# Review Article

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# Climate Therapy: Sustainability Solutions for Breast Cancer Care in the Anthropocene Era

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## Abstract

Climate change is the greatest threat to human existence. Currently it impacts breast cancer care by disrupting treatment, by food poverty and economic hardship and through fossil fuel pollution which increases breast cancer incidence. These impacts are greatest in those already experiencing deprivation. However, healthcare (including breast cancer care) is not an innocent bystander in climate change. The carbon emissions of healthcare are equivalent to the continent of Africa with 1.5 billion people. Like all other enterprises healthcare has an obligation to move to net zero carbon emissions. Previously conducted studies of healthcare professionals have highlighted the role of guidance documents to facilitate climate engagement by them. This prompted the formation of an interdisciplinary group to review the intersection points between breast cancer care and planetary health. A solution tree of sustainable solutions for practicing clinicians is proposed which can be integrated into daily clinical practice and into their personal lives.

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## Introduction

"The choices and actions implemented in this decade will have impacts now and for thousands of years" Intergovernmental Panel on Climate Change, 6th Assessment Cycle Synthesis Report[1]

The World Health Organization has called climate change "the single biggest threat facing humanity today."[2,3] Today we care for patients with breast cancer in the Anthropocene era, the period of time during which human activities have impacted the environment sufficiently to cause a distinct geological change. This change from accumulation of greenhouse gases in the atmosphere, largely due to the burning of fossil fuels, is leading to global warming, and consequently climate change.[4] Rising greenhouse gas levels are associated with increasing levels of carbon dioxide, rising temperatures, rising sea levels and increasing extreme weather events. Fossil fuel related nitrogen dioxide exposure increases the risk of developing breast cancer.[5] Cancer care, which requires consistent and timely access to health services, is particularly vulnerable to climate change disruption. Climate change is a stress multiplier putting pressure on vulnerable systems, populations and regions. When disruption by extreme weather events occurs (eg Hurricane Katrina), breast cancer survival has been compromised.[6] In addition, climate change disproportionately affects people disadvantaged by the system, which magnifies existing health inequalities.[7,8] These changes along with loss of biodiversity and pollution form a concurrent trinity of planetary threats which jeopardize how we practice, and how we live.

However, healthcare is not an innocent bystander in climate change.[9] Greenhouse gas emissions from healthcare account for between 3% and 8.5% of a country's total emissions.[10] Globally this equates to the emissions of the continent of Africa which has 1.5

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billion people among 54 countries.[11,12] A recent analysis highlighted that the long-term impact of annual carbon emissions from American health care delivery would result in up to 380,000 years of life lost or lived with preventable disability.[13] Greenhouse gas emissions from healthcare fall into 3 categories.[14] Scope 1 emissions are direct emissions such as fossil fuel boilers for building heating and cooling, anaesthetic gases and facility owned vehicles. Scope 2 emissions are indirect emissions from the generation of purchased energy, mostly electricity. Scope 3 emissions include all other indirect emissions such as medicines, medical imaging equipment, waste treatment, water use and employee commutes. Scope 3 emissions represent 82% of healthcare emissions in the United States, and approximately 71% of all emissions globally.[12] In the United Kingdom's National Health Service (NHS), 25% of all greenhouse gas emissions relate to medicines, with the majority of these from the manufacture, procurement, transport and use of medicines.

Recognition of the increasing importance of climate change and its interplay with healthcare[9] has prompted a gradual change in healthcare systems. In 2020, NHS England became the first health system in the world to commit to net zero emissions.[15,16] Since then, more than 60 countries have promised to develop climate resilient health systems, embrace sustainable low carbon healthcare, get to net zero by 2050, or all 3.[17] Nonprofit organizations such as Healthcare Without Harm Europe and the Global Green and Health Hospitals Network have been developed to promote member initiatives internationally. In the United Kingdom, the Union of Students have partnered with the Royal College of General Practice to develop a Green Impact Toolkit,[18] which provides recommendations relating to improving environmental sustainability. Professional bodies such as the European Society of Medical Oncology (ESMO), American Society for Radiation Oncology (ASTRO), European Society for Radiotherapy and Oncology (ESTRO) and the American Society of Medical Oncology (ASCO) have developed climate change task forces,[4,19] Contemporaneous with these developments has been the growth of the Choose Wisely campaign. Initially launched in the United States in 2012 due to concerns regarding the rising costs of healthcare, the organization now extends to 30 countries.[20,21] An important aspect of this campaign has been patient and public engagement to determine what drives demand for unnecessary tests and treatments.[22] Managing psychology related to patient expectations and doctors' perceptions of such expectations make such engagement central to reducing overtreatment. This campaign resonates with the need for improved stewardship of healthcare use as a climate responsive strategy[21] and serves as an exemplar for multi-stakeholder engagement to successfully alter clinical practice.

In 2020, over 2 million cases of breast cancer were diagnosed globally, accounting for 11.7% of all new cancer diagnoses and 6.9% of cancer deaths.[23] A 77% increase in all new cancer cases is predicted between 2022 and 2050,[24] and the impact of this increase will be greatest in lower income countries where cancer mortality is anticipated to double. Provision of breast cancer care in all countries regardless of income level will be jeopardized by climate change related disruption, while paradoxically provision of this care will contribute to climate change (Figure 1). A multinational survey of 4654 healthcare professionals which assessed views on climate change as a human health issue, demonstrated that awareness of the health implications of climate change was high, but barriers existed to engagement in advocacy and education.[25] Over 70% of respondents reported that policy statements by professional organizations would be helpful. Prompted by the initiatives of other groups, and by recognition of the need for accessible evidence-based climate smart strategies for breast cancer care providers, we assembled a multidisciplinary group to horizon scan modifiable touch points in breast care to provide practical guidelines for contemporary practice.

## Medical Oncology

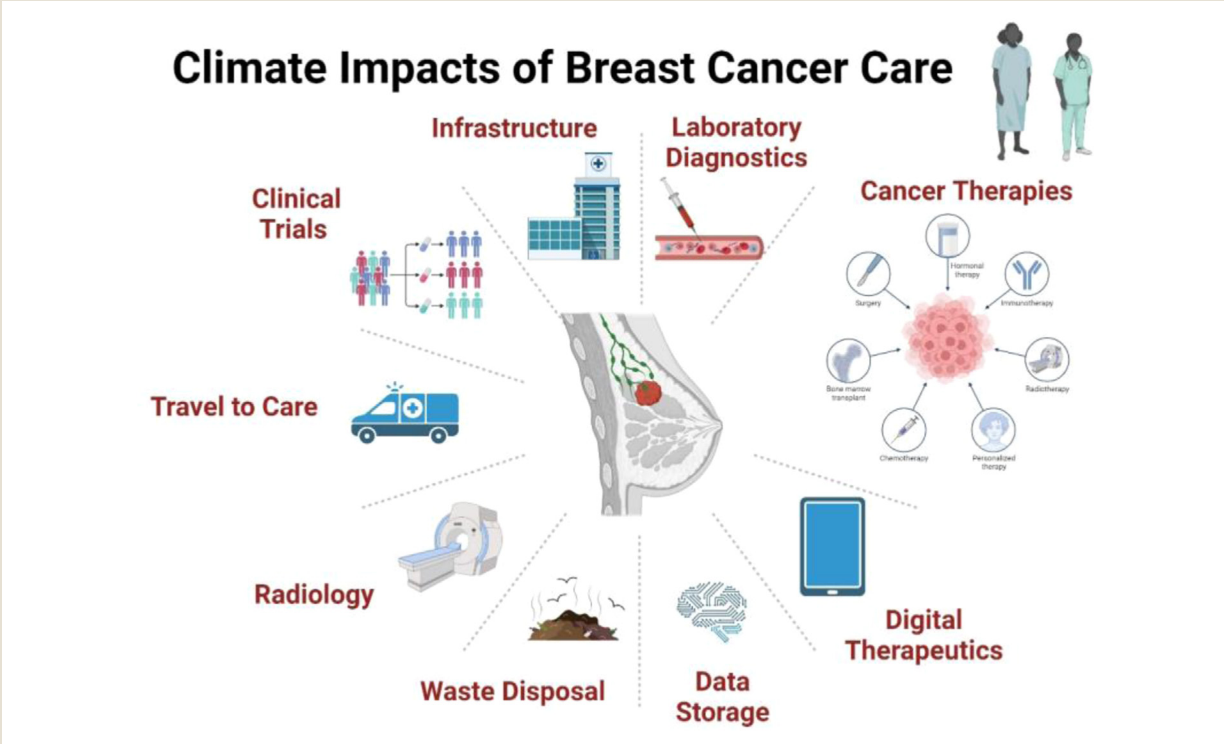
For medical oncologists breast cancer treatment is evolving from "maximum tolerable" toward "optimally effective" treatment.[26] Genomic platforms such as Oncotype Dx have facilitated chemotherapy omission in select patients,[27,28] while neoadjuvant chemotherapy strategies have facilitated tailored post-surgical therapy.[29] Nonetheless, overtreatment in breast cancer therapeutics persists,[30] resulting from rapidly changing care standards, a reimbursement system that rewards for doing more, lack of therapeutic humility, and care which is not always multidisciplinary in practice.[30] An added impact of such overtreatment is environmental. For medical oncology the most significant sustainability touch point is the prescription of systemic anticancer therapy (SACT).[31] In patients with metastatic disease such overtreatment particularly at the end of life results in poorer quality of death,[32] death in hospital, and higher health care costs.[32,33] Consequently, 30-day mortality rate after SACT is used as a key performance indicator.[34] Ireland's National Cancer Strategy 2017-2026 recommends that < 25% of patients should receive SACT in the last month of life.[35-37] Early referrals to palliative care are associated with less aggressive end of life care,[38] improved overall survival and quality of life,[39] reduced financial costs and consequently less climate impact.[40,41] Both ASCO and ESMO have developed validated frameworks [ASCO Value Framework (AVF) and ESMO Magnitude of Clinical Benefit Scale (ESMO-MCBS)] to evaluate the efficacy, toxicity and quality of life implications of anticancer therapies in order to quantify clinical benefit.[42]

Overuse of intravenous medicines when oral formulations would be more appropriate relates to all branches of medicine, including oncology.[43] For instance, the carbon footprint of administration of 1 gram of paracetamol orally is 68-fold lower than when that dose is administered intravenously in glass packaging.[44] In a Welsh teaching hospital where 80,000 g of intravenous paracetamol are administered annually, in addition to cost savings as the parenteral formulation is 44 times more expensive than the oral 1,[45] 5 tons of emissions per annum could be saved if oral paracetamol was used instead,[44] with cost savings of 98.3% in 1 study.[46]

These estimates don't include equipment needed such as giving sets, associated complications such as phlebitis,[47] the increased plastic waste,[48] nor the environmental impact of pharmaceutical ingredients.[49] Stewardship programmed analogous to those effectively developed for antimicrobial prescribing could assist in implementing this strategy in cancer centers, as well as assisting with deprescribing.[50-52]

Our current prescribing practices are linear rather than circular. Unused agents are disposed of with no potential for reuse.

**Figure 1** Climate impacts of breast cancer care.




Drug wastage accounts for 4%-18% of all cancer drug spending in the United States[53-55] and mitigation strategies have been shown to reduce drug spending by up to 17%,[55] reflecting a significant potentially modifiable, climate touch point. Many drugs dispensed as single-patient vials contain more product than a typical patient need, with up to 33% of product wasted in some cases.[54] Guidelines in many countries advise that once opened, vials must be disposed of within 6 hours,[56] but even within these constraints, saving the "waste" product to later formulate a dose for an extra patient ("vial sharing") can result in significant reduction in drug use. With the addition of steps such as dose banding or grouping patients being treated with the same drugs on the same days, up to 45% of drug waste can be avoided.[57] Closed system drug transfer devices used in compounding may maintain drug sterility beyond the 6-hour window,[58] allowing significantly more vial sharing.[59] Smarter formulations to facilitate dose adjustments, in addition to provisions for extended stability would also be of benefit to reduce waste.

For patients who receive oral anticancer therapy, drug wastage is experienced by 25%-41% of patients,[60-63] and in those who discontinue treatment unexpectedly, 46%-85%[63,64] have "leftover" doses. The cost of these drugs can be significant, with unopened packages worth a median of €2600 per patient in a Dutch study.[63] Traditionally, such medications are discarded, however several drug repositories are now established, primarily in the United States such as the Wexner Medical Center Oral Oncology Drug Repository Program,[65] and have been endorsed by ASCO guidelines.[66] This facilitates the donation of leftover medications to un- or under-insured patients. In nononcological studies, most patients indicate willingness to accept re-dispensed medications,[67,68] while in a small oncology study, theoretical willingness to participate in drug reuse was over 80%.[69] To our knowledge, no adverse outcomes have been reported from these repository programs.

