Review Article

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

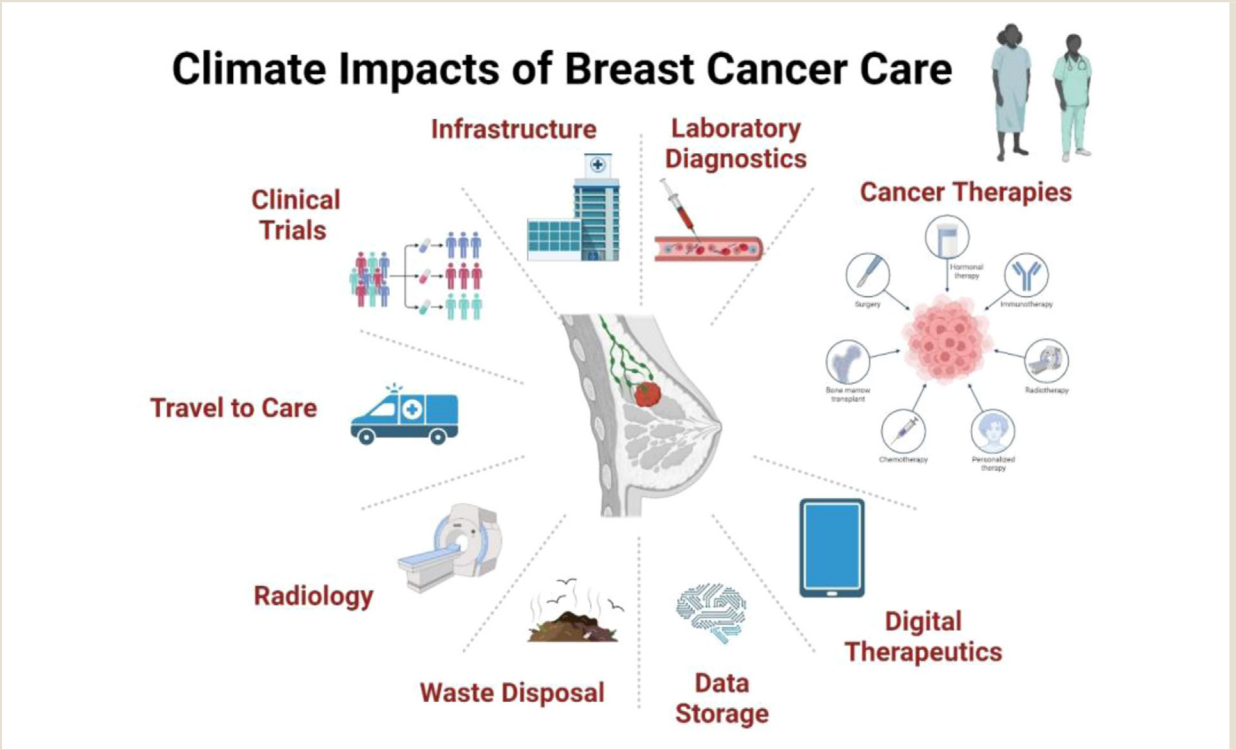
For medical oncologists breast cancer treatment is evolving from "maximum tolerable" toward "optimally effective" treatment.[26] Genomic platforms such as Oncotype Dx have facilitated chemotherapy omission in select patients,[27,28] while neoadjuvant chemotherapy strategies have facilitated tailored 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 underinsured 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 signifi-

cantly 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. https://tools.niehs.nih.gov/cchhl/ Excellent integrated, curated bibliographic database of global peer-reviewed research and gray literature on the science of climate impacts on health.
Healthcare Without Harm Europe – https://noharm-europe.org/ 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. 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." https://training.noharm.org/?lang=en&lang=en
Hospital Resources
Joint Commission International www.jointcommissioninternational Geneva Sustainability Centre Toolbox – testimony associated resource for sustainability integration into hospitals. https://ihf-fih.org/what-we-do/geneva-sustainability-centre/sustainability-toolbox
Global Green and Healthy Hospitals – https://greenhospitals.org/ 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
Irish College of General Practitioners –Glas Toolkit https://www.irishcollegeofgps.ie/Portals/0/Explore%20the%20College/Sustainability%20&%20Planetary%20Health/ETC_Sustainability_Glas_Toolkit_v7.pdf Downloadable toolkit including advice on prescribing, practice management, diet, lifestyle medicine
Royal College of Physicians London –Green Physician Toolkit https://www.rcp.ac.uk/media/tmqazjjl/green-physician-toolkit-july-2024.pdf Downloadable toolkit with advice on prescribing, waste management, advocacy, sustainable practice.
Royal College of General Practitioners – Green Impact for Health Toolkit https://toolkit.sos-uk.org/greenimpact/giforhealth/login Toolkit for general practice in the UK to improve sustainability
Royal College of Surgeons of England – Intercollegiate Green Theatre Checklist https://doi.org/10.1308/rcsbull.2023.25 The basis for the 5"Rs" of surgical sustainability – Reduce, reuse, recycle, rethink and research
Canadian Association of Physicians for the Environment – Climate Change Toolkit for Health Professionals https://chasecanada.org/wp-content/uploads/2021/01/Climate-Change-Toolkit-for-Health-Professionals-Full-Toolkit.pdf Toolkit with planetary health education, sustainability and preparedness solutions and engagement by health professionals.
Sustainability Infographic for Medical Oncology 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 – https://www.esmo.org/about-esmo/organisational-structure/esmo-task-forces/climate-change-task-force 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 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: Nagarajah S et al., Implementation and Impact of Choosing Wisely Recommendations in Oncology. JCO Oncol Pract 2022. 18, 703-712. https://doi.org/10.1200/OP.22.00130 Choosing Wisely Canada – Oncology: https://choosingwiselycanada.org/recommendation/oncology/
ESMO Magnitude of Clinical Benefit Scale: Framework to evaluate the magnitude of clinical benefit for SACT ESMO-Magnitude of Clinical Benefit Scale
The Surgical Care and Climate Change Matrix. 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 atten-

dance 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.

