Advancing Environmentally Sustainable Health Research

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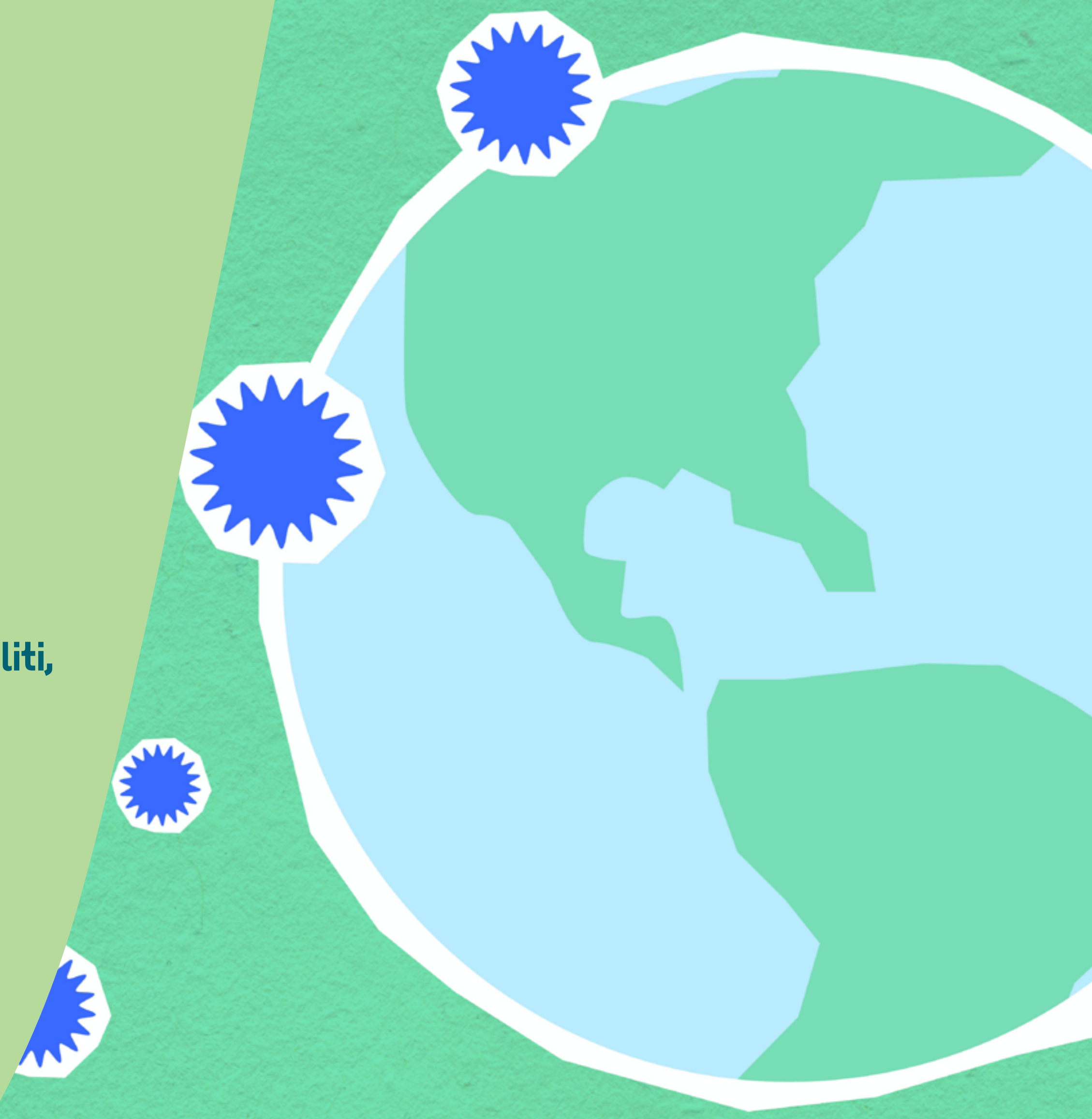

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Executive summary

Health research is conducted with the ultimate goal of improving global health; however, its practices and procedures contribute to one of the greatest health challenges of today: the climate crisis. Laboratory research, clinical research and computational research all have significant environmental impacts through the energy and resources they use and the waste they produce. The aim of this study is to identify tools and methods to address the environmental sustainability of health research, and to consider what is needed to support their development and implementation.

Through desk research, crowdsourcing, interviews, and focus groups and workshops RAND has identified 146 tools and initiatives relating to advancing sustainable health research, thus demonstrating significant action emerging in this area. These tools and initiatives have been categorised into eight groups reflecting their overarching approach: 1) networks; 2) campaigns; 3) measurement or efficiency tools; 4) guidelines; 5) education programmes; 6) standards or certifications; 7) funding schemes; and 8) service providers. These are summarised in Table 1 below.

Broadly, despite the diverse range of activity in this space, it is largely being conducted by individual researchers, unfunded and at the margins of their existing work, driven by their commitment to sustainability. Despite these limited resources, there are some relatively well-developed tools and approaches emerging, particularly for laboratory research, which has well-established networks and two certification programmes aimed at reducing the environmental impact of laboratories. In computational research, numerous calculators can be used to measure the carbon footprint of different types of computation or model. Clinical research has fewer well-established resources, although some measurement protocols and tools are under development. However, as well as a dearth of funding to support this work, researchers lack a central repository of knowledge that they can draw on regarding current practice. In addition, across all initiatives there is a lack of high-quality evaluative evidence to assess their impact, and very limited evidence of their implementation beyond high-income country settings.

At a sector level, there are several guidelines published by different organisations. Currently, these are relatively high level and broad brush, although there is work underway to develop a cross-organisation concordat in the United Kingdom. However, we have yet to see any funder mandate sustainability practices as a requirement of funding. Without funders and other key actors signalling the importance of sustainability at the system level, it will be difficult for researchers to drive progress. There is significant impetus amongst the research community to act at a grass-roots level, which now needs to be met by action across the sector.

Table 1
Overview of initiatives

Type of initiative	Description	Number identified	Key considerations	Examples
Networks	A group of individuals, organisations or smaller networks interested in sustainability issues	12	• Most focus on lab-based research, some cross-disciplinary examples. • Most originate from (and have their membership primarily based) in high-income countries	Laboratory Efficiency Action Network (LEAN) Sustainable European Laboratories (SELs) Future Earth Max Planck Sustainability Network
Campaigns	Raising awareness of sustainability through competitions/ other initiatives	9	• Typically focused on a specific issue or action • Most examples identified linked to either cross-cutting issues or lab-based research • Limited evidence of effectiveness	Radboud International Travel Challenge Be Good in the Hood International Freezer Challenge
Measurement or efficiency tools	Instruments for measuring the environmental impact of research activities or increasing the efficiency of research.	25	• Most help calculate carbon emissions from computational research • Limitations and caveats for many of these tools due to poor availability of data to enable accurate estimates • Tools necessarily trade off complexity/usability with precision • Use is ad hoc, and researchers lack clarity on which tools are available and useful	CodeCarbon fMRI prep carbon tracker Green Algorithms Carbon Footprint Modelling
Guidelines	Recommendations of good practice for implementing sustainability in research.	38	• Currently voluntary and broad brush, with the vast majority handling cross-cutting issues • Useful primarily in raising awareness of sustainability issues • Funders have yet to specify any mandatory standards for funding at scale	UKRI Net Zero Digital Research Infrastructure scoping project NIHR Carbon Reduction Guidelines Forthcoming concordat on research sustainability
Education programmes	Initiative to increase knowledge about sustainability, including sustainable practices.	37	• Typically (but not exclusively) associated with wider sustainability initiatives, such as certification programmes • Usually in the form of online resources • Impact of training not well established	Carbon Literacy Project International Institute for Sustainable Laboratories (I2SL) Beyond Benign
Standards or certification programmes	Initiatives that help an organisation or part of an organisation reach recognised assessed levels of sustainability	6	• Split between lab-based research and cross-cutting issues, no programmes focused on clinical or computational research • No research funders currently require environmental standards and certifications to be eligible for funded research	LEAF My Green Lab
Funding schemes	Investment in research/ evidence on sustainable health research	2	• Limited investment in evidence generation, research conducted to date has been primarily bottom-up and unfunded • No resources have been identified in low- and middle-income countries (LMICs)	UK Medical Research Council: Environmental sustainability in life sciences and medical practice
Sustainable service providers	Organisations that offer services to help implement sustainable practices	17	• Primarily cater to cross-cutting issues (e.g. plastics recycling, assessment services, carbon offsetting) and lab-based research • Can help researchers address challenges, including availability of evidence around supply chain and instrumentation sustainability • Care needs to be taken to make sure they offer truly effective environmental solutions to avoid any risk of 'greenwashing'	Green Machine Computers Green Light Laboratories

1. Introduction

1.1 Context

Health research is conducted with the ultimate goal of improving global health; however, its practices and procedures contribute to one of the greatest health challenges of today: the climate crisis.[2]

Laboratory research has a particularly large environmental imprint due to the high level of energy consumption,[3] the production of plastic waste,[4] and the carbon emissions caused by the manufacturing, distribution and use of reagents, chemicals, materials and equipment.[5,6] One researcher working in a bioscience lab is estimated to generate just under one ton of plastic waste in a year,[7] and the median energy usage of laboratories has been calculated to be nearly three times that of a similarly sized office.[8] Clinical trials produce carbon emissions through the travel of researchers and research participants, as well as the energy use in research premises.[7] Data-driven approaches to health research using methods such as artificial intelligence are bringing exciting opportunities, but also new environmental challenges. Generating and processing large amounts of data consumes significant amounts of energy, which is linked to carbon emissions[10] and associated with adverse environmental impacts such as the extraction of natural resources for technological components and equipment obsolescence.[11,12,13]

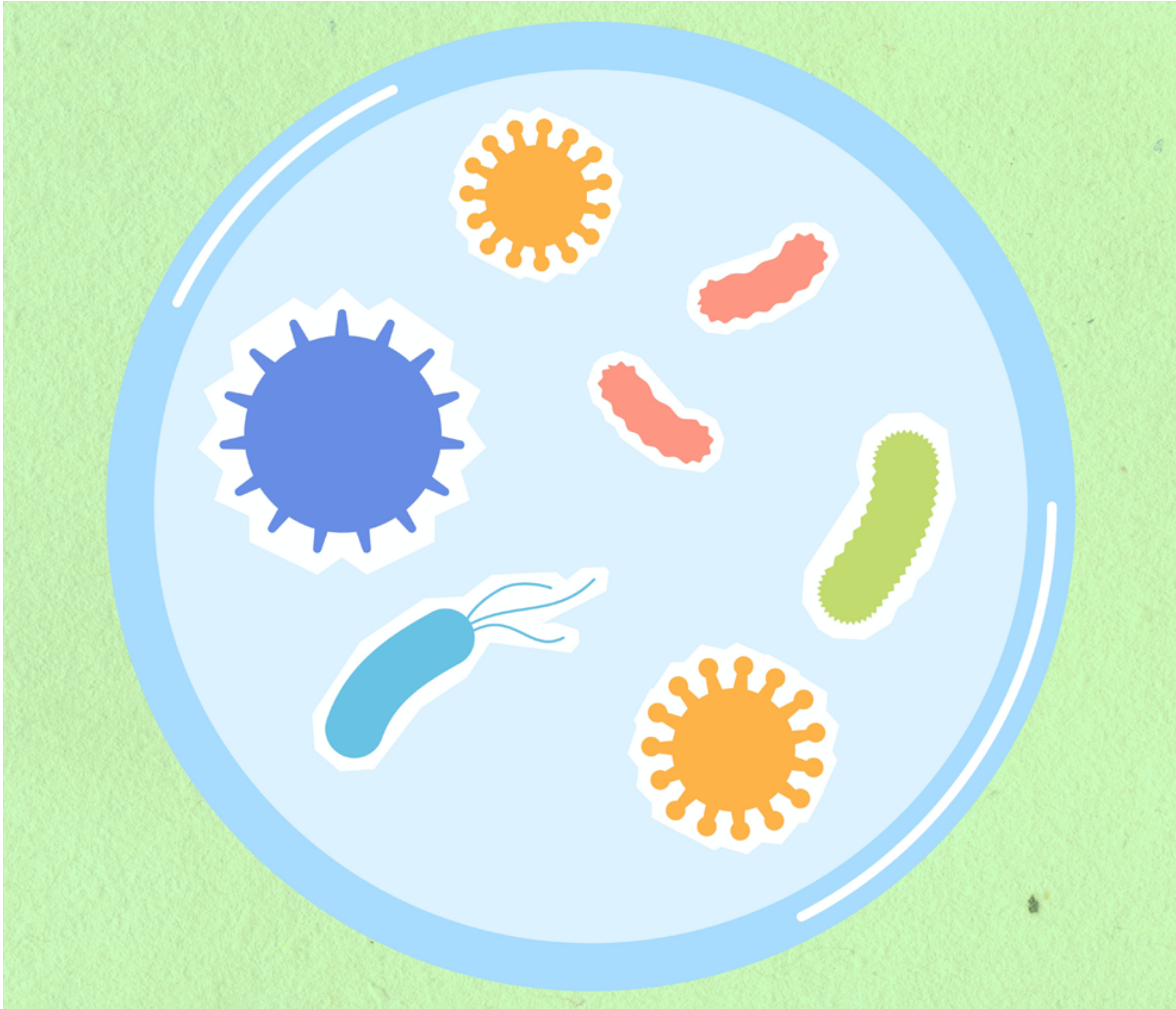
These environmental impacts contribute to climate change and therefore harm health, meaning that health research is working against its primary aim. While tools and methods for enhancing environmental sustainability in health research exist, surveys of these initiatives for those interested in adopting them are sparse and tend to explore the topic from specific (e.g. digital health research) or overlapping (e.g. sustainable laboratories, academia) angles.[14,15,16,17]

1.2 Study approach

The aim of this study is to explore the landscape of existing tools and methods being utilised to improve the environmental sustainability of health research and consider challenges and implications for their implementation. The work was conducted RAND Europe and was commissioned by Wellcome.

To create a map of currently available sustainable health research initiatives, the study primarily used desk research, crowdsourcing and case studies. Chapter 2 summarises the current landscape of sustainability initiatives identified, and the detailed case studies are provided in Annex A. A table of the initiatives identified is provided as a separate Excel file for ease of use. Desk research and interviews with Wellcome staff, as well as focus groups with Wellcome grant holders and non-researcher stakeholders, were conducted to understand the context and challenges around actions to encourage sustainable health research. These findings regarding the challenges and considerations for implementation of sustainability initiatives are set out in Chapter 3. This study, whilst comprehensive, is not exhaustive in its coverage, and can only be considered a starting point for further work on the topic (see Annex B for a more detailed description of the methodological approach, including a list of study limitations).

We hope that Wellcome and the wider health research community find it a useful guide for beginning to integrate environmental sustainability into their work.



2. Understanding the landscape

This section explains how the study defines health research and its environmental impacts. Findings on the current landscape of sustainability initiatives (classified by type) are presented and the current gaps and challenges identified. Full details on all the initiatives mentioned in this section are provided in a supplementary table of initiatives (provided separately in Excel format).

