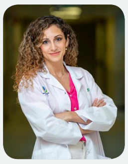
Climate change: The problems and potential solutions in oncology

Sarah EW Briggs, Academic Clinical Lecturer in Medical Oncology and Junior Research Fellow at the Centre for Personalised Medicine and St Anne's College, University of Oxford, UK; **Ilit Turgeman,** Medical Oncologist, Emek Medical Center, Israel; **Seamus O'Reilly,** Clinical Director of Cancer Services and Consultant Medical Oncologist, Cork University Hospital, Ireland; **Catherine S Weadick,** Medical Oncology Specialist Registrar, Cork University Hospital, Ireland; **Lucy Murphy,** Project Manager, Green Trials Initiative, Cancer Trials Ireland; **Roselle B De Guzman,** Medical Oncologist and Associate Professor, Manila Central University-FDT Medical Foundation Hospital, The Philippines; and **Rob Chuter,** Clinical Radiotherapy Physics Team, The Christie and University of Manchester, UK


SARAH EW BRIGGS


ILIT TURGEMAN


SEAMUS O'REILLY


CATHERINE S WEADICK


LUCY MURPHY


ROSELLE DE GUZMAN


ROB CHUTER

The effects of climate change are increasingly being felt around the world. Climate change directly impacts cancer patients and their healthcare, disproportionately affecting populations who have contributed little to the problem. Meanwhile, cancer care and research have a significant carbon footprint. In this article we discuss some of the key challenges, and potential solutions, to the challenge of climate change in oncology.

Climate change represents the biggest threat to human health of this century *(1)*, from threats including extreme weather events, food shortages, conflict, and water shortages *(2)*. From an oncological view point, changes in patterns of exposures and disrupted access to healthcare, will increase the burden of cancer globally. Extreme weather events such as flooding and heat disrupt cancer care, whilst migration as a result of climate-related problems will lead to insecure healthcare for millions *(3,4)*. Many of these issues have a greatest impact on populations with minimal historical emissions, widening health disparities.

However, emissions associated with cancer care and research also contribute directly to climate change. Healthcare accounts for 4.4% of emissions globally *(5)*, including the spectrum of cancer care – from screening for prevention to surgery, radiotherapy, and systemic therapy. In addition to this, cancer research and development, for example basic science, pharmaceuticals, and technology, and the large conferences associated with this work, have a significant footprint. Reducing these emissions as rapidly as possible needs to become an increasing focus. Health systems internationally have acknowledged this and are working hard to reach net zero *(6)*.

In this article we address some of the challenges in different areas of cancer care and highlight available and potential solutions to these (Figure 1), and discuss the role of the oncology community in supporting broader societal change to mitigate the impacts of climate change.

