisfaction, and safety, while minimising financial and environmental costs.[133]

It is also important to encourage both patient and staff to use sustainable methods of travel throughout the surgical patient pathway, especially where this involves active transport (with co-benefits to the individual's health). This may be supported through provision of appropriate infrastructure including showers, changing rooms, protected bike storage, and bike rental schemes.

CASE STUDY: Reducing same day surgery cancellations

Setting	Christie NHS Foundation Trust
Patients	Patients undergoing elective surgery
Intervention	Move bed planning and confirmation of bed spaces to the day before surgery, rather than on the morning of surgery
Outcome	Modelled 50% reduction in cancellations (previously 31 on the day cancellations/year), 20% reduction in over-runs
	↓ 871 kg CO_2e / year
	↓ £7,020 / year
	Reduce inconvenience to patients (e.g. time off work, unnecessary travel to hospital)

Source: Centre for Sustainable Healthcare[98]

3.2 Outpatient consultation

There were over 20 million outpatient consultations for surgical specialties in the NHS in England in the 2021/22 financial year.[134] Reducing the number of consultations, or (where appropriate) offering remote consultations, are ways to reduce environmental impact.

Providing specialist advice and guidance to primary care doctors may reduce outpatient consultations (only around a third of patients referred for advice and guidance go on to have an outpatient consultation).[135]

Within consultations, investigations may be over-ordered. For example, an Italian study of outpatient imaging requests deemed 44% inappropriate.[136] Choice of imaging can also have an impact: the carbon footprint of a Magnetic Resonance Imaging (MRI) scan has been estimated at 17.5 kg CO_2e, a Computerised Tomography (CT) scan at 9.2 kg CO_2e, an ultrasound at 0.5 kg CO_2e, and a chest X-ray at 0.5 kg CO_2e.[137] A study of cardiac imaging found that CO_2 emissions were lowest for transthoracic echocardiography, tenfold higher for cardiac computed tomography angiography, and hundredfold higher for cardiac magnetic resonance.[138] Where there is no effect on clinical care, education of doctors on the indications and selection of investigations can help reduce carbon footprint.

Patient follow-up can be reduced, for example by writing to patients with results of investigations,[139] and providing plans to patients and their General Practitioner (GP) for continuing management of their disorder through self-care or primary care. Consultants are less likely to follow up with patients than trainee doctors, but with appropriate training and supervision, this difference can be reduced.[140] Where follow-up is deemed necessary, this should be patient-initiated or undertaken remotely (wherever clinically appropriate). Patient initiated follow-up contributes to reductions in follow-up appointments by 0.8-1.8 per patient.[141]

Remote consultation (or **telehealth**) reduces the carbon footprint associated with patient transportation,[142] and can improve access to care for traditionally under-served and rural populations. This can address health inequalities, and may lead to fewer missed days from work. The average patient travels for 48 minutes to attend a hospital appointment.[143] For instance, a study of virtual visits for renal transplant clinics demonstrated a reduction of 200,000 km in travel distance and 51 tonnes CO_2e over 263 telehealth encounters.[144] In another study switching from face-to-face to virtual fracture clinics saved patients an average of £8.96 in travel costs, and achieved equivalent levels of patient satisfaction.[145]

Digitally enabled self-care can also create financial savings. For example, after lower limb arthroplasty a virtual exercise rehabilitation program was associated with savings of US$2,745 per patient (compared with traditional care).[146] Use of a remote monitoring text and voice messaging service to monitor surgical site infections led to savings of US$153,800 per year (assuming 20 patients/week, and replacing nursing care costs).[147]

However, some caution is also appropriate. A study of remote consultation in Ear, Nose and Throat surgery (ENT) found that newly referred patients undergoing remote consultation were more likely to have follow-up or investigations than those seen face-to-face, which could potentially increase overall financial or carbon cost,[148] as well as result in sub-optimal care. There is also the risk that telehealth will widen inequalities, potentially disadvantaging those without access to (or lacking capability to operate) necessary digital technology, or those with sensory impairment. Increased use of telehealth may also necessitate training of staff to enhance computer literacy.

Where possible, health systems can support **digitisation of health records and patient management systems**. Compared to paper records, electronic medical records have been associated with reduced waste and GHG emissions (taking into account patient transportation, paper, and energy consumption, including that of associated computers and data centres).[149] Use of electronic medical records has also been linked to a 5–11% age-adjusted decrease in face-to-face visits (for specialty care versus primary care respectively) without evidence of effect on quality of care.[150]

There are wider opportunities for digital technologies to reduce environmental impact, including utilising virtual wards, which enable patients to be treated in the community.

Whilst productivity and efficiency gains associated with digital transformation may reduce environmental impact of services, analysis of such changes when compared to conventional modes of treatment delivery does not always account for hosting (for example data centres), networking, and end-user devices and services: impacts that should be measured. We are also conscious that expanding digital ecosystems may increase the environmental impact of surgical care, including increased capture and use of data, expansion of robotic surgery, and the application of artificial intelligence.

CASE STUDY: Adopting digital care pathway programme for knee arthroplasty

Setting	Nottingham University Hospitals NHS Trust
Patients	Patients undergoing total knee arthroplasty
Intervention	Use of digital care pathway programme including patient education pack, online video streaming enabling self-management, accelerated physiotherapy, Enhanced Recovery after Surgery Protocols
Outcome	Reduced length of hospital stay
	↓ 50 kg CO_2e / patient

Source: Sustainable Healthcare Coalition[151]

3.3 Optimising pre-operative care

A co-ordinated peri-operative approach through patient optimisation and risk reduction can reduce length of hospital stay by 1-2 days, complications by 30-80%, and post-operative critical care admissions,[152] with likely reductions in associated environmental impact.

Surgery is a significant life event, and individuals are more likely to change their behaviour at moments of substantial change.[153] The pre-operative phase represents a 'teachable moment', where a patient may be receptive to suggestions from healthcare professionals which promote positive changes in **modifiable determinants of health** such as smoking cessation, alcohol moderation, increased exercise, and optimising nutrition (including weight loss for those overweight) (Table 2).[154] There may be other opportunities to optimise the patient, including improving glycaemic control, correcting anaemia, ensuring blood pressure is within target range, and psychologically preparing the patient for surgery. It may also be a chance to optimise and rationalise medication, minimising polypharmacy. Strong communication between the surgical team and primary care colleagues is important.

CASE STUDY: Consolidating Admission Booklet

Setting	Ashford and St Peter's Hospital NHS Trust
Patients	Patients attending Surgical Assessment Unit ahead of short-stay admissions
Intervention	Review of admission booklet, shortened booklet from 27 pages to 6 pages
Outcome	Booklets previously took more time to go through with patients, shortening enabled nursing team to spend more time with patients
	↓ 65.4 kg CO_2e / per year
	↓ £4,793 per year
	Reduce information overload

Source: Centre for Sustainable Healthcare[155]

Table 2: Perioperative modifiable determinants of health

<table>
<tr><th>Perioperative modifiable factor</th><th>Potential impact</th><th>Suggested action to engage patients</th></tr>
<tr><td>Smoking cessation</td><td>Review found every tobacco-free week (after 4 weeks) reduces postoperative morbidity by 19%[156]

Smoking impacts on cardiovascular function, pulmonary function, bone and wound healing[157]

Smoking is associated with increased post-operative opiate analgesia requirements[158]</td><td rowspan="4">Formal pre-habilitation programmes may work, and simple messages given by a trusted source are effective

Programmes such as www.movingmedicine.ac.uk teach simple motivational interviewing to clinicians

Use of apps and digital technologies may be helpful

NHS Live Well provides a useful resource to support living[159]</td></tr>
<tr><td>Alcohol moderation</td><td>Review found pre-operative alcohol consumption associated with increased postoperative complications, including[160] general morbidity, infections, wound complications, pulmonary complications, length of hospital stay, and admission to intensive care unit</td></tr>
<tr><td>Exercise</td><td>Varying evidence[152,161] that those who exercise have less post-operative pain, complications and length of stay, and better functional recovery and mobility</td></tr>
<tr><td>Optimising weight</td><td>Reducing weight may be recommended to those undergoing knee or hip arthroplasty to reduce risk of complications[162]

Obesity has been associated with increased risk of wound infection, greater intraoperative blood loss, and longer operating times.[163] Conversely being underweight has been associated with increased risk of major post operative complications including mortality[163]</td></tr>
<tr><td>Nutrition</td><td>Malnutrition and underfeeding risk complications,[164] including poor wound healing[165]</td><td>In line with Enhanced Recovery After Surgery[164]

• Avoid long periods of preoperative fasting

• Encourage carbohydrate loading up to 2 hours preoperatively

• Re-establish oral feeding as soon as possible post-operatively

• Nutritional therapy if at risk</td></tr>
</table>

3.4 Appropriate pre-operative investigation

Eliminating unnecessary pre-operative investigations may reduce emissions and cost without negatively impacting patient care. Pre-operative testing can be useful to stratify risk with the aim of improving outcomes, however, many institutions perform routine testing for all patients regardless of health status or procedure, perhaps with the intention of increasing patient safety or decreasing medico-legal consequences of adverse events.[166]

Reviews have found routine pre-operative testing (blood tests and electrocardiogram, ECG) prior to cataract surgery did not reduce the risk of adverse perioperative events.[167] Another review found a lack of evidence to support routine pre-operative testing in elective (noncardiac) surgical patients.[168] Numerous studies and guidelines recommend against routine pre-operative testing for healthy patients undergoing low risk procedures, and instead suggest that investigations are targeted to patient comorbidities and risks of the surgical procedure.[169–174]

CASE STUDY: Eliminating unnecessary pre-operative blood test

Setting	University Hospital Sussex NHS Foundation Trust
Patients	Patients undergoing laparoscopic cholecystectomies
Intervention	Streamlining pre-operative pathway for elective surgery by reducing number of Group and Save blood tests from two to one
Outcome	Low risk of significant perioperative bleed requiring urgent transfusion
	↓ 2.5 tonnes CO_2e / per year
	↓ £3,000 per year
	Improved convenience for patients (↓ appointments and travel)

In 2021, a team of clinicians led by Alyss Robinson, Shameen Jaunoo and Mansoor Khan at University Hospitals Sussex NHS Foundation Trust investigated the impact of eliminating one routine Group and Save (G&S) Test prior to laparoscopic cholecystectomy. On average 250-300 laparoscopic cholecystectomies are performed in the Trust per year. Patients who have day-case laparoscopic cholecystectomies (LC) were required (as per Trust guidelines) to have two separate G&S blood tests (taken on different days), to facilitate urgent perioperative transfusions, if needed. However the procedure has a low risk of bleeding.

Through a literature search and audit of current practice, the team concluded that eliminating the second G&S test from the preoperative workup for laparoscopic cholecystectomies is a safe intervention, resulting in carbon savings of 2.5 tonnes CO_2e/year (equivalent of driving 7,200 miles in an average car) and cost savings of £3,000/year. This simple intervention could be applicable to a variety of surgical procedures.

Source: Centre for Sustainable Healthcare Green Surgery Challenge 2021[186]

Other examples of unnecessary pre-operative investigation include blood tests (full blood count, coagulation testing, serum biochemistry, or routine group and save for surgery such as laparoscopic cholecystectomy), resting ECG for asymptomatic patients undergoing low-risk surgery,[175–177] and radiological investigations that rarely contribute to clinical management, for example lumbar spine, or knee radiographs.[178] Such investigations incur financial, carbon and time costs for the test itself, and the patient journey to perform the test. An Australian study estimated GHG emissions from common tests, including a full blood count (117 g CO_2e), urea plus electrolytes (274 g CO_2e), coagulation profile (233 g CO_2e), and urinalysis (538 g CO_2e).[179]

Where tests are necessary, they should be **streamlined** into a **'one-stop' clinic.** With this model, investigations, diagnoses, and integrated multidisciplinary care plans are provided in one visit thereby reducing delays in patient care, patient anxiety, and financial and carbon costs.[180–182] Previous studies of one-stop clinics have shown an increase in department capacity of 15%, and a 95% patient preference compared to the conventional siloed approach.[174] One-stop clinics also improve access for those in rural and remote regions; locations where populations may have inequitable and worse health outcomes compared to urban centres.[183–185]

3.5 Perioperative factors, including operative location and approach

Decisions relating to location, timing, and modality of treating surgical disease should be driven by patient care, but also be sensitive to environmental impact.

Surgical procedures are typically undertaken in the surgical operating theatre, outpatient clinic, clinical wards, or emergency departments. Decisions about where a procedure takes place will depend on a number of factors, including:

- Clinical considerations
- Patient preference and compliance
- Theatre availability
- Surgeon preference
- Cultures of practice

Undertaking **surgical procedures outside of the operating theatre** for selected patients (where clinically appropriate) may be more convenient and preferable for patients, well-tolerated by patients, and cost-effective. Feasibility of clinic-based procedures has been demonstrated for example for sialendoscopy,[187] carpal tunnel decompression,[188] grommet insertion,[189] and transperineal prostate biopsy.[190] Some key factors relating to the location of surgical operations which may influence environmental impact are considered in Table 3. Even in hospitals where reusable instruments and access to sterile services may be available within operating theatres, arrangements are not always in place to facilitate treatment in alternative settings (e.g. clinic, Accident and Emergency); it is important to address this gap. Conversely, once a procedure is deemed a 'surgical procedure' there can be a tendency towards over-materialisation. For example, it is commonplace for superficial traumatic wounds in emergency departments to be cleaned with sterile saline, when there is evidence to support cleaning with tap water.[191]

The choice of surgical approach is a clinical decision, influenced by individual patient and healthcare provider capabilities (surgical skill set and availability of equipment and facilities), but the approach can also determine the environmental impact. For example, the carbon footprint of abdominal or vaginal approaches to hysterectomy have been estimated at around 2% that of robotic approaches, with laparoscopic approaches intermediate between the two.[192] This is predominantly driven by the voluminous consumption of single-use equipment in the robotic or laparoscopic approaches. Opting for **reusable equipment** wherever possible, and encouraging industry to develop reusable equipment would reduce environmental impact (reusable medical products typically have a third to a half less carbon).[193] Similar findings were seen in an evaluation of surgery for staging of endometrial cancer.[194] While both these studies did not account for factors beyond the operating theatre, it can be inferred that these minimally invasive procedures can reduce length of hospital stay (sometimes enabling day-case surgery), and rates of complication, including atelectasis and respiratory compromise, wound complications, hernias and small bowel obstruction (the management of which would associate with further carbon burden). There will be differences in financial cost of alternative approaches also, for example a study of carpal tunnel decompression found that when these were undertaken using an open technique (rather than endoscopic) and under local anaesthetic (rather than regional or general), this would save US$3.6 billion per decade in the USA.[195]

Table 3: Environmental impacts of setting of surgical procedures

	Operating theatre	Non- operating theatre setting eg. outpatient setting, clinical ward, emergency department
Energy	High energy consumption (3-6 times more than rest of hospital)[42]	Lower energy consumption
Anaesthesia	Any anaesthetic modality. There may be tendency to opt for general anaesthesia in the operating theatre even where unnecessary	Procedures under local (or no) anaesthesia
Products	Reusable products more likely available Tendency to use sterile equipment even if not necessary	Option of reusables not always available
Healthcare staff	Likely to be more healthcare professionals involved (increasing personal protective equipment, staff travel etc.)	Likely to be fewer healthcare professionals involved
Time	Longer wait for operating theatre availability, increased time in the operating theatre department and increased length of stay	Faster process due to immediate availability, fewer resources and staff needed, shorter length of stay

For each row, factors which have greater environmental impact (between the two scenario columns) are indicated in orange, whilst green indicates those with lower environmental impact

The number of post-operative visits can also be reduced by opting for absorbable (rather than non-absorbable) sutures, or in appropriate cases, asking patients to remove their own sutures. Studies on closure of traumatic wounds found a reduced number of post-operative visits with absorbable sutures and no difference in wound infection or healing;[197] and where non-absorbable sutures were used, over 90% of patients were able to remove these themselves.[198] Adopting such practices to elective and non-elective settings will reduce the environmental impact of associated patient travel and outpatient appointment for suture removal, where this is the primary function of the appointment.

During operations, teams can **rationalise** routine histological examination where this is unlikely to alter management. For example, a study of 1,452 routine gall bladder histology specimens found 4 cases of malignancy, in all of which there was a high index of suspicion either pre- or intra-operatively.[199]

The environmental impact of medications administered perioperatively can be optimised by opting for oral routes where clinically appropriate. For example, the carbon footprint of oral paracetamol is 1/68th of that of intravenous paracetamol.[200] This may also apply to antimicrobials and antiemetics, although research is required to quantify this.

CASE STUDY: Undertaking carpal tunnel decompression in the procedure room

Setting	Betsi Cadwaladr University Health Board
Patients	Patients undergoing carpal tunnel decompression
Interventions	• Undertaking operation in procedure room instead of the operating theatre • Replace single-use plastic pots and bowls with reusable equivalents • Reduce size of drapes • Reduce number of instruments in set to extent could be housed in smaller tray
Outcome	↓ length of hospital stay ↓ theatre list and surgical wait times ↓ number of staff required per procedure
	↓ 11.6 tonnes CO_2e / year
	↓ £12,641 per year
	Reduces risk of cancellations

In 2021, a multi-disciplinary surgical team led by Prash Jesudason and Preetham Kodumuri at Wrexham Maelor and Ysbyty Gwynedd Hospitals, undertook a sustainable quality improvement project on the care pathway of carpal tunnel release surgery.

The team audited the consumables used and the volume of clinical waste generated during the procedure and used this to create a new procedure pack that involved the changes listed above. They gained approval to carry out carpal tunnel release surgery in a procedure room rather than theatres and for patients to bypass ward admission and come straight to the procedure room.

The project has forecast annual cost savings of £12,641 and carbon savings of 11.6 tonnes CO_2e/year (based on 75% applicability), equivalent to driving 33,285 miles in an average car.

Source: Centre for Sustainable Healthcare Green Surgery Challenge 2021[196]

3.6 Post-operative care

Opportunities to further streamline patient care are also available in the post-operative period, of which the most important is minimising inpatient stay, through maximising day-case surgery, employing enhanced recovery after surgery where appropriate, and using community-based support services to enable early discharge. GHGs attributed to general inpatient hospitalisation are estimated at 38 kg CO_2e (UK)[201] to 45 kg CO_2e (USA)[202] per day, with associated waste generation at 3 kg (UK) to 6 kg (USA) per day.[201,202] This is three times higher in critical care settings (103 kg CO_2e–138 kg CO_2e per day in the UK and the USA respectively[201,202]), and so initiatives targeted at avoiding or minimising the need for intensive care post-operatively are likely to be associated with environmental savings.