In patients at higher risks of toxicity, consideration could be given to how medications are dispensed, both by modifying the dosage formulations administered, and by split-fill dispensing, where patients may collect only part of an oral cycle at a time. This keeps residual medicines within the pharmacy supply chain and allows drugs to be reallocated to other patients. Wastage via these mechanisms can be reduced significantly[70] in up to 34% of patients,[61] saving $1000[70,71] per patient. This may be particularly important with more expensive oral agents, such as Palbociclib, in which at least 18% of women require a dose reduction,[71] with an estimated cost of approximately $5000 per patient.[71-73] Anticipating the potential for dose reductions when deciding how the prescription should be formulated may allow for less drug wastage particularly at the initiation of treatment. Figure 2 summarizes strategies that may facilitate sustainable prescribing.

## Surgical Oncology

Modern surgical practices, although central to the treatment of cancer, have led to undeniable impacts on environmental sustainability. Projections indicate that greenhouse gas emissions directly attributed to the healthcare sector rose 6% from 2010 to 2018,

Figure 2 Suggestions for sustainable prescribing in medical oncology.


a trend likely to continue in the absence of intentional intervention.[14] From the production and disposal of surgical equipment to the energy and resources required for hospital operations, the environmental footprint of cancer surgery is significant. Operating rooms generate 42% of a hospital's revenue, with 56% of total perioperative costs attributed to supply costs, largely from single-use disposable equipment.[74,75] Generating over 4 billion pounds of waste each year, the healthcare system in the United States is the second largest producer of greenhouse gas emissions, with 1-third of this produced by operating rooms.[74] The extent of the problem is staggering, and presents a mandate for wide-scale implementation of perioperative measures that can yield near term impact. Numerous sources of perioperative surgical waste have been identified: disposable supplies and energy consumption, anaesthetic waste, and patient transportation to centers for cancer treatment.[72,73] In 1 center 2.7 million liters of water was saved annually by converting from soap to alcohol based waterless scrub.[72] Surgical procedures generate large amounts of single-use materials such as gloves, gowns, drapes, and disposable instruments. The carbon footprint of cancer surgery extends beyond the hospital setting to include all components of the supply chain, including manufacturing, transportation, and disposal of medical products and equipment. Additionally, there is a considerable burden of biomedical waste generated from disposal of tissues, organs, and other biological materials removed during surgery. Improper disposal of medical waste can lead to pollution of land, water, and air, posing risks to both human health and the environment. Furthermore, the energy and resources consumed during cancer surgery contribute to greenhouse gas emissions and resource depletion. Operating rooms require significant amounts of electricity, water, and other utilities to maintain sterile conditions and power medical equipment.

Anesthesia is also a notable, albeit often overlooked, contributor to climate change. The gases used, such as nitrous oxide and desflurane, are potent greenhouse gases with a much higher global warming potential than carbon dioxide and can contribute to climate change if released into the atmosphere.[76] During routine clinical care, inhaled anaesthetics comprise 50% of perioperative emissions, and 3% of total national healthcare emissions.[16] In addition to waste generation and energy consumption, the transportation of patients and healthcare workers contributes to carbon emissions and air pollution. Patients often travel long distances to access specialized cancer care, resulting in increased vehicle emissions and traffic congestion. In the post-COVID era, telemedicine has emerged as a more sustainable alternative to in-person visits when appropriate, reducing the need for travel while maintaining access to high-quality care.

There has been growing interest in implementing perioperative waste management practices in healthcare facilities to minimise environmental harm.[77-81] Ewbank and colleagues convened a working group of surgical care providers who developed a matrix

**Table 1 Proposed Surgical Care and Climate Change Matrix to Plan Interventions That Mitigate the Impact of Surgical Practice on Greenhouse Gas Emissions (Modified From Ewbank et al, 2021)**

| | Pre-operative | Peri-operative | Post-operative |
|---|---|---|---|
| Prevention | electric vehicle uses for transport | limited use of vapor anaesthetics, especially desflurane | electric vehicle uses for transport |
| | promote and provide access to more plant-based food sources | sustainable packaging, minimized for climate impact | promote and provide access to more plant-based food sources |
| | efficient waste sorting processes | | |
| | proper disposal of biodegradable waste | | |
| | rational expiration dates on disposable equipment and supplies | | |
| Near-term measures | install motion-sensor lighting and climate control | | |
| | shift to reusable equipment | | |
| | install LED lighting | | |
| | upgrade surge capacity | | |
| Long-term measures | Telemedicine | increased use of robotic equipment | telemedicine |
| | clinic and hospital siting near public transportation | | |
| | use of robots, drones | | |
| | incorporate AI to streamline perioperative processes | | |
| | shift to sustainable energy sources | | |
| | LEED certified facilities | | |
| | increase footprint of urban green space | | |

to identify targetable priority areas.[82] The Surgical Care and Climate Change Matrix (Table 1), is based upon the Haddon Matrix developed for other areas such as injury prevention interventions and global surgery[83,84] and is a useful summary guide to identify measures for both *prevention* and *reduction* of surgical waste, outlining both short and long-term goals. These measures include implementing recycling programs, adopting strategies to reduce the overall volume of medical waste generated, exploring alternatives to single-use products, such as reusable surgical instruments and cloth gowns. In addition, healthcare facilities should implement energy-efficient practices and invest in renewable energy sources such as solar or wind power. Such measures have resulted in savings of tens of millions of dollars in utilities spending at Mass General Brigham, for example.[85] Improved architecture and insulation, energy-efficient lighting, and optimized heating, ventilation and air conditioning systems can reduce unnecessary energy consumption and significantly lower carbon emissions associated with cancer surgery. Hospitals can also priorities the procurement of eco-friendly products and pharmaceuticals with minimal environmental impact throughout their lifecycle. Studies have revealed large variations between health systems without sacrificing clinical quality, suggesting that there exist opportunities to learn from the highest performers and disseminate to those health systems with the greatest room for improvement.[14,86]

One of the earliest perioperative climate change programs was implemented by the Carolinas Medical Center which identified specific initiatives to recycle single-use devices, replace operating room (OR) foam padding with reusable gel pads, and a "power down" initiative to turn off all OR equipment when not in use. This resulted in a reduction of over 234 metric tons of $CO_2$ emissions annually.[72] Another example of a focused implementation strategy was undertaken by the Neurosurgery Department at Jackson Memorial Hospital where the "blue wrap" used to wrap sterile OR trays and instruments was recycled. This measure was fully implemented within 30 days, and yielded 32 pounds of recycled waste per day and almost $200,000 in cost reduction annually.[73] By adopting energy-efficient technologies, implementing waste generation reduction strategies, and promoting alternative transportation options, healthcare providers can contribute to global efforts to address climate change and create a more sustainable healthcare system while maintain high quality surgical care for patients with cancer. Numerous professional surgical societies are now starting to respond to a call for action, working together to design best practices for more sustainable surgical environments.

### *Diagnostic Imaging*

Diagnostic imaging plays a critical role in the detection, treatment and monitoring of breast cancer.[87] Investment in the imaging infrastructure needed to provide such imaging for breast cancer has a clear outcome and societal benefit especially in low- and middle-income countries.[8,88] Even in developed economies, access to technology is variable and contributes to disparities in outcomes.[89] However, the same imaging infrastructure, especially advanced resource and energy intense imaging modalities such as magnetic resonance (MR), contribute significantly to carbon emissions. At 1 Swiss hospital, 3 computed tomography (CT) and 4 MR scanners accounted for 4% of the hospital's energy use.[90] The downstream health effects of local air pollution and global climate change magnify existing inequities in environmental and social determinants of health which amplify systemic vulnerabilities to the impacts of climate change.

A Planetary Health framework for sustainable health systems includes 3 principles within which breast imaging can be considered.[91] The first principle is reducing demand for resource intense hospital healthcare with strategies to promote health and wellness. Screening mammography, through early detection of breast cancer, is an important tool in reducing incidence of severe disease. The second principle is to match supply to demand by ensuring the right person gets the right care at the right time, without over-or under-utilizing imaging tests. Reducing low value imaging exams through provider and patient education and clinical decision support tools is an essential measure.[92] It is similarly essential not to delay required imaging tests, as this may result in later presentation with more advanced disease and ultimately require more resource intense in-hospital care. The third principle is to reduce the environmental impact of medically necessary care. Opportunities available at the micro (radiologist/ radiology department) level include powering off medical imaging equipment, picture archiving and communication (PACS) machines and computers in non-operational hours and patient scheduling to reduce energy wasted by scanner idle time.[93] For centers performing contrast enhanced mammography, multidose delivery systems reduce waste of contrast by at least 73% and plastic by approximately 93%, and save money ($494,000 per annum in 1 center).[94]

Opportunities at the meso (facility/system) level involve interdisciplinary collaborations, such as with procurement teams to include sustainability criteria in purchase decisions. Trade groups such as the European Co-ordination Committee of the Radiological Electromedical and Healthcare IT Industry[95] have recently sought input on sustainability criteria for medical imaging equipment. Radiologists can support purchase of refurbished medical imaging equipment, which significantly reduces production phase (raw materials to delivery) emissions.[96] The technical guide to Good Refurbishment Practice (GRP) endorsed by Global Diagnostic Imaging Healthcare IT and Radiation Therapy Trade Association (DITTA); Medical Imaging and Technology Alliance (MITA) provides frameworks for safe use of refurbished medical imaging equipment. Recent technology innovations reduce production phase emissions, such as MRI machines that require less helium and are less susceptible to disruption of operations due to climate emergencies.[97,98]

New AI tools may allow shortening of protocols, saving time, money and improving patient experience. However, more data are required to measure trade-offs of increased energy use and data storage requirements for AI.[99] Radiologist engagement at the macro (state, national and international) level is building among the imaging community with grassroots efforts such as Radiologists for a Sustainable Future,[100] an environmentally sustainable medical imaging working group by the Canadian Association of Radiologists, and the creation of a taskforce on Climate Change and Sustainability by the American College of Radiology in 2022. Governmental agencies such as the US Environmental Protection Agency have developed criteria for energy efficiency for medical imaging equipment.[101] The Joint Commission, an accrediting body for healthcare organizations, has created a certification program in sustainable healthcare[102] but this program remains voluntary based on vigorous opposition from healthcare facilities.

## Radiation Oncology

International estimates suggest that over half of all patients with a cancer diagnosis will require radiotherapy at some point during their cancer journey.[103,104,105] Radiotherapy is a complex cancer treatment modality, reliant on energy dependent machine delivery systems such as patient encounter notes, simulation and contouring, planning, quality assurance, image storage and general machine use (including on/off time). Therefore, understanding factors with an environmental impact through the use of the multi-faceted radiotherapy patient care pathway is imperative to develop sustainable oncology mitigation tactics.

Advances in radiotherapy imaging, delivery and techniques have largely had a positive impact on patient care. Specifically, in breast cancer, there has been a radio-biologically driven clinical change in practice through the reduction of treatment days, by increasing treatment doses and delivering fractions over a shorter period of time.[106] Reducing the number of fractions reduces almost linearly the carbon footprint of a treatment strategy.[107] Such a reduction in resource utilization and patient footfall has reportedly a potentially positive environmental impact. Furthermore, by reducing hospital visits, patients may be less vulnerable to major climate events impacting and interrupting their attendance for treatments.[108] Such advances have also changed how we image patients with breast cancer, for example through the use of MR imaging and MR based treatment delivery.

Daily photon beams linear accelerator (linac) energy use and its environmental impact has yet to be quantified. Shenker et al.[109] aimed to report energy use and $CO_2$ emissions of a linear accelerator in a study of 10 patients who received varying fractionation schedules (including 2 patients with breast cancer). The authors described the linear accelerator "standby" mode on its "nonwork" day as using the most power, and hence greatest emissions, when compared to "ready" and "on-no" modes. Concerns regarding energy use when machines are in a "standby" mode are not unique to linear accelerators, but do present an opportunity for the major linear accelerator producers to assess for engineering solutions that may yield significant energy savings.[90]

Proton beam therapy is increasingly being considered as a treatment option in breast cancer patients when available due it's potential to reduce side-effects.[110] Dvorak et al quantified the energy utilization of proton beam therapy and potential ways to offset its carbon footprint.[111] The highest power consumption was in the treatment of breast and regional lymph nodes (140kwh per patient) versus prostate cancer (28kwh), with the authors estimating that in order to offset the environmental impact of the proton program, a staggering 6,867 new trees annually are required, or 37 trees per patient treated.