2.1 Defining health research and its environmental impacts

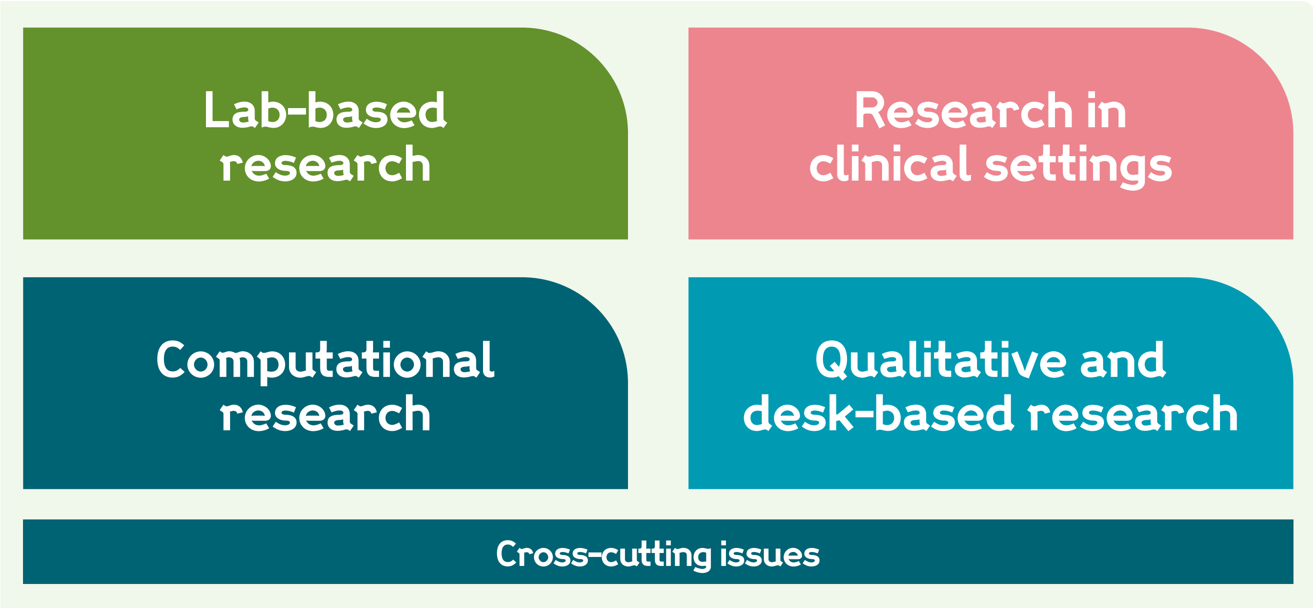
This study defines health research in a systemic way:

Health research systems broadly refer to the research, people, institutions and activities whose primary purpose is to generate high-quality knowledge that can be used to promote, restore and/or maintain the health status of populations. We consider health research to encompass lab-based research, research in clinical settings, computational research and qualitative/desk-based research.[18]

The boundaries of health research are presented in Figure 1. Health research activities can be broadly categorised into four main groups: 1) lab-based research; 2) research in clinical settings; 3) computational research; and 4) qualitative and desk-based research. Some research-related activities such as conferences and publishing are also found across all categories, and have been grouped under 'cross-cutting issues'. Boundaries of these groups are porous, as some health research encompasses more than one category (e.g. neuroscience can span all four). Developments in other research areas may feed into health research systems. For example, green chemistry[19] may not be directly linked to health research, but it can have major implications on its environmental sustainability. The structure presented in Figure 1 is flexible enough to accommodate other research areas, so it could serve as a starting point for other disciplines interested in addressing the topic. These categories were used to analyse initiatives in Section 3.2.

2.1 Defining health research and its environmental impacts

Figure 1
Details on the boundaries of health research



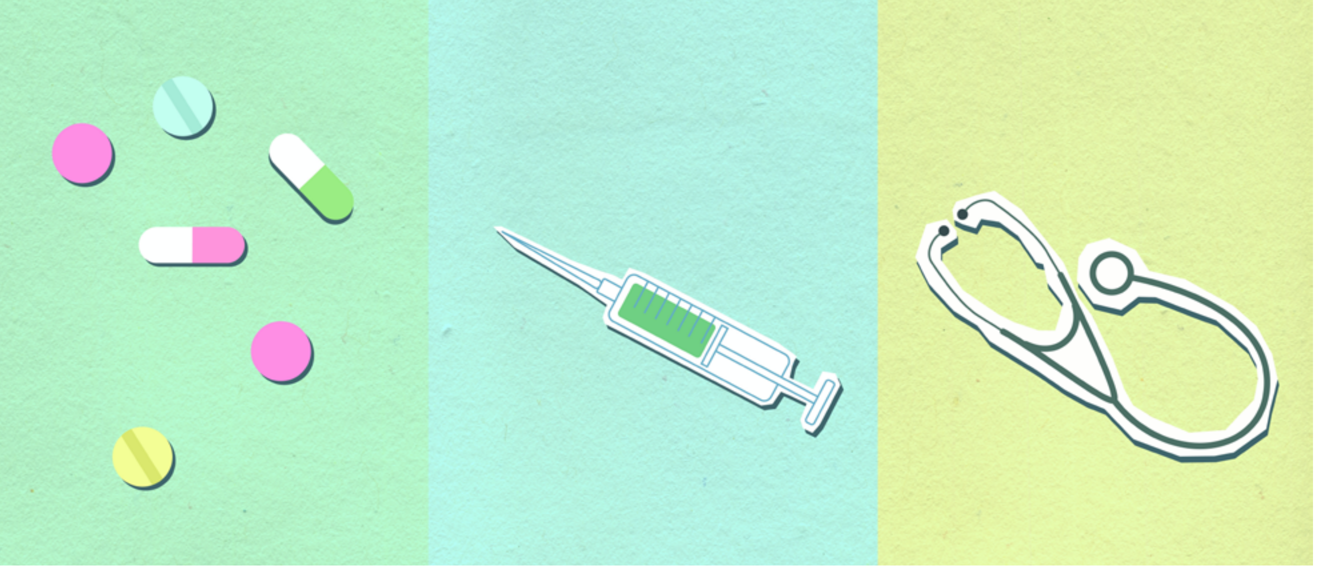
This study defines the environmental impacts of health research as any that originate from the various steps of the research cycle: inputs or upstream activities, the research process itself, and outputs or downstream activities. This definition intends to be inclusive of all impacts mentioned in the Greenhouse Gas Protocol Corporate Accounting and Reporting Standard,[20] ranging from generated waste and emissions (carbon dioxide, methane, perfluorochemicals, etc.) to the impact on ecosystems and biodiversity. Equipment for conducting lab experiments, a type of input, could be manufactured and discarded in a non-sustainable manner, and the running of algorithms in computer-based research releases carbon emissions, an impact of the research process. Given that most of the initiatives identified appeared to consider all of these areas, the analysis was structured around a typology relating to their primary method of encouraging environmental sustainability.

2.2 Existing initiatives

Through desk research and crowdsourcing, 146 initiatives related to advancing sustainable health research were identified, demonstrating that there is already significant action emerging in this area.[21] An overview of the initiatives and their coverage against different characteristics is provided in Figure 2. These have been categorised into eight groups to reflect their overarching approach:

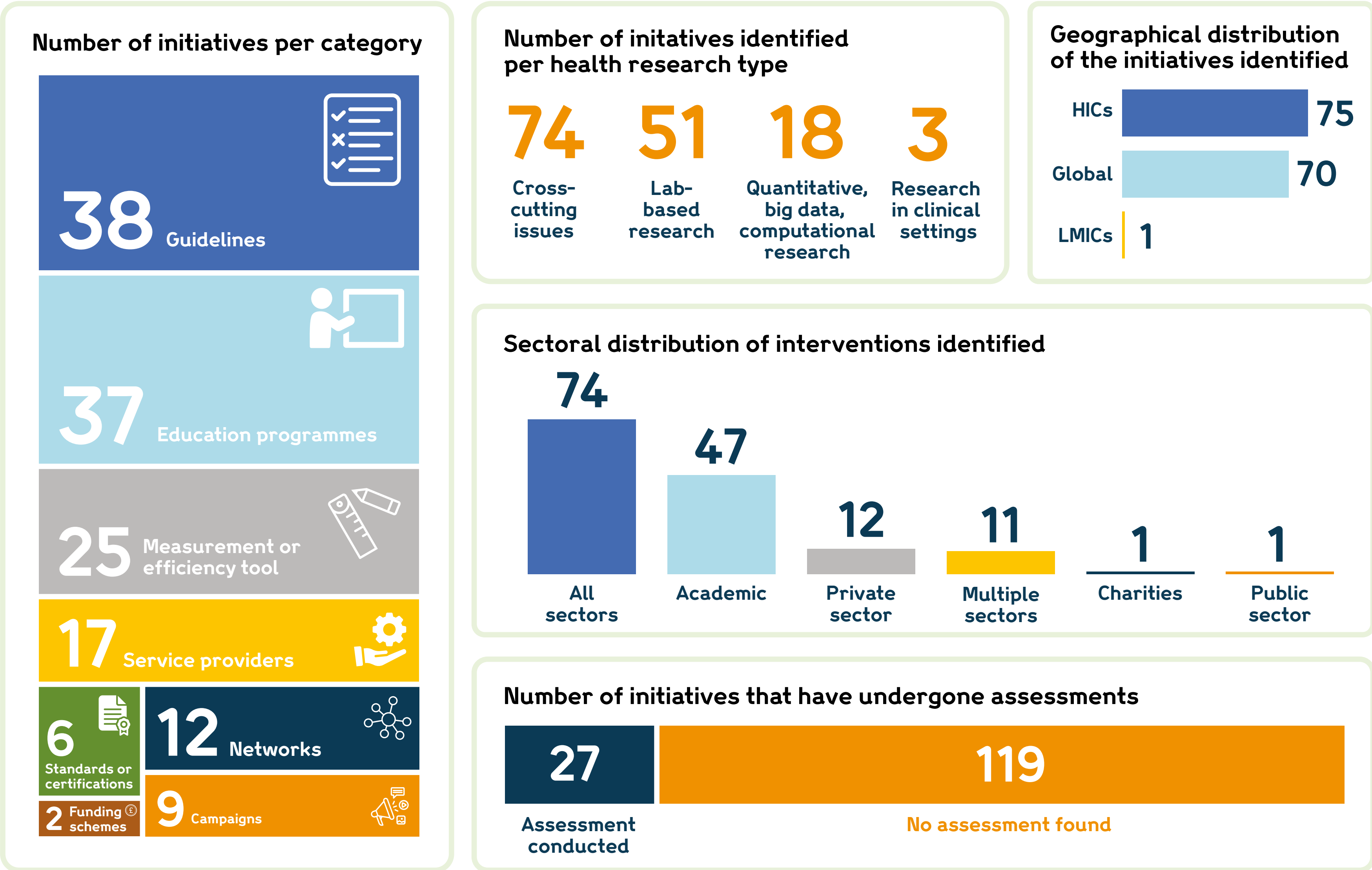
- Networks
- Campaigns
- Measurement or efficiency tools
- Guidelines
- Education programmes
- Standards or certifications
- Funding schemes
- Service providers

Some of these categories encompass others; for example, a sustainability standard can create its own measurement tools and educational programmes. Similarly, some initiatives could fit under more than one category (e.g. Green Labs NL could be classified as both an education programme and a network), but we selected the one that seemed to describe its mission best. Findings related to each of these categories of initiative are presented below. All initiatives are summarised in a separate Excel file with their health research category, evidence of impact, reference website and other relevant information.



Advancing sustainable health research: a review of the landscape

Download the full table of initiatives identified.



2.2.1 Networks

Twelve of the 146 initiatives identified (8%) were classified as networks. A network is a group of individuals, organisations or smaller networks interested in sustainability issues. They create opportunities for sharing knowledge, foster collaborations, help the take-up of sustainable practices and contribute to shaping the policy narrative. As a result they are a good conduit for communicating relevant updates in the field and building a community around the issue. **Most networks identified** (7/12) **focus on lab-based research** (e.g. Laboratory Efficiency Action Network (LEAN), Sustainable European Laboratories (SELs)), although there are some cross-disciplinary examples (e.g. Future Earth, Max Planck Sustainability Network). **We did not locate any existing networks that focus on computational, clinical settings or qualitative research.** Most networks are based in academia, with the members of those that cover multiple sectors including academia tending to be skewed towards academic institutions (e.g. SELs). **At present, most networks originate from (and have their membership primarily based) in high-income countries.** Beyond researcher networks, there are also (informal) networks between funders in the United Kingdom, including Wellcome, which are largely centred around work on a concordat for research sustainability.[22] There is less active networking and communication between funders internationally on sustainability related issues.[23] Although their impact is difficult to quantify, networks provide useful fora for the sharing of experiences and practice, and are valued by some researchers.

Table 2
Examples of networks

Name	Description
Future Earth	Global network in sustainability research and systems science. Includes academics, policymakers, entrepreneurs and artists working across all systems and disciplines. Secretariat based in eight global hubs: Canada, China, France, Japan, India, Sweden, Taiwan, United States. Governed by several international bodies including the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO).
The Sustainable European Laboratories (SELs) Network	Advocates for sustainable research laboratory practices in Europe. Comprises Green Labs Austria, Green Labs Netherlands, LEAN, Green Labs Portugal, Irish Green Labs and FENS-Kavli Network of Excellence. European level only.

Note: Table of initiatives in separate Excel file

2.2.2 Campaigns

Nine of the 146 initiatives identified (6%) were classified as campaigns. A campaign raises awareness of sustainability through competitions and other initiatives. **They are typically focused on a specific issue or action, and most examples identified are linked to either cross-cutting issues** (e.g. 'Radboud International Travel Challenge') **or lab-based research** (e.g. 'Be Good in the Hood' and 'International Freezer Challenge'). Some broader campaigns also exist, such as the 'Million Advocates for Sustainable Science' that funders can sign up to. Campaigns appear to be geographically split between having a global remit and restricted to high-income countries (HICs). Most (5/9) are also relevant to all sectors. It is unclear, based on existing evidence, how effective the campaigns are in reducing the environmental impacts of health research, but they are a relatively low-risk and low-burden activity if there are specific known actions that can be promoted.

Table 3
Examples of campaigns

Name	Description
Million Advocates for Sustainable Science (MASS)	Organised by My Green Lab and the International Institute for Sustainable Laboratories, MASS is a campaign that challenges research funders globally to improve and implement sustainability, resource efficiency and resiliency within research laboratories. Support for the campaign is pledged through signing a public letter
The Platinum Jubilee Challenge	This is an initiative created in 2022 by the Royal Anniversary Trust to help the UK tertiary education sector reach the target of Net Zero by requiring participants to create a standardised framework for reporting emissions.[24] The eligible (but not required) participants are the 21 winners of the 2020–2022 Queen's Anniversary Prizes, which are the highest national honour awarded in UK further and higher education

Note: Table of initiatives in separate Excel file

2.2.3 Measurement or efficiency tools

Twenty-five of the identified initiatives (17%) were classified as measurement or efficiency tools. A measurement or efficiency tool is an instrument for measuring the environmental impact of research activities or increasing the efficiency of research. Most tools (14/25) help calculate carbon emissions from computational research (e.g. 'CodeCarbon', 'fMRI prep carbon tracker', 'Green Algorithms' – see Box 1).

Box 1: Green algorithms case study

Green Algorithms is an online calculator that estimates the amount of carbon dioxide released into the atmosphere by computation, particularly bioinformatics. The tool aims to enable scientists, outside of the deep learning sector, to assess the environmental toll of the algorithms used in their studies and modify research accordingly to reduce emissions. Since its launch in 2020, the online calculator has had around 15,000 users and over 20,000 sessions, equating to ~200 users per week globally, with most located in the United States, France, Germany, the United Kingdom and Australia. The developers of the tool emphasise that its results must be understood as estimates rather than a definite measure. Limitations include the fact that the tool is dependent on information access, the location of a data centre can affect estimates due to differing carbon intensities in different locations, and the energy mix of each country varies by the hour, although most regions are stable.