Day-case surgery can be maximised through adoption of minimally invasive techniques, which are continually expanding (for example laparoscopic appendectomy for uncomplicated acute appendicitis)[203] and use of local or regional anaesthetic techniques (for example day-case total joint arthroplasties under spinal anaesthesia in select cases).[204,205] **Day-case surgery** is preferable from a cost as well as an environmental perspective. For example, in an international review of shoulder arthroplasty, opting for day-case over inpatient treatment was associated with cost savings of £529 with no adverse events or re-admissions,[206] and in France savings of €3,921 per laparoscopic fundoplication, with comparable functional outcomes and improvements in quality of life.[207] Elective ambulatory day-case carpal tunnel decompression under local anaesthetic only was associated with savings of £688 per case (compared with local and general anaesthetic mixed list), alongside reduced waiting times (from 36 weeks to 12 weeks).[208] Enabling patients to recover after surgery in their own homes is often preferred by patients themselves, and associated with high levels of satisfaction, for example for elective craniotomy,[209] and parent satisfaction for paediatric tonsillectomy.[210]

CASE STUDY: Early mobilisation in a Cardiac Intensive Care Unit

Setting	University Hospital Southampton NHS Foundation Trust 24 month period
Patients	238 patients admitted to cardiac intensive care unit post cardiac surgery
Intervention	Early mobilisation programme, including use of equipment for passive exercise
Outcome	↓ ventilation days by a mean of 4 days ↓ cardiac intensive care stay by a mean of 6 days
	↓ 48.5 tonnes CO_2e / 24 months
	↓ £1,266,327 / 24 months
	Enables patients to have more autonomy during their hospital stay and may improve the patients' sense of self-efficacy.

Source: Centre for Sustainable Healthcare[215]

When a person requires a procedure that will necessitate admission, effective implementation of **enhanced recovery protocols** (ERPs) may be used, and are associated with 2.5 days shorter stay after major abdominal surgery,[211] decreased readmission rates, and lower post-operative morbidity and complications.[212] An enhanced perioperative care program for major spine surgery found savings of over US$9,000 per year.[213] Many practices encouraged through ERPs, such as reduced intravenous fluids, early extubation, and avoidance of nasogastric tubes, also lead to overall reduced resource utilisation. There is also evidence that recovering with a view through a window overlooking natural scenery reduces length of hospital stay and analgesic requirements.[214]

Early discharge planning can contribute both to decreased length of stay and readmission rates.[216,217] Some components of patient care, such as physical therapy, could be performed in an outpatient setting to reduce hospitalisation or inpatient rehabilitation, although the frequency of follow-up required and requirement for patient travel to appointments should be considered.

Minimising unnecessary tests and imaging for inpatients is also important. A study of acute general surgical patients (including acute uncomplicated appendicitis, acute uncomplicated cholecystitis, choledocholithiasis, gallstone pancreatitis and non-operative adhesive small bowel obstruction) in Canada found 76% have unnecessary blood tests, with an estimated carbon footprint of 974 g CO_2e per patient and financial cost of CA$63 per patient.[218]

Routine follow-up may not be necessary after certain procedures, a concept explored as early as 25 years ago[219] and particularly suitable for low morbidity surgery such as carpal tunnel release, cholecystectomy, and inguinal hernia repair.[219-221] However, systems should be implemented to ensure patients are able to access good information, and which trigger appropriate follow up when needed. Remote follow up may also be possible, and there is no evidence of increased emergency department visits, re-admissions, re-operations, or mortality from such strategies,[222,223] with patient satisfaction similar to in-person encounters.[224,225] Advances in technology such as at-home vital sign monitoring and photography of surgical wounds,[226] support remote post-operative monitoring. The reduction in carbon emissions with reduced transport to hospital and potential earlier hospital discharge significantly outweigh technology emissions.[227-230] Simple tasks such as routine dressing care and suture removal may also be taught to patients or caretakers to perform at home.[231]

Section recommendations

Recommendation	Short term	Long term	Stakeholders
R3.1 Streamline surgical patient pathways e.g. reducing low-value steps and unnecessary consultations; rationalising unnecessary investigations (pre-, intra-, or post-operative); creating 'one-stop' clinics	Have conversations with colleagues about areas of patient journeys which do not add value, and brainstorm areas for improvement[a]	Design, implement, and evaluate interventions to streamline patient pathways where clinically appropriate[a,b] Develop outpatient department treatment rooms and increase day case lists where appropriate[b] Optimise and rationalise medication, minimising polypharmacy[a,c] Standardise and consolidate peri-operative investigations[a,d]	Surgical and anaesthetic team members[a] Healthcare provider management teams[b] Pharmacy team[c] Diagnostic services teams[d]
R3.2 Optimise patients pre-operatively (e.g. smoking cessation, alcohol moderation, exercise, nutrition, optimise weight)	During pre-operative consultations identify modifiable risk factors, and point patients in the direction of support and resources[a,b]	Design population level interventions around health optimisation, targeted at high risk groups[d]	Surgical and anaesthetic team members[a] Patients[b] Public health colleagues[d]
R3.3 Minimise length of hospital stay	Use enhanced recovery after surgery protocols and early discharge planning where appropriate[d,e]	Identify opportunities for surgery to be undertaken in ambulatory day-case theatre lists or outpatient settings[e], and develop infrastructure change to support this[b]	Surgical team[e] Healthcare provider management teams[b]

4. Operating theatre energy and design

Section key points

- Operating theatres are 3–6 times more energy intensive than clinical wards.
- The majority of theatre energy consumption relates to theatre maintenance (heating, ventilation, and air conditioning).
- There are three main types of ventilation systems: turbulent mixed airflow (least energy), temperature controlled airflow, laminar air flow (most energy).
- Shutdown checklists can be used to prompt staff to switch off theatre equipment out of hours and should be accompanied by turn-on checklists and safety protocols to ensure items are on when required.
- There are opportunities at the stage of theatre design (or retrofit) for installation of motion sensors to control lights, temperature, and ventilation, alongside energy efficient appliances and machinery, and automatic/pedal-controlled taps for surgical scrub.
- At the hospital level, contracts should be drawn with providers of renewable electricity, and installation of combined heat and power facilities.
- There are opportunities across the hospital for installing LED lighting and improving insulation.

4.1 Energy use in the operating theatre

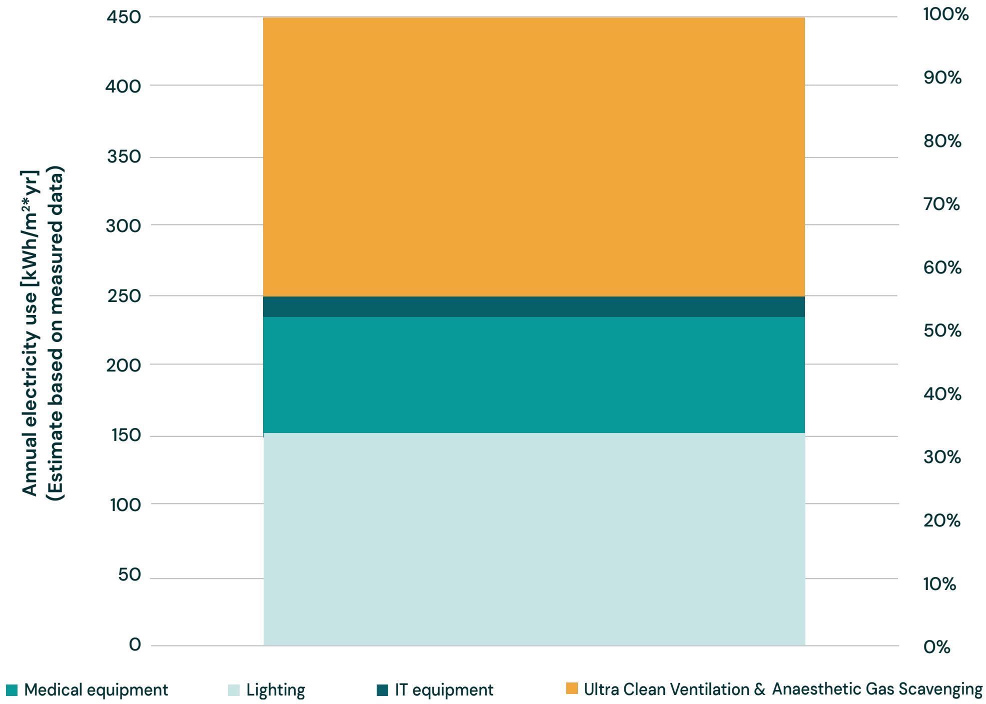
Energy use makes up 10% of the NHS carbon emissions footprint,[22] and rising energy prices may be an additional driver for hospitals to reduce their energy demand.

End-use data suggests that **operating theatres** are one of the most **energy intensive** areas of hospitals, using three to six times more energy than clinical wards.[42] The majority (90-99%) of operating theatre energy consumption relates to **theatre maintenance** (heating, ventilation and air conditioning), whilst the contribution from plug-loads and lighting is estimated at 1.5%-8.4%.[42] Another study found nearly half the energy use was to power the theatre ventilation and anaesthetic gas scavenging systems (AGSS), with the remainder from lighting, information technology and medical equipment, Figure 6),[232] with these items often left on when the theatre is not in use.

From 2017 to 2021 we have seen a 27.3% reduction in carbon emissions associated with building energy in the NHS.[233] If we are to further reduce this, it is important that **energy is derived from renewable sources**. At the time of writing, only 55% of NHS organisations procure 100% renewable electricity.[234] Furthermore, hospitals can install solar panels and generate renewable energy on-site.

It is also essential that healthcare organisations reduce energy consumption through installation of energy efficient appliances and machinery such as **light-emitting diode (LED) lighting, building management systems, heat recovery, insulation, and combined heat and power facilities**. Many of these energy initiatives are associated with cost savings over time (often relatively quickly), representing win-wins for both the public purse and the environment. Energy efficient appliances and machinery should be installed when new theatres are developed, but the environmental impact of replacing existing systems will depend on factors including how long existing systems have been in place: premature obsolescence needs to be balanced against energy savings associated with new systems.

Figure 6: Contributions to typical operating theatre energy consumption



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4.2 Optimising the maintenance of theatre environment

A collaborative approach between clinical and estates teams will help ensure appropriate energy use. This may include opting for renewable energy sources, use of heat pump systems, and analysing energy use in different areas (enabling air handling and climatic control to be optimised).

Anaesthetic Gas Scavenging Systems (AGSS) account for the majority of anaesthetic equipment energy consumption, and are often operating even when theatres are not in use.[235] AGSS may be switched off when operating theatres are not in use (or potentially where purely intravenous sedation, regional or Total Intravenous Anaesthesia (TIVA) techniques are used), where these are switch operated. Appropriate safety systems and standard operating procedures should be in place to ensure AGSS are switched back on when required. An open source calculator has been developed to estimate carbon and financial savings associated with switching off AGSS.[236]

Advanced ventilations systems play an integral role in controlling temperature, humidity, and airborne contamination within the operating theatre. Staff shed around 10,000 skin particles per minute and this is the main source of airborne contamination in the operating room.[237] The likelihood of developing a surgical site infection is however influenced by multiple variables, with the health state of the patient, and type of intervention being the main risk factors.[238]

The three main ventilation systems (Figure 7) used in operating theatres are:[239]

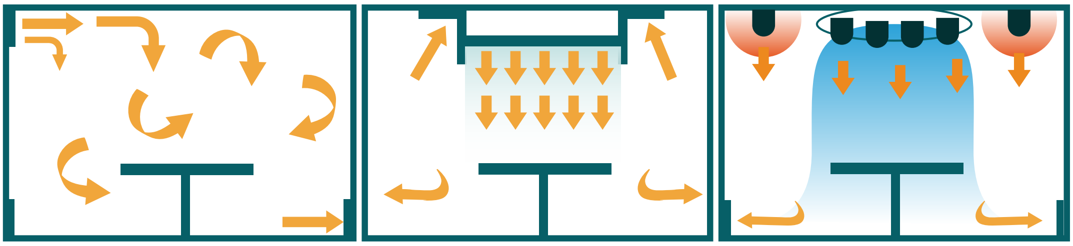
1. **Turbulent Mixed Airflow (TMA)**
   In TMA air is drawn into the theatre through high-efficiency particulate air (HEPA) filters. This method of ventilation relies on the dilution principle, with turbulent mixing of clean and contaminated air exponentially leading to lower counts of airborne microbes. TMA **uses the least amount of energy** of the three systems, but does not create ultraclean conditions.

2. **Laminar Air Flow (LAF)**
   LAF pushes air through HEPA filters in a unidirectional flow in a 2.75m^2 box around the operating table. This ultraclean zone around the patient can be affected by presence of equipment in and around the zone, and the opening and closing of doors. LAF uses the most energy of the three systems.

3. **Temperature Controlled Airflow (T_cAF)**
   T_cAF is the newest of the three systems and uses cool HEPA filtered air above the operating table which, due to its higher density than the warmer air around this zone, flows downwards. T_cAF **can achieve ultra clean conditions using less energy** than LAF.

It is desirable to opt for the lowest carbon ventilation system that is clinically appropriate for the procedure being performed. Although the National Institute for Health and Care Excellence (NICE) in the UK acknowledges lack of high quality evidence for the efficacy of ultra clean ventilation in preventing joint infections, it recommends its use for joint replacements[240] (along with the British Orthopaedic Association).[241] Two meta-analyses of laminar airflow compared with conventional ventilation found no reduction in surgical site infection for knee or hip arthroplasty, or for abdominal or open vascular surgery.[242,243]

Figure 7: Schematic showing the airflow principles of the three ventilation systems



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NHS Health Technical Memorandum 03-01,[244] provides advice and guidance on the design, installation and operation of specialist ventilation systems used in healthcare settings, including how many air changes per hour are required in each setting (Table 4). Within theatres, out of hours ventilation will often unnecessarily run in either a full power or low power mode ('set back', and a mode which varies in energy intensity between trusts). **Turning off theatre ventilation overnight or when unoccupied** is appropriate, and quickly reversible: an operating theatre can achieve safe operating conditions from a flow and temperature perspective after 20 (LAF) to 30 minutes (T_cAF) of full power ventilation.[245,246]

Table 4: Health Technical Memorandum 03-01 standards for minimum number of air changes per hour for various hospital settings[244]

Location	Air changes per hour
Anaesthetic room	15
Operating theatre (including UCV theatres)	22
Cranial surgery theatres	35
Preparation room	22
Sterile Pack Store	6
Recovery	15
Endoscopy	10

CASE STUDY: Switching off theatre ventilation systems overnight

Setting	Nuffield Health (Private) theatres
Intervention	Switching theatre ventilation from a low powered 'set back mode' to off overnight
Outcome	Adheres to HTM 03-01 guidelines
	↓ 15–36 tonnes of CO_2e/year per theatre ↓ If rolled out to the 3000 operating theatres in the NHS this could lead to national carbon savings of 108,000 tonnes of CO_2e per year
	↓ £30,000 per theatre per year Roll out as above associated with cost savings of £90 million per year.

Source: Direct submission from Jonathan Groome

Healthcare staff can play a key role in reducing energy emissions. For energy and work intensive areas such as operating theatres and pathology laboratories, a more formalised approach using a **shutdown checklist** can give staff comprehensive instructions on what to turn off out of hours (including the AGSS in the theatre suite where possible) and be accompanied by safety protocols and 'turn on' checklists. This approach may associate with financial savings. For example, a single setting in the USA found that turning off equipment when not in use (including anaesthetic equipment and operating room lights) generated savings of US$33,000 and 343 metric tons of CO_2 per year.[247] Automation using **passive infrared (PIR) sensors** controlling lights, ventilation, and temperature can also help reduce energy consumption if located and configured appropriately, and can eliminate human error (for example by ensuring the HVAC system is operating when theatres are running). Submetering and use of dashboards to feedback to staff members may also assist measurement and change.

CASE STUDY: Adopting elective theatre shutdown list

Setting	Swansea Bay University Hospital Health Board	
Intervention	'Shutdown' list poster used as prompt to turn off devices in elective operating theatres at end of day, including computers, anaesthetic machines, anaesthetic gas scavenging	
Outcome	↓ 144.8 tonnes CO_2e / year	
	↓ £26,000 per year	
	Noise reduction, reduced light pollution	

In 2022, a clinical team led by Elana Owen, Christine Range, and Gemma Hale, at the Swansea Bay University Health Board designed and implemented a Shutdown Check protocol in elective surgery theatres.

At the hospital, planned operating usually takes place during daytime hours and during the working week only, whereas emergency operating occurs around the clock. The team audited devices that can be turned off in elective operating theatres and created a "shutdown" list poster to promote turning things off.

Some machines need to be turned off and on again to activate their morning self-check, making the end-of-day shut-off routine an increase in workload, but staff members were supportive of this.

The team anticipates potential carbon savings of 44,774 kg CO_2e per year (equivalent to driving 129,000 miles in an average car) and cost saving of £26,000 annually (not including energy use of computers). There will also be an improvement in the immediate spatial environment in the vicinity of the theatres (for example, through reduced noise of ventilation systems).

Source: Centre for Sustainable Healthcare[248]

4.3 Optimising the built environment

It is important that when new hospitals and theatre suites are developed, they align with net zero ambitions and draw upon the NHS England Net Zero Building Standard, which provides guidance on development of sustainable, resilient and energy efficient buildings.[249] A **collaborative approach**, enacted by a multidisciplinary build team that includes healthcare workers, architects, contractors, engineers, and estates managers, involved in the whole life planning of the build is essential.[250] The UK Green Building Council framework definition of net zero buildings balances embodied emissions associated within construction and operational energy through the use of low carbon renewable energy sources, and **net export of renewable energy**.[251] A more recent approach adopted by the World Green Building Council looks at Net Zero Whole Life Carbon. It attempts to avoid future embodied carbon during and at the end of life, and account for **renovation, future adaptation, and circularity**.[252] Further research is required to determine circumstances in which it is more sustainable to renovate versus rebuild healthcare buildings and facilities.

Offsite, modular building of healthcare facilities can be an effective way to reduce onsite build time (limiting disruption to services), centralise expertise, and reduce emissions and costs.[253] Adopting this approach to the development of operating theatres could lead to 33% lower costs to the industry; 50% faster delivery due to a reduction in parts, fabrication, logistics and assembly; and a 50% reduction in emissions.[254]

A key part of reducing the whole life emission of healthcare builds is in ensuring that spaces created anticipate future developments in health pathways, for example through digitisation, the modernisation of medical equipment, and the developing needs of populations. Creating **flexible and multi-use spaces** such as theatres that can be converted to intensive care units, will also optimise building utility.