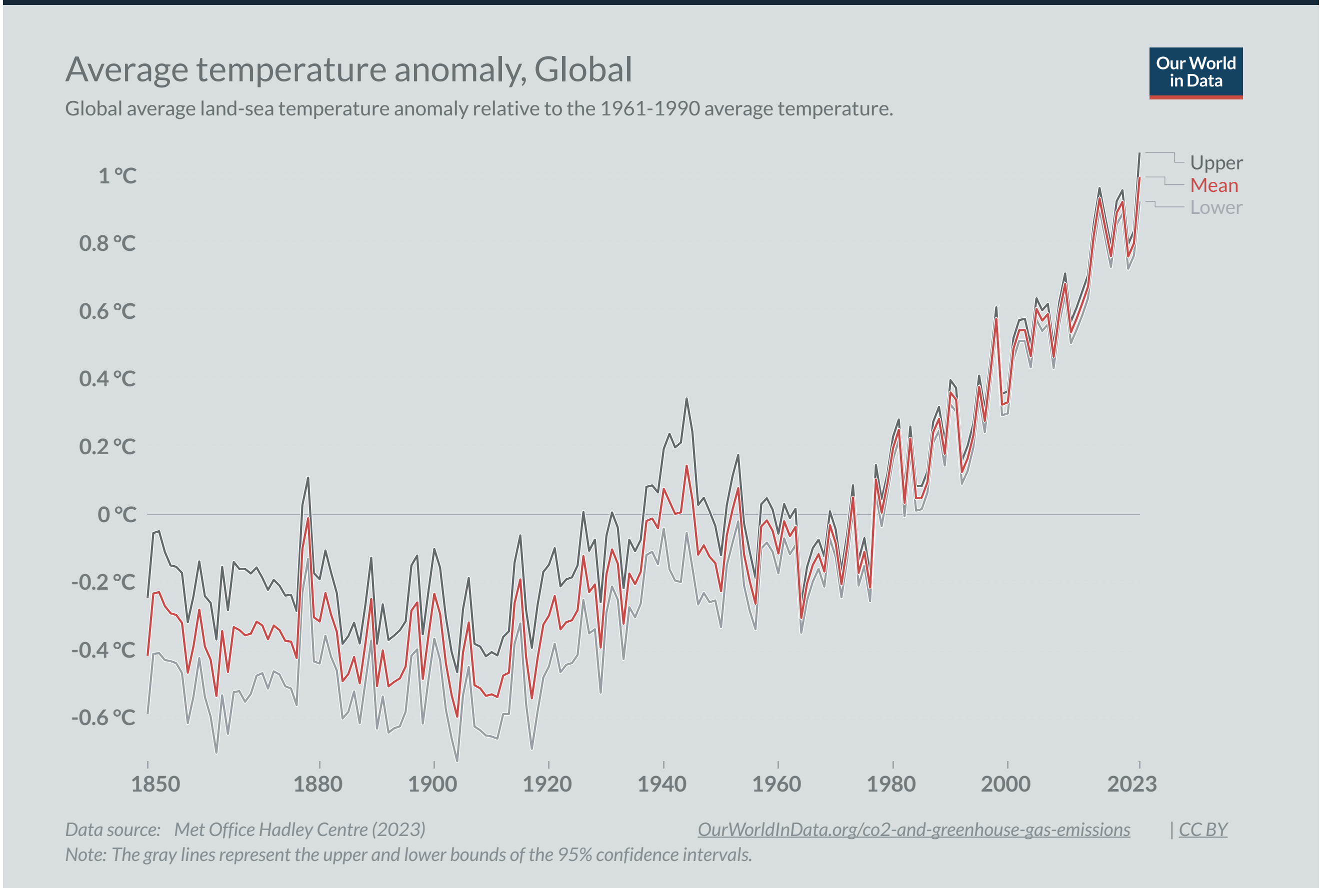
How climate change affects cancer

Challenges

The extensive effects of climate change on cancer are increasingly clear. Both direct exposures to cancer risk factors resulting from climate change, such as air pollution and ultraviolet radiation, and the disruptions to cancer care should be considered.

Air pollution is largely brought about by the combustion of fossil and biomass fuels emitted directly into the environment, simultaneously causing and worsened by climate change *(7)*. Carcinogenic pollutants include gases, namely nitrogen dioxide, sulphur dioxide and ozone, and particulate matter with a diameter of 10 micrograms/metre^3 or less (PM_{10} and $PM_{2.5}$) *(8)*. The vast majority of the global population currently resides in regions where pollution levels exceed the World Health Organization's guideline *(9)*, exacerbated by increasing urbanization in low- and middle-income countries (LMICs). Air pollution is the second leading cause of lung cancer after smoking, and responsible for 14% of lung cancer deaths *(9)*. Increasing $PM_{2.5}$ concentrations are associated with both incidence and mortality from lung cancer *(10–13)*, and recently, with epidermal growth factor receptor (EGFR)-driven

Figure 1: **Increase in average global temperatures relative to the 1961-1990 average temperature. Gray lines represent the upper and lower bounds of the 95% confidence interval. Reproduced under CC-BY licence from Our World in Data https://ourworldindata.org/co2-and-greenhouse-gas-emissions.**



lung cancer, commonly diagnosed in never-smokers, with evidence of an inflammatory mechanistic basis *(14)*. Additional data link pollution to cancers of the aerodigestive and urinary tract, breast, and other organs *(9)*. Besides air pollution, water, chemical and soil pollution may harm human health *(15)*.

Climate change has led to increases in ultraviolet radiation due to global warming and ozone depletion, a strong risk factor for melanoma and other skin cancers *(16–18)*. Moreover, reduced access and deleterious effects on water and food supply, including aflatoxin contamination of crops linked to liver cancer, are also projected to impact cancer deaths *(19–21)*.

Extreme weather events precipitated by climate change, such as wildfires, hurricanes, flooding, and drought, generate substantial carcinogenic exposures, and impact across the cancer care continuum, delaying new diagnoses and disrupting treatment, with an impact on cancer survival *(22–24)*. Shortages in supplies, damage to infrastructure, power systems, communication and transportation of patients and care teams further hamper cancer care *(25)*. Infectious diseases become more prevalent *(26)*, to which individuals with cancer may be more susceptible.

Climate change disproportionately affects socioeconomically disadvantaged communities, racial and ethnic minorities, and women and children. People living in LMICs, with historically low contributions to carbon emissions, have less accessibility to cancer care, that is more likely to be disrupted by natural disasters, and a lower capacity to mitigate them *(27)*. Early life exposures to pollution have been related to childhood and young adult cancers *(9)*, and nearly 92% of pollution-related deaths occur in LMICs *(15)*. It is anticipated that millions of climate refugees and displaced people due to uninhabitable conditions will have jeopardized healthcare security and cancer care in the future – making the social determinants of cancer fundamental to appreciating the impact of climate change *(28)*.

Solutions

Potential solutions for reducing the impact of climate change on cancer centre on addressing the causes of climate change, mitigating exposures to cancer-risk factors, and strengthening health systems *(28)*. Healthcare professionals have an opportunity to generate evidence and educate, to ultimately impact behaviours and climate-related policy. Recently, key medical journals published a united message to world leaders urging rapid climate action *(29)*, and action on pollution has been urged by the the International Association for the Study of Lung Cancer *(30)*. For the first time this year, the Conference of the Parties (COP) 28, the annual UN convention on climate change, will consider health issues in depth.

A global and rapid shift to renewable energy sources as well as increased use of efficient hardware is necessary to both reduce pollution and reduce the greenhouse gases emitted into the atmosphere that drive climate change, and typically have health co-benefits. For example, phase-out of fossil-fuel powered vehicles and increased use of active transport reduces pollution and increases physical activity, reducing cancer risk. Oncology professionals could play a key role in advocating for a rapid shift away from fossil fuels to clean our air, just as we have been an important voice in the fight against tobacco *(31,32)*.

Cancer systems and healthcare infrastructure must be made resilient and prepared for cancer threats as well as the changing patterns and burdens of disease. Care continuity during climate events, and health disparities based on social determinants should be prioritized.

How cancer treatment affects climate change

Challenges

Much of the infrastructure associated with healthcare contributes to emissions, from buildings and land use, to transport, energy, and food supply *(33)*. Many healthcare facilities in low-income countries use outdated medical equipment, which can be energy-inefficient and contribute to higher energy consumption and emissions. Cancer care is typically delivered in large centres, with patients often travelling a considerable distance for their care *(34,35)*, with hospital care disproportionately more carbon intensive than community-based care *(33)*.