Many tools are specifically designed to calculate emissions for machine learning activities, but others cover emissions from cloud computing, deep learning models, central processing unit (CPU)/graphics processing unit (GPU) devices or multiple settings. A minority handle cross-cutting issues such as the carbon footprint of travel (e.g. 'Model for selecting most sustainable location for conferences'). **Few focus specifically on lab-based research or research in clinical settings,** although there are some exceptions (e.g. 'Carbon audit methodology').

As they are available for anyone to use on the Internet, their reach is global and usually not restricted to any sector. **There are limitations and caveats for many of these tools due to poor availability of data to enable accurate estimates** (e.g. sometimes due to proprietary hardware, see 'Green Algorithms' case study), tools also necessarily trade off complexity/usability with precision in terms of their outputs.[25] At present, although a range of tools are available, at least for computational research, their use is ad hoc, and researchers lack clarity on which tools are available and useful.[26] For the tools that improve efficiency, researchers will need to make sure that these sufficiently guard against the rebound effect, where the improvement in efficiency also increases the capacity for consumption.[27] Although there are a range of resources available, their uptake is patchy due to lack of knowledge regarding both their existence and how to use them.[28]

Table 4
Further examples of calculators or measurement tools

Name	Description
CodeCarbon	CodeCarbon is an emissions tracker that is publicly available through github. It estimates the amount of carbon (measured as kilograms of CO2-equivalents (CO2eq) produced while running a code by estimating the hardware's electric power consumption (GPU + CPU + RAM) and comparing this to the carbon intensity of the region where the computing is taking place. It then shows developers how they can lessen emissions by optimising their code or by hosting their cloud infrastructure in geographical regions that use renewable energy sources
Carbon Footprint Modelling	A detailed method to model the carbon footprint of clinical labs, based on the types of clinical tests, operating times and instrument specifications, as well as the indoor environment used. The method was developed and proposed by researchers at the University of Liverpool (UK), University of Pretoria (South Africa) and CSols Ltd. (UK).

Note: Table of initiatives in separate Excel file

there are limitations and caveats for many of these tools due to poor availability of data to enable accurate estimates

2.2.4 Guidelines

Thirty-eight of the identified initiatives (26%) were classified as guidelines. Guidelines are recommendations of good practice for implementing sustainability in research. There are a wide range of existing guidelines that set out norms and recommendations for scientists across fields of health research. These are typically developed by funders (e.g. UK Research and Innovation (UKRI), see Box 2, and the National Institute for Health and Care Research (NIHR), see Box 3) or strategies set out by higher education institutions (HEIs). Guidelines are voluntary and broad brush, with the vast majority (30/38) handling cross-cutting issues. Guidelines share common principles and are useful primarily in terms of raising awareness of sustainability issues. Funders have yet to specify any mandatory standards for funding at scale.[29] It is worth noting that there is a forthcoming concordat on research sustainability which has been developed in collaboration by UK research funders, including Wellcome.

Box 2: UKRI net zero digital research infrastructure scoping project case study

The Net Zero Digital Research Infrastructure (DRI) scoping project conducted by UKRI, a major UK research funder, seeks to determine how its DRI can achieve net zero by 2040. Although unfinished, the project has already issued preliminary recommendations in an interim report, which demonstrates how solutions lie in both community organisations and setting technical requirements. The project team specifically characterised carbon offsetting as an 'explicit' last resort option only to be used together with all the other actions. Stakeholder feedback on the recommendations labelled those relating to procurement of equipment as the most relevant and clear. Although most regions are stable.

Box 3: NIHR carbon reduction guidelines case study

Published by NIHR in 2010, the 19 guidelines provide recommendations on how researchers can reduce carbon emissions associated with clinical trials and other forms of health research, while sustaining the same level of validity and reliability. In NIHR funding applications, researchers must confirm they have read the guidelines. A statement included in the NIHR application form also encourages applicants to 'consider, where feasible, addressing issues of environmental sustainability including their impact and appropriate outcomes within the remit of the applying programme'. As the first funder to develop emissions guidelines for clinical research, NIHR has significantly contributed to raising awareness of existing methods and strategies that can be used to reduce the carbon footprint of this research area. However, given the voluntary nature of the guidelines it remains unclear whether any significant actions have been implemented within NIHR-funded research institutions as a result.

Box 4: Sustainable healthcare coalition: lower carbon clinical trials project case study

The Sustainable Healthcare Coalition (SHC) is a partnership group that develops tools and guidance for members and other interested parties across the global healthcare sector to understand and measure their environmental impact. One of these is the NIHR-funded Lower Carbon Clinical Trials Project, which uses a carbon footprinting approach to estimate the carbon emissions of clinical trials. The first iteration of the tool will be a guidance document that links different activities in a clinical trial to a library of emission factors that can be used to estimate carbon footprints.

2.2.5 Education programmes

Thirty-seven of the identified initiatives (25%) were classified as education programmes. An education programme is an initiative to increase knowledge about sustainability, including sustainable practices. Few are standalone. **Typically, education programmes are associated with wider sustainability initiatives, such as certification programmes** that offer training (usually in the form of online resources) to help those being certified consider how to meet the necessary standards and improve their sustainability (e.g. Laboratory Efficiency Assessment Framework (LEAF), My Green Lab). The majority are for lab-based research, although **there are also wider training offers** (e.g. Carbon Literacy Project – see Box 5) **that are not necessarily lab (or even research) specific.** The value of training in reducing carbon emissions is not well established, and it is worth considering the nature of the skills required, and by whom, before selecting and deploying a training programme.[30] Not all researchers need to be experts in sustainability, but rather they need resources and skills available to access. Currently, some institutions have sustainability officers, but they are not universal and their role is often broad.

Box 5: The carbon literacy project case study

Run by the UK-based Carbon Literacy Trust, the Carbon Literacy Project is an educational programme that aims to improve carbon literacy through offering courses tailored to specific professions or industries, and programmes for developing trainers. Since its launch in 2020, 62,184 individuals have been certified across 4,419 organisations, mainly in the United Kingdom, but also in continental Europe, Singapore, the United States, Chile, Bangladesh and India. It has also been recognised by the United Nations at COP21 as 'one of 100 worldwide Transformative Action Programs'. Degrees of behavioural change have been noted in several cases, and the project hopes to conduct a more comprehensive study of the impact of its training in the near future.

Table 5
Further examples of education programmes

Name	Description
International Institute for Sustainable Laboratories (I2SL)	The International Institute for Sustainable Laboratories (I2SL) is a global organisation that aims to develop and promote principles of sustainable laboratories and related high-technology facilities. Its primary route to achieve this is through training, webinars, courses and other knowledge sharing initiatives. They also have a networking aspect (e.g. conferences and working groups).
Beyond Benign	Beyond Benign develops green chemistry and sustainable science educational resources for educators, students and the community at large in the United States. They work directly with educators and a network of strategic partners to create material for kindergarten to 12th grade to higher education, and have an important community engagement component.

Note: Table of initiatives in separate Excel file

2.2.6 Standards or certification programmes

Six of the initiatives identified (4%) were classified as standards or certification programmes. These are initiatives that help an organisation or part of an organisation reach recognised assessed levels of sustainability. **Certification programmes and standards are split between handling lab-based research and cross-cutting issues.** The two most well-established for lab-based research are the Laboratory Efficiency Assessment Framework (LEAF, Box 6) and the My Green Lab (MGL) certification (Box 7). **There are no comparable programmes focused on clinical, computational or qualitative research. No research funders currently require environmental standards and certifications to be eligible for funded research,** although the UK Medical Research Council has encouraged its facilities to achieve the gold level of LEAF by 2025, and the National Environmental Research Council has required LEAF to be implemented internally.[31] We also note that existing standards seem yet to be implemented in low- and middle-income countries (LMICs).

Box 6: The laboratory efficiency assessment framework (LEAF) case study

The Laboratory Efficiency Assessment Framework (LEAF) is a standard developed by University College London (UCL) for sustainable laboratory research. Depending on performance, laboratories can be accredited as bronze, silver or gold. LEAF's pilot showed that on average across two years, an organisation was able to save 2.9 tonnes of carbon dioxide equivalent (tCO_2e) and £3,700, which totalled to savings of 648 tCO_2e (equivalent to taking 140 passenger vehicles off the road a year) and £641,000. The standard was also popular among participants, with 99% of those surveyed stating they would use LEAF again. As of May 2023, LEAF is being implemented in 85 research institutions over 16 countries with 2,303 labs and 3,543 users.

Box 7: The My Green Lab® certification case study

My Green Lab®'s flagship tool, the My Green Lab® certification or standard, was developed in the United States. To date, there is no aggregate data available on the total impact of the MGL standard, only information from selected case studies and extrapolations from theoretical estimates. In 2021 in AstraZeneca, 20 research and development laboratories saved an estimated 1,270,185 kWh/year after implementing the standard – the equivalent of 900 tonnes of CO_2 emissions and over $315,000. The University of Alabama at Birmingham has saved 35,000 kWh/year per lab certified at the lowest tier of the standard on average, which is equivalent to 24.8 metric tons of CO_2e. Most recent figures in 2023 show around 1,700 labs have participated in the certification within over 220 institutions and 41 countries.

2.2.7 Funding schemes

A funding scheme is an investment in research and evidence regarding sustainable health research. Two such initiatives were identified (1%) by funders based in the United Kingdom that are beginning to invest resources to push sustainable research forward – for example, NIHR invested in a study around sustainability in clinical trials, thus demonstrating increasing interest in the area in the United Kingdom.[32] The overall investment in evidence generation, however, has been limited, and research conducted to date has been primarily bottom-up and unfunded. No resources have been identified in LMIC settings for research on sustainable research practices in health research.

Table 6
Examples of funding schemes

Name	Description
Environmental sustainability in life sciences and medical practice (by the Medical Research Council, MRC)	A funding opportunity by the MRC within UKRI for applicants interested in doing research on environmental sustainability in life science and medical practice

Note: Table of initiatives in separate Excel file

research conducted to date has been primarily bottom-up and unfunded

2.2.8 Sustainable service providers

Seventeen of the 146 initiatives identified (12%) were classified as service providers. A service provider is an organisation that offers services to help implement sustainable practices. In this category we have included four private-sector initiatives that attest to have improved the environmental sustainability of their services. Service providers primarily cater to cross-cutting issues (e.g. plastics recycling, consultancy-type work including assessment services, carbon offsetting) and lab-based research. Recycling services for computing equipment are also available. Of those identified so far, nearly half appear to be available globally (8/17), and the others limited to certain high-income countries. However, we anticipate there are a wider range of service providers available, given many of these would not be actively documented in the sources reviewed. **The use of these services could help support researchers and institutions to address challenges, including in the availability of evidence around supply chain and instrumentation sustainability.** Care needs to be taken in the use of sustainable service providers to make sure they offer truly effective environmental solutions (e.g. recycling services that genuinely do recycle materials, thus producing useful outcomes) to avoid any risk of 'greenwashing'.[33]

we anticipate there are a wider range of service providers available

Table 7
Examples of service providers

Name	Description
Green Machine Computers	This company is used by some UK academic researchers to recycle computers. They collect electrical items, remove all the data and recycle the parts
Green Light Laboratories	A specialist consultancy within sustainable labs and science based in the United Kingdom, North America and Europe. They provide independent studies on equipment performance and inform customers how to identify the most sustainable lab equipment and use it in the most efficient manner

Note: Table of initiatives in separate Excel file

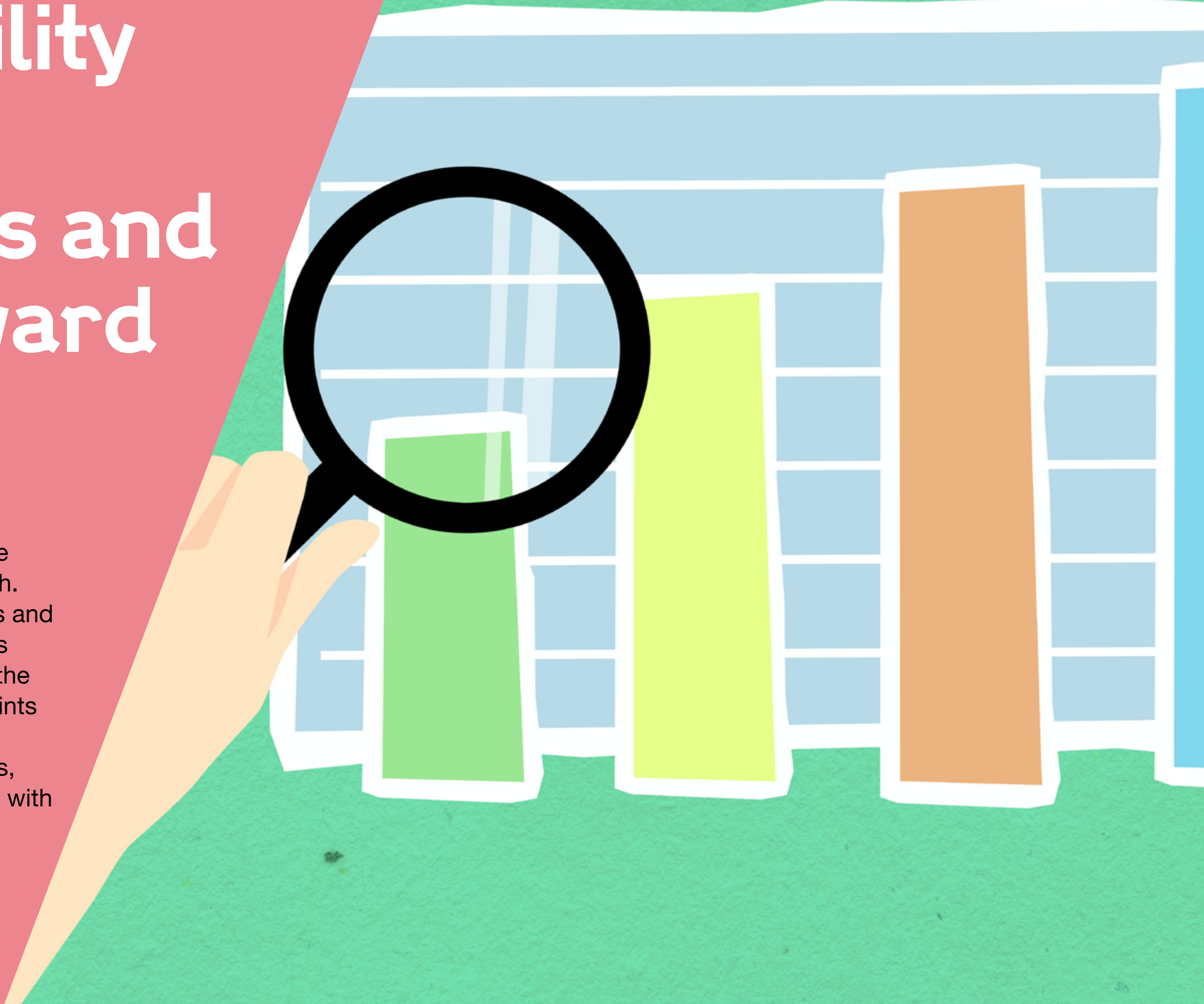
2.3 Gaps in existing initiatives

Of the initiatives identified, very few (3) are targeted towards research in clinical settings, and none have been identified for qualitative research. Cross-cutting initiatives were the largest category (74), with activity growing in targeted lab-based (51) and computational (18) research measures. Most initiatives can only be used in high-income countries (75) due to their restriction to particular research institutions or tools catering to being used in a particular HIC, among other reasons. The remaining initiatives, barring one, have the potential to be used in different geographies (70) (e.g. open-source initiatives) given their global remit, although we have no evidence of their use in LMICs. Only one has been designed specifically for LMICs. None of the tools and methods identified have been mandated by funders within their eligibility requirements.