Section recommendations

Recommendation	Short term	Long term	Stakeholders
R4.1 Ensure operating theatre equipment is switched off when not in use (e.g. Anaesthetic Gas Scavenging Systems, air handling units, lights, computers, other plug-ins)	Develop and use shutdown checklist (plus safety protocols) to prompt turning off equipment[a,b]	Install motion sensors to control lights, temperature control, and ventilation[b] Education[c]	Surgical team[a] Facilities and Estates[b] Educators[c]
R4.2 Improve environmental impact of operating theatre energy consumption		Opt for renewably sourced electricity[b] Install energy efficient appliances and machinery[b,d] Opt for clinically appropriate ventilation system with lowest energy consumption[b,d] Innovate towards energy efficient devices[e]	Facilities and Estates[b] Theatre managers[d] Industry[e]

5. Anaesthesia

Section key points

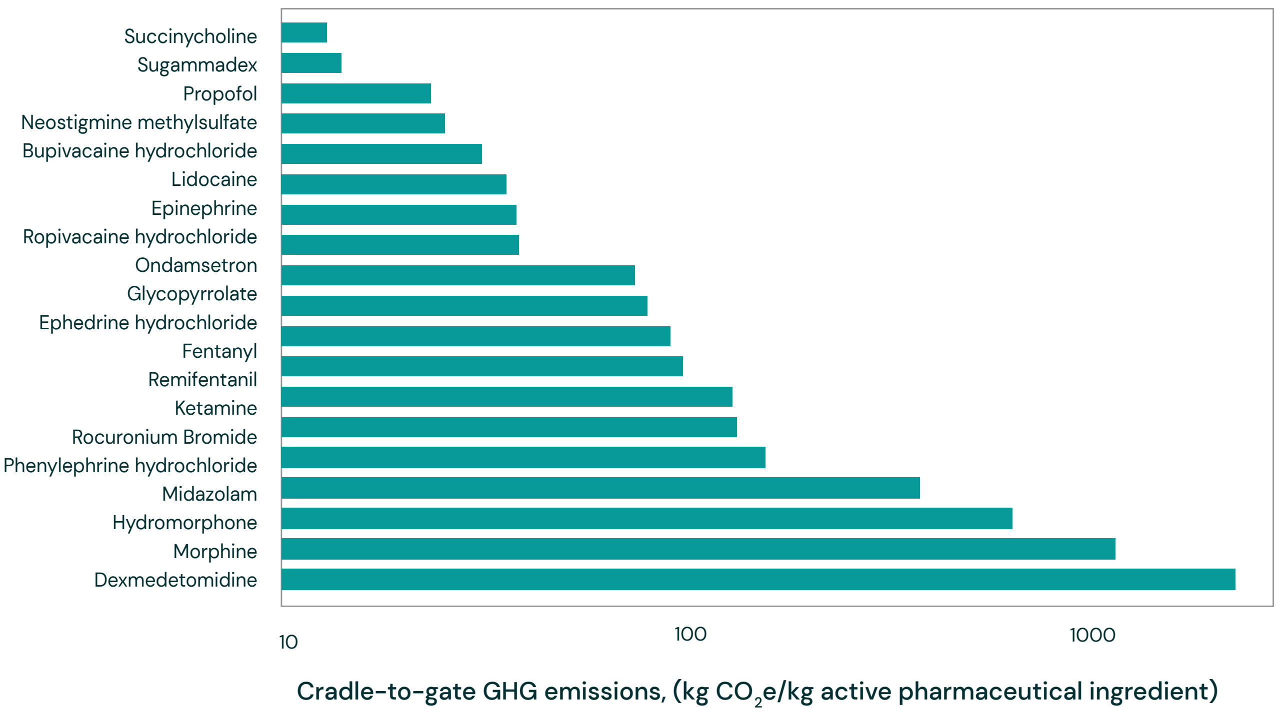
- Local, regional, and intravenous anaesthetic techniques may be associated with lower carbon footprint, compared with inhaled anaesthetics.
- Where inhaled anaesthetics are used, sevoflurane followed by isoflurane hold lowest global warming potential, and environmental impact can be further reduced through minimising fresh gas flows.
- Desflurane should not be used, bar exceptional circumstances.
- Nitrous oxide is another powerful greenhouse gas, and emissions can be minimised through non-pharmacological methods to manage patient anxiety, decommissioning of centrally piped nitrous oxide (and substitution by portable cylinders), and nitrous oxide cracking technologies.
- Pharmaceutical wastage can be reduced through only opening what is needed; all pharmaceutical waste should be disposed of appropriately.
- There is currently a lack of robust evidence on capture rates of volatile capture technologies for anaesthetic gas waste.

Since the discovery that inhaled anaesthetics are potent GHGs, efforts to mitigate pollution have been underway in the field of anaesthesia. This includes efforts to find low emissions substitutes, and to improve efficiency of existing materials.[255,256] Potential areas of improvement include: **minimising use of inhaled anaesthetics (including by using total intravenous anaesthesia (TIVA)), local, and regional anaesthesia as first-choice techniques**; shifting to reusable medical devices whenever clinically safe and feasible to do so; and reducing waste generation.[257-260] Surgeons have a role to play in ensuring that perioperative environmental impact is minimised by understanding where hotspots are, and facilitating environmentally preferable anaesthesia practices.[38]

5.1 Local, regional, and intravenous anaesthesia

Anaesthetic drugs used by surgeons and anaesthetists for local or regional techniques, and for intravenous administration, have embodied carbon emissions several orders of magnitude lower than inhaled anaesthetic drugs. This suggests they are environmentally preferable to inhaled anaesthetic drugs at equivalent doses (Figures 8 and 9)[261,262] even accounting for GHG emissions associated with manufacture, packaging, transportation, and waste.[261] However, care must be taken to ensure that **supplies are not opened or used unnecessarily**, otherwise the relative advantages of non-inhaled anaesthetic approaches will not be realised.[263] Surgeons can prioritise these approaches when clinically appropriate, including through ensuring there is sufficient time for performance of regional anaesthesia, and providing an accurate estimate of surgical time at the team brief, to allow dosing of regional anaesthesia to be optimised. Evaluating the environmental impact of different anaesthetic techniques has been identified as a research priority by the James Lind Alliance.[264]

Figure 8: Cradle-to-gate greenhouse gas emissions per kg drug for common injectable drugs used in anaesthesia care



Adapted from Parvatker et al.[262] This was a cradle-to-gate analysis, meaning the material and energy associated with raw material extraction and synthesis were included and evaluated, but the study excluded formulation, packaging, distribution, use, excretion or discard of unused drugs. Note that this accounts for the active pharmaceutical ingredient only, and so excludes excipients, packaging, or delivery systems

CASE STUDY: Switching to local anaesthesia for inguinal hernia repair

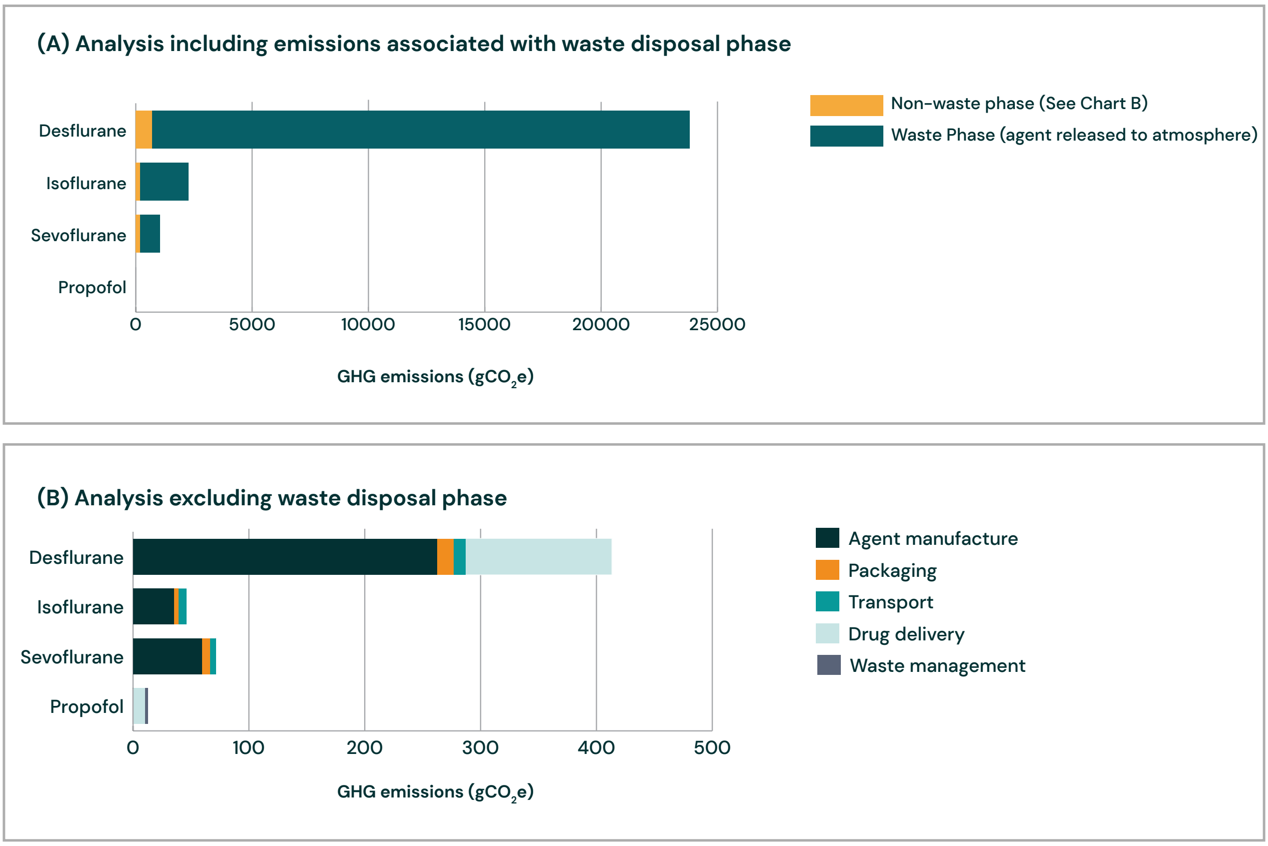
Setting	Imperial College Healthcare NHS Trust
Patients	Patients undergoing inguinal hernia repair
Intervention	Local anaesthesia with/without sedation instead of general anaesthesia
Outcome	Patients under local anaesthesia had a 53% shorter length of hospital stay and 40% lower incidence of complication compared to general anaesthesia
	↓ 10.2 kg CO_2e / case ↓ 2 tonnes CO_2e / year at NHS trust (assuming 64% local anaesthesia rate)
	↓ £16,000 / year

Source: Centre for Sustainable Healthcare[265]

Other emissions to the environment (beyond GHGs) are also concerning, and care must be taken to ensure that one type of pollution is not simply substituted with another; relative trade-offs must be considered. Potential water toxicity of pharmaceutical agents and their by-products, notably from propofol, has raised the question of whether intravenous approaches to general anaesthesia are superior to inhaled gases. Environmental persistence, bioaccumulation and toxicity indices are a means of characterising risk, but are not necessarily reflective of the presence of a substance in the environment. For example, the vast majority of propofol waste is incinerated. Attention to correct waste sorting by all perioperative staff is essential (for example, to **ensure pharmaceutical waste is incinerated**).

There are opportunities to avoid drug wastage, through only opening what is needed. For example, approximately half of propofol was estimated to be wasted over one year at a large tertiary care hospital,[266] with initiatives to reduce wastage including shifting from 50 ml or 100 ml vials to 20 ml.[267]

Figure 9: Life cycle greenhouse gas emissions of general anaesthetics (A) including emissions associated with waste disposal phase (B) excluding waste disposal phase.



Adapted from Sherman and Chesebro.[261] to align with UK practice to omit use of nitrous oxide as co-agent, and assuming fresh gas flows of 0.5 litres per minute; and 100 mcg/kg/min for 70 kg adult for propofol. We note there may be further differences in contributions from transport and energy in a UK setting, which has a higher proportion of renewable energy sources. This analysis included energy and materials required for drug delivery where these differed between the anaesthetic gases (for example syringes, intravenous line, energy required to heat the drug).

5.2 General inhaled anaesthetics

From a global warming perspective, the **environmentally preferable volatile anaesthetic drug of choice is sevoflurane** (Global Warming Potential over 100 years/GWP_{100} = 144), while **isoflurane** (GWP_{100} = 540) is a close second. Given its unique lack of pungency, sevoflurane can be used for mask induction and in the UK has become the preferred volatile anaesthetic from a clinical perspective. Due to the low solubility of desflurane, it can result in marginally faster wake-up times for cases of short duration (less than 90 minutes),[268] but without significant differences in post-anaesthetic care unit discharge times.[269] However desflurane is far less potent than sevoflurane or isoflurane (but more expensive), and so greater quantity of the drug is required to achieve similar anaesthetic effects. Additionally, due to its significantly higher global warming potential (GWP_{100} = 2,540), the climate impacts of desflurane are much greater than all other anaesthetic choices (Figure 9 and Table 5).[255,261] While its mild, transient sympathetic stimulating properties might make it slightly more desirable than sevoflurane and isoflurane in select cases, there is nothing unique about desflurane that cannot be achieved with other medications, meaning it is not essential.

Table 5: Greenhouse Gas Emissions of Common Inhaled Anaesthetic Agents.

MAC inhaled agent	Atmospheric lifetime (years)	100-year Global Warming Potential (GWP_{100}) (per kg, cf. 1 kg CO_2, where GWP CO_2 = 1)	Equivalent kilometres* driven in average car per MAC-hour anaesthetic use at 1 L/min
Isoflurane 1.2%	3.6	539	12
Sevoflurane 2.2%	1.9	144	6
Desflurane 6.7%	14	2,540	306
60% Nitrous Oxide (0.6 MAC)	114	273	78

*Adapted from Axelrod et al[257] *Based on US Environmental Protection Agency 2022 emission factor of 4.03×10^{-4} metric tons CO_2 equivalent/mile. MAC = mean alveolar concentration required to prevent movement upon surgical incision of an average adult patient.*

There is a growing movement led by anaesthetists in the UK to **eliminate desflurane from hospital formularies** on environmental grounds.[260] NHS Scotland was the first to cease procurement of desflurane in 2023,[270] and it is the first medicine to be decommissioned due to environmental impact. NHS England has also committed to decommissioning desflurane by early 2024,[271] and the European Union by 2026.[272,273] A study from the USA estimated substituting desflurane for sevoflurane would lead to cost savings of over US$100,000 in a year at a single medical centre.[274]

Anaesthetic induction rooms are no longer common throughout continental Europe and North America. In addition to equipment cost benefits, and the safety, and moving and handling advantages of avoiding transportation of a recently induced patient, there are also environmental advantages.[275,276] Induction of anaesthesia is a hotspot for waste of inhalational agent, and filling just one anaesthetic circuit, rather than two is beneficial. **Transition away from anaesthetic induction rooms** will require buy-in from surgeons and the wider surgical team.

Rapid advancement to minimal flow (250-300 ml/min) can be achieved by 'overpressure' of agent and control through end tidal agent and FiO_2 (fraction of inspired oxygen) monitoring.[277] Additional mechanisms to reduce wastage of volatile anaesthetics include ensuring that the fresh gas flow (FGF) is turned down for airway manipulation, and reducing loss of gas from the circuit. An educational intervention in the USA targeting flow rate reduction and volatile agent choice estimated carbon reductions of 64% per case, and cost savings of US$25,000 per month.[278] Further, automated end tidal agent target control anaesthetic machines are available, and show reproducible reductions in agent use[279] and should be considered with equipment upgrades.

Nitrous oxide (GWP_{100} 273) is an anaesthetic with relatively low potency, arguably beneficial to speed uptake of volatile gases during mask induction. The Association of Anaesthetists suggests using oxygen/air as a carrier gas, avoiding nitrous oxide.[280] Nitrous oxide is more commonly used for paediatric, obstetric, and dental procedural analgesia, without anaesthetists, and a growing area of decarbonisation interest.[281] Training for procedural sedation/analgesia should include non-pharmacological methods of managing the anxious patient as well as environmental considerations. Methoxyflurane (GWP_{100} = 4)[282] fell out of favour as a general anaesthetic due to nephrotoxicity, however has been used in Australia for many years for procedural pain such as in endoscopy,[283] transrectal ultrasound biopsy,[284] and dental extraction.[285] Methoxyflurane is licenced in the UK as an analgesia for moderate to severe pain associated with trauma,[286] and other indications are being explored.

While **reducing clinical use of nitrous oxide** is important, multiple hospitals on different continents have identified 77% to 95% losses pre-utilisation through leaking central piping manifolds, wasting money and with large environmental impact.[260,281,287] Large losses may go unnoticed where volumes used (demand) are not compared against volumes supplied: better communication between engineers and clinicians may identify leaks early.[288] The Nitrous Oxide Mitigation Project seeks to aid strategic **decommissioning of centrally piped nitrous oxide and substitution by portable cylinders** that should be closed between uses.[257,260,281,289] Clinicians influential in facilities operations management can support this strategy, and may draw upon a tool developed by NHS England for reducing waste emissions from piped nitrous oxide.[290] Nitrous oxide cracking technologies can be used to break nitrous oxide down into nitrogen and oxygen via catalytic destruction, reducing both environmental impact, and occupational exposure for staff.[291]

CASE STUDY: Decommissioning nitrous oxide manifold

Setting	Christie NHS Foundation Trust	
Patients	Patients requiring nitrous oxide	
Intervention	Decommissioning nitrous oxide manifold, replacing with on-demand portable nitrous oxide cylinders	
Outcome		No anticipated negative outcome to patients
		↓ 54 tonnes CO_2e / year
		↓ £1,681 / year

Source: Centre for Sustainable Healthcare[98]

Waste anaesthetic gases (WAGs) are partially collected through vacuum scavenging systems and typically vented off building rooftops. Waste volatile anaesthetics may be captured and purified, and stored or subsequently destroyed. WAG treatment technologies are commercially available and others are under development, and at present re-use of desflurane is only permitted in Canada. Currently, there is a lack of robust evidence on the capture rate of these technologies (which may be as low as 25%),[292] efficacy and efficiency of the technology, and actual vented WAG volumes, and how these balance in environmental impact when considering the manufacture, distribution, and processing associated with such technologies.

Belief in the value of WAG treatment may lead to lax behaviours by clinicians, and so, at present, avoiding inhaled anaesthetics (particularly desflurane and nitrous oxide) and **minimising fresh gas flows** (low flow anaesthesia) remain higher priorities.[257,260,281] Clinicians and hospitals are encouraged to wait for more research before investing in WAG treatment technologies, and to prioritise and facilitate clinician practice solutions.