Surgery, pharmaceuticals, and radiotherapy, the mainstays of cancer care, are likely to have significant environmental footprints though their relative contributions in oncology have not yet been quantified. Operating theatres have a significant carbon footprint, and newer surgical techniques are increasingly carbon-intensive *(36,37)*. Medicines and chemicals make up 20% of the total of the United Kingdom's NHS carbon footprint (when Scope 3 emissions are included) *(6)*, whilst in the US prescription drugs account for 14% of healthcare-associated carbon emissions *(38)*. The pharmaceutical industry has been found to be 55% more carbon intensive than the automotive industry *(39)*. The intensive prescribing practices in oncology makes pharmaceuticals likely a significant portion of oncology's environmental footprint. Treating a rising volume of increasingly complex cases, whilst also ensuring care is environmentally sustainable, is a huge challenge. Many limited-resource countries heavily rely on imported drugs, medical equipment, and supplies, transportation of which also contributes to carbon emissions.

A large part of cancer care is delivered in the context of clinical trials. The intensive monitoring, patient travel, and laboratory use result in a major environmental impact. Globally conducted clinical trials have a carbon footprint of just under a third of the annual emissions of Bangladesh *(40)*. In 2009, a study of 12 pragmatic randomized trials estimated that the average emission of a trial was equivalent to nine people in the United Kingdom in one year *(41)*. Compounding these figures are emissions and waste from laboratory based or "wet lab" bioscience research which is responsible for 2% of global plastic waste *(42)*. Laboratories are also resource intensive using higher amounts of water and 5–10 times more energy per square foot than standard office spaces *(43)*.

Solutions

At COP26, 52 countries committed to developing resilient, low-carbon healthcare systems, and high-income countries must lead the way in decarbonization *(44)*. Over 1000 hospitals in the United States have committed to emissions reductions, and the NHS in England has developed a comprehensive net-zero strategy *(6,44)*, In line with this, ensuring cancer centres are retrofitted or built to high environmental standards, and powered by renewable energy (with financial support for this in LMICs), is a key step. In low-income countries, regular maintenance and repair services help extend the lifespan of existing equipment. Collaboration with international organizations to secure funding or donations for updated, energy-efficient and environmentally-responsible medical equipment would contribute to sustainable solutions.

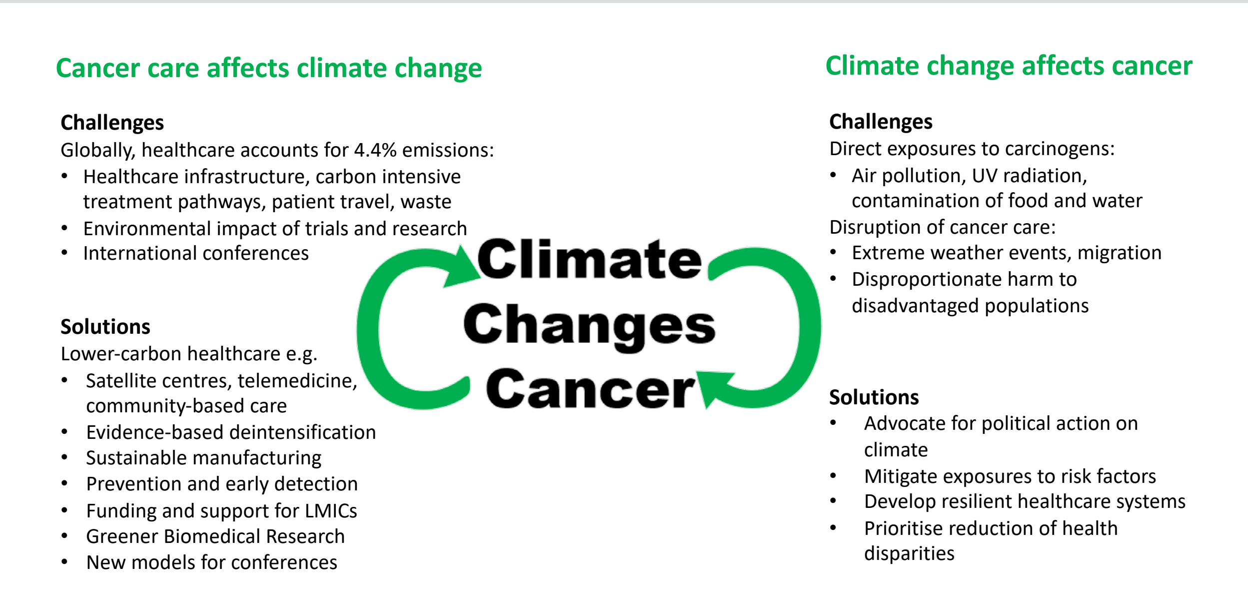
As travel is responsible for a large proportion of the emissions for cancer care, increasing the number of satellite centres, increased use of hypofractionated radiotherapy treatments, and use of telemedicine would also reduce emissions, and could improve patient experience *(45)*. Telemedicine can also help facilitate access to care for patients in remote regions. Community based cancer care, where possible, has a lower carbon footprint than hospital based care *(33)*. Improving public transport would also reduce travel emissions.