Only a small number of initiatives (27) have been assessed for impact in some form. All assessed have demonstrated impact, indicating a need to determine 'degree of impact' and thereby detect low-quality initiatives (e.g. those considered to be 'greenwashing'). In addition, many of these evaluations only explore the first-order level of impacts (e.g. uptake of intervention), rather than whether there have been environmental benefits – for example if carbon emissions have been reduced overall.

There is a need for more fundamental research on the sustainability of research equipment and practices, how to measure carbon emissions, and the largest origins of carbon emissions across the health system to improve the quality of existing initiatives.[34] Current measurement systems struggle to calculate the carbon intensity of electricity production, for example, as it can vary significantly between countries.[35]

3. Implementing sustainability initiatives: Challenges and ways forward



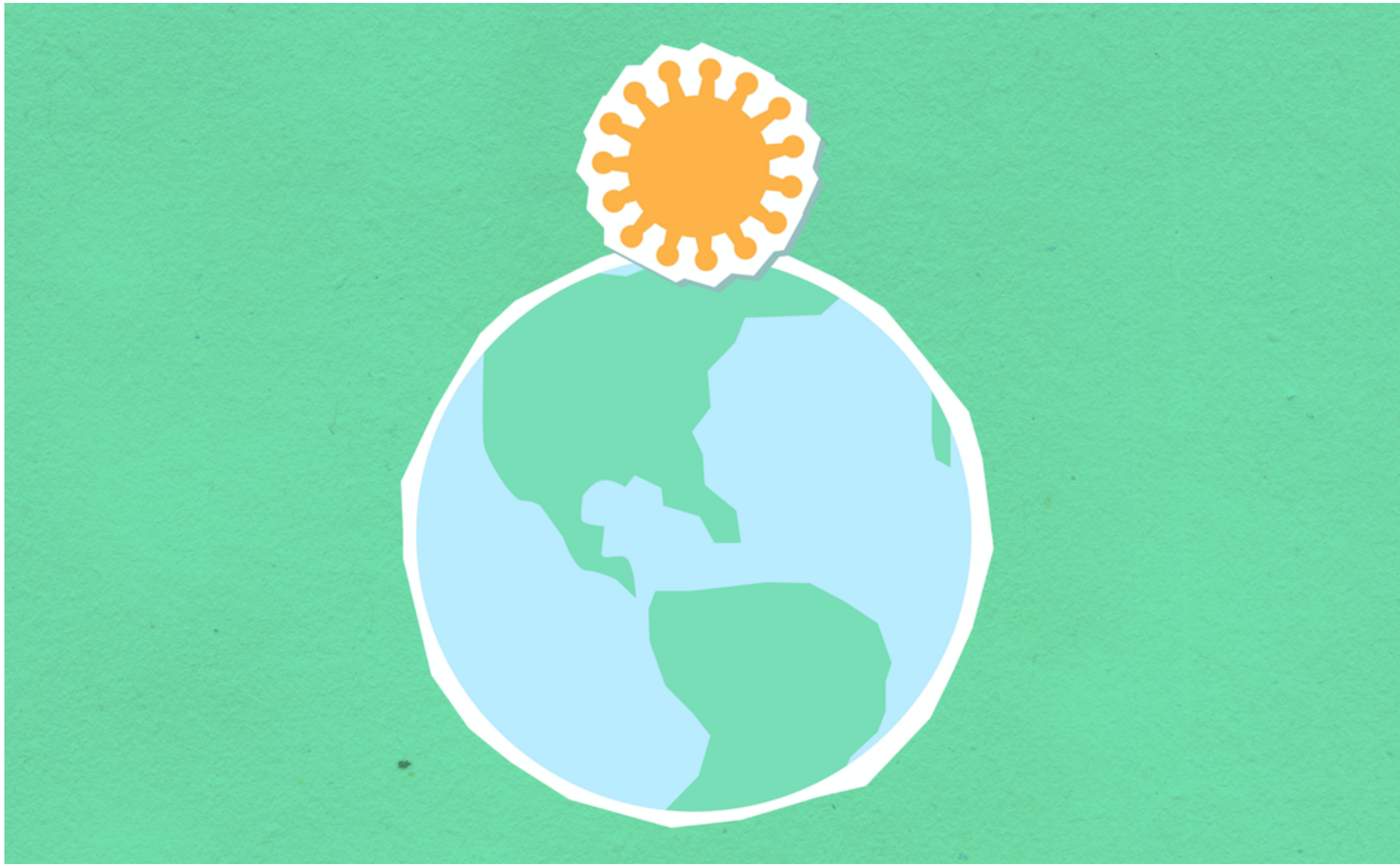
It is clear that there is significant scope – and a number of initial interventions developed – to measure and reduce the environmental impact of health research. However, implementing these initiatives and filling the gaps identified above requires confronting a number of challenges at the health research system level. These points have been drawn from focus groups conducted with Wellcome grant holders, case studies conducted and interviews with Wellcome staff.

3.1 Resources for researchers to address sustainability

The limited capacity of researchers, together with lack of funding, has created a large obstacle to the adoption of sustainability initiatives. Research into sustainability in health research has largely been conducted on an ad hoc, unfunded basis by researchers as an additional task alongside their core research. As such, progress to date has been reliant on the concern of those individuals in relation to this topic and their good will. There are also knowledge gaps, as most health researchers are unlikely to have training on sustainability issues and assessment, and no comprehensive repositories of information exist. No strong mechanism appears to be in place for the easy sharing of knowledge and good practice between actors, which would help to fill the gap from a grassroots level. To support the broad and effective implementation of initiatives there is a need to engage technicians, who have significant relevant expertise and typically work across multiple research projects and laboratories so have a broader reach than individual researchers.

3.2 The need for system-level action

System-level consensus is needed for action to happen. Without the support of research institutions (e.g. universities) and key actors in the health research ecosystem (e.g. journal publishers, funders), further developments will be limited and remain reliant on the good will of individual researchers. These wider system actors need to match researcher efforts and provide resources and impetus for action. Coordination at a system level is crucial to limit a profusion of different standards and requirements, which would create excessive burden on researchers and additional bureaucracy. Steps towards a concordat at a cross-organisation level in the United Kingdom are a positive development, but there is also a need for international cooperation given the increasingly global nature of the research endeavour. Equity considerations need to be considered to ensure that institutions with fewer resources can participate effectively in sustainability initiatives. Larger institutions in higher resource settings are typically the largest emitters (both historically and currently) and have the greatest resources to address sustainability. Expectations regarding sustainability practices should accommodate different contexts. Complex and unreliable procurement and supply chains for importing 'green' equipment, as well as a lack of sustainable state-funded facilities (e.g. for recycling), are examples of barriers that may particularly affect research in some LMIC contexts.



3.3 Managing the interaction of sustainability with wider research priorities

There may be tensions between research priorities and increased sustainability that need to be considered. Academia and funding processes typically place value on the speed and quantity of outputs, which in many instances runs counter to the adoption of sustainability measures. For example, journal peer review practices can encourage reviewers to request minor edits to experiments with questionable value compared to the resources required to re-run the research. Similarly, incentives at the end of grants drive researchers to 'spend out' the funding and use the resources available, regardless of whether there is value scientifically, which is not aligned with environmental drivers. However, many of these sustainability considerations are in alignment with other priority areas in the research system, such as reproducibility, open science and the wider research culture agenda.[36] For example, open science principles, such as open data, enable evidence produced through one study to be used for multiple purposes, thus reducing sustainability impacts. Similarly, it is worth considering the potential environmental benefits of conducting a study against its costs. It may be that the emissions of a specific research project are offset by the potential of its findings to reduce emissions in the long term. More broadly, the concept of sustainability in research is analogous to, and could be potentially incorporated within, existing expectations and requirements for research conduct, such as health and safety practices and ethical conduct.[37]

academic and funding processes typically place value on speed and quantity of outputs

3.4 Implications

Amongst the researchers consulted for this study we have seen significant enthusiasm for increased action to address the environmental sustainability of health research. However, there is a need for action at the system level to respond to and build on the work conducted by researchers, often in the margins of their core role, to start to develop approaches to make research more sustainable. At present, support to build the evidence based is limited and there is scope for more investment. However, there are also initiatives and tools in place that funders and institutions could review and adopt now to start to make meaningful changes. Potential actions and areas for development include:

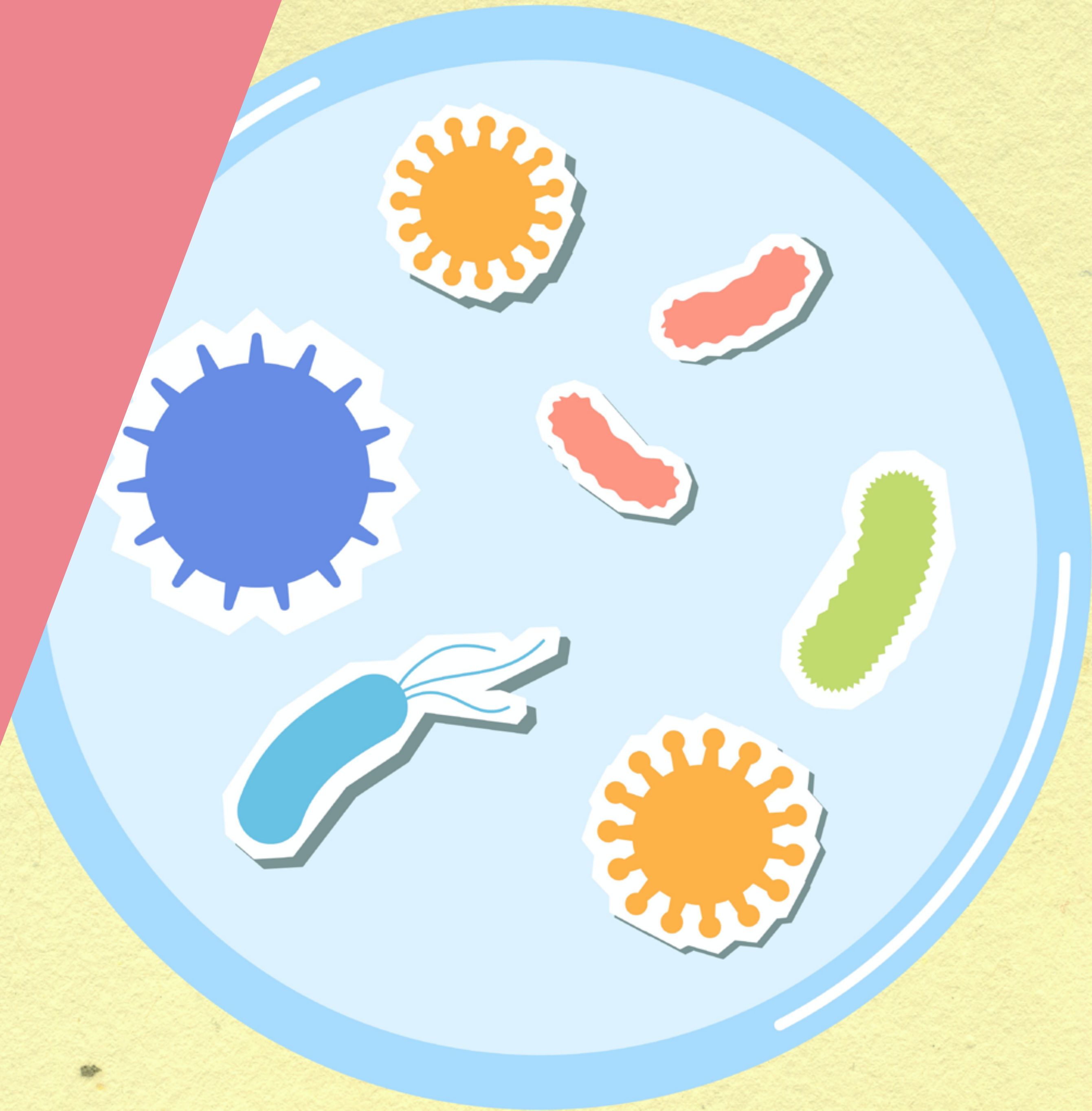
1. **Increase awareness of existing tools and initiatives:** There is an active community of researchers working on these issues but many still are unaware of the environmental impact of health research and how it can be addressed. Even researchers aware of these issues lack knowledge and resources to support them to act. Raising awareness of the existing tools and initiatives available could help to address this knowledge gap. This report and the accompanying table of initiatives provides a starting point for this, and we see other sets of resources starting to be compiled.38
2. **Share knowledge and experiences:** Networks provide a mechanism to easily share knowledge and good practice, particularly to provide opportunities for researchers and technicians to exchange ideas. In the case of lab-based research stakeholders based in the UK and Europe, there are existing networks (e.g. LEAN), but for researchers from other disciplines, sectors, and countries additional work is needed to create appropriate fora for discussion. UK funders are already in contact through their work on the sustainability concordat and this should be maintained.
3. **Develop the evidence base:** As set out in section 2.3 there are a number of gaps in the existing evidence based and further work is needed to develop and test tools and initiatives to address sustainability in health research. Key areas of focus for this research would be:
    - Evaluation of existing initiatives, to assess their effectiveness in improving sustainability outcomes
    - Developing standards of practice for clinical and computational research
    - Exploring implementation of existing and new practices in different research settings (e.g. in LMICs)
    - Producing additional data and evidence to inform the measurement of sustainability/emissions to inform standards, calculators and tools, and individual lab and institutional assessments

Filling the knowledge gaps identified in the environmental sustainability of health research will help to decrease the incidence of low-quality initiatives. In particular, increasing the number of formal evaluations of initiatives will enable the clear identification of measures that provide the most impact.

Over time, research organisations will need to consider what standards and expectations they will set in terms of the environmental sustainability of the research they support building on this evidence based. We have seen significant movement in the sector to try and improve the culture of research, considering aspects such as reproducibility, ethics and workload. Sustainability is aligned to these parallel aims and needs to become considered as a core part of conducting high quality, ethical research.

sustainability needs to become a core part of conducting high quality research

Annex A
Case studies



A.1 Laboratory Efficiency Assessment Framework (LEAF)

Introduction

The Laboratory Efficiency Assessment Framework (LEAF) is a standard developed by University College London (UCL) for sustainable laboratory research. It takes the form of an online software platform and comprises two parts:

1. The framework, which outlines requirements for achieving the various levels of the standard.
2. Tools such as online calculators and technical guides, as well as training to assist with implementing the framework.

Currently, LEAF only covers research and teaching labs.[39] The ultimate objective of the assessment framework is to help achieve long-term planetary sustainability.[40] LEAF is costed at the organisational level (£1,100–2,600 excluding VAT per institution, depending on its size), which allows all labs within an institution to be included.

More specifically, the framework lists necessary actions to take across ten categories: waste, people, purchasing, equipment, IT, sample and chemical management, research quality, teaching criteria, ventilation, and water.[41] Depending on performance, laboratories can be accredited as bronze, silver or gold (See Figure 3). To attain each level, the lab must have completed all the relevant actions from the previous levels. The LEAF certificate is awarded online, and the certification process runs on an annual basis, with re-certification conducted every year, two years or three years, depending on the lab requirements.[42] Steps for participating in LEAF for the first time take roughly the following order:[43]

1. Contact the LEAF e-mail address to sign up (usually done at the institutional level).
2. Gain access to the online platform to begin the process of establishing which actions should be implemented to attain bronze level.
3. Completion of actions according to the award level sought.
4. Submission of evidence of completed actions via online platform to LEAF team for review.
5. Assessment of submission either through ‘administrator assessments’ conducted by a lab administrator or through a peer audit by a lab that has participated in the programme and undergone audit training. This practice lessens the burden on lab administrators and allows for sharing of good practice directly between labs. Lab administrators still have final approval on peer audits.
6. Once the assessment is complete, labs are certified and receive an impact report with total financial and emissions savings, participation rates and other data.