Another method of radiotherapy delivery in breast cancer is the use of brachytherapy, a cost effective, adjuvant intent treatment option, often performed intraoperatively thus requiring less hospital visits compared with external beam fractionated radiotherapy. Coombs et al quantified journeys and $C0_2$ emissions in women with breast cancer who had single dose intra-operative treatment and demonstrated a statistically significant reduction in miles travelled and $CO_2$ emissions.[112] It is, however, a treatment modality that is resource intense and likely, overall, contributes significantly to healthcare emissions. In addition, brachytherapy, as per its name "short therapy," uses physical sources of radioactive material to deliver dose. Factors such as source extraction, manufacturing, transport, delivery and disposal are all important in understanding the overall potential environmental impact of such an oncologic therapy. In their paper "Environmentally Sustainable Brachytherapy Care" Lichter et al.[113] describe methods to adopt sustainable operating room practices, including the reduction of single-use medical products, reuse of, and appropriate disposal of, products and a review of inhaled anaesthetic products.

Considering the complexities of the radiotherapy pathway, Lichter et al.[108] used the framework of the 4 R's (reduce, reuse, recycle and rethink) to describe points of action to reduce climate toxicity in radiation oncology. These included the reduction in use of equipment energy, reuse and recycle of medical equipment and rethinking of quality of care and the incorporation of sustainability metrics into the treatment paradigm. A number of radiation oncology specific initiatives (ESTRO, ASTRO) on climate smart practices are being developed, with emphasis on awareness, education and accountability.[114,115] But, data along each section of the patient radiotherapy pathway is imperative for us to have a meaningful environmental impact.

## Clinical Trials

In 2023, the United States Food and Drug Administration approved 55 novel therapies, including 13 in oncology.[116] These approvals included nucleotide based therapeutics reflecting the increasing diversity of the medical toolbox, and resulted from over 103,531 cancer trials registered on www.clintrials.gov, 13738 (13%) of whom related to breast cancer. In parallel with this growth in size and diversity, has been the growth in data acquisition.[117] The volume of demographic, clinical, biologic and molecular information collected in a single trial over the past decade has tripled to over 3 million data elements.[118] Each data point requires storage in a data center. By 2026, the electricity consumption of these data centers globally are projected to reach Japan's total electricity consumption.[119] A third of data currently stored in these centers is healthcare related.[120]

Few studies have evaluated the carbon footprint of trials. In 2011, the Sustainable Clinical Trials Group (SCTG) published guidelines for reducing the carbon footprints of trials and demonstrated an improvement in carbon efficacy between 2 clinical trials when these were followed.[121] Improvements resulted from faster patient recruitment, lighter trial materials and web-based data entry.[121] A review by Lyle and colleagues of 12 United Kingdom pragmatic randomized trials averaging 402 participants reported that the average carbon emissions generated by a trial was 78.4 tonnes.[122] Conservatively extrapolating this figure to include all trials registered on ClinicalTrials.gov website would equate to the same total footprint of the United Kingdom NHS.[3,16]

A recent workshop forum, jointly hosted by the Academy of Medical Sciences, the Medical Research Council and the National Institute for Health and Care Research, has highlighted 4 key challenges to enabling greener biomedical research. These include prioritizing sustainability, generating and disseminating evidence on environmentally sustainable research practices, accelerating the introduction of environmentally sustainable practice in research and promoting behavioral change.[123] In the clinical trials arena, there are multiple actionable areas including reducing research waste, encouraging our healthcare systems to reduce their carbon footprint,[3] green clinical trial initiatives such as Cancer Trials Ireland Green Clinical Trials Charter (Table 2),[124] integrating sustainability practices into grant applications and integrating sustainability symposiums into medical conferences.[25,125] These developments are concordant with initiatives to streamline clinical research[126] and calls to priorities pragmatic, affordable and practice changing real-life clinical trials, digitally enabled trials[127] and ultrashort trials in oncology.[117,128] The latter trials refer to a strategy where patients selected on the basis of precise molecular and clinical risk are treated with curative intent with the minimum effective treatment for the shortest possible time.[129,130]

Cancer clinical trial organizations are critically placed to take a leading role in mitigating the climate change impact of health care. They have demonstrated adaptability during the COVID-19 pandemic[131,132] and with the successful integration of patient participation and involvement in routine trial conduct.[133] They have prioritized the development of less resource intensive treatment schedules,[134-137] and their collaborative nature offer the potential for less redundancy in cancer discovery.[138,139] Clinical trials provide opportunities for environmental impact assessments of care leading to an evidence base for sustainability integration. The focus of their investigators on translating laboratory-based discovery into clinical care integrates them with a community where climate smart initiatives such as "My Green Lab" are already successfully embedded.[140] The nature of their funding models would allow successful integration of sustainability policies analogous to those used to promote gender equality in research.[141,142]

## Role of Healthcare Professionals

Effectively reducing climate change requires marked, global behavior change,[144] including the professional and personal behavior of our health care community.[4,10] An online survey initiated in 2021 of medical students, residents, and staff physicians in Canada, India and the United States reported that only 20 of 162 respondents had ecologically favorable footprints. This was defined as eating meat $\leq$ 2 times per week, living in an apartment or condominium, and using public transport, bicycle, motorcycle or walking to work. Of those that had reduced their footprint, 49% had discussed climate change at work or home compared to 29% who rarely did. This study supports the promotion of climate awareness at work and home to increase climate engagement, with the ultimate goal of improved health[145] benefits in communities[146] (Table 3).

The initial educational initiatives in climate engagement have focused on the competencies needed by practitioners in a climate changing world, in which there will be an increased risk of zoonotic illness, extreme weather events, pandemics, and disrupted health care.[147] Students have been at the forefront of planetary health curricula developments.[148-150] The initiatives have evolved to include co-created curricula, embedding sustainability and health promotion.[151] These developments integrate planetary health concepts for a cohort who will be most impacted by climate change. Older generations including "the baby boomer generation," who are

**Table 2 Cancer Trials Ireland Green Clinical Trials Charter 2024**

| |
|---|
| **Theme 1: Individual Engagement** |
| 1. Participate as individuals in the EU Climate Pact. |
| 2. Use the European Commission's Consumer Footprint calculator. |
| Theme 2: Trial Design and Management; |
| 1. Integrate environmental sustainability statement and measures into protocol documents. |
| 2. Document protocol carbon footprint touch points including healthcare waste management, travel of staff and patients, diagnostics, cloud/data storage. |
| 3. Embed climate awareness into clinical trial education and professional development. |
| 4. Collaborate and information share with climate friendly initiatives of other clinical trial groups. |
| 5. Train algorithms to minimize energy consumption. |
| 6. Perform computing in the cloud rather than on premises. |
| Theme 3: Recycling and Waste Management; |
| 1. To implement best practice approaches to resource and waste management across CTI. |
| 2. To propagate best practice through education, empowerment . |
| 3. To maximize onsite composting of and recovery of waste nutrients from green waste generated at central office. |
| 4. To work with onsite food service providers to investigate the reduction and efficient management of post-consumer food waste. |
| 5. To take a life cycle approach to consideration of waste for large purchases . |
| 6. Information share at central office with resources to increase climate smartness such as The Little Book of Green Nudges (UN Environmental Programmed)[143] https://www.unep.org/explore-topics/education-environment/what-we-do/little-book-green-nudges. |
| Theme 4: Energy and Water; |
| 1. To optimize energy use continuously improving energy performance and systems. |
| 2. To priorities the use of low carbon energy sources. |
| 3. To optimize water management and reuse grey water where appropriate. |
| 4. Optimize computing infrastructure and power utilization. |
| 5. Select apps that are energy efficient and data sparing. |
| 6. Co-design apps with multiple stakeholders for optimizing longer term, equitable and scalable use |
| Theme 5: Procurement and Contracts; |
| 1. Promote green purchasing for materials and use alternatives to single use plastics and consumable items. |
| 2. Support the use of the most sustainable and low-carbon forms of transportation for project implementation. |
| 3. Include environmental and social sustainability clauses in all procurement procedures including pensions and financial management. |
| 4. Support the use of carbon offsetting where emissions can't be avoided. |
| 5. Engage with companies committed to improving their environmental performance (Eco-Management Audit Scheme (EMAS); |
| Theme 6: Meetings and Conferences; |
| 1. Employ teleconferencing tools as a complement to physical attendance at events where such attendance is not strictly necessary or advantageous. |
| 2. Selection of conference venues with environmental certification. |
| 3. Promotion of public transport for attendees. |
| 4. Selection of meeting venues based on accessibility by foot or public transport. |
| 5. Ensure catering during the conference is seasonal and regional. |
| 6. Vegetarian or vegan alternatives to be offered at all official catering functions. |
| 7. Only reusable tableware to be used. |
| 8. Partnership preference for hotels with ecolabels (www.bookdifferent.com). |
| 9. Only publishing small or online meeting programs. |
| 10. All printed matters on recycled or chlorine-free bleached paper. |
| 11. Name badges won't have plastic covers. |
| 12. Digital rather than printed signage. |
| 13. Encourage attendees to use their own reusable water bottles. |
| 14. Provision of onsite recycling. |
| 15. Carbon compensate for air travel when train alternative not feasible with funds to be donated to climate change directed work/charity. |
| Theme 7: Commuting and Business Travel; |
| 1. Reduce single use car journeys and encourage carpooling. |
| 2. Promote non travel options and encourage multi-purpose trips. |
| 3. Promote park and ride. |
| 4. Promote public transport use among staff and collaborator. |
| Theme 8: Outreach; |
| Share ideas and examples of best practice for improving the sustainability of research projects, including on social media, and help inspire others to reduce the environmental impact of their research and research related activities. |

**Table 3 Resource Toolkits**

| |
|---|
| **National Resources** |
| **National Institutes of Health Climate Change and Human Health Literature Portal.**<br>https://tools.niehs.nih.gov/cchhl/<br>Excellent integrated, curated bibliographic database of global peer-reviewed research and gray literature on the science of climate impacts on health.<br>**Healthcare Without Harm Europe** –<br>https://noharm-europe.org/<br>Global network of hospitals and healthcare professionals to promote sustainability in the workplace and transform healthcare systems, by pioneering projects, scaling up practical solutions and fostering collaboration.<br>Healthcare Without Harm Climate Impact Checkup online course: “a comprehensive online course and training program for our Climate Impact Checkup tool…developed to help professionals in the health care sector track their institutions’ emissions and design a successful carbon management plan.”<br>https://training.noharm.org/?lang=en&lang=en |
| **Hospital Resources**<br>**Joint Commission International**<br>www.jointcommissioninternational<br>Geneva Sustainability Centre Toolbox – testimony associated resource for sustainability integration into hospitals.<br>https://ihf-fih.org/what-we-do/geneva-sustainability-centre/sustainability-toolbox<br>**Global Green and Healthy Hospitals** –<br>https://greenhospitals.org/<br>International network of healthcare systems and organisations committed to reducing the environmental impact of healthcare, with tools and resources to assist with promoting and implementing sustainability initiatives. |
| **Toolkits from Professional Societies and Others**<br>**Irish College of General Practitioners –Glas Toolkit**<br>https://www.irishcollegeofgps.ie/Portals/0/Explore%20the%20College/Sustainability%20&%20Planetary%20Health/ETC_Sustainability_Glas_Toolkit_v7.pdf<br>Downloadable toolkit including advice on prescribing, practice management, diet, lifestyle medicine<br>**Royal College of Physicians London** –Green Physician Toolkit<br>https://www.rcp.ac.uk/media/tmqazjjl/green-physician-toolkit-july-2024.pdf<br>Downloadable toolkit with advice on prescribing, waste management, advocacy, sustainable practice.<br>**Royal College of General Practitioners** – Green Impact for Health Toolkit<br>https://toolkit.sos-uk.org/greenimpact/giforhealth/login<br>Toolkit for general practice in the UK to improve sustainability<br>**Royal College of Surgeons of England – Intercollegiate Green Theatre Checklist**<br>https://doi.org/10.1308/rcsbull.2023.25<br>The basis for the 5”Rs” of surgical sustainability – Reduce, reuse, recycle, rethink and research<br>**Canadian Association of Physicians for the Environment – Climate Change Toolkit for Health Professionals**<br>https://chasecanada.org/wp-content/uploads/2021/01/Climate-Change-Toolkit-for-Health-Professionals-Full-Toolkit.pdf<br>Toolkit with planetary health education, sustainability and preparedness solutions and engagement by health professionals.<br>**Sustainability Infographic for Medical Oncology**<br>Sustainable prescribing in oncology infographic – supplement in article contains Spanish, Dutch, Portugese, Swedish, German, French and Italian versions Lynch E et al . JCO Oncol Pract 2024. OP2400680. https://doi.org/10.1200/OP-24-00680 |
| **ESMO Climate Change Task Force** –<br>https://www.esmo.org/about-esmo/organisational-structure/esmo-task-forces/climate-change-task-force<br>Resources from ESMO 2023 and 2024 sessions including slide sets Newly launched #ESMO4Climate Portal of resources for healthcare professionals. |
| **Climate Change and Cancer Care: A Policy Statement From ASCO**<br>Bernicker E et al., Climate Change and Cancer Care: A Policy Statement From ASCO. JCO Oncol Pract 2024. 20, 178-186. https://doi.org/10.1200/OP.23.00637 |
| **Choosing Wisely in Oncology:**<br>Nagarajah S et al., Implementation and Impact of Choosing Wisely Recommendations in Oncology. JCO Oncol Pract 2022. 18, 703-712.<br>https://doi.org/10.1200/OP.22.00130<br>Choosing Wisely Canada – Oncology: https://choosingwiselycanada.org/recommendation/oncology/ |
| **ESMO Magnitude of Clinical Benefit Scale:**<br>Framework to evaluate the magnitude of clinical benefit for SACT ESMO-Magnitude of Clinical Benefit Scale |
| **The Surgical Care and Climate Change Matrix.**<br>Summary guide to identify measures to prevent and reduce surgical waste Ewbank C et al. The Development of a Surgical Care and Climate Change Matrix: A Tool to Assist with Prioritization and Implementation Strategies. Ann Surg. 2021;273(2):e50-e51. https://doi.org/10.1097/SLA.0000000000003980 |