Procurement and supply chain comprise over 70% of healthcare's emissions *(46)*, and reducing these requires coordinated effort between health systems and industry *(44)*. Regulations to ensure that manufacturers use sustainable practices have been implemented (e.g. ISO 14001) but need to be widely adopted to ensure standards are met. Embracing the circular economy, whereby a used product is returned to the manufacturer for reuse, refurbishment or recycling, can also contribute. In resource-limited settings, local production can reduce the need for extensive imports and transportation. Establishing partnerships with neighbouring countries for resource-sharing and reducing cross-border transportation

Table 1: Enabling greener biomedical research challenges and solutions

Challenge	Possible solutions
Prioritizing environmental sustainability within the biomedical research ecosystem	- Supporting "bottom up" activities with a more strategic and better resourced "top-down" approach - Develop a workforce specializing in improving the environmental sustainability of research practice - Integrating environmental sustainability into good research practice analogous to health and safety integration - Developing environmental sustainability standards to provide benchmarks and promote accountability - Central coordination for environmental sustainability in biomedical research
Generating and disseminating evidence on environmentally sustainable research practices	- Provision of additional data on the environmental impact of research activities, equipment and consumables - Standardized and evidence based metrics on sustainability to guide decision making - Mechanisms to ensure effective dissemination of information and sharing of experience - A critical mass of experts to study and develop environmentally sustainable research practices
Accelerating introduction of more environmentally sustainable practices in clinical research	- A greater focus on green practice in clinical trials and other clinical research - Public and patient engagement should be built into a sustainability agenda for clinical research
Promoting and informing behaviour change	- Coordinated engagement to ensure sustainability is embedded in the behaviour of individual researchers

Figure 2: An overview of the challenges of climate change in oncology and potential solutions



would also promote climate-friendly practices.

Over-prescription and pharmaceutical waste need to be addressed. The key actions of reduce, reuse and recycle are fundamental to all sustainability initiatives *(47)*, including clinical medicine and research. In 2012, the "Choose Wisely" campaign was launched in the United States, and is now active in 30 countries, discouraging the use of tests and interventions with minimal patient benefit over concerns of rising healthcare costs and concerns that a third of healthcare offered no clinical value to patients *(48)*. The recommendations target overuse and have been re-imagined for clinical climate change mitigation *(49)*. Evidence-based de-intensification of treatments (for example reductions in adjuvant therapy for colorectal cancer *(50)* and careful choice of treatment scheduling *(51)*, will reduce emissions associated with these treatment pathways.

A renewed focus on risk reduction and cancer prevention is essential to limit the rise in cancer cases. This includes public health measures to promote healthier lifestyles and address wider determinants of health, such as active travel, limiting UV-exposure, and more plant-based diets, much of which also reduces emissions. In LMICs, many patients present with advanced-stage cancers requiring more intensive treatments due to limited access to early detection, which can lead to increased energy and resource consumption. Cancer awareness and education campaigns to promote early detection, and support for low-cost or free cancer screening programmes would reduce the need for aggressive treatments, improving cancer care and reducing environmental impacts.

Palliative care is also often underdeveloped in low-income settings, which can lead to unnecessary and resource-intensive interventions at the end of life. Compared with other specialties, palliative care has relatively low greenhouse gas emissions *(52)*. Expanding palliative care provision and education, particularly community-based support, is essential both for patient care and emissions reductions.

To date, engagement in sustainability in the clinical research arena has been low. Following a landmark analysis by the Sustainable Trials Study Group in 2007 of MRC CRASH trial *(53)*, there has until recently been little progress, though we are now at a time of unprecedented activity in translational research. Over 2000 clinical trials evaluating immune checkpoint inhibitors were active last year *(54)*. The rapid expansion of clinical investigation has been largely uncoordinated, a divergence that will increase as molecular profiling and predictive biomarkers, targeted therapies, and novel combinations are tested *(55,56)*. Harmonization of trials, which would reduce waste, will be challenging given the disparate and growing number of pharmaceutical companies involved. When clinical engagement has been present it has been beneficial. In 2011, the UK Sustainable Clinical Trials Group (SCTG) published guidelines for reducing the carbon footprints of trials. Two subsequent trials demonstrated improved carbon efficacy due to faster patient recruitment, lighter trial materials and web-based data entry *(57)*.

In contrast, in the laboratory arena engagement has been significant, where "My Green Lab" a non-profit organization with a mission to build a global culture of sustainability in science *(58)*, is an exemplar. "My Green Lab" Certification is recognized by the United Nations "Race to Zero" campaign, and is considered gold standard for laboratory sustainability best practises internationally, with 1055 laboratories certified

Figure 3: Actionable areas in clinical trials

by July 2022 *(58)*.

Several recent initiatives are accelerating progress in clinical trials. A UK research project funded by the National Institute for Health and Care Research (NIHR) is developing a method to measure reliably and consistently the carbon footprint of clinical trials *(59)*. A recent forum workshop hosted by the Academy of Medical Sciences, the Medical Research Council, and the NIHR has highlighted four key challenges for greener biomedical research and proposed possible strategies to address these deficits (Table 1) *(60)*. Actionable areas for improvement are shown in Figure 2 *(59,61–64)*.

As with clinical work, there is a need to enhance value and reduce waste in research *(65–67)*. Integrating a "Green Choose Wisely" initiative into clinical research, as in clinical practice, would reduce waste, reduce trial costs, be climate smart, and could serve as a catalyst for engagement of the clinical trials community at this pivotal time.

Professional engagement and education is essential in both clinical and research settings. A multinational survey of 4654 healthcare professionals assessing their views on climate change as a human health issue showed that awareness was high, but barriers existed to their engaging in advocacy and education on this issue *(68)*. Over 70% of respondents reported that policy statements by professional organizations and guidance documents on workplace sustainability would be helpful to them.