LEAF is a standard developed by UCL for sustainable laboratory research

Figure 3
Key criteria for LEAF – examples per award level

Category	Bronze	Silver	Gold
Waste	Provide recycling bins in the lab	Single-use plastic waste has been reduce (guidance provided)	Recycling rates have been increased, or overall waste produced has been decreased
People	Samples owned by departing staff are cleared or tracked	The lab has engaged other labs on LEAF and sustainability	One action to reduce travel has been implemented
Sample and chemical management	Labels are legible, and there's a common labeling system in place	Procedures are in place in case cold storage equipment breaks down	At least 80% of all samples and/or chemicals are clearly catalogued
Equipment	Equipment is turned off when not in use	There is a system in place for communal equipment booking	Excess equipment is repaired, sold, and/or donated
Ventilation	There is a clear reporting system for building issues	Fume cupboard sashes are kept closed when not in use	Solvent vapours are condensed and disposed and not released into the atmosphere

Source: Reproduced with permission from UCL. 2020. 'Take part in LEAF.' Ucl.ac.uk. As of 3 July 2023: https://www.ucl.ac.uk/sustainable/case-studies/2020/aug/take-part-leaf

For tools, LEAF provides calculators and other practical resources and training for labs to support the standard. Two types of calculator, baseline and savings, calculate financial and carbon savings for waste, biosafety cabinets, fume cupboards, ULT freezers, -20C freezers, refrigerators, IT, water and equipment in terms of CO2/£.[44] The baseline calculator can be used when beginning the programme to determine the lab's starting point, and savings calculators are implemented at the end of the annual accreditation process to measure progress on sustainability.[45] Calculator usage is currently optional (and taken up by approximately one-fifth of labs) to ease burden on laboratories when adapting to the standard. Additional resources can be found under the 'Resources and Materials' tab of the LEAF website and are a mixture of technical and procedural guides, simplified infographics, and helpful stickers[46] to place on lab equipment. Training is available to introduce lab staff to the topic of sustainable science and help with implementing LEAF.[47] Given that determining which metrics to use when evaluating labs can be difficult (given the huge variability between labs), careful judgment must be used when comparing places that are designed and function differently in practice.[48] To address this challenge, LEAF allows for open-ended answers to explain the context of the lab.

Conceptualisation and implementation of initiative

The idea for LEAF originated from a discussion among members of the Laboratory Efficiency Action Network (LEAN), a network for UK university professionals aiming to increase the sustainability of their labs. LEAN sought for research funders to place conditions on lab sustainability into grant applications, due to dissatisfaction with other green lab standards at the time. LEAF began in 2018 as a two-year pilot programme for non-commercial wet labs, initially in 16 institutions including Imperial College London, the University of Cambridge, King's College London and the University of Manchester. Between 2018 and 2020, 253 research groups participated across 23 universities and research organisations in the United Kingdom and Ireland.[49] The pilot was considered a success, and UCL launched an online platform in January 2021. In 2022, LEAF updated the criteria for gold and silver levels, and multiple sessions were held with lab administrators of accredited institutions who provided ideas on improvements and feedback on updates proposed by the LEAF team.[50]

Evidence of effectiveness and impact

LEAF's pilot showed that, on average across the two years, an organisation was able to save 2.9 tonnes of carbon dioxide equivalent (tCO2e) and £3,700, which totalled to savings of 648 tCO2e (equivalent to taking 140 passenger vehicles off the road a year) and £641,000.[51] The standard was also popular among participants, with 99% of those surveyed stating they would use LEAF again.[52] As of May 2023, LEAF is implemented in 85 research institutions in 16 countries[53] with 2,303 labs and 3,543 users.[54]

Within the United Kingdom, both the Medical Research Council (MRC) and the Natural Environment Research Council (NERC) are integrating LEAF into their in-house laboratories.[55] The MRC has requested that their facilities aim to achieve the gold level by 2025.[56] The UK National Technician Development Centre (NTDC), an organisation that supports technicians, has publicly endorsed the standard for its ability to help the career development of lab technicians, as the standard provides a formal way to recognise any sustainability efforts they have undertaken (e.g. turning off lab equipment, promoting reuse of materials) and helps them quantify the impact of their actions.[57,58] LEAF is also supported by the UK reproducibility network (UKRN), a body that coordinates among UK research ecosystem actors to improve research culture and quality, as it is considered the first environmental sustainability standard to have a criteria on research quality.[59,60] LEAF's quality guidance ranges from encouraging experiments to ensure replicability, to simplifying procedures to reduce resource use.[61]

In the first pilot year, the majority (85%) of users and facilitators reported that 10 hours or less were spent applying for and maintaining accreditation.[62] The amount of time taken appeared to increase in the second pilot year, with the majority (60%) of users and facilitators spending at least 10 hours on the process.[63] The programme team speculates that this change was due to the challenges associated with administration during the COVID-19 pandemic shutdowns.[64]

Lessons learnt and key insights

According to some interviewees, the quality of communication and affordability offered by LEAF were the core reasons for selecting it over other similar tools.[65] The communication style appears to be connected to the personal approach offered by the team at UCL, which users found to be very dedicated and invested in helping on a day-to-day basis. Costing at the institutional level made LEAF more viable financially for some stakeholders. Another characteristic mentioned positively is the choice to have lab administrators fill out the assessment, thereby avoiding backlash from forcing those uninterested to participate. This was also viewed as leading to a quicker uptake within labs.[66]

The main weaknesses cited for the tool related to communication style, which some users have characterised as firm,[67] and the UK-centredness of its terminology and measurement tools.[68] Another stakeholder mentioned that its location within UCL made them question its independence and usage of funds.[69] The standard and its team are currently undergoing changes that will likely mitigate some of these concerns to a degree (see ‘Next steps’ section below).

Next steps

LEAF is in the process of formally separating from UCL and becoming an independent non-profit body. Although the standard is currently only available for non-commercial laboratories, by the end of 2023 an adapted version will also be offered to commercial entities. A pilot with 15 commercial labs will end around mid-2023, and the LEAF team is developing an appropriate validation process for their context (e.g. via an external auditor) to avoid a dramatic increase in costs. The team is also developing versions of the standard for clinical labs, digital infrastructures, animal facilities, lab refurbishments and workshops/engineering labs, which will be integrated into the platform once the separation process has concluded.

A.2 My Green Lab® certification

Introduction

My Green Lab® is a US-based non-profit organisation[70] founded in 2013 to promote environmental sustainability in lab-based research. It develops standards, undertakes research, educates and promotes community engagement on the topic.[71,72] Its partners are universities, non-profit organisations, government labs, healthcare organisations, laboratory suppliers, utilities and commercial organisations interested in the sustainability of science. It is funded through individual donations, grants, corporate sponsorships and earned income from the programme. An overview of all the initiatives developed by My Green Lab® is presented in Table 8.

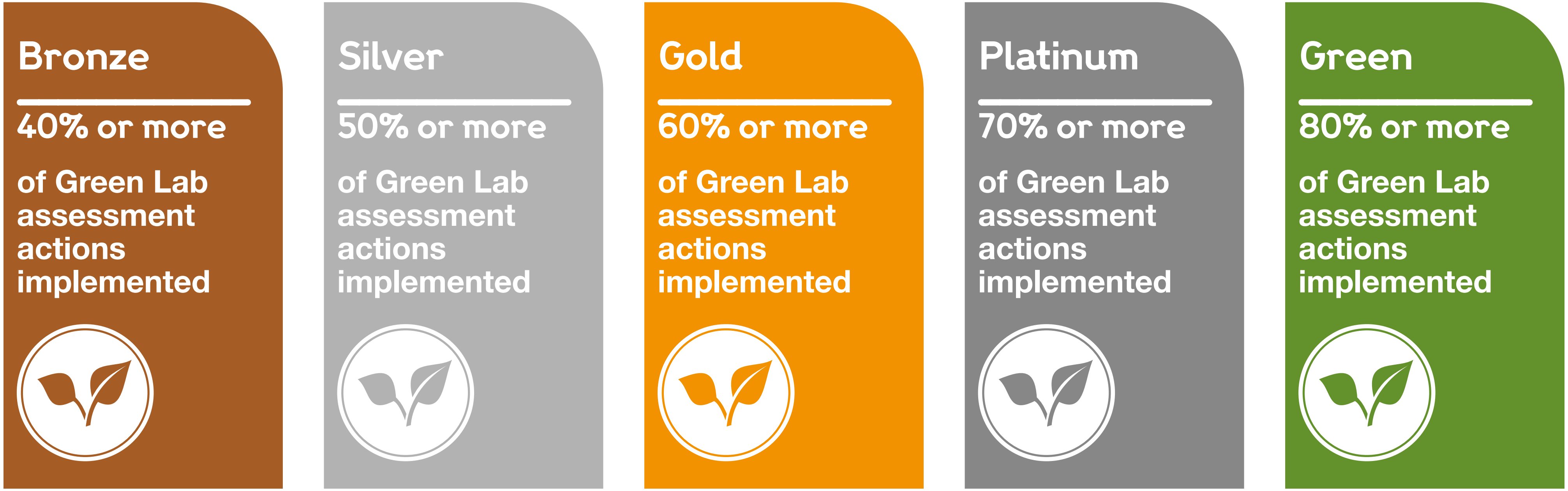
My Green Lab® has developed two standards: the flagship My Green Lab® (MGL) Certification and the Accountability, Consistency and Transparency (ACT) label. This case study focuses on the certification. Fourteen topics are covered in the MGL standard: community, recycling and waste reduction, resource management, purchasing, green chemistry and green biologics, water, plug load, fume hoods, cold storage, large equipment, infrastructure energy, field work, animal research, and travel.[73] The steps for a lab to become certified (adapted from the website text) are as follows:

1. **Conduct baseline assessment:** This is an online self-assessment survey about the lab's current actions, based on which MGL issues recommendations for further improvement. At least 50% of lab personnel must complete the assessment.[74]
2. **Make changes in the laboratory using MGL's recommendations as guidelines:** Labs can draw on the help of internal teams if available (e.g. sustainability team, safety, facilities).
3. **Re-take the baseline assessment to quantify progress:** A score is calculated, together with a certification level. Labs can only improve their score if they make more changes in addition to maintaining the existing improvements from the initial certification. Recommendations are issued for further steps that the laboratory may choose to undertake.
4. **Recertification:** This is required after two years, but possible to do sooner if desired.

There are five certification levels, bronze, silver, gold, platinum and green, with progression in accordance with the percentage of recommended Green Lab actions implemented (See Figure 4). These actions cover behaviour change, as well as changes to organisational investment, including upgrading equipment and the purchase of more sustainable products. MGL's approach of allowing labs to choose which categories to focus on, based on their capabilities, allows them to disregard certain categories if others are fully completed.

My Green Lab promotes environmental sustainability in lab-based research

Figure 4
Certification levels of MGL standard



Source: Reproduced with permission from My Green Lab. 2023. 'My Green Lab Certification.' My Green Lab. As of 3 July 2023: https://www.mygreenlab.org/green-lab-certification.html/#certificationprocess

The MGL standard is explicitly described as a self-assessment platform and continuous improvement process, rather than an audit programme 'visit[ing] your lab with a clipboard to ensure you are doing what you report'.[75] However, the standard team does review each submission and requests additional documentation if inconsistencies are suspected. If the lab cannot provide the documentation, a certification score will not be issued.[76] The score is based on answers provided on a Likert scale,[77] and during the assessment lab members are asked to determine the degree to which certain statements are true. There is space for open-ended answers, but these do not influence the ultimate certification score.

MGL encourages the entire lab to be involved in the assessment process, requiring a minimum of 50% of lab staff members to complete the assessment, which it identifies as a strength of the certification programme and more effective in driving culture change within a lab than completion by a single individual. For example, one MGL-certified lab educated all staff on environmental sustainability topics to ensure that they can answer the questions.[78] MGL bases this part of its methodology on research indicating that a tipping point of influence emerges when around 25% of the population begins to adopt a behaviour change.[79] In its experience, 50% participation helps to ensure the necessary adoption for driving cultural change.[80]

MGL covers both academic and commercial labs in research and clinical settings, quality control, manufacturing and production.[81] Prices for participating range from US$350–500 per academic lab and US$2,800–4,000 per commercial lab, with a discount applied as the number of labs within an organisation enrolled for certification increases (i.e. different offers exist for the following bands: 1 lab, 2–10 labs, 11–24 labs, 25–49 labs and 50+ labs). Each purchase includes access to the online self-assessment survey, a digital certificate with level reached, a feedback report,[82] a feedback presentation (the same as the report but in a simplified Microsoft Powerpoint format), tools including poster templates, pre-recorded training videos, customer support for technical issues and a marketing package.

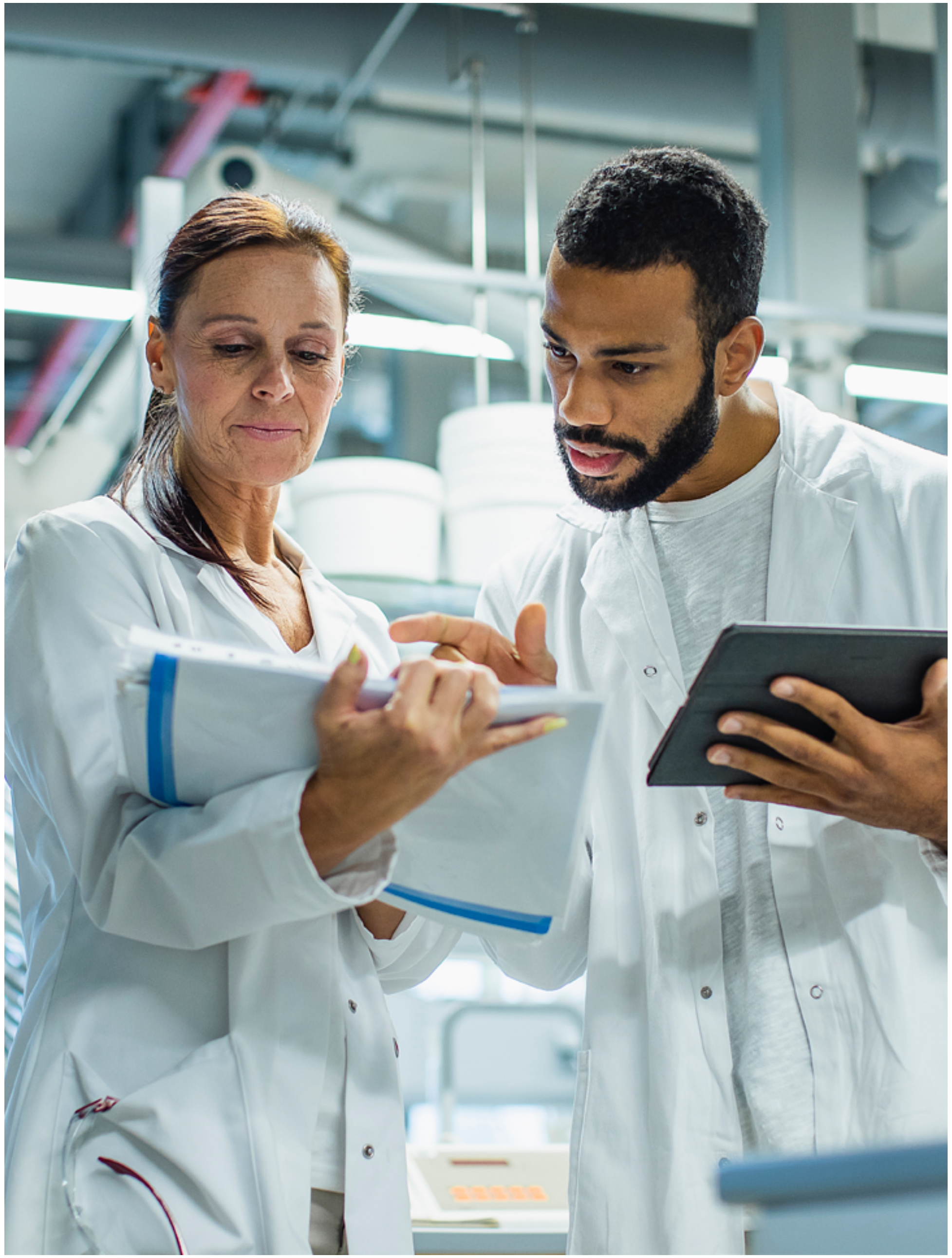


Table 8
Major interventions implemented by My Green Lab®

Type of intervention	Intervention name	Description
Standard	Green Lab Certification	Standard for laboratory sustainability best practices
	The ACT Label	The first label for laboratory products that supports sustainable laboratory procurement
Research	Center for Energy Efficient Laboratories (CEEL)	A think tank that aims to improve the energy efficiency of labs through its studies.
Education	My Green Lab Ambassadors	Free online course for laboratory professionals providing a 'crash course' on how to increase the environmental sustainability of lab-based research
	My Green Lab Accredited Professionals	Paid credential, described as the first credential related to Green Lab expertise available
Community engagement	Freezer Challenge	International competition encouraging researchers to implement better cold storage practices in the laboratory
	Million Advocates for Sustainable Science letter campaign	Encourages research funders to promote and set standards for improving environmental sustainability in research laboratories
	Advocacy groups – ACTivist 50, Procurement ACTivists	Support environmental sustainability in the supply chain of laboratory products and in procurement processes
Dissemination	MGL Summit, Out of the Box Stories podcast, Beaker Blog	Various communication activities