most responsible for climate change and will be less likely to bear the burden of a growing crisis, are less integrated.[152] These generations are often in spheres of influence professionally and socially. Spiraling the concepts and awareness in these undergraduate courses to postgraduate, continuing education, and medical conferences would increase eco-medical literacy into our all of our community.[153]

In-person attendance at medical conferences allows networking, interdisciplinary discussions, inspiration, full immersion in science and professional development.[154] However, delegate travel can generate carbon emissions equivalent to that of an entire city in a single week.[155] A comparison of in-person (2019) and enforced virtual (2020 COVID-19 pandemic) conference attendance of 4 meetings which included ASCO and ESMO's annual congresses demonstrated that virtual attendee emissions were 0.5% of in-person attendees.[156] The carbon footprint of holding ASCO virtually was equivalent to the yearly emissions of 89 United Kingdom residents. The in-person congress equivalent was the yearly emissions of 14,448 United Kingdom residents. Changing such meetings by investing in immersive and interactive experiences would be climate smart, as outlined by both ESMO and ASCO climate task forces. However, the economic model of many societies is contingent on conference related revenues. In 2018, education and meeting registration fees generated $43 million in revenue for ASCO.[157] Reimagining a climate smart future will also involve an appraisal of how such large organizations are funded.

Entanglement between the pharmaceutical industry and the medical community is common[158] particularly in medical oncology where the costs of newly approved agents are high.[159] Financial conflicts of interest resulting from pharmaceutical industry payments to physicians are increasingly recognized as a predictive factor for guideline incorporation of low value treatments.[160,161] In addition, authors of these guidelines often have significant financial interests with the pharmaceutical industry.[162] As outlined earlier related to the "Choose Wisely" campaigns, overtreatment has patient costs and climate costs. Greater awareness of our financial vulnerabilities[163] and the unconscious bias that they generate,[164] may reduce both of these costs.

As individuals, our food consumption is 1 of the most important touch points for impact on climate change. Food systems are the single largest driver of environmental degradation.[145,165] They produce 30% of all greenhouse gases, use at least 70% of the Earth's freshwater and are the leading driver of biodiversity loss and nutrient pollution. Meat-centric diets account for 14.5% of greenhouse gases. Shifting to a plant-based diet is 1 of the single largest climate change impacts we could make as individuals bringing meat, dairy and egg consumption in line with health guidelines.

The COVID-19 pandemic taught us that we can adapt our healthcare system when there is an eminent threat to health.[166] Equally, climate change is also a threat to human existence albeit with a more gradual pivot point. We have a personal duty of care as healthcare providers to engage in climate mitigation strategies and to make our healthcare systems more climate responsive and resilient.[167,168] More visible green leadership in the healthcare sector would also facilitate positive change. Greta Thunberg and William Nordhaus, the democrats of the climate change movement, have both emphasized the role of influencers in promoting positive change.[169,170] We need to become influencers in the climate change dialogue.[171-173]

Finally, it might well be that the most lasting and profound effects of climate change are through exposures that occur early in life and only manifest themselves decades later. Some of these effects could be on the biological mechanistic level, such as temperature effects, or climate change related extreme weather events (such as Superstorm Sandy) on the human epigenome.[174,175]

## Discussion

In 1962 the scientist Rachel Carson published "Silent Spring," a book whose title was derived from the lack of birdsong heralding spring due to pesticide related deaths.[176] The book marked the dawn of the Anthropocene era and has been viewed as 1 of 4 books including "The Origin of the Species" by Charles Darwin that have changed history. In her book she presciently wrote "we stand now where 2 roads diverge but unlike the roads in Robert Frost's familiar poem, they are not equally fair. The road we have long been travelling is deceptively easy, a smooth super highway on which we progress with great speed, but at its end lies disaster." A million copies of the book were sold before she died of metastatic breast cancer in 1964.

In the 6 decades since Rachel Carson's death, economic losses from climate change have been estimated at $23 trillion due to premature mortality, healthcare expenditure and healthcare related work loss.[177] In the past 2 decades climate change intensified weather events caused over 570,000 deaths.[178,179] Testimonies from those impacted by extreme weather highlight profound physical and mental impacts.[180] While the burden of climate-sensitive health outcomes and health disparities is anticipated to increase,[181] and future warming will depress global economic growth rates by 0.8% per year[182] debate persists about payment for implementing sustainability goals that would ameliorate them,[183] and the potential macro-economic losses to achieve sustainability goals.[184]

Economic evidence is a key component of public policy responses to complex societal and health problems such as climate change adaption (building resilience to untoward effects) and climate mitigation (reducing greenhouse gases).[185] The debate about costs is compounded by a lack of climate finance,[186,187] a lack of frameworks on implementation and evaluation of sustainability initiatives[188,189] and lack of funding availability for research on the impact of interventions to reduce greenhouse gases,[190] contributing to "discourses of delay" in climate action.[191]

The evidence however within, and outside healthcare, is that sustainability integration has economic benefits. Where sustainability projects are implemented such as eco-friendly respiratory healthcare resulting in EUR 49.1 million annual savings[192] or re-dispensing unused oral anticancer agents provided mean net annual cost saving of $680 and up to $1591 per participant,[193] financial and environmental co-benefits have resulted. In 2023 The Joint Commission International Accreditation body developed a HealthCare Sustainability Certificate program in conjunction with the International Hospital Federation's Geneva Sustainability Centre (Table 3) where added benefits of energy efficient practices included operational efficiencies leading to cost reductions. For NHS England, 80% of low carbon change is cost neutral; the remaining 20% needs some capital but the return on investment is 3.5 years.[194] The Ellen McArthur Foundation has highlighted that a circular economy approach promoting recycling and reusing materials could lead to annual savings of $1 trillion globally by 2025. For example, Unilever has saved over $200 million since 2008 by a "zero waste to landfill program."[195] Economic modelling has also demonstrated that by 2100 that more than half of climate change mitigation costs could be offset by economic benefits such as reduced heat related labor productivity loss for the world's largest emitters.[196]

Our Anthropocene era has presented us with 3 grand challenges[197]: (1) promote actions that both reduce carbon emissions and improve health; (2) build better, more climate

Figure 3 Personal and professional solution tree for breast cancer care.

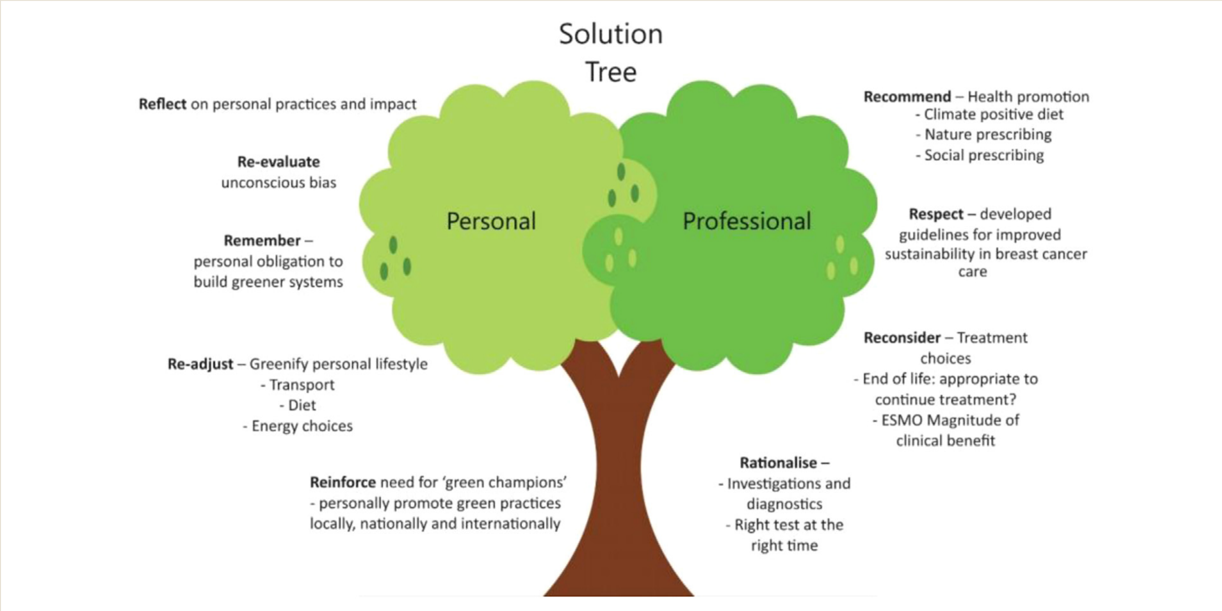
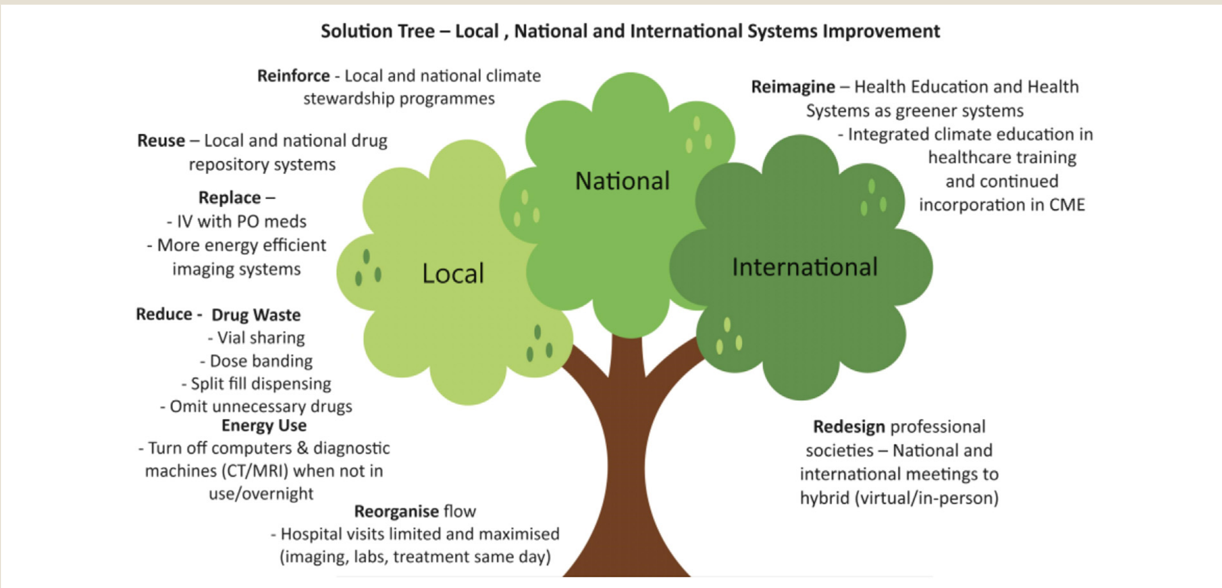



Figure 4 Solution tree for local, national and international systems improvement.




resilient and low–carbon health systems; and (3) implement public health measure to protect from the range of climate risks to health. In this paper we have focused on the first of these measures.[167] As a healthcare community we have enormous potential to influence the social and policy landscape in support of this, and we have an ethical duty to act.[160,168] Experience with the COVID-19 pandemic has demonstrated the ability of healthcare to pivot dramatically in response to a crisis.[170] The current crisis is more gradual and many are overwhelmed by its daunting uncertainties and a sense of futility of the power of individual actions.[171,172] Analogous to breast cancer care the earlier we act the less radical the treatment and the less suffering patients will experience. Equally the more diverse a community that is involved in sustainability integration the greater its impact.[198] Mirroring the tree of sustainability figures used to conceptualize the United Nations 17 sustainability goals[169] we propose trees of sustainability to present tool kits for our personal and professional lives (Figure 3 and 4) and summaries the information presented in this review. Their integration into care would be facilitated by "Sustainability Stewards" analogous to those engaged in antibiotic stewardship in healthcare today.[198] It has been estimated that 30% of healthcare is wasteful, and a further 10% is harmful,[199] facilitating a climate responsive breast care culture of reduce, reuse, recycle, reflect and research will consequently cascade into less treatment, time and financial toxicity in our communities.