CASE STUDY: Adopting cold sticks for testing spinal/ epidural blocks

Setting	University Hospitals Dorset NHS Foundation Trust	
Patients	Patients undergoing spinal/epidural blocks	
Intervention	Use 'cold sticks' (solid stainless-steel sticks with handles that can be reused and kept in the fridge) for testing spinal/epidural blocks in place of ethyl chloride spray	
Outcome	Satisfactory and accurate block level achieved when used appropriately	
	↓ 4.6 tonnes CO_2e / year	
	↓ £4,827 / year	

In 2020, Helen Spencer Jones, Emily Young, Sharon Clyde, and João Fontes, members of the Recovery Team at University Hospitals Dorset NHS Foundation Trust undertook a project to reduce the use of ethyl chloride spray for testing spinal/epidural blocks in RBH Recovery.

The two recovery units at the Trust used six cans of ethyl chloride spray in a week; a high use rate since the Trust is a centre for elective orthopaedic surgery. These were disposed of in the domestic waste stream, and if released into the environment ethyl chloride is acutely toxic to birds, animals and aquatic life and affects the growth rate of plants.

The team designed a project to switch to 'cold sticks' (solid stainless-steel sticks with handles that can be reused and kept in the fridge) for testing spinal/epidural blocks. They conducted a poster campaign to promote the use and audit of cold sticks, reviewing collected data on a weekly basis.

They found that the metal sticks were effective at assessing blocks, and patients were reported to 'jump' less when sticks were used in comparison with the spray, indicating a better patient experience. The team estimated overall carbon savings of 4,613 kg CO_2e and financial saving of £4,827 over one year. If the project was spread to 8 surgical wards the hospital could save 36 tonnes CO_2e (-13.76 kg CO_2e for procurement of 20 metal sticks for the hospital) and save £37,413.

Source: Centre for Sustainable Healthcare[293]

Section recommendations

Recommendation	Short term	Long term	Stakeholders
R5.1 Opt for anaesthetic modality with lowest environmental impact (as clinically appropriate)	For each patient consider whether local, regional, or intravenous techniques could be appropriate[a,b]	Further research into environmental impact of different anaesthetic techniques[c] Education[d]	Anaesthetists[a] Surgeons[b] Academics[c] Educators[d]
R5.2 Where inhaled anaesthetics are clinically necessary, avoid desflurane and minimise fresh gas flows	For each patient opt for lowest carbon inhaled anaesthetic gas that is clinically appropriate, and minimise fresh gas flows[a]	Decommission desflurane[a,e,f] Further research required to evaluate waste anaesthetic gas capture technologies[c] Education[d]	Anaesthetists[a] Theatre managers[e] Pharmacists[f] Academics[c] Educators[d]
R5.3 Reduce nitrous oxide use and waste	Consider non-pharmacological methods for managing anxious patients[a]	Decommission centrally piped nitrous oxide, substitute with portable cylinders[a,e,f] Introduce nitrous cracking technologies[a,e] Education[d]	Anaesthetists[a] Facilities and estates[e] Pharmacists[f] Educators[d]
R5.4 Minimise pharmaceutical wastage	Only open what is needed, and dispose of pharmaceuticals in medicinally contaminated waste appropriately[a,b,f]	Education[d]	Anaesthetists[a] Surgeons[b] Pharmacists[f] Educators[d]

6. Products used in surgical care

Section key points

- Circular economy principles can be applied to reduce environmental impact of products, seeking to minimise waste material and energy at all stages of a product's life cycle.
- At the stage of product design, this may be facilitated through adopting the Design for the Environment framework, and applying the principles of Green Engineering, and Green Chemistry.
- Core circular economy concepts which can be applied to healthcare products include refuse, reduce, reuse, recycle, renew (through repair or remanufacture) and recycle.
- Average reductions in carbon footprint of 38-56% are achieved through switching from single-use to reusable equipment.
- There are further opportunities to optimise environmental impact of reprocessing of reusable equipment; for example, through the preparation of instrument sets and by optimising the efficiency of washing and decontamination/sterilisation machines.

6.1 Principles of a circular economy for medical products

Evaluating ways to reduce the carbon footprint of products used in operating theatres will play an important role in the transition to sustainable models of surgical care. Manufacturing and distribution of medical and non-medical supplies, devices, and pharmaceuticals accounts for up to 71% of healthcare's global GHG emissions,[21] in concordance with estimated figures of nearly two-thirds of NHS England's carbon footprint.[22] Also called 'scope 3' emissions, these are beyond the direct control of a healthcare organisation, but can be influenced by healthcare professionals and procurement teams, for example through product selection and use. The principles outlined in this section apply to products used throughout the patient surgical care pathway, by both surgical and anaesthetic teams.

The operating theatre is an area of the hospital with particularly high medical product use and consumption. Surgical products have been associated with up to two-thirds of the carbon footprint of a cataract operation,[294] and a single adenotonsillectomy operation was found to generate over 100 separate single-use plastic items.[295] A number of items used in operating theatres are those with the highest GHGs, including single-use surgical instruments, gloves, surgical caps, drapes, tubing and drains.[296] Single-use products have also been found to be responsible for 68% of the carbon footprint of products used for the five most common operations in England.[297] This issue is increasing, with the global surgical equipment market growing at 9.8% per year, and anticipated to be worth US$24.5 billion by 2028.[298]

Many products have a linear 'life cycle', involving raw material extraction ('cradle'), production, distribution, use, and disposal ('grave'); which is unsustainable given finite planetary resources. By contrast in nature, all life cycles are cyclical, with 'waste' from one animal or biological system feeding another. The volumes of unused materials, such as the plastics filling our landfills, ditches, and oceans,[299] do not exist in natural systems.

Mechanisms to reduce the environmental impact of surgical products may include adopting **circular economy** principles, and developing and using products which are reused and re-engineered, ideally indefinitely. Whilst indefinite reuse is a theoretical concept (no product can be reused indefinitely), the composite elements of the product can be captured and reused in some form, using different processes. Here 'waste' is considered a valuable resource with potential for regeneration via repair, remanufacture, or recycling.[300] The circular economy framework builds on the Cradle to Cradle ideology popularised by Braungart and McDonough, whereby products are used as feedstock for other products at the end of their usable life (rather than Cradle to Grave linear economy, where such products end up as waste with no further use).[301]

The circular economy model maximises material and energy flows, with common principles known as the **5 Rs: Refuse, Reduce, Reuse, Renew and Recycle.**

Refuse

Healthcare professionals and those involved in healthcare procurement should feel able to refuse less sustainable items (for example single-use electrosurgical products)

Reduce

Largest environmental reductions will be associated with absolute reductions (rather than looking at alternative products)

Reuse
For almost all surgical products, opting for reusables is associated with lower environmental impact compared with single-use equivalents[45,193,302]

Renew
There are opportunities to extend the lifespan of healthcare equipment through repairing reusable items, or remanufacture of single-use items (enabling further use)

Recycle
As a last step, recycling enables materials within products to be recaptured and used in the manufacture of other products, preventing materials being lost as waste

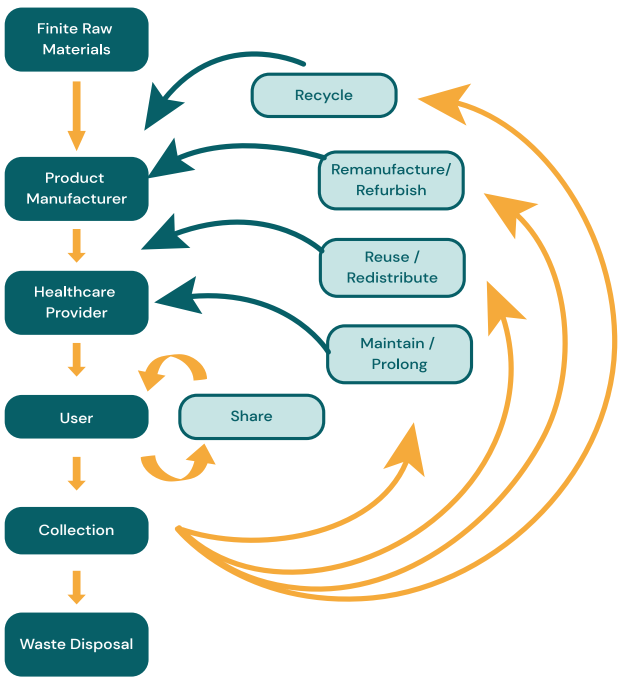
These concepts are considered in more detail in the following sections (6.2–6.7).[303]

CASE STUDY: Improving sustainability of laparoscopic appendectomy

Setting	Leeds Teaching Hospital NHS Trust
Patients	Patients undergoing laparoscopic appendectomy
Interventions	• Switch from single-use to reusable gowns and drapes • Replace single-use instruments with reusable instruments in appendectomy instrument tray
Outcome	↓ 2.6 tonnes CO_2e / year
	↓ £10,000 / year

Source: Centre for Sustainable Healthcare[304]

Figure 10: The circular economy



Adapted from Ellen MacArthur Foundation[304]

The diagram above (Figure 10) illustrates that most value (and carbon) can be captured by **retaining the 'embedded' value** of products. The tighter the circle, the more that route should be prioritised to maximise retention of product value. Product reuse, and the selection and use of products with a long life, ought to be a high priority.

As an example, most surgical instruments are made in Pakistan, sometimes from stainless steel manufactured in Japan or Germany, and then shipped to healthcare facilities around the world. There is considerable embedded energy and carbon associated with the manufacture and distribution of those instruments, and reusing these retains the embedded value of that energy and carbon. Single-use devices that are remanufactured by a third party (represented by the refurbishment or remanufacturing loop, Figure 10), undergo transportation, repair, and loss, requiring additional resources and reducing the value compared to reusable instruments. Recycling is associated with the largest loop, as materials of products must be separated, and often undergo many steps to be made into new products. Currently, recycling markets are unreliable and contamination of recycling streams leads to much recyclable material being thrown away.[305] In the case of medical supplies, recycling could be called 'downcycling' as the recycled materials are of lower quality and functionality and so will almost never be able to be used to make medical supplies again. It can instead be used in other industries such as construction (e.g. steel for construction beams) and horticulture (e.g. PVC tree ties), and these usually cannot be further recycled at the end of their lifespan.

6.2 Manufacture and distribution

Provision of healthcare will always require manufacture and use of medical products and pharmaceuticals. There are frameworks which can be used at the product manufacturing stage to evaluate and encourage sustainability for medical devices, supplies, and pharmaceuticals. Surgical teams and procurement staff can challenge industry representatives to understand how a given product aligns with these sustainability frameworks, and to signal to manufacturers that this is what is expected of products used in healthcare.

The **Design for the Environment** or DfE framework (Box 2) emerged in the 1990s, providing guidance for product designers or research and development teams.[306] Applied to products of any sort, DfE prioritises environmental protection, human health and safety, and sustainability of resources. In essence, designers of medical products should think about all life cycle stages of their product: raw material extraction and sourcing, production and distribution, use and potential reuse, and end of life or disposal. They should estimate and track the environmental performance of their products and integrate learnings into new designs. Elements of DfE might include designing products with lower material diversity and interchangeable parts (modular) so that materials can be easily replaced or recovered (also known as 'design for revalorisation'). DfE might also encourage designers to 'design for detoxification'; that is, selecting materials that minimise the use of hazardous substances in either the product itself, the creation of the product, the use stage, or its final disposal.

Box 2: The 7 principles of Design for the Environment[306]

1. Embed life cycle thinking into the product development process
2. Evaluate resource efficiency and effectiveness of the overall system
3. Select appropriate metrics to represent product life cycle performance
4. Maintain and apply a portfolio of systematic design strategies
5. Use analysis methods to evaluate design performance and trade-offs
6. Provide software capabilities to facilitate the application of Design for the Environment practices
7. Seek inspiration from nature for the design of products and systems

Aligned with this, there are principles of Green Engineering,[307] which encourage designers to:

- Seek to ensure material and energy inputs are renewable and inherently non-hazardous
- Maximise efficiency of mass, energy, space, and time
- Reduce complexity and material diversity, making recycling and reuse easier
- Design products to meet (not exceed) needs
- Design products with the 'end of life' in mind
- Prevent waste wherever possible rather than handling once formed

Another widely popular framework is that of the Circular Economy (as discussed in section 6.1), which takes a life cycle view prioritising minimisation or elimination of produced waste. The principles of circular economy overlap with DfE, but they target whole companies or economies rather than single products or product lines. Aligning with these principles, some innovative companies are integrating recycled content into products and product packaging. Others have been developing compostable, bio-based plastics for medical supplies including Personal Protective Equipment (PPE) and disposable surgical products including receptacles, needle counters, and skin staplers.[308] However, a study evaluating the impact of substituting plastics within single-use hysterectomy devices with biopolymers found some environmental impacts (e.g. acidification, cumulative energy demand, carcinogenic effect) to be lower, and others (e.g. GHG emissions, eutrophication, ozone-depletion, smog-generation) to be higher.[309] Some studies outside of the healthcare context have associated bio-based plastics with lower carbon footprint, but the net environmental impact of using biopolymers is dependent on agricultural processes, waste systems enabling biodegradation, and potential recycling.[310]

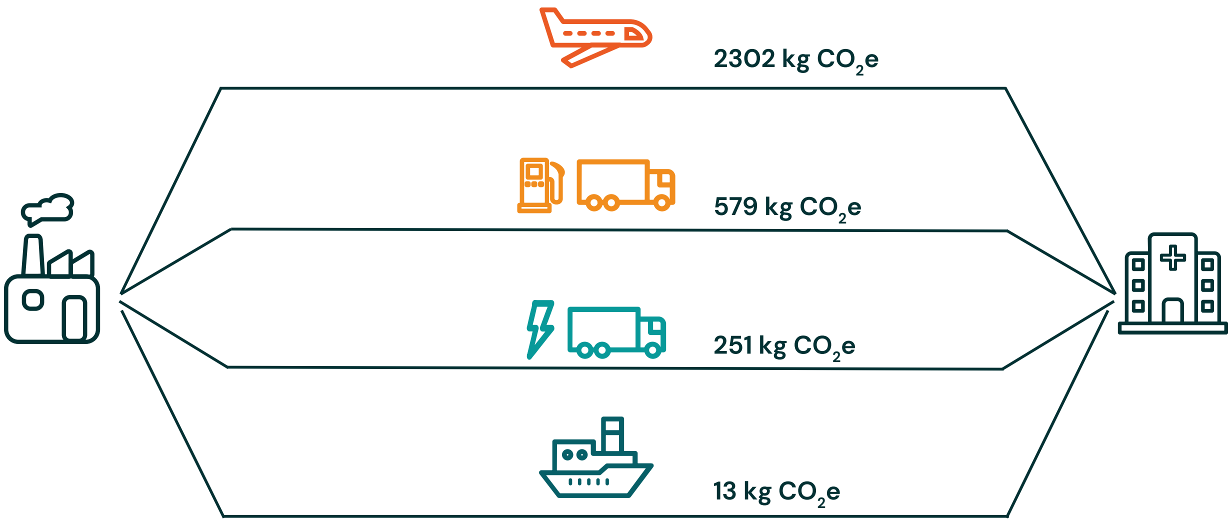
The predominant framework for improving sustainability of pharmaceuticals is called **Green Chemistry**,[311,312] which includes twelve principles ranging from waste reduction and energy efficiency, to less hazardous components and accident prevention.[313] Evidence on estimating and monitoring the environmental impact of pharmaceutical manufacturing and use are limited, as few methods exist, and we identify this as an area in need of development.

For the production and distribution of medical supplies, manufacturers need to apply DfE, Circular Economy, Green Engineering, Green Chemistry, and other environmental design principles to address sustainability. Manufacturers can also use standard life cycle thinking to minimise emissions associated with electricity use in factories and fuel use along distribution routes. For example, they can increase the proportion of **renewable energy sources** in manufacturing processes, through on-site renewable electricity generation (e.g. solar panels), supporting 'green' energy tariffs, or manufacturing in countries with higher proportions of renewables. There may also be opportunities to recover waste heat or to use natural cooling systems.

There are opportunities to reduce emissions associated with distribution processes through choice of mode of transportation (Figure 11), in particular **eliminating air freight** from healthcare supply chains. This may necessitate adequate planning and sufficient stocks to improve resilience, and avoid the need for urgent supplies. This can be further facilitated by expectations from healthcare providers, and a shift away from rapid (e.g. 48 hour) delivery requests.

Healthcare professionals can play a role in engaging with industry representatives about some of these factors (for example whether air freight is used within any stage of the product supply chain). Surgical teams may further ask suppliers whether they have sustainability plans to meet net zero targets, whether they publicly publish their emissions, or have set Science Based Targets.[314] Perhaps most importantly, they can ask why their product was not designed for reuse and longevity. The NHS roadmap for supplier alignment is considered in section 7.6.

Figure 11: Carbon footprint of alternative modes for transporting one tonne of medical products 1000km



Comparing transportation of 1 tonne of healthcare product 1,000 km, based on short-haul flight to and from UK, average diesel van, average battery electric van, average general cargo ship[315] We recognise there are wider environmental impacts beyond greenhouse gases, for example shipping contributes towards local ocean acidification through emissions of sulfur and nitrogen oxides in heavily trafficked routes.[316]

The wider context of the care pathways in which products are used should also be taken into account when considering sustainable product design, alongside logistical considerations associated with reuse, reprocessing and recovery of materials. For example, if there is robust evidence to support that use of a product over an alternative is associated with quicker operating time or reduced clinical complications, this should be included in analysis.

6.3 Opportunities to reduce and rationalise equipment

The largest reductions in environmental impact may be seen through reducing consumption of unnecessary items where this does not negatively impact on patient care.

Opportunities for making reductions (where clinically appropriate) include:

- Shifting the culture of opening items 'just in case', to '**open when required**', having items ready on standby, to be opened at the point of use
  - An evaluation of the cost of wasted single-use items (opened but not used) during endovascular neuro-interventional procedures found a mean average €679 per case[317]
- **Streamlining** single-use pre-prepared sets by liaising with industry to remove items not routinely used, and switching items in these sets to reusable alternatives where possible
  - One study found that 12 out of 40 single-use products in a pre-packaged tonsillectomy kit were unnecessary[318]
  - A study of hand operations found that an average of 11.5 products (out of 51 items) were disposed of without use, the majority of which were from a pre-prepared hand set,[319] whilst the development of a 'minimal' pre-prepared single-use set for hand surgery was associated with financial savings of US$125 per case[320]
- **Appropriate use of personal protective equipment**
  - For example, NHS standard infection control precautions indicate gloves should be worn when direct contact with blood and/or other body fluids, non-intact skin or mucous membranes is anticipated or likely.[321] However, habitual use of gloves for a wide range of tasks has become commonplace across healthcare settings including theatres, and is often inappropriate.[322,323] Not only does overuse of gloves increase the carbon footprint of care, but when they are put on too early and removed too late, they increase risk of microorganisms transmission between equipment and patients and vice versa.[324] Hand hygiene with either soap and water or alcohol hand gel is a more effective means of prevention cross-transmission and associated with lower CO_2 emissions (given that hand washing is required in addition to wearing gloves).
- **Eliminate unnecessary packaging** of surgical supplies and double wrapping where not indicated
  - For example, the Association of Surgical Technologists recommends double wrapping of individually wrapped 'supplementary' instruments only when packaging multiple or multi-component instruments,[325] yet this is sometimes seen for individual instruments, in part due to perceived convenience for theatre staff
  - There may be future opportunities for use of QR codes for accessing instructions for use, saving their inclusion in packaging
- Reduce volumes of paper using digital technologies (as per Section 3.1)

- Conventional scrubbing is associated with water wastage, with an estimated cost of around US$2,000 per year in an operating theatre in the USA.[326] At theatre design stage there may also be opportunities to reduce water consumption, for example through installing automatic or pedal controlled taps for surgical scrubbing, the latter estimated to save 5.7 L hot water, and 80 g CO_2e per surgical scrub.[327] The Intercollegiate Green Theatre Checklist[110] (Section 7) suggests use of alcohol gel in place of water and antiseptic scrub between cases.