Source: https://www.mygreenlab.org/

Conceptualisation and implementation of initiative

MGL was founded to build a culture of sustainability in science and thereby address the environmental impact of research. It aimed to gather key players in the area to help drive forward sustainable change. At the time, several US universities had independently started green lab initiatives (e.g. University of California, Santa Barbara (UCSB); University of California, Los Angeles (UCLA); Harvard University, Dartmouth; University of Colorado, Boulder), and some grouped together to collaborate with MGL on the creation of the first pilot certification programme, which was implemented at UCLA in 2013.[83] The volunteers behind the initiative thought it would be helpful to invest in a programme that could support all universities rather than each developing their own programme independently.[84] The pilot was successful and subsequently updated several times to support labs in their certification process with tools they can implement to effectively lower emissions.[85] Minor updates to the programme occur regularly based on user feedback, but significant changes are conducted through a formal voluntary stakeholder consensus process.[86] As of May 2023, MGL certified labs can be found in 41 countries, in over 220 organisations and in around 1,700 labs.[87] The standard has participating labs in LMICs, all of which are commercial labs primarily in the pharmaceutical and biotechnology sectors.

Evidence of effectiveness and impact

To date, there is no aggregate data available on the total impact of the MGL standard, only information from select case studies and extrapolations from theoretical estimates. MGL provided figures from an AstraZeneca case study of 20 research and development labs which estimated that 1,270,185 kWh/year was saved after implementing the standard: the equivalent of 900 tonnes of CO2 emissions and over $315,000 across 2021.[88] The University of Alabama at Birmingham has saved 35,000 kWh/year per lab certified at the lowest tier of the programme on average,[89] which is equivalent to 24.8 metric tons of CO2e.[90] The founder of MGL estimates that labs could save 6,000 kWh/year, the equivalent of removing one car from the road, provided the labs choose to implement certain recommendations of the standard.[91] The MGL standard has worked with over 220 institutions and nearly 1,500 labs in 41 countries, mostly concentrated in North America and Europe.[92]

AstraZeneca also noted an eight-point increase in employees answering ‘yes’ to the question ‘I understand how I contribute to AZ’s sustainability goals’ in a survey conducted across Q2 2019 to Q2 2020 (MGL certification took place in 2020).[93] The company cites this increase in ‘employee engagement’ as a main driver for participating in the standard.[94] MGL attest that other labs adopting the standard experience similar benefits, but there is no additional data to support this claim.[95]

The standard was selected as a breakthrough outcome for the UN Race to Zero Campaign for Pharma and MedTech in 2021, with the UN setting a goal for 95% of biotechnology and pharmaceutical companies to achieve the MGL standard at the highest level by 2030.[96] It has also been endorsed by the American Association for Higher Education, and AstraZeneca has announced that it will be implementing the standard across its entire global research and development portfolio.[97]

There are no data available on the time burden for researchers to apply and maintain the accreditation. MGL estimates from its records that it takes between three and nine months to go from initial assessment to final certification. One lab stated it took eight months to complete the certification study.[98]

Lessons learnt and key insights

For the MGL standard, its key strength seems to lie in its affiliation with the pharmaceutical and biotechnology industries, given that some research institutions also hire scientists from these industries. Two stakeholders mentioned selecting the standard on this basis, describing its ability to see the bigger picture beyond academia as an asset.[99] One interviewee also acknowledged a preference for its independent non-profit organisation status due to the transparency that it offers.[100] Although no interviewees mentioned this explicitly, its approach of allowing institutions to build from their existing strengths related to sustainability permits those with fewer resources an easier entrance into the space. However, this characteristic also means that there is no exact comparability among labs using the standard.

The main weaknesses mentioned regarding the standard are its cost, the terminologies being too US focused, and its more professional/commercial approach, which comes across as more disconnected and 'sales-y'. However, stakeholder accounts have indicated that MGL is willing to lower the cost to a very generous degree if it is mentioned that affordability is a problem.[101] Another stakeholder stated that MGL was not a good fit partially because the community-level engagement in practice was too onerous, and some labs struggled to meet the 50% requirement. The standard and its team will implement changes in the near future that might address these concerns to a degree (see 'Next steps' section below).

Next steps

MGL recently began an update to the MGL standard that will involve a formal stakeholder engagement process that will be available to the public. The process will run through 2023, with piloting beginning near the end of 2023 and a planned launch in 2024.[102] The organisation is also currently building an 'Impact Estimator' tool to help the standard better estimate energy saved and the equivalent in carbon emissions.[103]

A.3 NIHR Carbon Reduction Guidelines

Introduction

The NIHR Carbon Reduction Guidelines were published in 2010 by the National Institute for Health and Care Research (NIHR). Developed in consultation with clinical researchers and methodologists, they comprise 19 recommendations for how health researchers can reduce the carbon emissions associated with clinical trials and other forms of health research without negatively impacting validity and reliability. The guidelines cover the following topics: setting the research question and making full use of existing evidence, efficient study design, study set up and conduct, avoiding unnecessary data collection, sensible clinical trial monitoring, good practice in reporting research, and reducing the environmental impact of the NHS through research.[104] The document is publicly available on NIHR's website and is attached to all research application forms for NIHR funding.[105]

The objective of the guidelines is to provide a framework to inform researchers of what tools and methods they may use, rather than enforcing mandatory compliance. To submit an NIHR funding application, researchers must tick a box to confirm that they have read the guidelines. In addition, a statement included in the application form encourages candidates to 'consider, where feasible, addressing issues of environmental sustainability including their impact and appropriate outcomes within the remit of the applying programme'.[106]

The objective of the guidelines is to provide a framework to inform researchers of what tools and methods they may use

Conceptualisation and implementation of initiative

The NIHR Carbon Reduction Guidelines emerged from an interest to operationalise the findings of an article from 2009 that calculated the carbon emissions of 12 clinical trials.[107,108] This analysis was conducted by researchers at the NIHR and the London School of Hygiene and Tropical Medicine (LSHTM), and built on an earlier publication by Professor Ian Roberts at the LSHTM from 2007.[109] The 2009 paper suggested that there were a number of ways in which clinical trials can lower their carbon footprint, particularly through reducing the travel of researchers and research participants associated with the trials.[110] Building on these findings, the guidelines were initiated by the NIHR R&D Department of Health and produced by a working group that included NIHR employees and a number of academic researchers.[111,112]

The working group met on three occasions. In January 2020 an early draft of the guidelines was presented at a workshop that collected input from senior clinical researchers, other experts within academia and the NIHR on the content of the guidelines. This feedback was incorporated and a new draft subsequently circulated to a wider audience of 300 NIHR stakeholders, along with an online questionnaire. This survey included 12 questions asking for feedback on the guidelines, both multiple choice and free-text, and was completed by 49 people during the two weeks that it ran, equalling a response rate of 14%. The guidelines were revised based on the feedback from this electronic consultation phase and other final input relating to clarity and potential misunderstandings.[113]

No funding or resources were put aside or formally allocated to this project. The development of the guidelines required working time from NIHR staff and others in the working group, but this time was spent in a more opportunistic fashion rather than according to a structured plan. The implementation of the guidelines was described as straightforward and relatively low cost given that the end result was published on NIHR platforms, including its website and funding application forms. Some publishing activities were made in relation to the launch, including a launch event and a podcast, but were relatively inexpensive.[114]

Evidence of effectiveness and impact

The guidelines have not been assessed through any evaluation, so it is not possible to say whether they have contributed to an actual reduction in carbon emissions from clinical trials. NIHR has tried to find examples of best practice to show their effectiveness, but these have been challenging to identify.[115]

One stakeholder argued that the guidelines have been ineffective in their aim as they are not mandatory and therefore allow NIHR researchers to perform a commitment without actually integrating it into their research. In this sense, the guidelines are counterproductive to their aim, reducing incentives for NIHR researchers to lower their carbon footprint in practice.[116] This perspective is represented by only one account in our research, but the risk that the guidelines have become reduced to a box-ticking exercise was acknowledged by others involved in their development.[117]

However, there are indications that the guidelines have fulfilled at least the aim of spreading awareness about strategies and methods for reducing emissions from clinical trials.[118] The guidelines have been referenced in different publications,[119,120,121] including a 2021 Lancet article, which stated that the NIHR Carbon Reduction guidelines were virtually the only major initiative aimed at reducing the carbon emissions of clinical trials.[122] One interviewee described being approached by international colleagues about the guidelines at a conference in early 2023, although they were designed in 2010.[123] Other NIHR researchers and one interviewed researcher from the working group also suggested that they may have helped to spread awareness.[124,125]

The implementation of the guidelines was described as straightforward and relatively low cost

Lessons learnt and key insights

Best practices and key factors for success:

Raising awareness of existing methods and strategies that can be used to reduce the carbon footprint of clinical research is the biggest achievement from the NIHR guidelines.[126,127] Some argue that the guidelines have helped to promote sustainability within the clinical research community in recent years when little else has been driving the issue forward.[128,129,130]

Involving clinical researchers, who are the primary audience, in the design of the guidelines has also enabled them to be written in a way that makes it easy for researchers to understand in the context of their own area of expertise (e.g. referencing case studies drawn from clinical trials that demonstrate the guidelines in practice). Their practicality may be especially important given the demand among researchers to reduce the burden of funding application processes.[131]

Challenges:

The main challenges facing the guidelines are ensuring that researchers apply them in practice, and evaluating the effectiveness of implementation and impact. NIHR recognises and is motivated to address the box-ticking exercise characterisation of the guidelines. Some stakeholders argue that measures will only be adopted broadly when there is no other choice (i.e. a funding requirement), given that implementing change takes effort and resources, citing the example of environmental measures only adopted post COVID-19.[132,133]

However, there are barriers to tackling these challenges. First, it could be burdensome and resource intensive to evaluate the guidelines. There is currently limited research or examples of best practice to inform such an evaluation of projects. Basing funding decisions on demonstrated practical efforts to reduce carbon emissions would require the development of robust assessment criteria that give accurate estimates of effort and impact, which are currently not available.[134] Second, there is demand from the research community to reduce the work and administrative burden involved in applying for research funding. Requiring applicants to gather and submit more evidence demonstrating compliance with the NIHR guidelines would run counter to this trend, and may be met with resistance.[135]

Next steps

NIHR are in the process of updating the guidelines, and are particularly interested in exploring case studies that exemplify how they can be used in practice.[136] It is also looking to fund more projects that explore the tools and methods that can help to reduce the carbon emissions of health research, and is considering how the guidelines can address a wider audience. Targeting the guidelines primarily at clinical trials researchers has enabled the guidelines to be designed in a clear and efficient way. This will continue to be part of the strategy, but research sustainability is an important issue across research disciplines, and some strategies for clinical trials research could be translated and applied in other fields.[137]

Finally, NIHR has expressed a strong interest in increased collaboration among funders and actors in other fields, such as chemistry and engineering.[138] It believes that transparency and avoiding duplicating effort across the board are needed, and see NIHR as having an important role to play in communicating to other actors what tools and methods are being used for increased sustainability to identify and fill gaps. For example, many carbon calculators are currently being developed simultaneously across the sector, and there is no system to keep track of these developments and any potential overlaps.

A.4 Sustainable Healthcare Coalition: The Lower Carbon Clinical Trials Project

Introduction

The Sustainable Healthcare Coalition (SHC) is a partnership group that aims to inform and inspire sustainable practices across the global healthcare sector to reduce carbon emissions. Members include world-leading healthcare companies within pharmaceutics, medical technologies, clinical research and other healthcare fields, as well as the NHS Sustainable Development Unit for health and social care in England. The group shares insights and collaborates to develop guidance and tools for helping the healthcare sector become more sustainable.[139] SHC's online resources are openly available to the public.

Some of its activities focus on measuring and reducing the impacts of clinical trials. One of these is the NIHR-funded Lower Carbon Clinical Trials Project led by the Institute for Cancer Research and the University of Liverpool.[140,141,142] Using a carbon footprinting approach, the first iteration of the tool is planned to be guidelines that link different activities in a clinical trial to a library of emission factors that can be used to estimate its carbon footprint. These guidelines are expected to be ready for publication by the end of June 2023. The project involves stakeholders such as the SHC itself, Environmental Resources Management, MRC-NIHR Trials Methodology Research Partnership, as well as the funding branch and sustainability unit within NIHR. Clinicians and patients directly affected by the framework are stakeholder groups that will become increasingly important as the guidelines are rolled out.