Rachel Carson wrote about another road 1 that is "less travelled by others but 1 that offers our only chance to reach a destination that assures the preservation of our earth." We hope our review will serve as a map for those on, or considering joining this road, and complement maps developed by other communities[200] accelerating much needed integration of climate awareness in how we care for patients with breast cancer.

## CRediT authorship contribution statement

**Seamus O'Reilly:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Emer Lynch:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **E. Shelley Hwang:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Conceptualization. **Maura Brown:** Writing – review & editing, Writing – original draft, Project administration, Investigation, Data curation, Conceptualization. **Theresa O'Donovan:** Writing – review & editing, Writing – original draft, Investigation, Data curation, Conceptualization. **Maeve A. Hennessy:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Data curation, Conceptualization. **Geraldine McGinty:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Conceptualization. **Aisling Barry:** Writing – review & editing, Writing – original draft, Investigation, Data curation, Conceptualization. **Catherine S. Weadick:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Data curation, Conceptualization. **Roelof van Leeuwen:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **Matthijs van de Poll:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Conceptualization. **Giuseppe Curigliano:** Writing – review & editing, Writing – original draft, Conceptualization. **Martin J O'Sullivan:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization. **Alexandra Thomas:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Data curation, Conceptualization.

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## References

1. Core Writing Team, Lee H, Romero J, eds. *Sections in: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Summary for Policymakers*. Geneva, Switzerland: IPCC; 2023:1–34.
2. Moeti DM. World Health Day 2022 - Message from WHO Regional Director for Africa, Dr Matshidiso Moeti. World Health Organization. Ed: WHO Regional Office for Africa; 2022. Hyperlink: https://reliefweb.int/report/world/world-health-day-2022-message-who-regional-director-africa-dr-matshidiso-moeti (Accessed May 15, 2024).
3. Griffiths J, Fox L, Williamson PR. Quantifying the carbon footprint of clinical trials: guidance development and case studies. *BMJ Open*. 2024;14:e075755. doi:10.1136/bmjopen-2023-075755.
4. Bernicker E, Averbuch SD, Edge S, et al. Climate change and cancer care: a policy statement from ASCO. *JCO Oncology Practice*. 2024;20:178–186. doi:10.1200/op.23.00637.
5. Praud D, Deygas F, Amadou A, et al. Traffic-related air pollution and breast cancer risk: a systematic review and meta-analysis of observational studies. *Cancers (Basel)*. 2023;15. doi:10.3390/cancers15030927.
6. Bell SA, Banerjee M, Griggs JJ, Iwashyna TJ, Davis MA. The effect of exposure to disaster on cancer survival. *J Gen Intern Med*. 2020;35:380–382. doi:10.1007/s11606-019-05465-x.
7. Roy AM, George A, Attwood K, et al. Effect of neighborhood deprivation index on breast cancer survival in the United States. *Breast Cancer Res Treat*. 2023;202:139–153. doi:10.1007/s10549-023-07053-4.
8. Deivanayagam TA, Osborne RE. Breaking free from tunnel vision for climate change and health. *PLOS Glob Pubc Health*. 2023;3:e0001684. doi:10.1371/journal.pgph.0001684.
9. Weadick CS, Keogh RJ, Carroll HK, et al. Climate toxicity: an increasingly relevant clinical issue in Cancer Care. *J Cancer Policy*. 2023;35:100410. doi:10.1016/j.jcpo.2023.100410.
10. Braithwaite J, Pichumani A, Crowley P. Tackling climate change: the pivotal role of clinicians. *BMJ*. 2023;382:e076963. doi:10.1136/bmj-2023-076963.
11. Ritchie H, Rosado P, Roser M.$CO_2$ and greenhouse gas emissions. Our World in Data. 2023 [Online Resource]. Published online at OurWorldinData.org. Retrieved from: https://ourworldindata.org/co2-and-greenhouse-gas-emissions. Accessed April 6, 2024.
12. Karliner J, Slotterback S, Boyd R, Ashby B, Steele K Health care's climate footprint. Health Care Without Harm and ARUP. 2019. Retrieved from: https://global.noharm.org/sites/default/files/documents-files/5961/HealthCaresClimateFootprint_092319.pdf. Accessed May 15, 2024.
13. Eckelman MJ, Sherman JD. Estimated global disease burden from US health care sector greenhouse gas emissions. *Am J Public Health*. 2018;108:S120–s122. doi:10.2105/ajph.2017.303846.
14. Eckelman MJ, Huang K, Lagasse R, Senay E, Dubrow R, Sherman JD. Health care pollution and public health damage in the United States: an update. *Health Aff (Millwood)*. 2020;39:2071–2079. doi:10.1377/hlthaff.2020.01247.
15. NHS England and NHS Improvement. Delivering a 'Net Zero' National Health Service. NHS; 2020. Retrieved from: https://www.england.nhs.uk/greenernhs/wp-content/uploads/sites/51/2020/10/delivering-a-net-zero-national-health-service.pdf. Accessed June 6, 2024.
16. Tennison I, Roschnik S, Ashby B, et al. Health care's response to climate change: a carbon footprint assessment of the NHS in England. *Lancet Planetary Health*. 2021;5:e84–e92. doi:10.1016/S2542-5196(20)30271-0.
17. World Health Organization: The Alliance for Transformative Action on Climate and Health (ATACH). Country Commitments 2022. 2022. Retrieved from: https://www.who.int/initiatives/alliance-for-transformative-action-on-climate-and-health. Accessed June 6, 2024.
18. .Royal College of General Practitioners. Greener practice: addressing climate change and sustainability within general practice. 2023. Retrieved from: https://www.rcgp.org.uk/blog/greener-practice-initiative. Accessed November 9, 2024.
19. European Society for Medical Oncology. ESMO Climate Change Task Force. 2024. Available at:https://www.esmo.org/about-esmo/organisational-structure/esmo-task-forces/climate-change-task-force2024. Accessed November 9, 2024.
20. Born K, Kool T, Levinson W. Reducing overuse in healthcare: advancing choosing wisely. *BMJ*. 2019;367:l6317. doi:10.1136/bmj.l6317.
21. Born KB, Levinson W, Vaux E. Choosing wisely and the climate crisis: a role for clinicians. *BMJ Quality & Safety*. 2023:015928 bmjqs-2023-. doi:10.1136/bmjqs-2023-015928.
22. Zikmund-Fisher BJ, Kullgren JT, Fagerlin A, Klamerus ML, Bernstein SJ, Kerr EA. Perceived barriers to implementing individual choosing wisely® Recommendations in two national surveys of primary care providers. *J Gen Intern Med*. 2017;32:210–217. doi:10.1007/s11606-016-3853-5.
23. Sung H, Ferlay J, Siegel RL, et al. Global cancer statistics 2020: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. *CA Cancer J Clin*. 2021;71:209–249. doi:10.3322/caac.21660.