CASE STUDY: Reducing unnecessary patient transfer sheets

Setting	Hywel Dda University Health Board
Patients	Endoscopy patients
Intervention	Elimination of slide sheet use for patient transfer where patient able to transfer self (estimated 90% of baseline use unnecessary)
Outcome	No impact on patient care
	↓ 3,726 kg CO_2e / year
	↓ £2,160 / year
	Improves patient independence

Source: Centre for Sustainable Healthcare[328]

6.4 Reusable equipment

There has been a disturbing trend toward single-use disposable medical devices over the past three decades that is rapidly accelerating. Simple devices such as blood pressure cuffs,[329] pulse oximetry probes, and laryngoscopes,[330] as well as complex devices such as laparoscopic instruments,[331] duodenoscopes,[332] and bronchoscopes[333] may now be single-use. In addition to ecosystem destruction from natural resource extraction, fossil fuel combustion to provide energy for manufacturing, and waste disposal management also harms human health. Whilst reuse is not appropriate for items difficult-to-decontaminate with current technologies (such as needles and intravenous tubing), reviews in surgical contexts[45] and across healthcare[193,302] associate reusable equipment with lower environmental impact relative to single-use equivalents in almost all cases (Table 6), with average **reductions in carbon footprint of 38-56% through switching from single-use to reusable products.**[193]

Whilst reductions in GHG emissions have been demonstrated for reusable products across a range of categories (Table 6), shifting towards reusable textiles may have particular potential for impact as these are common to most surgical procedures and associated with high carbon burden. For example, single-use personal protective equipment, and patient and table drapes were responsible for mean 25% of carbon footprint of products used in five common operations.[297] Previous review of **surgical gowns and drapes** found **reductions in carbon footprint (200-300%), water footprint (25-330%), and waste generation (750%).**[334] A review by the WHO Global Guidelines for Prevention of Surgical Site Infection found no evidence of difference in surgical site infection rates when single-use versus reusable drapes were utilised.[335] In fact, there are potential benefits (beyond environmental) associated with reusable linens including higher water resistance, strength, and pilling resistance (demonstrated for gowns).[336]

Table 6: Evidence for lower carbon footprint associated with reusable products compared with single-use equivalent

Product group	Product	Carbon footprint per case of reusable (X%) relative to single-use	Source
Airway devices	Laryngoscope blade Laryngoscope handle	14-50% 4-14%	Sherman et al. (2018)[330]
	Laryngeal mask airway	65%	Eckelman et al. (2012)[337]
Surgical instruments	Dental burr	35%	Unger et al. (2014)[338]
	Laparoscopic clip applier**	17%	Rizan et al.(2022)[339]
	Laparoscopic trocar**	18% 27%	Boberg et al.(2022)[340] Rizan et al.(2022)[339]
	Laparoscopic scissor**	33%	Rizan et al.(2022)[339]
	Surgical scissor	3%*	Ibbotson et al. (2013)[341]
	Vaginal speculum	33-37% 17%	Donahue et al. (2020)[342] Morris and Hicks (2022)[343]
Surgical scopes	Cystoscope	22%	Kemble et al.(2023)[344]
	Duodenoscope	2-4%	Le et al.(2022)[345]
Surgical products	Anaesthetic drug tray	87%	McGain et al. (2010)[346]
	Blood pressure cuff	7-8%	Sanchez et al (2020)[347]
	Laparotomy pad	54%	Kummerer (1996)[348]
Textiles	Surgical face mask	58%	Lee et al. (2021)[349]
	Surgical gown (and huck towel)	34% 51%	Vozzola et al. (2020)[350] Carre et al. (2008)[351]
Waste products	Suction receptacle	3%*	Ison et al (2000)[352]
	Sharps container	17% 35% 16%	Grimmond et al. (2012)[353] McPherson et al. (2019)[354] Grimmond et al. (2020)[353]

=estimated from chart,= hybrid (predominantly reusable, small single-use component)*

There are a small number of studies which suggest that the carbon footprint of single-use products is lower than reusable equivalents (Appendix 3). The majority of these studies were undertaken in Australia,[355-357] or have assumed Australian electricity supply.[358] Australia has a high proportion of non-renewable energy sources and has been slow to decarbonise its energy supply. These results do not apply where surgical products are used and reprocessed using electricity with higher proportion of renewable (versus non-renewable) energy sources, such as Europe or the USA. Other studies that apparently favour single-use products lack transparency,[359] compare inequivalent products (the same 'functional unit' should be compared in such studies),[360] or have methodological flaws.[358]

Reliable analysis of the carbon footprint of endoscopes are an important gap in knowledge. One study found single-use duodenoscopes generated up to 47 times the carbon footprint of reusable duodenoscopes (with production accounting for up to 96% of the carbon footprint),[345] whereas a study of cystoscopes suggested single-use was better[358] but was subsequently shown to have methodological flaws.[361]

CASE STUDY: Switching to reusable named surgical caps

Setting	Liverpool University Hospitals NHS Trust
Intervention	Reusable named fabric surgical caps
Outcome	Better communication between staff members
	↓ carbon footprint- see systematic review above
	↓ £53,202 / 3 years
	↓ patient anxiety Staff reported feeling more valued being addressed by name

Source: Centre for Sustainable Healthcare[162]

In summary, in almost all cases reusable products are associated with lower carbon footprint compared with single-use items.[45,193,302] The switch to reusable alternatives should be particularly encouraged in settings where single-use equipment is commonly used, including emergency departments, outpatient and primary care settings, and operating theatres. Some of the potential barriers to switching to reusables such as infection prevention policy and practice, and supporting infrastructure are considered in sections 7.4 and 7.6.

There are often **cost savings associated with switching to reusables** where full life cycle costs are taken into account. For example, switching from single-use to reusable laryngoscope blades and handles was associated with savings of up to US$604,000 and US$265,000 respectively per year at a single hospital.[330] Switching from single-use to reusable anaesthetic equipment was associated with an estimated £19,220 per year saving (46% decrease) in an Australian hospital.[355] Switching from single-use to hybrid (predominantly reusable) laparoscopic scissors, ports, and clip appliers was modelled to save over £11 million if adopted for all laparoscopic cholecystectomies in England.[339] There are also initiatives to increase reuse of equipment in the wider surgical patient pathway. For example, reusing walking aids (such as crutches, frames and walking aids) is estimated to save the average hospital £46,000 per year (assuming just one in every five is returned).[363]

CASE STUDY:
Switching to reusable ports and instruments for laparoscopic appendectomy

Setting	University Hospitals Plymouth NHS Trust
Patients	Patients undergoing laparoscopic appendectomy
Intervention	Replacing single-use ports and instruments (Johann graspers, scissors, Maryland forceps) with reusable equivalents
Outcome	↓ 0.5 tonnes CO_2e / year
	↓ £34,400/ year
	>90% staff responding to survey would now consider sustainability within their practice

Source: Centre for Sustainable Healthcare[162]

6.5 Reprocessing

In between uses, reusable products must be reprocessed. This involves cleaning, followed by microbial inactivation through disinfection and/or sterilisation, thereby enabling safe reuse.[365] Microbial inactivation for reusable instruments is most often achieved using steam (recommended as preferred method of sterilisation by WHO),[366] although alternative low-temperature methods include ethylene oxide, vaporised hydrogen peroxide gas plasma, formaldehyde gas, or ozone.[365,366] Different sterilisation methods will be appropriate for different surgical products, for example ethylene oxide is suitable for devices that would otherwise be damaged by moisture and/or heat, and also suitable for devices with lumens,[366] such as endoscopes.

Whilst significant carbon footprint reductions (average 38-56%)[193] are seen through switching from single-use to reusable products, once a reusable item is in place the majority of the carbon footprint typically relates to this reprocessing phase; as illustrated in studies evaluating laryngoscope blades and handles (reprocessing responsible for almost all greenhouse gas emissions),[330] and surgical scissors (85%).[341] Sterilisation of reusable products was also found to be responsible for 20% of the carbon footprint of all products (including both single-use and reusable) used for the five most common operations in England.[297]

Strategies that can be used to optimise the carbon footprint of sterilisation processes include:

- Reprocessing **instruments as sets containing multiple instruments** (rather than supplementary, individually wrapped items)
  - The carbon and financial cost of processing an instrument as part of a set (66-77g CO_2e, £0.90-0.92 per instrument undergoing steam sterilisation) is lower than individually wrapped instruments (189 g CO_2e, £6.34 per instrument)[367]
  - Individually wrapped items are usually prepared in single-use flexible peel pouches, associated with inefficient loading of decontamination machines

- Conduct decontamination machine test-runs loaded with sets
    - Decontamination machine test-runs (to verify sterility assurance standards) can be conducted loaded with instruments, which can then be put into circulation for clinical use (provided the test passed, as is the norm)
- **Maximise loading** of decontamination machines (washer-disinfector and steriliser)[367]
    - This can be facilitated through adequate stocks of reusable equipment to ensure clinical requirements for instruments can be met, and may be easier where sterilisation facilities are centralised
- **Minimise** decontamination machine **standby time**
    - In one study standby time was found to be responsible for 40% of a steam steriliser's daily total energy and 20% of its water consumption[368]
    - Switching off decontamination machines idle for two or more hours (estimated to be 42% of the time in an Australian study) can save a quarter of electricity use and 13% of water consumption of steam sterilisers[369]
- Increase proportion of **renewable** energy supplies
    - Achieved through local on-site renewable energy generation, or encouraged through green energy tariffs

Surgical teams may liaise with on and off-site sterile services to encourage adoption.

Different sterile barrier systems (used to house surgical instruments) will also have different carbon footprints, with highest impacts associated with single-use flexible peel pouches for individually wrapped instruments.[367] The carbon footprint of reusable rigid containers has been found to be higher (721 g CO_2e per set), than single-use tray wraps (387 g CO_2e per set) principally due to the additional washing required for the rigid containers (which is inefficient due to their bulkiness).[367] This contrasts with findings from a different study[367] which found that the carbon footprint of reusable rigid containers was 85% less than that of single-use tray wraps,[370] with significantly lower estimate for reusable rigid containers (57 g CO_2e per use); however, the underlying assumptions about energy consumption in the latter study need reconsideration.[370] Regardless of the choice of sterile barrier systems, the most important take-home message is to use reusable instruments where possible, to prepare these as sets, and to only remove items from the set that are never or very rarely used. There are opportunities also to **recycle sterile barrier systems**, modelled to reduce the carbon footprint of single-use tray wrap by 6%, and 3% for reusable rigid containers.[367]

Reusable linens need to be laundered (enabling cleaning and disinfection), and sterile linens (such as surgical gowns and drapes) undergo steam sterilisation in a similar manner to surgical instruments. Opportunities to optimise the environmental impact of healthcare linen laundering has received little attention. However, the principle of optimising machine loading and utilising renewable energy sources can also be applied here, alongside use of **environmentally preferable detergents**,[371] and **capture of microfibres** which may be released during washing.[372]

CASE STUDY: Switching to reusable linens and optimising reprocessing

Setting	Royal Cornwall Hospitals NHS Trust
Patients	Specialist Orthopaedic and Breast Surgery hospital, with four operating theatres
Interventions	• Switch from single-use surgical gowns and operating theatre drapes to reusable equivalents • Installation of modular medical textiles reprocessing unit on site • Developing and validating low temperature decontamination processes
Outcome	↓ 67 tonnes CO_2e / year (assuming 75% capacity THR equivalents for 4 theatres working 5 days a week for 52 weeks)
	↓ £10,000/ year

Source: Direct Submission from Tom Dawson

6.6 Extend lifespan of products: repair and remanufacture

There are opportunities to extend the lifespan (number of uses) of a given product through repair of reusable items and remanufacture of single-use products. When a reusable surgical item becomes damaged, or no longer functions optimally, there may be options for **repair rather than replacement**. Repair forms part of the 'circling longer' principle, that reduces the need for acquisition of virgin materials, consumption of energy, and use of labour.[373]

Analysis of >14,000 repairs over 11 years at Barts Health NHS Trust reported that of instruments successfully repaired, over half were general surgical scissors such as Mayo, Metzenbaum or McIndoe scissors (52%), followed by osteotomes (6%), needle holders (6%), retractors (4%), and clamps (4%).[374] Surgical scissors repair was associated with **carbon savings of 20%**, and cost savings of one-third, compared with purchase of a new pair of scissors (Figure 12).[374] However, offsite repair can sometimes cause delays, and so good communication between parties is needed to optimise services, and in some cases may also require hospitals having spare stock.[374]

Figure 12: Repair of surgical scissors

Where 'single-use' products are in use, it is possible to gain one or more additional uses through remanufacture, whereby products are evaluated, parts are repaired or replaced as necessary, and products are re-certified. Carbon reductions have been demonstrated for remanufacture compared to single-use products, including for electrophysiology catheters (half the carbon footprint)[375,376] and a range of other products (arthroscopic shaver, deep vein thrombosis compression device, endoscopic trocar, ligasure, pulse oximeter, scissor tip, and ultrasonic scalpel).[377] This has also been associated with cost savings, for example reprocessing of a deep vein thrombosis compression sleeve once was estimated to save around US$75,000 at a US hospital per year, whilst reprocessing it five times (getting total of six uses out of the device) was associated with cost savings of over US$123,000.[377]

However, the reductions associated with switching from single-use to reusable products are usually greater than switching from single-use products to remanufactured products. We also caution that the environmental impact of using remanufactured products will depend upon the transportation distances and modes of travel (for example reductions may be offset if air freight is used), alongside the proportion of products which can be successfully remanufactured, which is product dependent.

6.7 Waste and recycling

When seeking to improve sustainability, waste disposal and recycling are prioritised and considered to be important sources of emissions. However, waste plus water are together responsible for only 5% of NHS England's carbon footprint,[22] and analysis focusing exclusively on the products used in five common operations found waste disposal was responsible for 9% of the carbon footprint.[297] In contrast, seeking to reduce volumes of waste has a larger potential (beyond the environmental impact of processing of waste), indicating reduced embodied carbon upstream in the supply chain (including manufacture and distribution of single-use products). Auditing the generation of waste in a surgical department can be used as a **proxy for volumes of single-use items consumed**, but should primarily be used to identify opportunities for upstream reduction.[378]

Nevertheless, optimising healthcare **waste disposal** does present an opportunity to further reduce the carbon footprint. Hospitals can seek contracts with companies that **recover energy from waste** (whereby energy is generated, bottom ash and slag metals are recovered and reused), which is feasible for both high and low temperature incineration (42%[379] and 50%[380] reductions in carbon footprint respectively). Infectious waste is defined as waste contaminated by a known pathogen, not just contaminated with blood and/or body fluid. Infectious waste (orange bags) must undergo decontamination prior to waste disposal (for example via autoclave, dry heat, micro-/macrowaves, steam auger, or chemical disinfection),[381] with additional environmental impacts (338kg CO_2e/tonne waste autoclaved).[380] An audit of anaesthetic waste found 16% of waste disposed in infectious waste streams was not contaminated, whilst 7% of waste disposed of in general waste streams was infectious.[382] This highlights the importance of accurately segregating waste to ensure the carbon footprint associated with its disposal is as low as possible.

The environmental impact of using landfill (relative to the impact of sending items for incineration) is dependent upon the waste materials (and their biogenic and fossil fuel-derived carbon content). For instance, disposing one tonne of metal or plastic via landfill is associated with 9 kg CO_2e, one tonne of linens with 445 kg CO_2e, paper with 1,042 kg CO_2e, and food and drink with

627 kg CO_2e.[315] However, there are factors beyond GHG emissions that affect the environmental impact of waste streams, for example landfill has a lower impact on human toxicity and photochemical oxidation but higher impact on terrestrial ecotoxicity than incineration.[379,383]

Table 7: Disposal of healthcare waste

Waste stream		Waste receptacle	Description
Non-hazardous waste	Dry mixed recyclable waste	Clear bag	This will depend on local recycling facilities, but may include sterile packaging, paper, cardboard, plastic bottles
	Domestic waste	Black bag	This is the equivalent to municipal household waste, for example hand towels
	Non-infectious offensive waste	Yellow/black striped bag	This should be used for item which 'may cause offence' e.g. contaminated with body fluids, odour
	Infectious waste	Orange bag	This should be reserved for items in contact with a patient known (or suspected) to have a disease caused by a microorganism or associated toxins (where hazardous waste criteria not fulfilled)
Hazardous waste	Clinical waste	Yellow bag	Infectious waste contaminated with chemicals or pharmaceuticals
	Medical contaminated sharps waste	Yellow lidded yellow box	Sharp products contaminated with medications
	Anatomical waste	Red lidded yellow container	Body parts, including anatomical waste such as amputated tissue, diagnostic specimen, blood bags
	Medicinal waste	Blue lidded yellow box	Unused (or part used) medicines

Waste types based upon UK Department of Health guidelines.[381] Note hazardous waste contains infectious pathogens, cytotoxic medicines, or medicines/ chemicals that harm humans or the environment including those with radioactive properties.