Some of its activities focus on measuring and reducing the impacts of clinical trials

Conceptualisation and implementation of initiative

The SHC was formed in 2013 by the NHS Sustainable Development Unit after a report revealed how most NHS carbon emissions were associated with supply chains, especially from pharmaceutical products and medical devices.[143] The unit invited relevant industry groups to a roundtable discussion on how to measure the existence and size of these impacts, which led to the establishment of the SHC. Its creation enabled effective data and expertise sharing between NHS and industry actors, and resulted in the world's first guidance on how to measure carbon emissions associated with pharmaceutical products and medical devices.[144,145] Over time, the coalition membership became more diverse, and the focus broadened to producing guidance for measuring the environmental impacts of whole care pathways, rather than only pharmaceuticals and medical devices. Currently, NHS England and NHS Scotland are involved in driving the SHC forward.[146,147]

Lower Carbon Clinical Trials Project

The Lower Carbon Clinical Trials Project was initiated in 2021 after actors within the SHC approached the MRC/NIHR Trials Methodology Research Partnership to join a discussion around how to achieve environmentally sustainable practices in clinical trials.[148] Around the same time, SHC stakeholders published an article in the Lancet calling for researchers to develop methods to measure the carbon emissions of clinical trials.[149] These actions resulted in a meeting where an attendee from the Institute of Cancer Research (ICR) initiated the project together with colleagues at the University of Liverpool, using funding from the NIHR. The guidance was developed by mapping the process of clinical trials and identifying all activities that could have a carbon footprint. Once complete, the study team developed methods that could be used to measure these impacts, one of which involved creating a library of emission factors. At the time of writing, the 12-month project is still underway and is expected to be published in summer 2023. The long-term goal is for the guidance to become standard procedure in all trial designs, first in the United Kingdom and then globally.[150]

Evidence of effectiveness and impact

The guidance of the Lower Carbon Clinical Trials Project is not yet finalised and therefore has not been evaluated. A pilot version of the guidance has been tested on clinical trials conducted first within and then outside ICR, which resulted in effective carbon footprint measurements, according to an interviewee.[151]

Lessons learnt and key insights

One advantage of the SHC is its approach to evaluating the whole healthcare system to understand where carbon impacts are the greatest and how they can be reduced. Had it promoted measuring and reducing the carbon footprint of specific elements without understanding its carbon impact in relation to the broader care pathway, effort and attention may have been misplaced[152] Moreover, the SHC follows a user-centred approach, where tools and guidance are co-developed with and customised for practitioners in the sector.[153]

One of the most common challenges for the SHC and associated initiatives is the difficulty of securing funding for work aimed at improving the environmental sustainability of clinical research.[154,155,156] Despite growing interest among actors in the healthcare system to work on this issue, a lack of funding means that many efforts are voluntary and executed on top of other paid duties. One interviewee argued that for sustainability to be more substantially integrated into health research it must be more formally recognised and supported within the system with appropriate funding, rather than relying on the enthusiasm of certain individuals.[157] Some interviewees believe that this lack of funding is partially due to a tendency among funders to avoid supporting new types of research projects, which suppresses innovation in sustainable research practices.[158,159,160]

For the Low Carbon Clinical Trials Project, one challenge has been to develop a calculation method that strikes the right balance between accuracy and ease of use for researchers. The more data incorporated into the calculation, the more robust estimates achieved. However, given that staff involved in clinical trials have both limited time and access to data, designing too advanced and complex a calculator reduces the likelihood that the tool will be widely adopted. Another challenge has been to identify the appropriate and most up to date emission factors for the activities being measured, as there are multiple emission factors for one activity and deciding which is the most suitable can be difficult.[161]

Next steps

Stakeholders involved in the Lower Carbon Clinical Trials Project are currently discussing how to take the project forward once the initial report is published. The ICR hopes to work on spreading awareness of the tool and updating it with new data to ensure its usefulness. Once the guidance is considered sufficiently robust, the plan is to convert it into a digital tool that can be easily accessed and used online.[162,163]

A.5 Green Algorithms Calculator

Introduction

The Green Algorithms calculator was developed as an open-source and open-access tool to assess and report the carbon footprint of computation, particularly bioinformatics. The tool aims to enable scientists outside of the deep learning sector to estimate the environmental toll of the algorithms used in their studies. The calculator can be used with minimal information, does not affect existing code and considers a wide range of hardware configurations. Its creators have also released information on ways to avoid unnecessary CO2 emissions and increase awareness of green computation.[164] For projects requiring many different computations, the High Performance Computing (HPC) tool was created to help researchers save time entering relevant details.[165] The calculator is maintained and updated by Loïc Lannelongue and funded by the Inouye lab and the Department of Public Health and Primary Care at the University of Cambridge, UK.

Conceptualisation and implementation of initiative

The Green Algorithms calculator was conceptualised in January 2020 after the Australian bushfires and their subsequent environmental damage.
The creators, Loïc Lannelongue, Jason Grealey and Michael Inouye, took inspiration from a paper written by Emma Strubell, which was among the first to discuss the carbon footprint of training machine learning language models.[166] Their lab at the University of Cambridge focused on computational biology, with algorithms running most of the time. Although tools existed that estimated the carbon footprints of deep learning, the creators could not find calculators for some of their research activities (e.g. large genomic analysis). As a result, Lannelogue and Grealey created a tool that measured the carbon footprint of bioinformatics. The first version of the tool was created within three months and followed by several improved releases. A pragmatic scaling factor is employed to allow for an empirical estimation of the emissions of computations happening repeatedly for a specific task. The estimated grams of carbon dioxide equivalent (gCO2e) is then set against the amount of carbon sequestered by trees and the emissions of everyday activities such as driving a car.[167]
The Green Algorithms calculator considers factors such as the hardware requirements, runtime and location of the data centre.

The calculator has been implemented widely, including in fields beyond bioinformatics such as particle physics simulations and weather forecasting.[168] The journal article that presented Green Algorithms has received 87 citations to date, predominantly by those using the calculator to measure the impact of their research. Since its launch in 2020, the calculator has had around 15,000 users and over 20,000 sessions, equating to ~200 users per week globally, with most located in the United States, France, Germany, the United Kingdom and Australia.[169]

Its creators have also released information on ways to avoid unnecessary CO2 emissions

Evidence of effectiveness and impact

No formal evaluation of Green Algorithms has been conducted, although it may have demonstrated some effectiveness. In April 2021, a preprint released by Google compared the estimates from the Green Algorithms calculator and another tool, the Machine Learning (ML) Emissions calculator, to the real emissions of servers used in deep learning tasks.[170] This comparison is displayed in Figure 5, which shows that the Green Algorithms calculator has high accuracy for all commercially available processors (P100 and V100). It was less accurate in estimating the consumption of Google's custom processors (TPU v2, TPU v3), although this is largely explained by the fact that these are Google proprietary hardware and data on their power usage is not shared by the company[171,172] This illustrates how the calculator is heavily dependent on information access, which could become a limitation whenever such information is restricted.

Other limitations of the calculator include the lack of consideration for other factors such as the preservation (i.e. the condition) of the power plants in its estimations, which can reduce emissions if operating efficiently. The location of a data centre will also affect estimates due to differing carbon intensities,[173] depending on the sources used to generate energy in that particular area. Similarly, the energy mix (e.g. solar, wind, gas) of each country can vary by the hour, and even though most regions are stable, the averaging of carbon emissions within the possible ranges by the calculator may skew estimates. In South Australia, for example, usage can cause emissions ranging from 112 to 592 gCO_2e kWh−1 within one day, depending on how much coal-produced electricity is brought in from the state of Victoria.[174] Power usage effectiveness as a measure of data centre energy usage is also often not measured consistently. Additionally, the conversion of the impact of various greenhouse gases into CO_2e is often done according to a 100-year timescale. Nowadays, this practice is often disputed as it may not be accurate for short-lived climate pollutants (e.g. methane). These constraints demonstrate that the results of the calculator must be understood as estimates rather than definite measures.

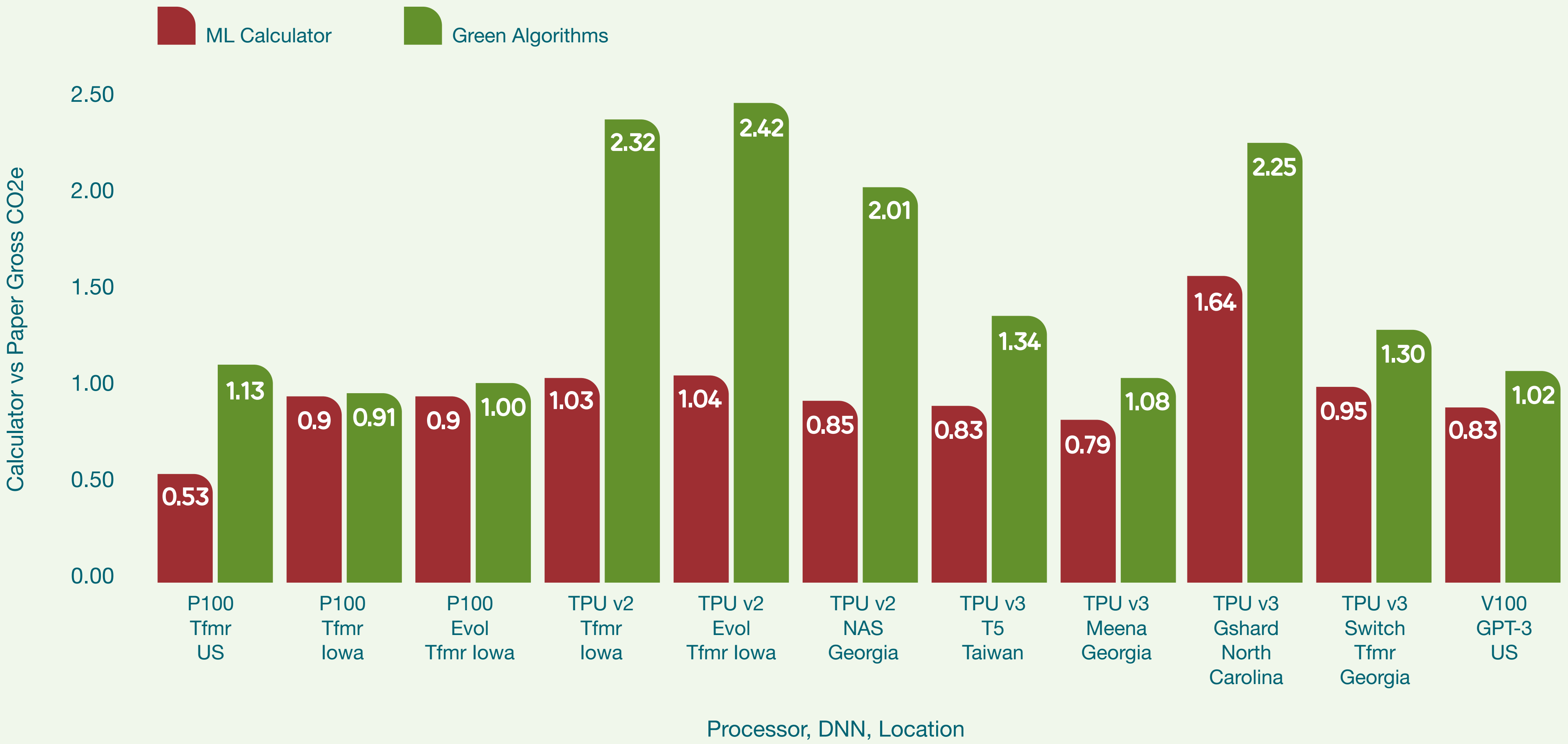
Lessons learnt and key insights

Transparency across the sector, from hardware manufacturers to data centre providers, is crucial. If the necessary information about carbon footprint and efficiency at all levels is not provided, estimates will not be as accurate.[175] The open-access and open-source nature of the tool has also allowed scientists globally to tailor it to their needs and create local versions. For example, the Institute of Radio Astronomy and Astrophysics (Instituto de Radioastronomía y Astrofísica, UNAM) in Mexico has replicated the calculator, adapting it to the hardware, infrastructure and location of the institute.[176,177] Another main challenge is the lack of available funding in the field to dedicate to the calculator's maintenance.

Next steps

Future developments of the tool will add new functionalities, help with continuous calibration, and provide more guidance and training for scientists on how to use it.[178,179] The team also plans to create additional versions for specific types of research.[180]

Figure 5
Ratio of ML Emissions and Green Algorithm calculators vs. actual gross CO2e



Note: Calculator estimates against actual gross CO2e should result in a ratio that is as close to 1 as possible. Source: Patterson, D., et al. 2021. 'Carbon Emissions and Large Neural Network Training.' arXiv:2104.10350. As of 4 July 2023: https://arxiv.org/abs/2104.10350

A.6 Carbon Literacy Project

Introduction

The Carbon Literacy Project is an education programme that aims to improve carbon literacy, defined as 'an awareness of the carbon dioxide costs and impacts of everyday activities and the ability and motivation to reduce emissions on an individual, community and organisational basis'.[181] The project aims to embed climate action competence across the workforce and optimise the impact that every individual can make.[182]

Organisations[183] approach the Carbon Literacy Project for training, and learners are accredited with a Carbon Literacy (CL) badge after completing the required lessons within a specific toolkit.[184] Toolkits cover core topics such as climate change to ensure consistent values and quality across all training, as well as customised content relevant to specific organisational needs. Action is encouraged by requiring learners to form two low carbon pledges, one at an individual level and another on a group level, to make the training more impactful.[185]

The host institution is then encouraged to follow up on the pledges of learners. Partaking organisations are accredited with Carbon Literate Organisation badges along four tiers, depending on their commitment to lowering their carbon emissions.[186] One-day training sessions are offered as well as those spread out across a longer period. Most learners are UK-based, but others are in continental Europe, Singapore, the United States, Chile, Bangladesh and India.[187] As of June 2023, 62,184 individuals have been certified across 4,419 organisations.[188]

Conceptualisation and implementation of initiative

The Carbon Literacy Project is run out of the Carbon Literacy Trust, a global charity based in Manchester, UK. The project was conceptualised after working closely with an ambulance service to create a specialised course of lessons, or 'toolkit', which was subsequently adopted by other healthcare and NHS services. To date, toolkits have been developed with various courses for specific professions or industries (e.g. civil service, automotive). The original materials have been therefore adapted into more generic content applicable across a wider variety of settings. Toolkits facilitate:

1. A process of co-production with representatives from across an organisation in the relevant field
2. An assessed pilot process.

The original funding mechanism for the public sector toolkits came from the Department for Business, Energy and Industrial Strategy (BEIS), but now much of the work is self-funded.[189] Fees and grant funding also support the project in general, including from Greener NHS, a programme that aims to help the NHS reach net carbon zero.[190,191]

Toolkits cover core topics such as climate change to ensure consistent values and quality across all training

Evidence of effectiveness and impact

The project launch was during the COVID-19 pandemic, which caused delays in its development. However, its uniqueness had already been recognised by the UN at COP21 as 'one of 100 worldwide Transformative Action Programs'.[192]

There has been no evaluation of the project's impact on reducing emissions. Learners give estimates of the carbon-saving potential of their pledges, but it is difficult to measure individual carbon savings as other behavioural and cultural changes are not taken into account.[193] Nonetheless, several academic studies note the positive behavioural shift brought about by the training.[194] For example, evaluation from a training course conducted in Manchester identified that learners demonstrated behaviour change by performing daily energy-saving actions in household tasks such as cooking or seeking to install solar panels.[195] Some trainers also ask participants to voluntarily complete a feedback survey and organise an informal follow-up meeting two months after the completion of training, where successes and challenges faced are shared. However, no data are available at the aggregate level as to the prevalence of this practice or its results. In the future, the Carbon Literacy Project hopes to conduct a more comprehensive study of the impact of its training.[196]

Lessons learnt and key insights

One of the main challenges for the programme is adapting the material to the needs of different sectors given the particular barriers each face.[197] For example, in healthcare the material must be divided into shorter sections to ensure that everyone finds time to undertake the training given the erratic and long hours of participants. Another trainer recommended including lessons about engaging leadership in the behavioural change.[198] In the evaluation of a training course conducted in Manchester, trainee trainers argued that more follow-up and networking among themselves and learners would be beneficial.[199] It has been suggested that engagement and accessibility could be improved if more interactive formats such as videos or podcasts are introduced.[200]

However, learners do report feeling more confident and empowered to affect positive change on the environment. A trainer confirmed that community is a key factor for the project's success, with people across varying roles and backgrounds coming together in the training to share their learning and develop a sense of camaraderie.[201] For this reason, group learning was also deemed a strength.[202]

Next steps

The project's main short-term target is the good deployment of its new NHS e-learning course. In the long term it aims to develop more toolkits based on demand and available funding. Future toolkits would target healthcare researchers, medical suppliers and pharmaceutical organisations. Availability in German, Arabic, Spanish and Welsh will soon be offered, and international expansion is also being considered.[203,204]