24. International Agency for Research on Cancer; World Health Organization. Global cancer burden growing, amidst mounting need for services. *Press Release No. 345* 2024. Retrieved from: https://www.iarc.who.int/wp-content/uploads/2024/02/pr345_E.pdf. Accessed November 9, 2024.
25. Kotcher J, Maibach E, Miller J, et al. Views of health professionals on climate change and health: a multinational survey study. *Lancet Planetary Health*. 2021;5:e316–e323. doi:10.1016/S2542-5196(21)00053-X.
26. Veronesi U, Stafyla V, Luini A, Veronesi P. Breast cancer: from "maximum tolerable" to "minimum effective" treatment. *Front Oncol*. 2012;2. doi:10.3389/fonc.2012.00125.
27. Kalinsky K, Barlow WE, Gralow JR, et al. 21-gene assay to inform chemotherapy benefit in node-positive breast cancer. *N Engl J Med*. 2021;385:2336–2347. doi:10.1056/NEJMoa2108873.
28. Sparano JA, Gray RJ, Makower DF, et al. Adjuvant chemotherapy guided by a 21-gene expression assay in breast cancer. *N Engl J Med*. 2018;379:111–121. doi:10.1056/NEJMoa1804710.
29. Minckwitz Gv, Huang C-S, Mano MS, et al. Trastuzumab emtansine for residual invasive HER2-positive breast cancer. *N Engl J Med*. 2019;380:617–628. doi:10.1056/NEJMoa1814017.
30. Pak LM, Morrow M. Addressing the problem of overtreatment in breast cancer. *Exp Rev Anticancer Ther*. 2022;22:535–548. doi:10.1080/14737140.2022.2064277.
31. Schiller JH, Bernicker E, Thomas A. Climate change and cancer care—feeling the heat. *JAMA Oncol*. 2023;9:1495–1496. doi:10.1001/jamaoncol.2023.3511.
32. Prigerson HG, Bao Y, Shah MA, et al. Chemotherapy use, performance status, and quality of life at the end of life. *JAMA Oncol*. 2015;1:778–784. doi:10.1001/jamaoncol.2015.2378.
33. Wright AA, Zhang B, Keating NL, Weeks JC, Prigerson HG. Associations between palliative chemotherapy and adult cancer patients' end of life care and place of death: prospective cohort study. *BMJ: Br Med J*. 2014;348:g1219. doi:10.1136/bmj.g1219.
34. Wallington M, Saxon EB, Bomb M, et al. 30-day mortality after systemic anticancer treatment for breast and lung cancer in England: a population-based, observational study. *Lancet Oncol*. 2016;17:1203–1216. doi:10.1016/S1470-2045(16)30383-7.
35. Department of Health and Children. National Cancer Strategy 2017 - 2026. 2017. Government of Ireland. Retrieved from: www.gov.ie/pdf/?file=https://assets.gov.ie/9315/6f1592a09583421baa87de3a7e9cb619.pdf#page=null. Accessed June 6, 2024. www.assets.gov.ie.
36. Mallett V, Linehan A, Burke O, et al. A multicenter retrospective review of systemic anti-cancer treatment and palliative care provided to solid tumor oncology patients in the 12 weeks preceding death in Ireland. *Am J Hosp Palliat Med®*. 2021;38:1404–1408. doi:10.1177/1049909120985234.
37. O'Sullivan H, Conroy M, Power D, et al. Immune checkpoint inhibitors and palliative care at the end of life: an Irish multicenter retrospective study. *J Palliat Care*. 2022. doi:10.1177/08258597221078391.
38. Jewitt N, Rapoport A, Gupta A, et al. The effect of specialized palliative care on end-of-life care intensity in AYAs with cancer. *J Pain Symptom Manage*. 2023;65:222–232. doi:10.1016/j.jpainsymman.2022.11.013.
39. Temel JS, Greer JA, Muzikansky A, et al. Early palliative care for patients with metastatic non–small-cell lung cancer. *N Engl J Med*. 2010;363:733–742. doi:10.1056/NEJMoa1000678.
40. Seow H, Barbera LC, McGrail K, et al. Effect of early palliative care on end-of-life health care costs: a population-based, propensity score–matched cohort study. *JCO Oncol Pract*. 2022;18:e183–e192. doi:10.1200/op.21.00299.
41. Davis MP, Vanenkevort EA, Elder A, et al. The financial impact of palliative care and aggressive cancer care on end-of-life health care costs. *Am J Hosp Palliat Med®*. 2023;40:52–60. doi:10.1177/10499091221098062.
42. Cherny NI, Dafni U, Bogaerts J, et al. ESMO-magnitude of clinical benefit scale version 1.1. *Ann Oncol*. 2017;28:2340–2366. doi:10.1093/annonc/mdx310.
43. Cyriac JM, James E. Switch over from intravenous to oral therapy: A concise overview. *J Pharmacol Pharmacother*. 2014;5:83–87. doi:10.4103/0976-500x.130042.
44. Myo J, Pooley S, Brennan F. Oral, in place of intravenous, paracetamol as the new normal for elective cases. *Anaesthesia*. 2021;76:1143–1144. doi:10.1111/anae.15482.
45. Hanks F, McKenzie C. Paracetamol in intensive care – intravenous, oral or not at all? *Anaesthesia*. 2016;71:1136–1140. doi:10.1111/anae.13517.
46. Davies JF, McAlister S, Eckelman MJ, et al. Environmental and financial impacts of perioperative paracetamol use: a multicentre international life-cycle analysis. *Br J Anaesthesia*. 2024. doi:10.1016/j.bja.2023.11.053.
47. Eii MN, Walpole S, Aldridge C. Sustainable practice: prescribing oral over intravenous medications. *BMJ*. 2023;383:e075297. doi:10.1136/bmj-2023-075297.
48. Dennis P Report: more single-use plastic waste in the world than ever before. Circular. Circular Economy, Environment and Energy, Sustainability. 6th February 2023. Webpage, Retrieved from: https://www.circularonline.co.uk/news/report-more-single-use-plastic-waste-in-the-world-than-ever-before/. Accessed April 7, 2024.
49. Daughton CG. Eco-directed sustainable prescribing: feasibility for reducing water contamination by drugs. *Sci Total Environ*. 2014;493:392–404. doi:10.1016/j.scitotenv.2014.06.013.
50. Goff Z, Abbotsford J, Yeoh DK, et al. The impact of a multifaceted tertiary pediatric hospital's antimicrobial stewardship service. *Pediat Infect Dis J*. 2022;41:959–966. doi:10.1097/inf.0000000000003704.
51. Gillies MB, Burgner DP, Ivancic L, et al. Changes in antibiotic prescribing following COVID-19 restrictions: Lessons for post-pandemic antibiotic stewardship. *Br J Clin Pharmacol*. 2022;88:1143–1151. doi:10.1111/bcp.15000.
52. Chaput G, Bhanabhai H. Deprescribing: a prime opportunity to optimize care of cancer patients. *Curr Oncol*. 2023;30:9701–9709. doi:10.3390/curroncol30110704.
53. Hess LM, Cui ZL, Li XI, Oton AB, Shortenhaus S, Watson IA. Drug wastage and costs to the healthcare system in the care of patients with non-small cell lung cancer in the United States. *J Med Eco*. 2018;21:755–761. doi:10.1080/13696998.2018.1467918.
54. Bach PB, Conti RM, Muller RJ, Schnorr GC, Saltz LB. Overspending driven by oversized single dose vials of cancer drugs. *BMJ*. 2016;352:i788. doi:10.1136/bmj.i788.
55. Leung CYW, Cheung MC, Charbonneau LF, Prica A, Ng P, Chan KKW. Financial impact of cancer drug wastage and potential cost savings from mitigation strategies. *J Oncol Pract*. 2017;13:e646–e652. doi:10.1200/jop.2017.022905.
56. The United StatesPharmacopeia. Pharmaceutical Compounding – Sterile Preparations. General Chapter <797>. 2022. Retrieved from: www.usp.org/compounding/general-chapter-797. Accessed May 5, 2024.
57. Fasola G, Aprile G, Marini L, Follador A, Mansutti M, Miscoria M. Drug waste minimization as an effective strategy of cost-containment in Oncology. *BMC Health Ser Res*. 2014;14:57. doi:10.1186/1472-6963-14-57.
58. Ho KV, Edwards MS, Solimando Jr Johnson AD. Determination of extended sterility for single-use vials using the phaseal closed-system transfer device. *J Hematol Oncol Pharm*. 2016;6(2):46–50. www.jhoponline.com.
59. Edwards MS, Solimando DA, Grollman FR, et al. Cost savings realized by use of the PhaSeal® closed-system transfer device for preparation of antineoplastic agents. *J Oncol Pharm Pract*. 2013;19:338–347. doi:10.1177/1078155213499387.
60. Staskon FC, Kirkham HS, Pfeifer A, Miller RT. Estimated cost and savings in a patient management program for oral oncology medications: impact of a split-fill component. *J Oncol Pract*. 2019;15:e856–e862. doi:10.1200/jop.19.00069.
61. Khandelwal N, Duncan I, Ahmed T, Rubinstein E, Pegus C. Impact of clinical oral chemotherapy program on wastage and hospitalizations. *J Oncol Pract*. 2011;7:e25s–e29s. doi:10.1200/jop.2011.000301.
62. Monga V, Meyer C, Vakiner B, Clamon G. Financial impact of oral chemotherapy wastage on society and the patient. *J Oncol Pharm Pract*. 2019;25:824–830. doi:10.1177/1078155218762596.
63. Dürr P, Schlichtig K, Krebs S, et al. Economic aspects in the care of patients with new oral anticancer drugs: findings from the AMBORA trial. *Zeitschrift für Evidenz, Fortbildung und Qualität im Gesundheitswesen*. 2022;169:84–93. doi:10.1016/j.zefq.2022.01.002.
64. Bekker CL, Melis EJ, Egberts ACG, Bouvy ML, Gardarsdottir H, van den Bemt BJF. Quantity and economic value of unused oral anti-cancer and biological disease-modifying anti-rheumatic drugs among outpatient pharmacy patients who discontinue therapy. *Res Soc Admin Pharm*. 2019;15:100–105. doi:10.1016/j.sapharm.2018.03.064.
65. Stanz L, Ulbrich T, Yucebay F, Kennerly-Shah J. Development and implementation of an oral oncology drug repository program. *JCO Oncol Pract*. 2021;17:e426–e432. doi:10.1200/op.20.00513.
66. American Society of Clinical Oncology. Position Statement on Drug Repository Programs. 2022. Retrieved from: https://society.asco.org/sites/new-www.asco.org/files/content-files/advocacy-and-policy/documents/2022-Drug-Repository-Statement.pdf. Accessed June 6, 2024.
67. Bekker C, Bemt Bvd, Egberts TC, Bouvy M, Gardarsdottir H. Willingness of patients to use unused medication returned to the pharmacy by another patient: a cross-sectional survey. *BMJ Open*. 2019;9:e024767. doi:10.1136/bmjopen-2018-024767.
68. Alhamad H, Donyai P. Intentions to "reuse" medication in the future modelled and measured using the theory of planned behavior. *Pharmacy*. 2020;8:213. doi:10.3390/pharmacy8040213.
69. Smale EM, Egberts TCG, Heerdink ER, van den Bemt BJF, Bekker CL. Key factors underlying the willingness of patients with cancer to participate in medication redispensing. *Res Soc Admin Pharm*. 2022;18:3329–3337. doi:10.1016/j.sapharm.2021.12.004.
70. Young S, Zigmond M, Lee S. Evaluating the effects of a 14-day oral chemotherapy dispensing protocol on adherence, toxicity, and cost. *J Hematol Oncol Pharm*. 2015;5(3):75. www.openurl.ebsco.com.
71. Dalal AA, Gagnon-Sanschagrin P, Burne R, et al. Dosing patterns and economic burden of Palbociclib drug wastage in HR+/HER2− metastatic breast cancer. *Adv Ther*. 2018;35:768–778. doi:10.1007/s12325-018-0701-5.
72. Biskupiak J, Oderda G, Brixner D, Tang D, Zacker C, Dalal AA. Quantification of economic impact of drug wastage in oral oncology medications: comparison of 3 methods using Palbociclib and Ribociclib in advanced or metastatic breast cancer. *J Manag Care Spec Pharm*. 2019;25:859–866. doi:10.18553/jmcp.2019.25.8.859.
73. Li N, Du EX, Chu L, et al. Real-world palbociclib dosing patterns and implications for drug costs in the treatment of HR+/HER2- metastatic breast cancer. *Expert Opin Pharmacother*. 2017;18:1167–1178. doi:10.1080/14656566.2017.1351947.