It is important that healthcare staff have access to appropriate waste disposal routes, alongside education on how to sort waste appropriately (Table 7). For example, **infectious waste bags should be used only when there is clear risk of infection** because inappropriate use causes unnecessary carbon and financial burden. **Segregation** of waste could be improved through clearer waste terminology. For example, the stream for infectious waste contaminated with chemicals is commonly confusingly labelled 'clinical waste', which leads people to utilise this route for disposal of waste from an operating theatre that is not infected.[381] Appropriate waste segregation is also associated with financial savings,[380] for example a series of initiatives to improve use of medical waste streams in a USA tertiary hospital was associated with financial savings of around US$288,012 per year.[384]

Recycling

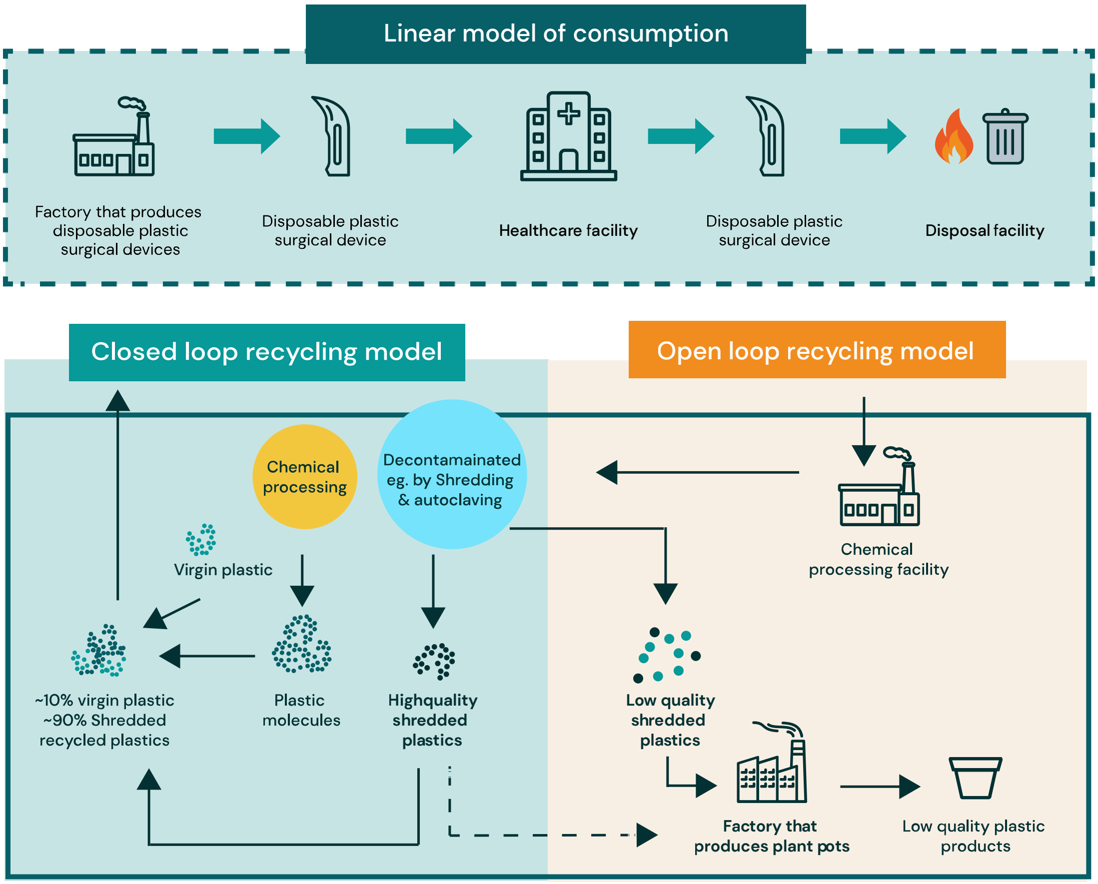
In line with circular economy principles, waste minimisation ought to be pursued, alongside efforts to recover and reuse materials, keeping them in use at their highest function for as long as possible. Where items are recycled, emissions associated with the transportation from hospital to recycling facility, and recycling process, are assigned to the products for which the recycled materials are integrated. Similarly the benefit of not needing to acquire new virgin materials is also assigned to the new product.[385] For example, where stainless steel instruments are recycled into materials for construction, the offsets due to reduced need for virgin metal extraction are assigned to that construction. This means that for the healthcare sector to be assigned benefit from recycling, we need to **increase the proportion of recycled content** (amount of recycled materials) used within healthcare products themselves.

The proportion of operating theatre waste that is potentially recyclable has previously been estimated at 55% by weight.[386] This can be increased if infectious waste is decontaminated before recycling. For example, there are services which decontaminate surgical instruments prior to using that steel in the construction industry, and there is potential to expand this to other healthcare waste materials. There can be financial savings associated with recycling. In a hospital in the USA, the sale of recycled blue instrument tray wrap was estimated to generate US$5,000 per year and a further annual saving of US$174,240 from avoided waste disposal.[387] There is large variation in recycling rates between UK hospital sites. For example, an evaluation of Mohs micrographic surgery at twelve sites across the UK found the recycling rate ranged 0-44%.[388]

The ability of a product to be recycled depends on several factors, one of which is the circularity potential, meaning the potential ability of recycled elements to be reused and meet the high-quality standards necessitated by the healthcare industry.[389] There are many challenges associated with plastic recycling.

To improve their circularity potential, healthcare products should be created in ways that allow for easy disassembly into component parts for recycling, and which minimise the mixing of different plastics in waste. If the plastics can be sorted, they can be used for products of different material quality. When recycled plastic is used to create a lower quality product, such as a plant pot, this is known as downcycling. The process of downcycling falls into a category known as open loop recycling, which refers to a recycling process where the recycled material is used for a different market application than that of the previous life cycle.[390] However the ideal recycling process is one called a **closed loop recycling process**, whereby the quality of the material is kept high during recycling, and so the recycled material could be reused for the same market application as that of its previous life cycle (Figure 13). For example this could be achieved through novel processes such as autoclaving and shredding,[391] to create shredded safe plastics feedstock to create similar healthcare products. Another process within the closed loop model is chemical recycling whereby plastics are broken down and depolymerised, and can subsequently be used to produce fuels, or virgin plastics.[390]

Figure 13: Open versus closed loop models of recycling



CASE STUDY: Recycling surgical wrap

Setting	Cork University Maternity Hospital, Gynaecological theatre
Intervention	Recycling of single-use polypropylene surgical wrap used for gynaecological surgeries
Outcome	No impact on clinical care
	↓ 2.2 tonnes CO_2 / year
	Cost €733/ year

A team at the Cork University Maternity Hospital (CUMH), in Wilton, Cork, Ireland, prospectively quantified the polypropylene surgical wrap generated by a single gynaecology theatre in the hospital, with a view to recycling. In 2019, 1,909 gynaecological surgeries were performed at CUMH.

The group found that surgical wrap comprised 11% of operating theatre waste. A total of 66 surgeries were performed over a five-week period in 2022, from which 221 individual sheets of surgical wrap were collected, equating to 282m^2 of polypropylene wrap. The team estimated 711 kg of surgical wrap could be recycled annually from their gynaecology theatre, equating to 2.2 tonnes of CO_2e. It was estimated that disposal of the wrap in the general waste stream would cost €107 per annum, but only €35 per annum in the recycling stream (although due to contractual obligations these cost savings were not realised at CUMH).

Source: Direct submission David James Rooney

Section recommendations

Recommendation	Short term	Long term	Stakeholders
R6.1 Ensure that design and manufacture of products minimise the environmental impact throughout the product lifespan	Opt for renewable energy sources[a] Ask suppliers if they have a carbon reduction plan[b,c]	Apply principles such as Circular Economy, Design for the Environment framework, principles of Green Engineering, or Green Chemistry principles[a] Develop a carbon reduction plan (if not already in place)[a]	Industry[a] Procurement teams[b] Surgical and anaesthetic teams[c]
R6.2 Ensure that modes of distribution with lowest environmental impact are chosen	Ask industry representatives whether air freight is used at any stage of product supply chain[b,c]	Shift culture away from urgent delivery requests (reducing reliance on air freight) through adequate planning, sufficient stocks[b,c] Seek to eliminate air freight from distribution, electrify vehicular fleet[a]	Industry[a] Procurement teams[b] Surgical and anaesthetic teams[c]
R6.3 Reduce and rationalise equipment	Only open items when required[c] Rationalise unnecessary equipment and investigations (e.g. avoid gloves where hand washing appropriate)[c]	Streamline single-use pre-prepared sets[a,b,c] Eliminate unnecessary packaging[a]	Surgical and anaesthetic teams[c] Procurement teams[b] Industry[a]

R6.4 Switch from single-use to reusable equivalents where available	Opt for reusable equivalents where currently stocked are available[c]	Explore whether reusable alternative currently available on the market and trial/purchase[c,b] Model increase in demand for reprocessing of reusable equipment, plan to increase capacity accordingly[b,d,e] Design products for safe reuse[a]	Surgical and anaesthetic teams[c] Procurement teams[b] Instrument and textile reprocessing services[d] NHS and healthcare provider management teams[e] Industry[a]
R6.5 Optimise reprocessing of reusable equipment	Switch off idle machines[d] Run decontamination machine test-runs loaded with sets[d]	Prepare instruments as sets[d] Use renewable energy sources, environmentally preferable detergents[d] Maximise loading of decontamination machines, whilst minimise standby time[d]	Instrument and textile reprocessing providers[d]
R6.6 Extend the lifespan of reusable products through repair and remanufacturing	When an item is damaged find out if it can be repaired[c,d]	Explore opportunities for repair and remanufacturing (where such contracts not in place)[f,d,g] Design products that are modular, facilitating repair[a]	Surgical and anaesthetic teams[c] Theatre managers[f] Instrument and textile reprocessing services[d] Repair services providers[g] Industry[a]

R6.7 Optimise waste	Use appropriate waste streams[c]	Education on appropriate use of healthcare waste streams[h] Opt for contracts with waste handling companies which enable recycling and recovery of energy from waste where possible[i] Facilitate appropriate waste segregation[i] Design products to facilitate recycling (e.g. made of as few different materials as possible)[a] Design products using maximal recycled content[a]	Surgical and anaesthetic teams[c] Educators[h] Facilities and estates[i] Industry[a]

7. Barriers and facilitators to implementation

Section key points

- Surveys indicate the majority of the public are concerned about climate change and support NHS net zero carbon ambitions.
- Many surgical teams are motivated to improve sustainability but perceived barriers to change include lack of awareness, lack of information, feeling disempowered, financial costs, lack of time, inadequate facilities or resources, and lack of leadership and guidance.
- Surgeons may look to Surgical Colleges, and specialty associations for guidance. Bottom-up leadership may be facilitated by sustainability champions and networks.
- Sustainability is now a GMC mandated core outcome for undergraduates.
- Few resources are available for postgraduate training e.g. the SusQI model enables sustainability to be integrated into Quality Improvement teaching and the Royal College of Anaesthetists has integrated sustainability into curricula and examinations.
- Infection prevention and control policy and practice is often perceived as a barrier to sustainability. More consistent and permissive policy is needed, without compromising safety.
- The medical supply chain is globalised, complex and fragmented, posing a challenge to enacting change to favour sustainability.
- Transition to sustainable models of surgical care requires appropriate supporting policy and infrastructure, including physical facilities and financial models.

7.1 Knowledge, attitudes, and behaviours

A YouGov survey of over 2,500 **healthcare staff** (2021) found **87% support NHS net zero carbon targets**.[392] However, surveys point to varying levels of awareness and engagement with sustainability issues amongst healthcare staff. For example:

- A 2022 survey of healthcare workers in the UK, revealed that 74% of staff were aware of the negative environmental impact of surgery[393]
- A 2022 study of Finnish perioperative nurses found they were aware of ecological sustainability, but most thought this unnecessary in hospital settings[394]
- A 2021 survey of UK surgeons found 82% were willing to make changes to their clinical practice to improve sustainability[395]
- A 2015 survey of nursing staff found sustainability was considered lower priority in daily work compared to issues relating to preventing infection[396]
- A 2012 study of anaesthetists from Australia, New Zealand and England found 93% would like to increase recycling rates in the operating room[397]

Other barriers to transitioning to sustainability identified by healthcare professionals include a lack of leadership or managerial support,[395] perceived economic cost,[396] and lack of time,[396] whilst enablers include development of leadership and education.[395] In a survey of surgical staff in 2022, 71% had not received any form of education on environmental sustainability in the workplace.[393]

To bring about change in behaviours to enable more sustainable models of surgical care, surgical teams and personnel within supporting services need appropriate knowledge about environmentally preferable models of care, alongside a shift in attitudes. This is illustrated in the COM-B model, whereby **change in behaviour (B) requires capability, opportunity, and motivation (COM)**.[398] This highlights that even where individuals are highly motivated, they may not feel they have permission or appropriate resources to facilitate such change.

A survey exploring attitudes and behaviours towards environmental sustainability of surgeons and surgical trainees in the UK and Ireland found that respondents expressed concern about climate change, and many were willing to engage in efforts to transition to more sustainable practices.[395] They reported that actions towards sustainability were greater in their personal lives than the surgical workplace,[395] aligning with findings from an older survey.[399] The finding that the majority (82%) of respondents were **willing to make changes in their clinical practice**[395] is supported by surveys of surgeons in the USA,[400] ophthalmologists in New Zealand,[401] disease control and prevention specialists in China,[402] anaesthetists in Australia and New Zealand,[397] and obstetricians and gynaecologists in the USA.[403] In the latter survey, **two-thirds support a shift to reusable surgical equipment where clinically equivalent**.[403]

Perceived barriers to change include lack of awareness, lack of information, feeling disempowered, financial costs, lack of time, and inadequate facilities or resources.[395,397,400] Surgeons surveyed would also welcome **greater support, guidance, and leadership**.[395] The growing engagement of surgeons in sustainability[395] (motivation) now needs to be matched with greater education (capability), guidance, leadership and support (opportunity) in pragmatic actions to reduce environmental harm. This may include protected time to work on improving sustainability (and quality) of care.

A 2021 survey of 1,858 members of the **UK general public**, commissioned by the Health Foundation,[404] found:

- The majority (82%) were concerned about **climate change**
- 94% supported NHS net zero carbon targets
- A quarter recognised **climate change** as one of the **biggest threats** to their health

A 2022 survey found that 41% of the public stated procedure duration did not matter to them and almost a third would be happy to undergo a more sustainable procedure even if twice as long in duration, whilst a quarter of surgical staff felt prolongation would be unacceptable.[393] There is little evidence to support the notion that performing an operation in a more sustainable manner will lengthen its duration, and on first principles a longer duration would tend to add to its environmental impact, not reduce it. The majority of both public and staff respondents (72% and 66% respectively) indicated patient outcomes were more important than sustainability, however the vast majority of both groups felt that financial cost is of equal importance to environmental sustainability. The majority of public (69%) and staff (79%) surveyed thought that sustainability should be a high spending priority for the NHS, and that choice of equipment should be driven by sustainability, even where these are associated with increased financial cost.[393] In contrast a 2021 study by the Health Foundation found that whilst the majority of public respondents (70%) were supportive of the NHS net zero carbon aim, they ranked minimising the NHS impact on climate change and the environment as low in priority (second least important out of 15 proposed priorities for the NHS, although the COVID-19 pandemic may have impacted these results).[405]

Surgical teams can engage with patients and the public to raise awareness of the inter-dependence of human and planetary health, and involve patients in promoting sustainable high quality surgical care.

7.2 Clinical leadership

One of the main perceived barriers to sustainability in surgery is a lack of leadership.[395] Effective, efficient, visionary and responsive leadership will be central to delivering the service provision changes necessary for sustainable healthcare. This may be facilitated by the Kotter model for leading innovation change:[406]

1. Establish a sense of urgency
2. Create a guiding coalition
3. Develop a vision and strategy
4. Communicate the change vision
5. Empower individuals for broad-based action
6. Generate short-term wins
7. Consolidate gains and produce more change
8. Anchor new approaches in the culture

It is important that healthcare leaders spearhead this challenge, with **top-down leadership both at national and local levels**, within surgery and across wider healthcare services, and with appropriate governmental support. There is a tendency towards a culture of siloed thinking and working within the NHS, and moving towards systems-level thinking and improving the coordination of leadership will be helpful in the transition to sustainable models of delivery of surgical care.

The UK Health Alliance on Climate Change brings together 46 national healthcare organisations (including medical and nursing Colleges, national associations, and leading medical journals) and advocates for action towards mitigating climate change and promoting public health.[407] The NHS was the first national health system in the world to commit to reaching carbon neutrality,[23,33] with endorsement from the NHS England Chief Executive providing a high level mandate for action. In 2022 NHS England integrated this commitment into legislation, by including components of the Climate Change Act and the Environment Act into the new Health and Care Act.[35]

The Roger's Diffusion of Innovation model predicts that once a critical mass has adopted a particular change in behaviour, the change will become self-sustaining and further adoption becomes inevitable.[408] National and regional bodies are well placed to promote engagement and to facilitate education enabling this. Whilst the Royal College of Anaesthetists paved the way with their Sustainability Strategy,[409] the Allied Health Professions (AHPs) five-year strategy now includes environmental sustainability as one of five key areas,[410] and the Royal College of Nursing have demonstrated leadership on sustainable nursing practice.[411] The British Society of Gastroenterology was one of the first specialist societies to publish a sustainability strategy,[412] and has supported development of consensus position statements in environmentally sustainable practice in endoscopy, looking at all stages of the patient pathway.[413]

Surgeons will look to the **Colleges and national specialty organisations** for guidance and leadership to support individual members of the surgical team to embed sustainability into surgical practice. Many have now released sustainability strategies directed outwardly to action by members, including the Royal College of Surgeons of England,[414] Royal College of Surgeons of Edinburgh,[415] Royal College of Physicians and Surgeons of Glasgow,[416] and the Royal College of Surgeons of Ireland.[417] The declaration of climate emergency by these colleges, was aligned with the release of an **Intercollegiate Green Theatre Checklist** (Figure 14), designed to facilitate surgical teams to bring about change, and supported by an extensive compendium of relevant evidence.[110] A scorecard has been developed to evaluate action towards climate change by health organisations, and the Royal College of Surgeons of England was one of those piloted, highlighting areas for improvement including embedding sustainability within the postgraduate curriculum, developing an internal decarbonisation and divestment plan, and engaging with policy makers.[418]

At regional levels, the 2021/2022 NHS England Standard Contract mandated for the first time that all NHS Trusts (regional organisational units of healthcare providers) and Integrated Care Systems (partnerships bringing together healthcare commissioners, providers and partner organisations within a geographical region) must submit a **Green Plan** outlining local strategy for mitigating GHGs and should have a net zero board lead, in alignment with the NHS net zero carbon ambition.[419] NHS Wales published its Decarbonisation Strategic Delivery Plan in 2021, and NHS Scotland published its Climate Emergency and Sustainability Strategy in 2022. All NHS Trusts in England now have a Green Plan in place, representing over 1,000 healthcare organisations and facilities.[420] Surgical teams can identify members of the team involved at their local NHS Trust, as a starting point to join a local network of engaged individuals.