Challenges

In order to share ideas and practices, members of the oncology community regularly meet for national or international meetings and conferences. This is key to research and development but also has a large environmental impact. Air travel to these meetings has a huge environmental footprint, but accommodation and event spaces also contribute significantly to conference emissions. Initial work estimates the carbon footprint of medical conferences is about 2–3 tCO_2e per delegate *(69,70)*, and rough values for a European radiotherapy and oncology conference estimated per person emissions of about 1.1 tCO2e per person (personal communication). It is thought that to stay within 1.5°C each person globally would need to use less than 2.3 tCO2e per year by 2030, so one conference is a significant proportion of that yearly limit *(71)*.

Solutions

One solution to conference emissions would be to embrace the move to online conferences which the COVID-19 pandemic did much to normalize. This has been shown to reduce the carbon footprint of conferences by 94% *(70)* but also broadens access, including for colleagues in LMICs and those with caring responsibilities, and improves equity of delegates that can attend *(72)*. Another possibility is to use a hub model to conferences whereby for example delegates meet face-to-face locally but join the international community virtually *(73)*. A simpler approach would be to hold the meetings/conferences less frequently or alternate them between face-to-face and virtually each year. Such changes will require the support of both major cancer organizations and large pharmaceuticals.

Conclusion

The circular impact of climate change on the provision cancer care to patients across the world, and of cancer care and research on the climate, are an urgent and essential issue within oncology. These interlinked issues replicate injustices noted across the climate and health movement: the greatest oncology-associated emissions arise from cancer care in high-income countries, whilst the impacts are felt by patients in countries with historically very low emissions, and poor access to newer cancer treatments and technologies. These issues cannot be tackled without also addressing this injustice *(74)*. Physicians are trusted messengers and powerful advocates. We suggest that the international oncology community has a key, and as yet largely unrealised role, not only in mitigating climate change by reducing our own impacts, but also in advocating for others – at individual, organizational, and governmental levels – to urgently and rapidly do the same. ■

Dr Sarah EW Briggs is an Academic Clinical Lecturer in Medical Oncology, and Junior Research Fellow at the Centre for Personalised Medicine and St Anne's College, at the University of Oxford, UK, and a clinician in the NHS. Her research interests are in evaluating the environmental impact of healthcare, with a particular focus on oncology, and in considering how sustainability is weighed against other priorities in decision making around health and emissions reductions.

Dr Ilit Turgeman is a medical oncologist at Emek Medical Center in Israel, specializing in thoracic oncology. She graduated from Hebrew University, completed her residency in Rambam Hospital, and undertook a short fellowship in Clinical Trials at Sarah Cannon Research Institute-UK. In her current position, Dr Turgeman is involved in the development of a comprehensive Cancer Centre, including the establishment of a clinical trials platform and satellite clinics in peripheral regions of the country. She also leads an integrative Young-Onset Cancer Center. Her passion and research interests lie in oncogene-driven lung cancer, care equity, global oncology, and climate and health.

Professor Seamus O'Reilly, BSc, MD, PhD, FRCPI is a Clinical Director of Cancer Services and Consultant Medical Oncologist at

Cork University Hospital. A graduate of University College Galway he completed medical oncology training at John Hopkins Hospital, Baltimore, MD, USA, where he was subsequently Assistant Professor in Medical Oncology and completed a PhD in Clinical Investigation focusing on Cancer Pharmacology. He was National Specialty Director in Medical Oncology at the Royal College of Physicians from 2013–2021. He is Vice Clinical lead at Cancer Trials Ireland where he has established the National Green Cancer Clinical Trials Initiative in 2022, is a founding trustee and co-Chairperson Cork ARC Cancer Support House, Deputy Editor of BJC reports, and is a member of the Executive Board of the Breast International Group.

Dr Catherine Weadick, MB, BCh, BAO, MSc, MRCPI is a Medical Oncology Specialist Registrar at Cork University Hospital. She is a graduate of University College Cork and recently completed a MSc in Clinical Trials.

Lucy Murphy graduated from Maynooth University with a BSc in Biomedical Science, and went on to work as a clinical trials manager in the Rotunda. She has been working in Cancer Trials Ireland for over two years as a project manager with an extensive portfolio in gynaecology and other clinical trials. She is currently working on a Green Trials Initiative with Professor Seamus O'Reilly and his team in Cork University Hospital, Ireland, focusing on how to "green" a clinical trial and it's processes to pave the way for future clinical trial design.

Dr De Guzman is a medical oncologist and associate professor at the Manila Central University-FDT Medical Foundation Hospital in the Philippines. She is the immediate past chair of the Asia Pacific Regional Council of the American Society of Clinical Oncology. She has specific interests on breast, head and neck, and thoracic cancer. Dr De Guzman has written about concerning issues in global oncology including the vulnerability of patients in Asia Pacific due to climate change and natural disasters. As a member volunteer, she has served on ASCO committees and working groups including international affairs, leadership development programme, and resource-stratified CPG advisory group.

Dr Rob Chuter works within the clinical radiotherapy physics team at The Christie as well as the radiotherapy related research (RRR) group at The University of Manchester. His main focus is MR-Linac research but he is also founder and Chair of the IPEM Environmental Sustainability Committee and lead of the joint Radiotherapy Board working party on environmental sustainability. He has recently published a paper estimating the carbon footprint of radiotherapy.