74. Wormer BA, Augenstein VA, Carpenter CL, et al. The green operating room: simple changes to reduce cost and our carbon footprint. *Am Surg*. 2013;79:666–671. doi:10.1177/00031348130790.
75. Babu MA, Dalenberg AK, Goodsell G, Holloway AB, Belau MM, Link MJ. Greening the operating room: results of a scalable initiative to reduce waste and recover supply costs. *Neurosurgery*. 2019;85:432–437. doi:10.1093/neuros/nyy275.
76. Sherman JD, Chesebro BB. Inhaled anaesthesia and analgesia contribute to climate change. *BMJ*. 2022;377:o1301. doi:10.1136/bmj.o1301.
77. Qin RX, Velin L, Yates EF, et al. Building sustainable and resilient surgical systems: a narrative review of opportunities to integrate climate change into national surgical planning in the Western Pacific region. *Lancet Region Health – Western Pacific*. 2022;22. doi:10.1016/j.lanwpc.2022.100407.
78. Guetter CR, Williams BJ, Slama E, et al. Greening the operating room. *Am J Surg*. 2018;216:683–688. doi:10.1016/j.amjsurg.2018.07.021.
79. McLeod R. ASA presidential address: greening the operating room. *Ann Surg*. 2021;274:403–405. doi:10.1097/sla.0000000000004995.
80. Wyssusek KH, Keys MT, van Zundert AAJ. Operating room greening initiatives – the old, the new, and the way forward: a narrative review. *Waste Manag Res*. 2019;37:3–19. doi:10.1177/0734242x18793937.
81. Anand SK, Culver LG, Maroon J. Green operating room—current standards and insights from a large north American medical center. *JAMA Surg*. 2022;157:465–466. doi:10.1001/jamasurg.2022.0140.
82. Ewbank C, Stewart B, Bruns B, et al. The development of a surgical care and climate change matrix: a tool to assist with prioritization and implementation strategies. *Ann Surg*. 2021;273:e50–e51. doi:10.1097/sla.0000000000003980.
83. William Haddon J. The changing approach to the epidemiology, prevention, and amelioration of trauma: the transition to approaches etiologically rather than descriptively based. *Injury Preven*. 1999;5:231–235. doi:10.1136/ip.5.3.231.
84. Kushner AL. A proposed matrix for planning global surgery interventions. *World J Surg*. 2014;38:1. doi:10.1007/s00268-014-2748-z.
85. Rabin AS, Pinsky EG. Reducing health care's climate impact — mission critical or extra credit? *N Engl J Med*. 2023;389:583–585. doi:10.1056/NEJMp2305709.
86. MacNeill AJ, Lillywhite R, Brown CJ. The impact of surgery on global climate: a carbon footprinting study of operating theatres in three health systems. *Lancet Planet Health*. 2017;1:e381–e388. doi:10.1016/S2542-5196(17)30162-6.
87. Bevers TB, Niell BL, Baker JL, et al. NCCN guidelines® insights: breast cancer screening and diagnosis, version 1.2023: featured updates to the NCCN guidelines. *J Natl Compr Canc Net*. 2023;21:900–909. doi:10.6004/jnccn.2023.0046.
88. Ward ZJ, Atun R, Hricak H, et al. The impact of scaling up access to treatment and imaging modalities on global disparities in breast cancer survival: a simulation-based analysis. *Lancet Oncol*. 2021;22:1301–1311. doi:10.1016/S1470-2045(21)00403-4.
89. Waite S, Scott J, Colombo D. Narrowing the gap: imaging disparities in radiology. *Radiology*. 2021;299:27–35. doi:10.1148/radiol.2021203742.
90. Heye T, Knoerl R, Wehrle T, et al. The energy consumption of radiology: energy- and cost-saving opportunities for CT and MRI operation. *Radiology*. 2020;295:593–605. doi:10.1148/radiol.2020192084.
91. MacNeill AJ, McGain F, Sherman JD. Planetary health care: a framework for sustainable health systems. *Lancet Planet Health*. 2021;5:e66–e68. doi:10.1016/S2542-5196(21)00005-X.
92. Canadian Institute for Health Information and Choosing Wisely Canada. Overuse of Tests and Treatments in Canada: Progress Report 2022. 2022. Retrieved from: https://www.cihi.ca/en/overuse-of-tests-and-treatments-in-canada. Accessed April 7, 2024.
93. Doyle PW, Frederick-Dyer K, Martin B, Stokes LS. Reducing the environmental and economic costs of single-department infectious waste disposal. *J Am Coll Radiol*. 2024;21:229–233. doi:10.1016/j.jacr.2023.11.018.
94. Lindsey JS, Frederick-Dyer K, Carr JJ, Cooke E, Allen LM, Omary RA. Modeling the environmental and financial impact of multi-dose vs. single-dose iodinated contrast media packaging and delivery systems. *Acad Radiol*. 2023;30:1017–1023. doi:10.1016/j.acra.2022.12.029.
95. European Co-ordination Committee of the Radiological Electromedical and Healthcare IT Industry. COCIR Advancing Healthcare. 2024. Retrieved from: https://www.cocir.org. Accessed March 1, 2024.
96. DITTA: Global Diagnostic Imaging Healthcare IT & Radiation Therapy Trade Associated. ECHNICAL GUIDE: NEMA Standards Publication NEMA/MITA 1. Good Refurbishment Practices for Medical Imaging Equipment. Retrieved from: https://www.nema.org/docs/default-source/standards-document-library/ditta-grp-implementation-guide-watermarked.pdf?sfvrsn=a69008ce_2. Accessed June 6, 2024.
97. Siemens Healthineers. MAGNETOM Prisma1: The 3T PowerPack for Exploration. 2024. Retrieved from: https://www.siemens-healthineers.com/magnetic-resonance-imaging/3t-mri-scanner/magnetom-prisma. Accessed April 8, 2024.
98. Philips. BlueSeal magnet: The new reality in helium-free MR operations. 2021. Retrieved from: https://www.philips.ie/healthcare/resources/landing/sealed-mr-technology. Accessed April 8, 2024.
99. Doo FX, Vosshenrich J, Cook TS, et al. Environmental sustainability and ai in radiology: a double-edged sword. *Radiology*. 2024;310:e232030. doi:10.1148/radiol.232030.
100. Radiologists for a Sustainable Future [Internet]. RfaSF. R4SF. 2024. R4SF. Retrieved from: https://twitter.com/Rads4SF. Accessed June 6, 2024.
101. ENERGYSTAR® ENERGY STAR® Program Requirements for Imaging Equipment. Retrieved from: https://www.energystar.gov/sites/default/files/ENERGY%20STAR%20Imaging%20Equipment%20Version%203.2%20Final%20Specification_0.pdf. Accessed March 1, 2024.
102. The Joint Commission. Sustainable Healthcare Certification. Retrieved from: https://www.jointcommission.org/what-we-offer/certification/certifications-by-setting/hospital-certifications/sustainable-healthcare-certification/. Accessed March 1, 2024.
103. Borras JM, Lievens Y, Dunscombe P, et al. The optimal utilization proportion of external beam radiotherapy in European countries: an ESTRO-HERO analysis. *Radiother Oncol*. 2015;116:38–44. doi:10.1016/j.radonc.2015.04.018.
104. Baskar R, Lee KA, Yeo R, Yeoh KW. Cancer and radiation therapy: current advances and future directions. *Int J Med Sci*. 2012;9:193–199. doi:10.7150/ijms.3635.
105. Delaney G, Jacob S, Featherstone C, Barton M. The role of radiotherapy in cancer treatment. *Cancer*. 2005;104:1129–1137. doi:10.1002/cncr.21324.
106. Murray Brunt A, Haviland JS, Wheatley DA, et al. Hypofractionated breast radiotherapy for 1 week versus 3 weeks (FAST-Forward): 5-year efficacy and late normal tissue effects results from a multicentre, non-inferiority, randomised, phase 3 trial. *The Lancet*. 2020;395:1613–1626. doi:10.1016/S0140-6736(20)30932-6.
107. Dupraz C, Ducrot C, Allignet B, et al. The carbon footprint of external beam radiotherapy and its impact in health technology assessment. *Clin Transl Radiat Oncol*. 2024;48:100834. doi:10.1016/j.ctro.2024.100834.
108. Lichter KE, Anderson J, Sim AJ, et al. Transitioning to environmentally sustainable, climate-smart radiation oncology care. *Int J Radiat Oncol, Biol, Phys*. 2022;113:915–924. doi:10.1016/j.ijrobp.2022.04.039.
109. Shenker RF, Johnson TL, Ribeiro M, Rodrigues A, Chino J. Estimating carbon dioxide emissions and direct power consumption of linear accelerator–based external beam radiation therapy. *Adv Radiat Oncol*. 2023;8. doi:10.1016/j.adro.2022.101170.
110. Mondal D, Jhawar SR, Millevoi R, Haffty BG, Parikh RR. Proton versus photon breath-hold radiation for left-sided breast cancer after breast-conserving surgery: a dosimetric comparison. *Int J Part Ther*. 2021;7:24–33. doi:10.14338/ijpt-20-00026.1.
111. Dvorak T, Meeks S, Dvorak L, Rineer JM, Henig T, Zeidan OA. Carbon footprint of proton therapy: how many trees do we need to offset it? *Int J Radiat Oncol, Bio, Phys*. 2022;114:S129–S130. doi:10.1016/j.ijrobp.2022.07.583.
112. Coombs NJ, Coombs JM, Vaidya UJ, et al. Environmental and social benefits of the targeted intraoperative radiotherapy for breast cancer: data from UK TARGIT-A trial centres and two UK NHS hospitals offering TARGIT IORT. *BMJ Open*. 2016;6:e010703. doi:10.1136/bmjopen-2015-010703.
113. Lichter KE, Baniel CC, Anderson J, et al. Environmentally sustainable brachytherapy care. *Brachytherapy*. 2022;21:712–717. doi:10.1016/j.brachy.2022.06.002.
114. The European Society for Radiotherapy and Oncology. ESTRO Green Task Force. Sustainability. Retrieved from: https://www.estro.org/About/Sustainability#:~:text=Thus%2C%20ESTRO%20will%20support%20efforts,environmental%20impact%20of%20ESTROs%20activities. Accessed April 15, 2024.
115. American Society for Radiation Oncology. Climate Change Statement. Retrieved from: https://www.astro.org/patient-care-and-research/climate-change-statement. Accessed April 15, 2024.
116. Mullard A. 2023 FDA approvals. *Nat Rev Drug Discov*. 2024;23:88–95. doi:10.1038/d41573-024-00001-x.
117. Leary A, Besse B, André F. The need for pragmatic, affordable, and practice-changing real-life clinical trials in oncology. *The Lancet*. 2024;403:406–408. doi:10.1016/S0140-6736(23)02199-2.
118. Tufts Center for the Study of Drug DevelopmentProtocol Complexity and Patient Enrollment Intensify Challenges in Oncology Trials. *Tufts University*. 2021;23(3). Retrieved from:. https://csdd.tufts.edu/impact-reports. Accessed February 17, 2024.
119. Berreby D As Use of A.I. Soars, So Does the Energy and Water It Requires. Yale Environment. 2024. Yale School of the Environment. Webpage: https://e360.yale.edu/features/artificial-intelligence-climate-energy-emissions. Accessed 6th April 2024.
120. Rydning D, Reinsel J, Gantz J The digitization of the world from edge to core. In: IDC White Paper - #US44413318. Framingham. International Data Corporation. 16:1-28.
121. Subaiya S, Hogg E, Roberts I. Reducing the environmental impact of trials: a comparison of the carbon footprint of the CRASH-1 and CRASH-2 clinical trials. *Trials*. 2011;12:31. doi:10.1186/1745-6215-12-31.
122. Lyle K, Dent L, Bailey S, Kerridge L, Roberts I, Milne R. Carbon cost of pragmatic randomised controlled trials: retrospective analysis of sample of trials. *BMJ*. 2009;339:b4187. doi:10.1136/bmj.b4187.
123. Academy of Medical Sciences. Enabling greener biomedical research. Forum workshop on Wednesday 15th March 2023. Retrieved from: https://acmedsci.ac.uk/file-download/61695123. Accessed May 4, 2024.
124. O'Reilly S, Weadick C, Murphy L, Kivlehan P, Clayton-Lea A, Mulroe E. Climate therapy: developing a climate change charter for cancer trials Ireland (CTI). *J Clin Oncol*. 2024;42:e23214 -e23214. doi:10.1200/JCO.2024.42.16_suppl.e23214.