Bottom-up leadership from individual healthcare professionals is also required and could be fostered through the development of **sustainability champions and networks**, supported by platforms for dissemination of best practice. Such engagement is considered essential for delivering sustainable healthcare.[421] Surgeons and anaesthetists have expertise and authority in surgical care provision, and should be **ambassadors for change**, encouraging, supporting and collaborating with others in the surgical team, and colleagues in supporting services. This can include: staff in facilities and estates switching to renewable energy and heating; staff in sterile services increasing capacity or introducing/seeking systems for instrument repair and maintenance; and procurement teams integrating environmental sustainability into purchasing decisions (preferencing reusable options where possible). Improving disease prevention and health optimisation will require surgeons to engage with patients, and primary care and public health colleagues.

Figure 14: Intercollegiate Green Theatre Checklist[110]

THE ROYAL COLLEGE OF SURGEONS OF EDINBURGH · Royal College of Surgeons of England (ADVANCING SURGICAL CARE) · ROYAL COLLEGE OF PHYSICIANS AND SURGEONS OF GLASGOW · RCSI

Intercollegiate Green Theatre Checklist

Below are a list of recommendations to reduce the environmental impact of operating theatres. All the relevant guidance and published evidence has been included in the Compendium of evidence, accessed via the QR code:

Anaesthesia

1 Consider local/regional anaesthesia where appropriate (with targeted O_2 delivery only if necessary)

2 Use TIVA whenever possible with high fresh gas flows (5-6 L) and, if appropriate, a low O_2 concentration

3 Limit Nitrous Oxide (N_2O) to specific cases only and if using:
- check N_2O pipes for leaks or consider decommissioning the manifold and switching to cylinders at point of use;
- introduce N_2O crackers for patient-controlled delivery.

4 If using inhalational anaesthesia:
- use lowest global warming potential (sevoflurane better than isoflurane better than desflurane);
- consider removing desflurane from formulary;
- use low-flow target controlled anaesthetic machines;
- consider Volatile Capture Technology.

5 Switch to reusable equipment (e.g. laryngoscopes, underbody heaters, slide sheets, trays)

6 Minimise drug waste ("*Don't open it unless you need it",* pre-empt propofol use)

Preparing for Surgery

7 Switch to reusable textiles, including theatre hats, sterile gowns, patient drapes, and trolley covers

8 Reduce water and energy consumption:
- rub don't scrub: after first water scrub of day, you can use alcohol rub for subsequent cases;
- install automatic or pedal-controlled water taps.

9 Avoid clinically unnecessary interventions (e.g. antibiotics, catheterisation, histological examinations)

Intraoperative Equipment

10 REVIEW & RATIONALISE:
- surgeon preference lists for each operation - separate essential vs. optional items to have ready on side;
- single-use surgical packs - what can be reusable and added to instrument sets? what is surplus? (request suppliers remove these);
- instrument sets - open only what and when needed, integrate supplementary items into sets, and consolidate sets only if it allows smaller/fewer sets (please see guidance).

11 REDUCE: avoid all unnecessary equipment (eg swabs, single-use gloves), "*Don't open it unless you need it*"

12 REUSE: opt for reusables, hybrid, or remanufactured equipment instead of single-use (e.g. diathermy, gallipots, kidney-dishes, light handles, quivers, staplers, energy devices)

13 REPLACE: switch to low carbon alternatives (e.g. skin sutures vs. clips, loose prep in gallipots)

After the Operation

14 RECYCLE or use lowest carbon appropriate waste streams as appropriate:
- use domestic or recycling waste streams for all packaging;
- use non-infectious offensive waste (yellow/black tiger), unless clear risk of infection;
- ensure only appropriate contents in sharps bins (sharps/drugs);
- arrange metals/battery collection where possible.

15 REPAIR: ensure damaged reusable equipment is repaired, encourage active maintenance

16 POWER OFF: lights, computers, ventilation, AGSS, temperature control when theatre empty

DISCLAIMER: These suggestions are based upon current evidence and broadly generisable, however, specific environmental impacts will depend upon local infrastructure and individual Trusts' implementation strategies.

Intercollegiate Green Theatre Scorecard. November 2022.

7.3 Education and support

Education on sustainable healthcare has been defined as, 'the process of equipping current and future health professionals with the knowledge, values, confidence and capacity to provide environmentally sustainable services through health professions education'.[422] The surgical workforce needs theoretical knowledge and theory on the environmental impacts of surgery and the principles of sustainable practice, to support their ability to drive change.[422,423]

Sustainability in Quality Improvement (SusQI)

The **SusQI model developed by the Centre for Sustainable Healthcare integrates sustainable healthcare with Quality Improvement** (QI) in patient care.[424] As QI is now a core requirement in undergraduate and postgraduate training for most healthcare professionals, this model can be effective in driving change. It can be used by multi-professional teams in a wide variety of settings, enabling staff to engage in greening surgery while achieving training and continuing professional development, and obtaining leadership and change management skills.[425] A multi-centre, multi-disciplinary evaluation found that use of SusQI in healthcare professional education increased engagement with QI, with learners describing a new sustainability 'lens' guiding their professional practice.[426]

Progress in undergraduate education

The requirement in the **2018 General Medical Council (GMC) Outcomes for Graduates** that: 'newly qualified doctors must be able to apply the principles of sustainable healthcare to medical practice'[427] marked a recognition of the importance of this topic in medical education and training. Although implementation across medical schools varies, educators are making efforts to connect sustainability to core curricular themes such as disease prevention, patient safety, and health systems design and operation.[428,429] A new Sustainable Healthcare curriculum, endorsed by the Medical Schools Council and the GMC, aims to support educators[430] to develop their capacity and confidence.[431] The Standards of Proficiency for midwives includes demonstration of 'knowledge and understanding of the principles and methods of sustainable healthcare'[432] and successful integration of QI has begun in several nursing and allied health professional undergraduate programmes.[433] Similar developments for nurses and operating department practitioners (ODPs) need to be developed.

The Planetary Health Report Card is an international initiative led by medical students, providing a scoring system for the integration of sustainability within the taught curriculum.[429] This initiative involves 96 medical schools across 12 countries, with 11 of the 25 UK medical schools included awarded the highest marks (A or B overall). This tool accounts for the integration of sustainability into the curriculum, research, community outreach and advocacy, support for student-led initiatives, and campus operations.[429]

Opportunities in Postgraduate training

Colleges can ensure sustainability is included in specialty training programmes by incorporating it into their **curricula and examinations**, alongside accreditation as part of continuing professional development. The Royal College of Anaesthetists pioneered requirements that a trainee 'applies principles of sustainability to clinical practice' and 'promotes strategies to support sustainable healthcare in clinical practice'.[434] There are no such requirements at present in the core or specialist surgical training curriculum, but there are many examples of trainees using SusQI projects in their training portfolios.

Three levels of training are also available through NHS England, including an entry level Environmentally Sustainable Healthcare programme (in partnership with the Centre for Sustainable Healthcare) which some NHS Trusts are using within induction and mandatory training,[435] intermediate level Sustainability Leadership for Greener Health via the NHS Leadership Academy,[436] and carbon literacy training to NHS leaders.[437] Useful resources are also available via the Greener NHS Knowledge Hub on the FutureNHS Collaboration Platform.[290]

Support

There are rising levels of climate and eco-anxiety, especially amongst children and young people.[438] Raising awareness of the impact of surgical care on planetary health could induce this amongst healthcare professionals. We encourage healthcare individuals and organisations to consider mechanisms to support members of the surgical team who may experience eco-anxiety.

7.4 Infection prevention and control

Infection prevention and control is often cited as a barrier in transitioning to reusable equipment use, but is often misunderstood.

Medical devices and equipment can become contaminated with microorganisms and subsequently transmit pathogens if used on another patient, and the requisite decontamination after use depends on the risk of the equipment transmitting infection. High-risk items are those which penetrate the skin/mucous membranes or have direct or indirect contact with sterile tissues.[439] These items must be decontaminated by sterilisation and sterility guaranteed until subsequent re-use. Medium-risk (or semi-critical) items are those that have contact with mucous membranes, where some pathogens but not bacterial spores present a risk of infection.[439] They include respiratory therapy and anaesthetic equipment such as endoscopes (and other body cavity scopes) and probes.[440] High-level disinfection is adequate for these items, although sterilisation is often preferred as it can provide a more reliable method, and can be safely re-processed using heat or chemicals and appropriate quality control systems.[440] Equipment used on intact skin presents a low risk and is unlikely to transmit infection, so cleaning is generally an adequate approach to decontamination, although disinfection using heat (e.g. for textiles) or chemicals (e.g. for surfaces) are sometimes appropriate.[439,440] We note lack of international consensus on classification for some items, for example laryngoscope blades are classified as semi-critical, and therefore do not require sterilisation,[441] whilst in the UK they are considered critical (due to regular contamination with blood implying penetration of mucous membranes), and therefore must undergo sterilisation.[442]

Prior to 2000 most NHS hospitals had their own sterile services departments (SSD) and reprocessed surgical instruments (and a large proportion of other theatre equipment) on-site. However, guidance published by the Department of Health in 2004 emphasised the need for purpose-built centralised departments to enhance quality control and support the development of an expert workforce.[443] The Health and Social Care Act 2008[63] formalised Quality Requirements, set out in a series of Health Technical Memoranda (HTM).[444]

This change was driven by concerns about the emergence of Creutzfeldt–Jakob disease (CJD) in the early 2000s,[445] with fear from the ability of abnormal CJD prion proteins to adhere strongly to surgical instruments and withstand conventional sterilisation procedures.[446] As a result, stringent regulations for instrument reprocessing, especially those used on tissues at potential risk of accumulating high concentrations of prion proteins were introduced.[444] These included the requirement to ensure surgical instruments are kept moist until cleaned (to counteract protein adherence to the surface),[446] to track surgical instruments throughout the decontamination process, and (more recently) to reduce the protein load to 5µg or less prior to sterilisation.[444] Centralised SSDs were seen as key to enhancing quality, efficacy and safety of cleaning through the use of automated washer-disinfectors.[444] The logistics and costs associated with applying these controls and the perceived costs and risks associated with surgical equipment and its re-processing have been accompanied by increasing use of single-use disposable equipment in operating theatres.

Although vCJD controls were introduced in the UK in 1997, the outbreak of vCJD peaked in 2000, and only 2 of the 178 cases have been detected after 2012. Prevalence of vCJD is estimated to be 1–2 per 1 million population, although retrospective analysis of appendix specimens for prion proteins suggest prevalence may be higher, albeit with risk of developing clinical disease likely low.[445,447] Less than 1% of vCJD has been classified as iatrogenic and has predominantly been associated with historic blood or human products transfusions,[446] with only four known cases of surgically transmitted vCJD (3 UK; 1 France), potentially linked to contaminated neurosurgical instruments.[446] Some relevant infection prevention controls remain in place because of concerns about the long incubation period of prion disease,[445,446] although such controls are not applied elsewhere in the world.[439,440]

Meeting the obligations of current HTMs, depends on high performance washer disinfectors, tracking, validation and protein detection systems and a skilled workforce and is therefore only feasible within large-scale centralised SSDs. Whilst this might be interpreted as limiting flexibility for extending the reuse of surgical or endoscopy equipment (particularly semi-critical items) it is more correct to interpret this as a need for the NHS to prioritise and invest in reusable devices and sufficient capacity to manage increased reprocessing. Careful planning will also be required to ensure **effective integration of reusable equipment in current systems of work and logistics to support transportation to and from central reprocessing centres**.

There is also a need to explore opportunities for expanding point-of-care decontamination of medical equipment (that does not require sterilisation), for example through using detergent wipes or ultraviolet light exposure.

7.5 Medical supply chain

Medical supply chains are a major source of GHG emissions (almost two-thirds of the NHS carbon footprint),[22] but are not within the direct control of healthcare providers, posing a challenge. Health sector facilities, systems, and ministries will need to work with manufacturers and suppliers of healthcare goods and services, to encourage healthcare climate action. Making impactful change to reduce emissions upstream of the hospital requires alignment of actors across a highly **globalised, complex, and fragmented supply chain**. **Unified international action** will be important to apply collective pressure on industry, and may be facilitated, for example, by collaboration between the World Health Organization and the NHS, which can support policy alignment, shared learning, and coordinated procurement processes.[448] Given the globalised nature of healthcare supply chains, effective procurer engagement processes need to be similarly harmonised, with substantive social and environmental value requirements also having global currency.[449]

An important first step is setting and implementing **measurement and action criteria for low-carbon or zero emissions** to drive supply chain decarbonisation. This strategy must involve policy, facility, procurement and clinical decision-makers so that approaches, and the messaging to supply chain industries, are coherent. Policy makers and regulators (such as Medicines and Healthcare Regulatory Agency) can assist clinical and procurement professionals **by integrating sustainability into product registration, funding approval processes, and product placement rules** to facilitate innovation in healthcare research, manufacture and supply chains. Such positive action can enable new ways of thinking about healthcare procurement, mirroring the impacts of value-based procurement with a sustainability focus.

Large-scale change is required and will need concerted time and effort, but has the potential for system-wide impacts, and is an opportunity for the healthcare industry to lead the way. There is a growing commitment from suppliers to join up along value chains.[450,451] **Annualised contracts** rather than spot-buying may facilitate building enduring supply chain relationships that enable holding a long-term strategic view alongside short-term contractual commitments, and building trust and commitment to common value-building. Only by engaging those deeper relationships can **whole chain stewardship**[452] reach all the way back through suppliers-of-suppliers to raw commodity producers and deliver deep and enduring results.

Reliance on just-in-time delivery or short lead times for **single-use disposable items leaves health systems vulnerable to supply chain interruptions**, for example, from pandemics such as COVID-19 or weather-related disasters.[453] There are global calls for reversion back to reusable medical devices, requiring re-evaluation of evidence for infection control practices, policy to facilitate better design to make it easier to clean and re-use devices, as well as procurement practices that prioritise reusable devices and avert greenwashing.[454] This may be supported by policies such as **extended producer responsibility**, whereby product manufacturers take on increased responsibility for products after the point of sale, including beyond use by the primary customer.

Where clinicians interact with industry partners, there may be opportunities to encourage the following:

- Streamline single-use sets
- Develop reusable and durable alternatives
- Design products which specifically enable repair and recycling
- Increase recycling potential of products through encouraging design of modular products (can be easily disassembled), with as few different material types as possible
- Clear labelling to facilitate waste segregation and recycling

7.6 Supporting policy and infrastructure

Supporting policy

In accordance with Procurement Policy Note PPN 06/21 (2021)[455] all major government contracts (> £5 million per year) are required to consider Carbon Reduction Plans in the procurement process.

NHS England has outlined an NHS Net Zero Supplier Roadmap which stipulates:[456]

- From April 2023, for all contracts above £5 million per annum, all suppliers to the NHS must publish a Carbon Reduction Plan for their UK scope 1 and 2 emissions and a subset of scope 3 emissions as a minimum
- From April 2024, this requirement will extend to a carbon reduction plan to cover all procurements
- From April 2027 all suppliers will be required to publicly report targets, emissions and publish a carbon reduction plan for scope 1, 2 and 3 emissions
- From 2028 new requirements will be introduced overseeing the provision of carbon foot printing for individual products supplied to the NHS

To support this, in 2022, NHS England adopted the UK Government Social Value Model for commissioning and purchase of NHS goods and services whereby a minimum of 10% weighting is applied to **net zero and social value** when evaluating tenders for NHS contracts,[457] and in 2023, launched the Evergreen Sustainable Supplier Assessment,[456] a tool to aid suppliers in this process. In Scotland, public procurement contracts must maximise environmental benefits, in line with the Procurement Reform (Scotland) Act 2014.[458]

The **National Institute for Health and Care Excellence** (NICE) provides evidence-based recom-mendations for healthcare in England, and in 2021 pledged to develop frameworks for evaluating environmental sustainability to inform future NICE guidance.[459] A handbook is available for the decarbonisation of operational Public Finance Initiative (PFI) projects.[460]

Supporting infrastructure

Alongside these policies and regulation, transition to sustainable models of surgical systems will require appropriate supporting infrastructure, including physical facilities and financial models.

To enable the shift towards reusable equipment, there will be increased demands placed on reprocessing infrastructure (such as sterilisation and laundering), and this will need to be anticipated with plans to expand capacity. There is also sometimes a need to link up with existing infrastructure. For example, plans are needed to enable areas which typically are less likely to use reusable equipment (such as Accident and Emergency, or outpatient departments) to access reprocessing systems that are used in operating theatres.

When the financial cost of products are estimated across the full product life span this enables the **total cost of ownership** to be determined, and the majority of evidence indicates financial costs reduce with reductions in carbon footprint. For example, financial savings have been demonstrated when switching from single-use to reusable laryngoscopes,[330] and when repairing surgical scissors.[374] Recycling companies sometimes do not charge for waste removal and processing of items including surgical products.[461] Surgical departments often underestimate the true financial cost of single-use products, for instance due to the cost of waste disposal being centrally accounted for within the hospital, whilst the cost of reusables may be overestimated due to difficulties in accurately estimating the number of uses of reusable products over their lifespan.

The preparation of contracts with instrument suppliers can also incentivise companies to adopt these principles. Where surgical products are leased rather than owned by hospitals, and where these are associated with managed service contracts (also known as **servitisation**), companies can be nudged to design products that are durable and modular by design, and potentially increase the incentive to actively maintain and repair rather than replace them where appropriate. Such initiatives may confer environmental savings.