References

1. World Health Organisation. COP26 special report on climate change and health: the health argument for climate action [Internet]. 2021 Oct [cited 2023 Sep 8]. Available from: https://www.who.int/publications/i/item/9789240036727
2. Ballester J, Quijal-Zamorano M, Méndez Turrubiates RF, Pegenaute F, Herrmann FR, Robine JM, et al. Heat-related mortality in Europe during the summer of 2022. *Nat Med.* 2023 Jul;29(7):1857–66.
3. Romanello M, Di Napoli C, Drummond P, Green C, Kennard H, Lampard P, et al. The 2022 report of the Lancet Countdown on health and climate change: health at the mercy of fossil fuels. *The Lancet.* 2022 Nov;400(10363):1619–54.
4. Schwerdtle P, Bowen K, McMichael C. The health impacts of climate-related migration. *BMC Med.* 2018 Dec;16(1):1.
5. Pichler PP, Jaccard IS, Weisz U, Weisz H. International comparison of health care carbon footprints. *Environ Res Lett.* 2019 Jun 1;14(6):064004.
6. NHS England and NHS Improvement. Delivering a 'Net Zero' National Health Service [Internet]. NHS England; 2020 Oct. Available from: https://www.england.nhs.uk/greenernhs/wp-content/uploads/sites/51/2022/07/B1728-delivering-a-net-zero-nhs-july-2022.pdf
7. Berg CD, Schiller JH, Boffetta P, Cai J, Connolly C, Kerpel-Fronius A, et al. Air Pollution and Lung Cancer: A Review by International Association for the Study of Lung Cancer Early Detection and Screening Committee. *Journal of Thoracic Oncology*. 2023 Jun;S1556086423006019.
8. Loomis D, Grosse Y, Lauby-Secretan B, Ghissassi FE, Bouvard V, Benbrahim-Tallaa L, et al. The carcinogenicity of outdoor air pollution. *The Lancet Oncology.* 2013 Dec;14(13):1262–3.
9. Turner MC, Andersen ZJ, Baccarelli A, Diver WR, Gapstur SM, Pope CA, et al. Outdoor air pollution and cancer: An overview of the current evidence and public health recommendations. *CA A Cancer J Clinicians.* 2020 Nov;70(6):460–79.
10. Coleman NC, Burnett RT, Higbee JD, Lefler JS, Merrill RM, Ezzati M, et al. Cancer mortality risk, fine particulate air pollution, and smoking in a large, representative cohort of US adults. *Cancer Causes Control.* 2020 Aug;31(8):767–76.
11. Hamra GB, Guha N, Cohen A, Laden F, Raaschou-Nielsen O, Samet JM, et al. Outdoor Particulate Matter Exposure and Lung Cancer: A Systematic Review and Meta-Analysis. *Environ Health Perspect.* 2014 Sep;122(9):906–11.
12. Pun VC, Kazemiparkouhi F, Manjourides J, Suh HH. Long-Term PM2.5 Exposure and Respiratory, Cancer, and Cardiovascular Mortality in Older US Adults. *American Journal of Epidemiology.* 2017 Oct 15;186(8):961–9.
13. Ciabattini M, Rizzello E, Lucaroni F, Palombi L, Boffetta P. Systematic review and meta-analysis of recent high-quality studies on exposure to particulate matter and risk of lung cancer. *Environmental Research.* 2021 May;196:110440.
14. Hill W, Lim EL, Weeden CE, Lee C, Augustine M, Chen K, et al. Lung adenocarcinoma promotion by air pollutants. Nature. 2023 Apr 6;616(7955):159–67.
15. Landrigan PJ, Fuller R, Acosta NJR, Adeyi O, Arnold R, Basu N (Nil), et al. The Lancet Commission on pollution and health. *The Lancet.* 2018 Feb;391(10119):462–512.
16. Diffey B. Climate change, ozone depletion and the impact on ultraviolet exposure of human skin. *Phys Med Biol.* 2004 Jan 7;49(1):R1–11.
17. Arnold M, De Vries E, Whiteman DC, Jemal A, Bray F, Parkin DM, et al. Global burden of cutaneous melanoma attributable to ultraviolet radiation in 2012. *Int J Cancer.* 2018 Sep 15;143(6):1305–14.
18. Kaffenberger BH, Shetlar D, Norton SA, Rosenbach M. The effect of climate change on skin disease in North America. *Journal of the American Academy of Dermatology.* 2017 Jan;76(1):140–7.
19. Baan R, Grosse Y, Straif K, Secretan B, El Ghissassi F, Bouvard V, et al. A review of human carcinogens—Part F: Chemical agents and related occupations. *The Lancet Oncology.* 2009 Dec;10(12):1143–4.
20. Battilani P, Toscano P, Van Der Fels-Klerx HJ, Moretti A, Camardo Leggieri M, Brera C, et al. Aflatoxin B1 contamination in maize in Europe increases due to climate change. *Sci Rep.* 2016 Apr 12;6(1):24328.
21. Springmann M, Mason-D'Croz D, Robinson S, Garnett T, Godfray HCJ, Gollin D, et al. Global and regional health effects of future food production under climate change: a modelling study. *The Lancet.* 2016 May;387(10031):1937–46.
22. Nogueira LM, Yabroff KR, Bernstein A. Climate change and cancer. *CA A Cancer J Clin.* 2020 Jul;70(4):239–44.
23. Zhang D, Xi Y, Boffa DJ, Liu Y, Nogueira LM. Association of Wildfire Exposure While Recovering From Lung Cancer Surgery With Overall Survival. JAMA Oncol [Internet]. 2023 Jul 27 [cited 2023 Aug 3]; Available from: https://jamanetwork.com/journals/jamaoncology/fullarticle/2807729
24. Nogueira LM, Sahar L, Efstathiou JA, Jemal A, Yabroff KR. Association Between Declared Hurricane Disasters and Survival of Patients With Lung Cancer Undergoing Radiation Treatment. *JAMA.* 2019 Jul 16;322(3):269–71.
25. Man RXG, Lack DA, Wyatt CE, Murray V. The effect of natural disasters on cancer care: a systematic review. *The Lancet Oncology*. 2018 Sep 1;19(9):e482–99.
26. Shuman EK. Global Climate Change and Infectious Diseases. *N Engl J Med.* 2010 Mar