125. Chalmers I, Glasziou P. Avoidable waste in the production and reporting of research evidence. *The Lancet*. 2009;374:86–89. doi:10.1016/S0140-6736(09)60329-9.
126. Perez-Gracia JL, Penel N, Calvo E, et al. Streamlining clinical research: an ESMO awareness call to improve sponsoring and monitoring of clinical trials. *Ann Oncol*. 2023;34:70–77. doi:10.1016/j.annonc.2022.09.162.
127. Franzoi MA, Gillanders E, Vaz-Luis I. Unlocking digitally enabled research in oncology: the time is now. *ESMO Open*. 2023;8. doi:10.1016/j.esmoop.2023.101633.
128. Ribeiro JM, Dixon-Douglas J, André F. Moving to ultra-short therapy to cure patients with cancer: a solution for sustainable cancer care. *ESMO Open*. 2024;9. doi:10.1016/j.esmoop.2024.102238.
129. Chalabi M, Fanchi LF, Dijkstra KK, et al. Neoadjuvant immunotherapy leads to pathological responses in MMR-proficient and MMR-deficient early-stage colon cancers. *Nat Med*. 2020;26:566–576. doi:10.1038/s41591-020-0805-8.
130. Reijers ILM, Menzies AM, van Akkooi ACJ, et al. Personalized response-directed surgery and adjuvant therapy after neoadjuvant ipilimumab and nivolumab in high-risk stage III melanoma: the PRADO trial. *Nat Med*. 2022;28:1178–1188. doi:10.1038/s41591-022-01851-x.
131. O'Reilly S, Murphy V, Mulroe E, et al. The SARS-CoV-2 pandemic and cancer trials ireland: impact, resolution and legacy. *Cancers*. 2022;14:2247. doi:10.3390/cancers14092247.
132. Waterhouse DM, Harvey RD, Hurley P, et al. Early Impact of COVID-19 on the Conduct of Oncology Clinical Trials and Long-Term Opportunities for Transformation: Findings From an American Society of Clinical Oncology Survey. *JCO Oncol Pract*. 2020;16:417–421. doi:10.1200/op.20.00275.
133. Needham J, Taylor J, Nomikos D. Integrating patient-centred research in the canadian cancer trials group. *Curr Oncol*. 2021;28:630–639. doi:10.3390/curroncol28010062.
134. Patil VM, Noronha V, Menon N, et al. Low-dose immunotherapy in head and neck cancer: a randomized study. *J Clin Oncol*. 2023;41:222–232. doi:10.1200/jco.22.01015.
135. Malmberg R, Zietse M, Dumoulin DW, et al. Alternative dosing strategies for immune checkpoint inhibitors to improve cost-effectiveness: a special focus on nivolumab and pembrolizumab. *Lancet Oncol*. 2022;23:e552–e561. doi:10.1016/S1470-2045(22)00554-X.
136. Merrick S, Nankivell M, Quartagno M, et al. REFINE (REduced Frequency ImmuNE checkpoint inhibition in cancers): a multi-arm phase II basket trial testing reduced intensity immunotherapy across different cancers. *Contemporary Clin Trials*. 2023;124:107030. doi:10.1016/j.cct.2022.107030.
137. Piccart-Gebhart MJ, Goulioti T, Straehle C, Cameron D. Overcoming barriers to clinical trials cooperation: the breast international group example. *Am Soc Clin Oncol Educ Book*. 2021:231–239. doi:10.1200/edbk_321475.
138. Beaver JA, Pazdur R. The wild west of checkpoint inhibitor development. *N Engl J Med*. 2022;386:1297–1301. doi:10.1056/NEJMp2116863.
139. The Lancet Oncology (Editorial). Calling time on the immunotherapy gold rush. *Lancet Oncol*. 2017;18:981. doi:10.1016/S1470-2045(17)30521-1.
140. My green lab. Building a Culture of Sustainability in Science. Retrieved from: www.mygreenlab.org. Accessed September 19, 2023.
141. European Commission: Directorate-General for Research & Innovation. . H2020 Programme: Guidance on Gender Equality in Horizon 2020. Version 2.0. 2016. Retrieved from: https://eige.europa.eu/sites/default/files/h2020-hi-guide-gender_en.pdf. Accessed April 3, 2024.
142. Bousema T, Burtscher L, van Rij RP, Barret D, Whitfield K. The critical role of funders in shrinking the carbon footprint of research. *Lancet Planet Health*. 2022;6:e4–e6. doi:10.1016/S2542-5196(21)00276-X.
143. United Nations Environment Programme, GRID-Arendal and Behavioural Insights Team. The Little Book of Green Nudges: 40 Nudges to Spark Sustainable Behaviour on Campus. Nairobi and Arendal: UNEP and GRID-Arendal; 2020. Retrieved from: https://www.bi.team/wp-content/uploads/2020/09/LBGN-2.pdf. Accessed June 6, 2023.
144. Vlasceanu M, Doell KC, Bak-Coleman JB, et al. Addressing climate change with behavioral science: a global intervention tournament in 63 countries. *Science Advances*. 2024. doi:10.1126/sciadv.adj5778.
145. Jabbari-Zadeh F, Karbassi A, Khetan A. The ecological footprint of physicians: a survey of physicians in Canada, India, and USA. *PLOS ONE*. 2023;18:e0291501. doi:10.1371/journal.pone.0291501.
146. Roca-Barceló A, Rice MB, Nunez Y, et al. Climate action has valuable health benefits. *Environ Epidemiol*. 2024;8:e288. doi:10.1097/ee9.0000000000000288.
147. Bell EJ. Climate change: what competencies and which medical education and training approaches? *BMC Med Educ*. 2010;10:31. doi:10.1186/1472-6920-10-31.
148. Navarrete-Welton A, Chen JJ, Byg B, et al. A grassroots approach for greener education: an example of a medical student-driven planetary health curriculum. *Front Pub Health*. 2022;10. doi:10.3389/fpubh.2022.1013880.
149. Blanchard OA, Greenwald LM, Sheffield PE. The climate change conversation: understanding nationwide medical education efforts. *Yale J Biol Med*. 2023;96:171–184. doi:10.59249/pyiw9718.
150. Boekels R, Nikendei C, Roether E, Friederich HC, Bugaj TJ. Climate change and health in international medical education - a narrative review. *GMS J Med Educ*. 2023;40:Doc37. doi:10.3205/zma001619.
151. Liu I, Rabin B, Manivannan M, Laney E, Philipsborn R. Evaluating strengths and opportunities for a co-created climate change curriculum: medical student perspectives. *Front Pub Health*. 2022;10. doi:10.3389/fpubh.2022.1021125.
152. MacDonald L. *Am I too old to save the planet? A boomer's guide to climate action. 2023. Changemakers Books*; 2023.
153. Bates OB, Walsh A, Stanistreet D. Factors influencing the integration of planetary health topics into undergraduate medical education in Ireland: a qualitative study of medical educator perspectives. *BMJ Open*. 2023;13:e067544. doi:10.1136/bmjopen-2022-067544.
154. Sarabipour S, Khan A, Seah YFS, et al. Changing scientific meetings for the better. *Nature Human Behaviour*. 2021;5:296–300. doi:10.1038/s41562-021-01067-y.
155. Klöwer M, Hopkins D, Allen M, Higham J. An analysis of ways to decarbonize conference travel after COVID-19. *Nature*. 2020;583:356–359. doi:10.1038/d41586-020-02057-2.
156. Gattrell WT, Barraux A, Comley S, Whaley M, Lander N. The carbon costs of in-person versus virtual medical conferences for the pharmaceutical industry: lessons from the coronavirus pandemic. *Pharmaceut Med*. 2022;36:131–142. doi:10.1007/s40290-022-00421-3.
157. Moynihan R. Who pays for the pizza? Redefining the relationships between doctors and drug companies. 1: Entanglement. *BMJ*. 2003;326:1189–1192. doi:10.1136/bmj.326.7400.1189.
158. Moynihan R, Albarqouni L, Nangla C, Dunn AG, Lexchin J, Bero L. Financial ties between leaders of influential US professional medical associations and industry: cross sectional study. *BMJ*. 2020;369:m1505. doi:10.1136/bmj.m1505.
159. Schnog JB, Samson MJ, Gersenbluth I, Duits AJ. Pharmaceutical industry payments to medical oncologists in the netherlands: trends and patterns provided by an open-access transparency data set. *JCO Oncol Pract*. 2024;0 OP.23.00533. doi:10.1200/op.23.00533.
160. Mitchell AP, Dusetzina SB, Meza AM, Trivedi NU, Bach PB, Winn AN. Pharmaceutical industry payments and delivery of non-recommended and low value cancer drugs: population based cohort study. *BMJ*. 2023;383:e075512. doi:10.1136/bmj-2023-075512.
161. Tabatabavakili S, Khan R, Scaffidi MA, Gimpaya N, Lightfoot D, Grover SC. Financial conflicts of interest in clinical practice guidelines: a systematic review. *Mayo Clin Proceed: Innovations, Quality & Outcomes*. 2021;5:466–475. doi:10.1016/j.mayocpiqo.2020.09.016.
162. Carey C, Daly M, Li J. *NBER Working Paper Series No. 32336*. Nothing for something: marketing cancer drugs to physicians increases prescribing without improving mortality. Cambridge, Massachusetts: National Bureau of Economic Research; 2024 JEL No. I11,L15.
163. Moynihan R. Who pays for the pizza? Redefining the relationships between doctors and drug companies. 2: Disentanglement. *BMJ*. 2003;326:1193–1196. doi:10.1136/bmj.326.7400.1193.
164. O'Reilly S, Kathryn Carroll H, Murray D, et al. Impact of the COVID-19 pandemic on cancer care in Ireland – Perspectives from a COVID-19 and cancer working group. *Journal of Cancer Policy*. 2023;36:100414. doi:10.1016/j.jcpo.2023.100414.
165. Clark B, Auerbach D, Longo SB. The bottom line: capital's production of social inequalities and environmental degradation. *J Envir Stud Sci*. 2018;8:562–569. doi:10.1007/s13412-018-0505-6.
166. D'Souza J, Samuel G. Clinical research risks, climate change, and human health. *JAMA*. 2023;330:2247–2248. doi:10.1001/jama.2023.23724.
167. Sergeant M, Hategan A. What healthcare leadership can do in a climate crisis. *Healthc Manage Forum*. 2023;36:190–194. doi:10.1177/08404704231157035.
168. Berniak-Woźny J, Rataj M. Towards green and sustainable healthcare: a literature review and research agenda for green leadership in the healthcare sector. *Int J Envir Res Pub Health*. 2023;20:908.
169. Thunberg G. *No one is too small to make a difference*. Penguin; Allen Lane; 2019 ISBN: 9780241453445.
170. Nordhaus WD. *The Spirit of Green: The Economics of Collisions and Contagions in a Crowded World*. Princeton, New Jersey: Princeton University Press; 2021 ISBN: 9780691214344.
171. Larsen PB, Tararas K. Editorial: enhancing the right to science: the triple planetary crisis and the need for comprehensive approaches. *Front Sociol*. 2024;9. doi:10.3389/fsoc.2024.1406640.
172. Gregory RD, Bridle J, Wilson JD. What is the role of scientists in meeting the environmental challenges of the twenty-first century? *Royal Soc Open Sci*. 2024;11:240498. doi:10.1098/rsos.240498.
173. Schiller JH. Climate change: why oncologists need to get involved. *BJC Rep*. 2024;2:20. doi:10.1038/s44276-023-00023-9.
174. Nomura Y, Zhang W, Hurd YL. Stress in pregnancy: clinical and adaptive behavior of offspring following superstorm sandy. *Develop Psychopath*. 2022;34:1249–1259. doi:10.1017/S0954579421000304.
175. Aldern CP. *The weight of nature*. Great Britain: Allen Lane; 2024 ISBN: 9780241597378.
176. Carson R Silent Spring: Penguin Modern Classics. 2000. ISBN: 9780141184944
177. Nordeng Z, Kriit HK, Poltimäe H, et al. Valuation and perception of the costs of climate change on health. *Scand J Public Health*. 2024. doi:10.1177/14034948241247614.
178. Lee G Climate change intensified weather events causing over 570,000 deaths. 2024. Retrieved from: https://www.rte.ie/news/environment/2024/1031/1478316-climate-change-extreme/2024. Accessed October 31, 2024.

179. Chloe B, Jennifer DR, Cascade T, et al. Preventing heat-related deaths: the urgent need for a global early warning system for heat. *PLOS Climate*. 2024;3:e0000437. doi:10.1371/journal.pclm.0000437.
180. Lenharo M. How to heal after a climate disaster. *Nature*. 2024;634:1032–1036.
181. Carleton TA, Hsiang SM. Social and economic impacts of climate. *Science*. 2016;353:aad9837. doi:10.1126/science.aad9837.
182. Park J. How can we pay for it all? Understanding the global challenge of financing climate change and sustainable development solutions. *J Envir Stud Sci*. 2022;12:91–99. doi:10.1007/s13412-021-00715-z.
183. Limaye VS, Max W, Constible J, Knowlton K. Estimating the costs of inaction and the economic benefits of addressing the health harms of climate change. *Health Affairs*. 2020;39:2098–2104. doi:10.1377/hlthaff.2020.01109.
184. Köberle AC, Vandyck T, Guivarch C, et al. The cost of mitigation revisited. *Nat Climate Change*. 2021;11:1035–1045. doi:10.1038/s41558-021-01203-6.
185. Elstow L, Rojas Parra F, MacAskill K. Tracking climate adaptation in hospitals: an inventory of structural measures. *Climate Risk Management*. 2024;46:100657. doi:10.1016/j.crm.2024.100657.
186. Watkiss P, Ebi KL. A lack of climate finance is harming population health. *BMJ*. 2022;376:o313. doi:10.1136/bmj.o313.
187. Borghi J, Cuevas Garcia-Dorado S, Anton B, et al. Climate finance opportunities for health and health systems. *Bull World Health Organ*. 2024;102:330–335. doi:10.2471/blt.23.290785.
188. Braithwaite J, Smith CL, Leask E, et al. Strategies and tactics to reduce the impact of healthcare on climate change: systematic review. *BMJ*. 2024;387:e081284. doi:10.1136/bmj-2024-081284.
189. Zurynski Y, Herkes-Deane J, Holt J, et al. How can the healthcare system deliver sustainable performance? A scoping review. *BMJ Open*. 2022;12:e059207. doi:10.1136/bmjopen-2021-059207.
190. Bonner AC, Biglan A, Drugan-Eppich K. The dismal state of federal funding for experimental evaluations of interventions to reduce greenhouse gas emissions. *Perspect Behav Sci*. 2023;46:5–34. doi:10.1007/s40614-021-00316-9.
191. Cherry C, Verfuerth C, Demski C. Discourses of climate inaction undermine public support for 1.5°C lifestyles. *Glob Envir Change*. 2024;87:102875. doi:10.1016/j.gloenvcha.2024.102875.
192. ten Have P, van Hal P, Wichers I, et al. Turning green: the impact of changing to more eco-friendly respiratory healthcare – a carbon and cost analysis of Dutch prescription data. *BMJ Open*. 2022;12:e055546. doi:10.1136/bmjopen-2021-055546.
193. Smale EM, van den Bemt BJF, Heerdink ER, et al. Cost savings and waste reduction through redispensing unused oral anticancer drugs: the ROAD study. *JAMA Oncol*. 2024;10:87–94. doi:10.1001/jamaoncol.2023.4865.
194. Shanoor Seervai, "Getting to Net Zero: One Health System Fights Climate Change," Jan. 28, 2022, in The Dose, produced by Jody Becker, Julia Melfi, Naomi Leibowitz, and Joshua Tallman, podcast, MP3 audio, 24:30. https://doi.org/10.26099/55b9-s751Seervai S The Dose. *Getting to Net Zero: One Health System Fights Climate Change*. The Commonwealth Fund; 2022. doi:10.26099/55b9-s751.
195. Collins N What is ROI in sustainability? Insights: Lexicon. Institute of Sustainability Studies; 2024. Retrieved from: https://instituteofsustainabilitystudies.com/insights/lexicon/the-roi-of-business-sustainability/. Accessed October 30, 2024.
196. Zhao M, Huang X, Kjellstrom T, et al. Labour productivity and economic impacts of carbon mitigation: a modelling study and benefiand cost analysis. *Lancet Planet Health*. 2022;6:e941–e948. doi:10.1016/S2542-5196(22)00245-5.
197. Campbell-Lendrum D, Neville T, Schweizer C, Neira M. Climate change and health: three grand challenges. *Nat Med*. 2023;29:1631–1638. doi:10.1038/s41591-023-02438-w.
198. Lynch E, Bredin P, Weadick CS, Dorney N, Leeuwen RWFV, O'Reilly S. Why we should, and how we can, reduce the climate toxicity of cancer care. *JCO Oncol Pract*. 2024;0:00680 OP-24-. doi:10.1200/op-24-00680.
199. Barratt AL, Bell KJ, Charlesworth K, McGain F. High value health care is low carbon health care. *Med J Aus*. 2022;216:67–68. doi:10.5694/mja2.51331.
200. Brown M, Schoen JH, Gross J, Omary RA, Hanneman K. Climate change and radiology: impetus for change and a toolkit for action. *Radiology*. 2023;307:e230229. doi:10.1148/radiol.230229.