Section recommendations

Recommendation	Short term	Long term	Stakeholders
R7.1 Bolster top-down sustainability leadership		Increase time and investment in leadership[a,b,c,d] Develop sustainability strategy[a,b,c,d] Work collaboratively across national organisations to minimise duplication and to learn from one another[a,b,d] Provide a forum for shared learning and to celebrate successes[d] Advocate for sustainability, signalling the demand for sustainable products and services from industry, encouraging wider systems change towards disease prevention and health promotion, and equitable access[a,b]	Surgical Royal Colleges[a] Surgical and anaesthetic specialty associations[b] Greener NHS[c] Healthcare provider management teams[d]

R7.2 Foster bottom-up sustainability leadership	Become a green champion in local Trust (or equivalent, where scheme exists)[e] Look to existing resources including collegiate sustainability strategies and the Intercollegiate Green Surgery Checklist[e]	Develop sustainability champions for each specialty and geographical region[a,b] Develop sustainability champions locally within each department[d] Ensure ring-fenced time and resources are allocated to support individuals in driving sustainability initiatives[d] Invite representatives from surgical teams to be part of organisational decarbonisation planning[d]	Surgical and anaesthetic teams[e] Surgical Royal Colleges[a] Surgical and anaesthetic specialty associations[b] Healthcare provider management teams[d]
R7.3 Develop surgical sustainability networks	Healthcare professionals can act as ambassadors or leaders for change[e] Join local sustainability network (where these exist)[e]	Develop sustainability networks for scaling of initiatives and dissemination of knowledge[a,b]	Surgical and anaesthetic teams[e] Surgical Royal Colleges[a] Surgical and anaesthetic specialty associations[b]

R7.4 Develop effective education in sustainable surgery	Draw on existing resources when teaching, including the SusQI, Intercollegiate Green Theatre Checklist[f]	Integrate sustainability into undergraduate and postgraduate specialty curricula and examinations[a,b,f] Develop resources to teach principles of sustainable surgery[a,b] Develop case study repositories, and feature within specialty conferences enabling shared learning[a,b] Develop educational opportunities including leadership programmes, fellowships[a,b,f] Address the capacity of educators and trainers to teach this using a train the trainer approach[f]	Surgical Royal Colleges[a] Surgical and anaesthetic specialty associations[b] Educators[f]
R7.5 Provide support for those experiencing eco-anxiety	Signpost appropriate existing resources and support groups[d]	Develop support services for those with eco-anxiety[d]	Healthcare provider management teams[d]
R7.6 Address infection prevention and control (IPC) concerns	Work alongside surgical groups to consider opportunities for improving sustainability whilst addressing IPC concerns[g] Use evidence-based approach and avoid acting on hypothetic risk[g]	Develop research to evaluate evidence-based infection risk associated with reusable equipment[g,h] Design products enabling safe decontamination, with clear instructions for reprocessing[i]	Infection Prevention and Control Teams[g] Academics[h] Industry[i]

R7.7 Coordinate international action relating to supply chains		Develop unified international action towards whole chain stewardship across globalised supply chains[c,i,j]	Greener NHS[c] International partner organisations with net zero ambitions[j] Industry[i]
R7.8 Develop policies and infrastructure that supports transition to sustainable surgery		Develop regulations and policies for medical device and pharmaceuticals (end to end full life cycle processes)[k] Evaluate likely requirements to increase capacity of reprocessing facilities and plans to meet this demand[c,d,k] Evaluate ways to integrate environmental impact into healthcare product and pharmaceuticals procurement decisions[c,d,k,l]	Policy makers[k] Greener NHS[c] Academics[h] Pharmacists[l]

8. Areas for future research and development

Section key points

- The James Lind Alliance 'Greener Operations' Priority Setting Partnership identified questions or topics that people want researchers to investigate, to help reduce the environmental impact of operations.
- Further research is needed to evaluate the role of surgical disease prevention, minimising unwarranted variation, de-adoption of low value care, and digital technologies, in relation to sustainable surgery.
- There is need to evaluate the relative contribution of different mitigation strategies to model how to achieve net zero surgical care, and understand the scale and requirements of resources change to facilitate transition to sustainable surgery.
- We need to understand how surgical care services can adapt to climate change.
- Research is needed on how to increase scale and spread of sustainable surgery innovations.

8.1 James Lind Alliance sustainable perioperative practice priority setting partnership

The James Lind Alliance (JLA) is a not-for profit organisation that brings together patients, carers and clinicians in Priority Setting Partnerships (PSPs).[264] The 'Greener Operations' PSP aimed to identify the questions or topics that people want researchers to investigate, to help reduce the environmental impact of operations.[462,463] Through an iterative process the 'top ten' unanswered research questions[462] were identified.

Greener Operations research priorities

The top ten priorities were:

1. How can more sustainable reusable equipment safely be used during and around the time of an operation?
2. How can healthcare organisations more sustainably procure medicines, equipment and items used during and around the time of an operation?
3. How can healthcare professionals who deliver care during and around the time of an operation be encouraged to adopt sustainable actions in practice?
4. Can more efficient use of operating theatres and associated practice reduce the environmental impact of operations?
5. How can the amount of waste generated during and around the time of an operation be minimised?
6. How do we measure and compare the short- and long-term environmental impacts of surgical and non-surgical treatments for the same condition?
7. What is the environmental impact of different anaesthetic techniques used for the same operation?
8. How should the environmental impact of an operation be weighed against its clinical outcomes and financial costs?
9. How can environmental sustainability be incorporated into the organisational management of operating theatres?
10. What are the most sustainable forms of effective infection prevention and control used around the time of an operation?

These priorities can be used by funders and academics as a basis for research strategy.[463]

8.2 Wider research and innovation

This report synthesises evidence to date, and whilst the research field of sustainable surgical care is rapidly expanding, there are gaps in our knowledge requiring further research, which should be designed to inform real-world change in practice and policy.

The role of surgical disease prevention, minimising unwarranted variation, and de-adoption of low value care (ensuring carbon burden associated with surgery is necessary rather than avoidable) is an important area of future research. The process of digitising surgical care is currently unclear, and models need to include the growing awareness of carbon and water footprint associated with data centres. The emergence of artificial intelligence and its anticipated application within healthcare settings needs careful evaluation, in particular where it may lead to over-diagnosis and therefore excessive use of healthcare and associated carbon.

Research can also be used to evaluate how best to enact interventions at national scale, taking into account different settings, such as urban, inner-city, rural, and coastal hospitals, seeking equitable access to sustainable surgical care.[464] This should include evaluating the current capacity and future needs of reprocessing facilities (including decontamination, sterilisation, laundering, and repair sites) to facilitate the anticipated increased use of reusable equipment.

There is much heterogeneity in the conduct and reporting of environmental impact assessments for products within healthcare[45] and also methodological concerns for some published studies,[361] signalling a need for consensus on the conduct and the reporting of such assessments, improving their reliability and validity for informing policy and purchasing decisions. There is also a need to improve methods to quantify environmental impact of other mitigation strategies (for example, remote or digital care).[465] We encourage industry to anticipate this, and to develop products and solutions that help meet the goal of net zero surgery, including a focus on reusable products. Alternative economic models of purchasing to support such a transition, such as servitisation, are also worthy of exploration.

Future research should also evaluate how surgical operating theatres and wider surgical care delivery facilities can adapt to climate change, including building resilience to withstand extreme weather events (for example the UK is particularly susceptible to flooding) and sea level rises.

Behavioural change research is required to identify challenges to transitioning to sustainable healthcare, and to understand how to overcome these.

Section recommendations

Recommendation	Short term	Long term	Stakeholders
R8.1 Conduct further research to evaluate ways to improve sustainability of surgical care		Design research questions targeted towards major contributors of environmental impact[a] Develop targeted funding opportunities to support identified research gaps[b]	Academics[a] Research funders[b]

9. Recommendations

Patients

Patients can be key supporters of sustainable surgery, and we invite patients to work alongside healthcare professionals in transitioning towards sustainable models of care which do not harm the health of future generations through impacts of climate change.

We recommend that patients:

- Engage in conversations with their health provider about the link between human and planetary health (Recommendation R1.1)
- Have open conversations with healthcare professionals to understand the benefits, risks and alternatives of any intervention, and what would be likely if nothing were done (R2.3); improving the sustainability of surgery involves making sure the right high-quality care is provided to patients at the right time, and in the right place
- Consider ways to optimise their health and wellbeing, in particular in the run up to any planned surgery; this may include exercising more (especially where this involves accessing nature, and where walking or cycling can be used in place of using vehicles), improving diet, optimising weight, stopping smoking, and reducing alcohol (R3.1).

Healthcare professionals

Transitioning towards green surgical care will require engagement and action from all members of the surgical team, including surgeons, nurses, operating department practitioners, and other allied health professionals. We encourage every healthcare professional to consider their scope of clinical care and to think about the one thing they can do tomorrow to improve sustainability, and to communicate that commitment to someone else.

We recommend that members of surgical and anaesthetic teams:

- Raise awareness of the links between human and planetary health, and sources of greenhouse gas emissions in surgery, have conversations with colleagues, and share this report (R.1.1)
- Develop quality improvement projects, audits, and research projects relating to sustainability, and that consider environmental, financial, and social sustainability for all (R1.2)
- Identify modifiable risk factors during every patient encounter, have conversations and point patients in the direction of further support and resources (R2.1)
- Use shared decision making and 'choosing wisely principles' in every patient encounter, ensuring intervention is the right option for the individual patient (R2.3)
- Design, implement, and evaluate interventions to streamline patient pathways where clinically appropriate (R3.1)
- During pre-operative consultations identify modifiable risk factors, and point patients in the direction of support and resources (R3.2)
- Use enhanced recovery after surgery protocols and early discharge planning where appropriate (R3.3)
- Develop and use shutdown checklist (plus safety protocols) to prompt turning off equipment (R4.1)

- For each patient consider whether local, regional, or intravenous techniques are appropriate (R5.1)
- Where inhaled anaesthetics are clinically necessary, opt for lowest carbon inhaled anaesthetic gas that is clinically appropriate, and minimise fresh gas flows (R5.2)
- Work with facilities and estates to decommission desflurane and decommission centrally piped nitrous oxide, substitute with portable cylinders, introduce nitrous cracking technologies (R5.2,5.3)
- Minimise pharmaceutical wastage through only opening what is needed, and disposing medicinally contaminated waste appropriately (R5.4)
- Ask industry representatives whether air freight is used at any stage of product supply chain (R6.2)
- Shift culture away from urgent delivery requests (reducing reliance on air freight) through adequate planning, sufficient stocks (R6.2)
- Only open packaged surgical items when required (R6.3)
- Rationalise unnecessary equipment and investigations (e.g. avoid gloves where hand-washing is appropriate) (R6.3)
- Opt for reusable equivalents where currently stocked and available (R6.4)
- Explore whether reusable alternatives are currently available on the market and trial/purchase (R6.4)
- Use appropriate waste streams (R6.7)
- Become a green champion in local trust (or equivalent, where scheme exists) (R7.2)
- Look to existing resources including collegiate sustainability strategies and the Intercollegiate Green Surgery Checklist[110] (R7.2)
- Act as ambassadors or leaders for change (R7.2)
- Join local sustainability network (where these exist) (R7.2)

We recommend that public health practitioners:

- Develop public health initiatives to prevent the need for surgical interventions, targeted at high-risk populations (R2.1)
- Design population level interventions around health optimisation, targeted at high-risk groups (R3.2)

Healthcare organisation leadership

Leadership is required at the healthcare organisational and departmental levels.

We recommend that leadership teams:

- Consider sustainability at all stages of surgical care delivery, including upstream supply chain and supporting services (R1.2)
- Develop outpatient department treatment rooms and increase day-case lists where appropriate (R3.1)
- Develop infrastructure change to support day-case theatre lists or outpatient settings where appropriate (R3.3)
- Provide a forum for shared learning and to celebrate successes (R7.1)
- Develop sustainability champions locally within each department (R7.2)

- Identify a named champion with protected time and budget to lead on sustainable healthcare initiatives (R7.2)
- Invite representatives from surgical teams to be part of organisational decarbonisation planning processes (R7.2)
- Identify individuals at risk of eco-anxiety and signpost appropriate existing resources and support groups (eco-anxiety), develop support services for those with eco-anxiety (R7.5)

Wider hospital teams

We rely on wider hospital/healthcare provider teams to assist in transition to sustainable healthcare systems.

We recommend that Facilities and Estates teams alongside theatre managers:

- Develop initiatives to encourage green patient transport (R2.1)
- Install motion sensors to control lights, temperature control, and ventilation in theatres (R4.1)
- Install automatic/pedal-controlled taps for surgical scrub (R4.1)
- Opt for renewably sourced electricity (R4.2)
- Install energy efficient appliances and machinery (R4.2)
- Opt for clinically appropriate ventilation system with lowest energy consumption (R4.2)
- Use ventilation systems with lowest energy requirements while meeting clinical need (R4.2)
- Decommission desflurane (R5.2)
- Decommission centrally piped nitrous oxide, substitute with portable cylinders, introduce nitrous cracking technologies (R5.2)
- Opt for contracts with waste handling companies which enable recycling and recovery of energy from waste where possible (R6.7)
- Facilitate appropriate waste segregation (R6.7)

We recommend that Procurement teams alongside theatre managers:

- Ask suppliers if they have a carbon reduction plan (R6.1)
- Ask industry representatives whether air freight is used at any stage of product supply chain (R6.2)
- Shift culture away from urgent delivery requests (reducing reliance on air freight) through adequate planning, sufficient stocks (R6.2)
- Streamline single-use pre-prepared sets (R6.3)
- Explore whether reusable alternatives are currently available on the market for a given product, and trial/purchase (R6.4)
- Explore opportunities for repair and remanufacturing (where such contracts are not in place) (R6.6)

We recommend that Infection prevention and control teams:

- Work alongside surgical groups to consider opportunities for improving sustainability whilst addressing IPC concerns (R7.6)
- Use evidence-based approaches to IPC and avoid acting on hypothetic risk (R7.6)

We recommend that instrument and textile reprocessing providers:

- Work with NHS and healthcare provider management to model increase in demand for reprocessing of reusable equipment, plan to increase capacity accordingly (R6.4)
- Switch off idle machines (R6.5)
- Run decontamination machine test-runs loaded with sets (R6.5)
- Prepare instruments as sets (R6.5)
- Use renewable energy sources, environmentally preferable detergents (R6.5)
- Maximise loading of decontamination machines, whilst minimising standby time (R6.5)
- When an item is damaged find out if it can be repaired (R6.6)

We recommend that pharmaceutical teams:

- Work alongside surgical teams to optimise and rationalise medication, minimising polypharmacy (R3.1)
- Support the decommissioning of desflurane (R5.2)
- Support the decommissioning of centrally piped nitrous oxide, and its substitution with portable cylinders (R5.3)
- Minimise pharmaceutical wastage through encouraging surgical and anaesthetic teams to only open what is needed, and to dispose of pharmaceuticals in medicinally contaminated waste appropriately (R5.4)
- Evaluate ways to integrate environmental impact into healthcare product and pharmaceuticals procurement decisions (R7.8)

We recommend that diagnostic services teams:

- Work with surgical teams to standardise and consolidate peri-operative investigations (R3.1)

National representative bodies

We encourage national representative bodies to provide leadership, including Royal Colleges, Specialty Associations and other clinical national groups.

We recommend that national representative bodies:

- Develop initiatives to minimise unwarranted variation (R2.2)
- Increase time and investment in leadership (R7.1)
- Develop sustainability strategy, including for sub-specialties, focusing on what members can do to improve sustainability of clinical practice (R7.1)
- Work collaboratively across national organisations to minimise duplication and to learn from one another (R7.1)
- Advocate for sustainability, both signalling the demand for sustainable products and services from industry, encouraging wider systems change towards disease prevention and health promotion, alongside equitable access to high quality care (R7.1)
- Develop sustainability champions for each specialty and region nationally (R7.2)
- Develop sustainability networks for scaling of initiatives and dissemination of knowledge (R7.3)
- Integrate sustainability into postgraduate specialty curricula and examinations (R7.4)
- Develop resources to teach principles of sustainable surgery (R7.4)

- Develop centralised national case study repositories enabling shared learning and scaling of sustainable practice (R7.4)

Educators

We call upon NHS and NHS education bodies (Health Education England, NES Education for Scotland, and Health Education and Improvement Wales), to provide training for the existing surgical workforce. Colleges, the General Medical Council, Nursing and Midwifery Council, Health and Care Professions Council, and universities may all play a role in integrating sustainability within the core undergraduate and postgraduate curricula.

We recommend that educators:

- Raise awareness of links between human and planetary health, and sources of greenhouse gas emissions in surgery (R1.1)
- Draw on existing resources when teaching, including the SusQI model, Intercollegiate Green Theatre Checklist (R7.4)
- Integrate sustainability into undergraduate postgraduate specialty curricula and examinations for the entire surgical workforce including for nurses, ODPs, and surgical and anaesthetic trainees (R7.4)
- Develop case study repositories, and feature within specialty conferences enabling shared learning (R7.4)
- Develop resources to teach principles of sustainable surgery (R7.4)
- Develop educational opportunities including leadership programmes, fellowships (R7.4)
- Address the capacity of educators and trainers to teach knowledge, skills, and dispositions for sustainable surgery using a train the trainer approach (there is a wider requirement that the NHS, NHS education bodies, and universities do this) (R7.4)

Government

To bring about transformational change, there are a number of systems changes required. Given the globalised nature of healthcare supply chains, collaboration with international partners is required.

We recommend that government:

- Shift resource allocation towards disease prevention, and initiatives that support equitable access of high-quality healthcare (R2.1)
- Develop initiatives to minimise unwarranted variation (R2.2)
- Develop unified international action towards whole chain stewardship across globalised supply chains (R7.7)
- Develop regulations and policies for medical device and pharmaceuticals (end to end full life cycle processes) (R7.8)
- Evaluate likely requirements for expansion of appropriate infrastructure to support the use of higher volumes of reusable equipment, including reprocessing facilities (including sterilisation, linen laundering, and repair) (R7.8)
- Evaluate ways to integrate environmental impact into healthcare product and pharmaceuticals procurement decisions (R7.8)

Academics and research funders

Research and innovation is required to deepen understanding of evidence-based approaches to sustainable surgical care.

We recommend that academics:

- Design research questions targeted towards major contributors of environmental impact (R8.1). Examples may include:
  - Improve understanding of unwarranted variation in surgical care (R2.2)
  - Develop research on personalised medicine, to better understand likelihood of success and impact of a given intervention for an individual (R2.3)
  - Evaluate environmental impact of different anaesthetic techniques (R2.4)
  - Develop research to evaluate evidence-based infection risk associated with reusable equipment (R7.6)
  - Evaluate likely requirements for increase in capacity of reprocessing facilities and plan to meet this demand (R7.8)
  - Evaluate ways to integrate environmental impact into healthcare product and pharmaceuticals procurement decisions (R7.8)

We recommend that research funders:

- Develop targeted funding opportunities to support identified research gaps (R8.1)

Industry

Industry can play a key role in innovation towards sustainable surgical products and solutions. We encourage industry to collaborate openly and transparently to accelerate sustainable innovation, and that where environmental claims are made this is founded on verifiable data.

We recommend that industry:

- Innovate towards energy efficient devices (R4.2)
- Apply principles such as Circular Economy, Design for the Environment framework, Green Engineering and Green Chemistry in their operations (R6.1)
- Develop a carbon reduction plan (if not already in place) (R6.1)
- Opt for renewable energy sources (R6.1)
- Seek to eliminate air freight from distribution, electrify vehicular fleet (R6.2)
- Eliminate unnecessary packaging (R6.3)
- Design products for safe reuse (R6.4)
- Design products that are modular, facilitating repair (R6.6)
- Design products with the end-of-life in mind, recycling component materials wherever possible and using as few materials as possible, aligning with extended producer responsibility, and circular economy principles to facilitate recycling (R6.7)
- Design products using maximal recycled content (R6.7)
- Design products enabling safe decontamination, with clear instructions for reprocessing (R7.6)
- Develop unified international action towards whole chain stewardship across globalised supply chains (R7.7)

Conclusion

This report highlights emerging evidence that can support the transition to green surgical care. Bringing about real-world change relies upon coordinated action from all individuals and organisations influencing surgical care. Given the threat to human health posed by climate change, we urge immediate action.

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