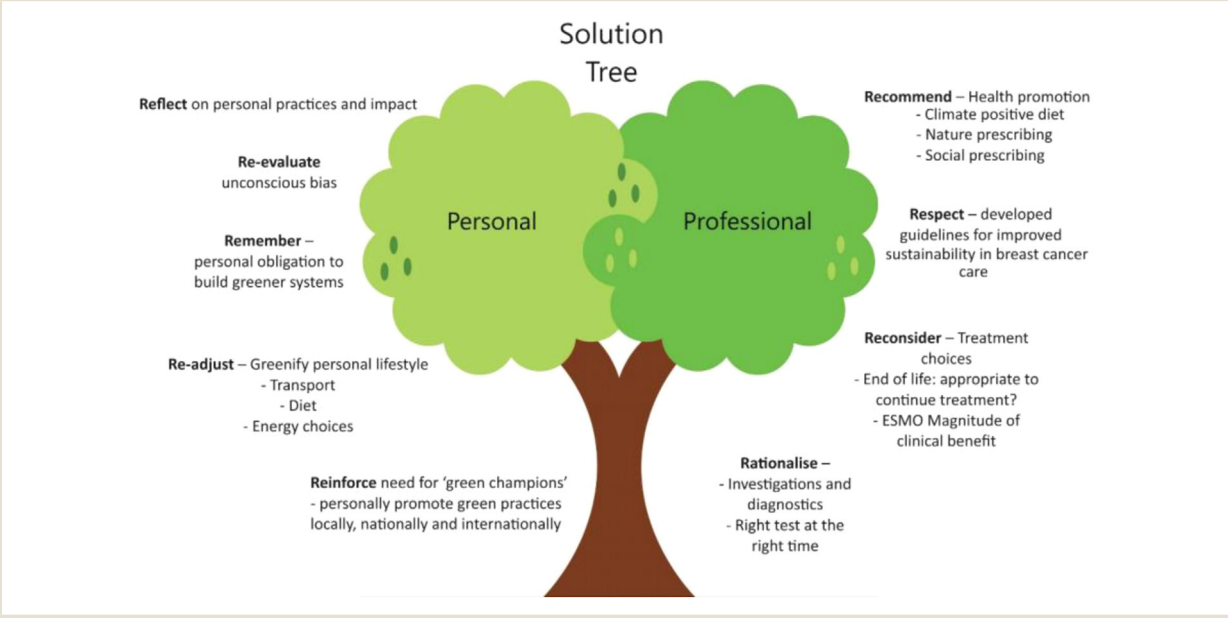
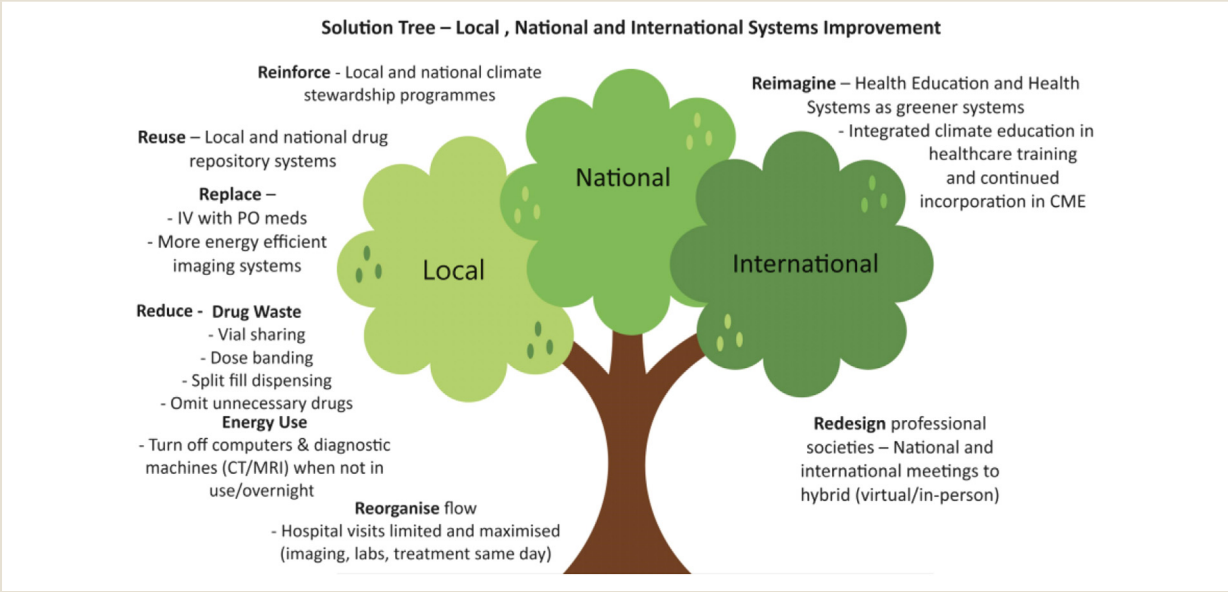


Figure 4 Solution tree for local, national and international systems improvement.



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

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