25;362(12):1061–3.
27. Yu P, Xu R, Yang Z, Ye T, Liu Y, Li S, et al. Cancer and Ongoing Climate Change: Who Are the Most Affected? *ACS Environ Au.* 2023 Jan 18;3(1):5–11.
28. Hiatt RA, Beyeler N. Cancer and climate change. *The Lancet Oncology.* 2020 Nov;21(11):e519–27.
29. Atwoli L, Baqui AH, Benfield T, Bosurgi R, Godlee F, Hancocks S, et al. Call for emergency action to limit global temperature increases, restore biodiversity, and protect health. *BMJ.* 2021 Sep 5;n1734.
30. Berg CD, Stephen L, Aggarwal C, Bernicker E, Boffetta P, Milena C, et al. Air Pollution and Lung Cancer - The IASLC Position Statement [Internet]. 2022 Apr [cited 2023 Sep 8]. Available from: https://www.iaslc.org/iaslc-news/press-release/air-pollution-and-lung-cancer-iaslc-position-statement
31. Hanna N, Mulshine J, Wollins DS, Tyne C, Dresler C. Tobacco Cessation and Control a Decade Later: American Society of Clinical Oncology Policy Statement Update. *JCO.* 2013 Sep 1;31(25):3147–57.
32. Krech R, Peters S, Kroemer H, Fu D, Giuliani R, Sehouli J, et al. Tobacco cessation and the role of ESMO and medical oncologists: addressing the specific needs of cancer patients in times of the COVID-19 pandemic. *ESMO Open.* 2023 Jun;8(3):101579.
33. Pencheon D, Wight J. Making healthcare and health systems net zero. *BMJ.* 2020 Mar 30;m970.
34. Coombs NJ, Coombs JM, Vaidya UJ, Singer J, Bulsara M, Tobias JS, 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 May;6(5):e010703.
35. Chuter R, Stanford-Edwards C, Cummings J, Taylor C, Lowe G, Holden E, et al. Towards estimating the carbon footprint of external beam radiotherapy. *Physica Medica.* 2023 Aug;112:102652.
36. Stanford-Edwards C, Edwards M, Selby A, Lewis R, Powell C, Nicholas O. Creating a Sustainable Future of Radiotherapy Following COP26: A Case for Lung Stereotactic Ablative Radiotherapy Over Surgery? *Clinical Oncology.* 2022 Mar;34(3):e105–6.
37. Rizan C, Steinbach I, Nicholson R, Lillywhite R, Reed M, Bhutta MF. The Carbon Footprint of Surgical Operations: A Systematic Review. *Annals of Surgery.* 2020 Dec;272(6):986–95.
38. Chung JW, Meltzer DO. Estimate of the Carbon Footprint of the US Health Care Sector. *JAMA.* 2009 Nov 11;302(18):1970.
39. Belkhir L, Elmeligi A. Carbon footprint of the global pharmaceutical industry and relative impact of its major players. *Journal of Cleaner Production*. 2019 Mar;214:185–94.
40. Adshead F, Salman RAS, Aumonier S, Collins M, Hood K, McNamara C, et al. A strategy to reduce the carbon footprint of clinical trials. *The Lancet.* 2021 Jul 24;398(10297):281–2.
41. 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 Oct 30;339:b4187.
42. Urbina MA, Watts AJR, Reardon EE. Labs should cut plastic waste too. *Nature.* 2015 Dec;528(7583):479–479.
43. United States Environmental Protection Agency. Laboratories for the 21st Century: An Introduction to Low-Energy Design [Internet]. 2008 [cited 2023 Sep 8]. Available from: https://www.nrel.gov/docs/fy08osti/29413.pdf
44. Karliner J, Osewe P, Neira M, Arora D, Galvao L, Reddy KS. Momentum builds for health-care climate action. *The Lancet.* 2023 Aug;402(10402):595–7.
45. Patel KB, Gonzalez BD, Turner K, Alishahi Tabriz A, Rollison DE, Robinson E, et al. Estimated Carbon Emissions Savings With Shifts From In-Person Visits to Telemedicine for Patients With Cancer. *JAMA Netw Open.* 2023 Jan 31;6(1):e2253788.
46. J Karliner, Slotterback, S, Boyd, R, Ashby, B, Steele, K. Health care's climate footprint: how the health sector contributes to the global climate crisis and opportunities for action. Health Care Without Harm Climate-Smart Health Care Series Green Paper Number One. [Internet]. 2019 [cited 2023 Sep 8]. Available from: https://healthcareclimateaction.org/sites/default/files/2021-05/HealthCaresClimateFootprint_092319.pdf
47. Nordhaus W. The Spirit of Green. Princeton University Press; 2021.
48. Levinson W, Kallewaard M, Bhatia RS, Wolfson D, Shortt S, Kerr EA. 'Choosing Wisely': a growing international campaign. *BMJ Qual Saf.* 2015 Feb;24(2):167–74.
49. Born KB, Levinson W, Vaux E. Choosing Wisely and the climate crisis: a role for clinicians. *BMJ Qual Saf.* 2023 Jun 2;bmjqs-2023-015928.
50. Grothey A, Sobrero AF, Shields AF, Yoshino T, Paul J, Taieb J, et al. Duration of Adjuvant Chemotherapy for Stage III Colon Cancer. *N Engl J Med.* 2018 Mar 29;378(13):1177–88.
51. Jacobson SI, Kacew AJ, Knoebel RW, Hsieh PH, Ratain MJ, Strohbehn GW. Alternative Trastuzumab Dosing Schedules Are Associated With Reductions in Health Care Greenhouse Gas Emissions. *JCO Oncology Practice.* 2023 Jul 14;OP.23.00227.
52. Dokal K, Morris M, Spooner R, Perkins P. The carbon footprint of a hospice. BMJ Support Palliat Care. 2022 Oct 7;spcare-2022-003972.
53. Roberts I, Yates D, Sandercock P, Farrell B, Wasserberg J, Lomas G, et al. Effect of intravenous corticosteroids on death within 14 days in 10 008 adults with clinically significant head injury (MRC CRASH trial): randomised placebo-controlled trial. *The Lancet.* 2004 Oct;364(9442):1321–8.
54. Beaver JA, Pazdur R. The Wild West of Checkpoint Inhibitor Development. *N Engl J Med.* 2022 Apr 7;386(14):1297–301.
55. Franzoi MA, Romano E, Piccart M. Immunotherapy for early breast cancer: too soon, too superficial, or just right? *Annals of Oncology.* 2021 Mar;32(3):323–36.
56. Santa-Maria CA. Optimizing and Refining Immunotherapy in Breast Cancer. *JCO Oncology Practice.* 2023 Apr;19(4):190–1.
57. 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 Dec;12(1):31.
58. My Green Lab. My Green Lab [Internet]. [cited 2023 Sep 9]. Available from: https://www.mygreenlab.org
59. National Institute for Health and Care Research. Fund and Awards [Internet]. 2021 [cited 2022 Sep 25]. Available from: https://fundingawards.nihr.ac.uk/award/NIHR135419
60. The Academy of Medical Sciences. Enabling Greener Biomedical Research [Internet]. 2023 [cited 2023 Sep 12]. Available from: https://acmedsci.ac.uk/file-download/61695123
61. Chalmers I, Glasziou P. Avoidable waste in the production and reporting of research evidence. The Lancet. 2009 Jul;374(9683):86–9.
62. Weadick CS, Keogh RJ, Carroll HK, Boldrin S, Mulroe E, Murphy L, et al. Climate toxicity: An increasingly relevant clinical issue in Cancer Care. *Journal of Cancer Policy*. 2023 Mar;35:100410.
63. Griffiths J, Fox L, Williamson PPR, Adshead F, Salman PRAS, Anderson C, et al. Quantifying the carbon footprint of clinical trials: guidance development and pilot study [Internet]. In Review; 2023 [cited 2023 Sep 12]. Available from: https://www.researchsquare.com/article/rs-2936937/v1
64. Cancertrials.ie. Greening Cancer Trials [Internet]. 2022 [cited 2023 Sep 12]. Available from: https://www.cancertrials.ie/2022/11/greening-cancer-trials/
65. Moher D, Glasziou P, Chalmers I, Nasser M, Bossuyt PMM, Korevaar DA, et al. Increasing value and reducing waste in biomedical research: who's listening? *The Lancet.* 2016 Apr;387(10027):1573–86.
66. Numerous Challenges Create Clinical Research Crisis. *Cancer Discovery*. 2022 Oct 5;12(10):OF2–OF2.
67. Von Niederhäusern B, Guyatt GH, Briel M, Pauli-Magnus C. Academic response to improving value and reducing waste: A comprehensive framework for INcreasing QUality In patient-oriented academic clinical REsearch (INQUIRE). Page MJ, editor. *PLoS Med.* 2018 Jun 7;15(6):e1002580.
68. Kotcher J, Maibach E, Miller J, Campbell E, Alqodmani L, Maiero M, et al. Views of health professionals on climate change and health: a multinational survey study. *The Lancet Planetary Health.* 2021 May;5(5):e316–23.
69. Zotova O, Pétrin-Desrosiers C, Gopfert A, Van Hove M. Carbon-neutral medical conferences should be the norm. *The Lancet Planetary Health.* 2020 Feb 1;4(2):e48–50.
70. Tao Y, Steckel D, Klemeš JJ, You F. Trend towards virtual and hybrid conferences may be an effective climate change mitigation strategy. *Nat Commun.* 2021 Dec 16;12(1):7324.
71. OXFAM. Carbon inequality in 2030. Per capita consumption emissions and the 1.50C goal [Internet]. 2021 [cited 2023 Sep 13]. Available from: https://www.oxfam.org/en/research/carbon-inequality-2030
72. Skiles M, Yang E, Reshef O, Muñoz DR, Cintron D, Lind ML, et al. Conference demographics and footprint changed by virtual platforms. *Nat Sustain.* 2022 Feb;5(2):149–56.
73. Parncutt R, Lindborg P, Meyer-Kahlen N, Timmers R. The Multi-hub Academic Conference: Global, Inclusive, Culturally Diverse, Creative, Sustainable. Frontiers in Research Metrics and Analytics [Internet]. 2021 [cited 2023 May 9];6. Available from: https://www.frontiersin.org/articles/10.3389/frma.2021.699782
74. Rouf K, Wainwright T. Linking health justice, social justice, and climate justice. T*he Lancet Planetary Health.* 2020 Apr;4(4):e131–2.