A.7 UKRI Net Zero Digital Research Infrastructure scoping project

Introduction

In a video uploaded to YouTube in 2021, engineers conduct a final check before permanently switching off ARCHER, the UK's most powerful supercomputer.[205] With the constant noise of the servers, their voices are barely audible. When ready, they enter 'y' for the necessary function ('Do you want to shutdown 'archer' (y/n) [n]?'), and programming lines run down the screen until power to the cabinets is finally turned off; the sound immediately reduces and begins to fade away. ARCHER's replacement, ARCHER2, is much quieter than its predecessor. According to ARCHER2's director, this is because it uses only a very small number of fans.[206]

Fans blowing air onto the machines to lower their temperature so that they can properly function represents an outdated technology for cooling computers. Engineers now favour liquid immersion methods due to their higher energy savings rate and therefore lower carbon footprint.[207] The Net Zero Digital Research Infrastructure (DRI) scoping project funded by UKRI aims to identify such carbon-reduction technologies for users of DRI in the UK research and innovation (R&I) ecosystem. DRI is a category that covers all hardware and software related to digital research used to run complex models, including supercomputers such as ARCHER and ARCHER2. The scoping project also considers other devices linked to Scope 3 emissions,[208] such as the smartphones that researchers handle daily to check emails.[209,210] The scoping project operates from the perspective that lowering carbon emissions and ensuring DRI remains cutting-edge are not mutually exclusive goals: the pursuit of the former will not be allowed to negate the latter.[211]

Objectives

The Net Zero transition is one of UKRI's highest priorities, as mentioned in its latest Sustainability Strategy, published in 2020.[212] To address the area of digital research, UKRI commissioned a plan for reducing the carbon emissions from the data generation, analysis, storage and dissemination of its DRI by 2040. The study was launched in November 2021 as a scoping project, with its main output to develop recommendations or guidelines for change rather than actually implementing changes within UKRI. It has five goals (adapted from the source): 1) develop a map of the UKRI digital research carbon landscape; 2) identify challenges and opportunities to accomplishing zero carbon DRI within UKRI owned and majority funded DRI; 3) scope a framework for implementing a roadmap towards net zero; 4) create a roadmap towards net zero; and 5) consult stakeholders to understand how this roadmap can be realised.[213]

Conceptualisation and implementation of the initiative

The Net Zero DRI scoping project originated from UKRI's commitment to achieve Net Zero greenhouse gas emissions, and began in the context of general UK governmental agreement to prioritise sustainability.[214] The project is administered and funded by the Natural Environment Research Council (NERC) on behalf of UKRI, but the core project team is comprised of staff at the Centre for Environmental Data Analysis (CEDA) and the Science and Technology Facilities Council (STFC) scientific computing department, who together manage a budget of nearly £1.9m.[215] A consortium of representatives from all UKRI research councils and DRI experts advises on several components of the study (e.g. the selection of the proof of concept studies). There are quarterly meetings with a steering committee, and there is also a scientific advisory board.

The project incorporates the following elements:

1. A literature review.
2. Proof of concept studies[216] (also referred to as 'sandpit projects', explained further below) that analyse the implementation of current sustainability measures in existing facilities and programmes.[217]
3. A user outreach survey.
4. Case studies on exemplary DRI (e.g. ARCHER2 and Jasmin supercomputers).
5. An artistic commission for collective action on sustainable DRI, among other smaller studies.[218]

Two 'sandpit events' played a pivotal role in the project. The UK research and innovation community were invited to contribute ideas for the proof-of-concept studies, workshops and other user engagement activities. One sandpit event focused on community and organisational challenges and the other on technical and operational challenges. Any helpful evidence that could be used towards recommendations for UKRI were also noted.[219] At the conclusion of the events, project teams formed in the sandpits were invited to submit proposals for evaluation by an expert panel. Topics not covered by projects funded through the sandpits were picked up in stakeholder workshops run by the core project team or through consortium partners invited into the project.

Regular open meetings were held for any interested stakeholders to familiarise themselves with the project and its goals. These occurred at the beginning of the study (December 2021, January 2022) and during 2022 in the form of progress webinars (January, March, April, July, September). Meetings were also held at the beginning of 2023 (January, February) to share outcomes from research conducted so far. The project also led an engagement session at the Computing Insight UK conference in Manchester in December 2022 to receive more input from stakeholders.

The project published an interim report in August 2022 based on the literature review findings, which included initial recommendations based on the evidence collected. Stakeholders provided feedback on the report and gave recommendations, which are covered below.

Evidence of effectiveness and impact

As the project is ongoing, it is difficult to make any claims related to effectiveness or impact; the final report is due to be published in summer 2023. It has also not been evaluated at a project or sub-project level.

Lessons learnt and key insights

The Net Zero DRI scoping project provides useful lessons for organisations running similar programmes to determine and implement sustainability measures. Ensuring community engagement was viewed as a key element. Stakeholders described this type of initiative as requiring a 'transformation' in terms of connecting previously separate departments or actors within the general community.[220] To promote such engagement, framing questions carefully according to disciplines (e.g. physical scientists tend to measure things in a precise manner often not possible with sustainability issues) and encouraging interdisciplinarity were seen as effective. Having a 'constant steady trickle' of events throughout the year also ensured the project remained on everyone's minds,[221] and offering creative/artistic workshops attracted a broader range of stakeholders than usual, which allowed for a wider perspective to contribute. The following preliminary recommendations were presented in the interim report.

Table 9
Interim report recommendations, incorporating stakeholder feedback

Building consensus	
1	The UKRI DRI needs to ensure that investment decisions are backed by a deep understanding of the views of the research community
2	UKRI should use its capacity in social, arts and humanities, as well as in economics, to understand the range of societal views, the avenues of consensus which open-up potential for accelerating transition, and the emerging (or exploding) discords which can block or reverse change
Leading	
3	Create a focal point which can bring together the strands of activities across the research sector to enable a coherent approach on the Net Zero DRI roadmap
Technology and capability	
4	The UKRI DRI needs to invest in the development of capability to deliver effective scientific throughput in a rapidly evolving digital landscape
5	Steps must be taken to minimise barriers to the adoption of potential efficiencies arising from new technologies
User efficiency and market rebound	
6	Ensure the introduction of new technologies is matched by appropriate resources for training and user support
7	Ensure the procurement framework enables the conversion of efficiency gains into carbon savings
Electricity supply	
8	Best practice for an individual institution is to adopt a 100% off-grid renewable electricity supply
9	Adoption of multi-year power purchase agreements with renewable investment clauses
10	Construction of grid-scale battery storage matched to the institutional power demands
11	Building on-site renewable generation and grid-connected power storage to mitigate load on the national grid

Procurement of equipment	
12	Institutions making purchases on behalf of UKRI must be empowered to balance investments in efficiency against investments in energy intensive infrastructure
13	Add sustainability clauses in procurement contracts
14	Build relationships along the supply line to work on mutually beneficial solutions
15	Look at the whole life cycle of equipment and opportunities to extend the life and re-use potential of equipment
Estates and travel	
16	Fossil-free on-site operations should be established in the near term. There does not appear to be a need to wait for further information before setting a timeline for elimination by 2025
17	The UKRI DRI should facilitate and promote digital collaboration tools and awareness to reduce carbon intensity and enhance access to the research programmes
Offsetting, sequestration and biochar	
18	UKRI needs to be exhaustive in exploring what can be avoided before, during and after taking steps to deal with unavoidable emissions
19	Given uncertainty in the scalability of biochar and other carbon removal innovations, the UKRI needs to couple investments with research into their sustainability
20	UKRI should ensure that any offsetting investments are linked to guarantees of institutional continuity, e.g. through a trust
Wielding impact	
21	There is currently no requirement for researchers to consider that their research could have a negative impact on sustainability. The existential crises that face those in climate and biodiversity need to be reflected in every grant application as a key element of ethical and societal responsibility
Delivering the Net Zero DRI	
22	The UKRI DRI must ensure continuity of activities to assess best practice and deliver guidance to all those involved in funding, procuring, operating and using digital research infrastructure

Source: Woodward, L., P. Townsend and M.N. Juckes. 2022. 'Net zero DRI scoping interim report: Stakeholder feedback.' Report on meeting held July 21st, 2022. Centre for Environmental Data Analysis. As of 4 July 2023: https://doi.org/10.5281/zenodo.6962305

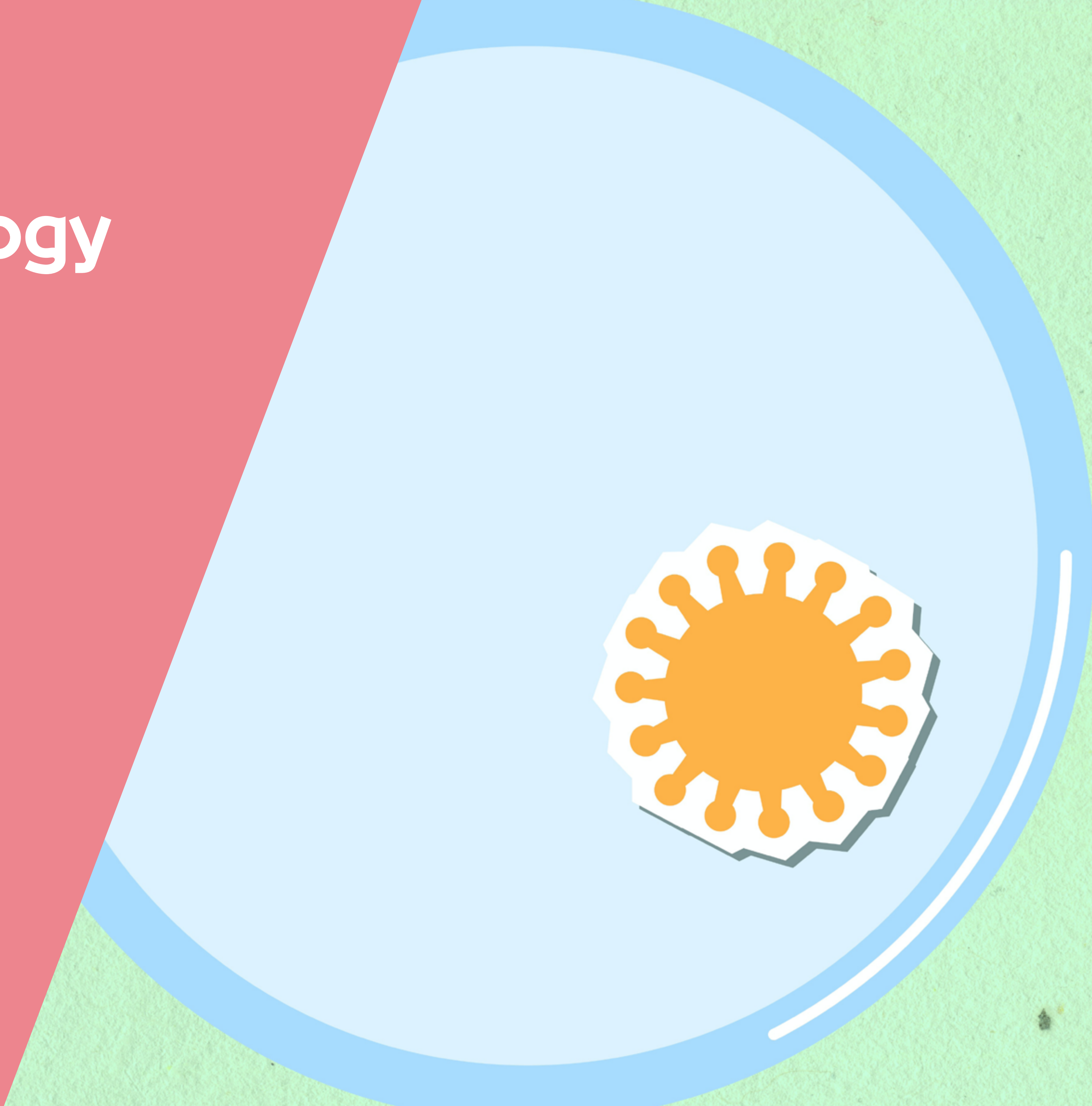
These recommendations range from general steers on how the institution should manage the subject (e.g. 'UKRI needs to be exhaustive in exploring what can be avoided…') to specific requirements (e.g. 'Add sustainability clauses in procurement contracts.') The themes convey how the task at hand relies on both community organising and technical elements, which are the two categories that the project used to distinguish between proof-of-concept studies at the sandpit events. Stakeholder feedback on the recommendations referred to these areas as 'consultation' and 'appropriate procurement'.[222] Carbon offsetting was specifically characterised as an 'explicit' last resort option, only to be used together with all the other actions.[223] Out of the 15 recommendations, stakeholders categorised recommendations 4 and 21, which concern capability building and requiring researchers to consider the impact of their research on sustainability through the grant application process, as 'not very relevant' and 'unclear'.[224] Recommendations 12 to 15, which relate to procurement of equipment and are some of the most specific recommendations, were labelled 'highly relevant' and 'very clear'.[225] These recommendations are perhaps also some of the easiest to implement straight away. Some actions, if undertaken by UKRI, would be mainly applicable to UKRI internally given its unique needs (e.g. 'Construction of grid-scale battery storage matched to the institutional power demands'), but lessons from implementing the others should be shared with the wider community (e.g. 'Ensure the introduction of new technologies is matched by appropriate resources for training and user support.')

Next steps

The final report, due summer 2023, will summarise all that has occurred over the entire project and provide final recommendations for UKRI.

Annex B
Methodology

This section showcases our approach and work plan, which includes modifications based on discussions with Wellcome and experts.



B.1 Phase 1: Inception

This first phase of the work refined the scope, definitions and approach through an initial scoping of the evidence and engagement with Wellcome and our expert panel. It included the following tasks:

- Task 1.1: Kick-off meeting
- Task 1.2: Refine scope, definitions and approach.

Kick-off meeting

The kick-off meeting with Wellcome provided further guidance on the direction of the study (Task 1.1). Wellcome and RAND agreed to keep a broad definition of what is classed as health research in terms of research types and topics to ensure that less relevant but nonetheless interesting insights were included. It was also proposed that the scope of the study could have a focus on institutions and stakeholders. Wellcome offered to share a list of experts to contact for external advice and for the crowdsourcing exercise conducted by RAND at a later stage. Two additional focus groups were added to the study to target research managers and administrators, and other similar profiles.

Refine scope, definitions and approach

RAND also assembled a group of 12 experts with whom we discussed the scope, definitions and approach for this study (Task 1.2). The selected experts brought knowledge and experience from across the public and private sectors and academia, and provided suggestions of sources and stakeholders to engage with. Further details on the composition of the expert group are provided in Table 10, and the main insights from the initial discussions are presented in Section 3.

The selected experts brought knowledge and experience from across the public and private sectors

Table 10
Expert group assembled for the study

	Institution	Expertise
1	NHS Digital	Digital sustainability, net zero and climate resilience agendas
2	University of Sussex	Environmental impacts of academic activities and sustainability initiatives
3	Sustainable Healthcare Coalition	Sustainable healthcare, wellbeing and sustainability
4	Kings College London	Ethical issues associated with big data and artificial intelligence (AI) in the health arena, and innovative health technologies more generally
5	My Green Lab	Corporate sustainability, green building movement, regenerative design, sustainable business, and laboratory sustainability
6	University of Colorado Boulder	Efficiency and sustainability in lab environments
7	Sustainable Healthcare Coalition	Corporate energy, environmental impacts and sustainability
8	University of Cambridge	Sustainability in research, measuring and reducing the carbon footprint of computational science
9	Carbon Literacy Project	Carbon literacy training
10	LEAF	Lab sustainability, green lab practices, sustainable lab programmes
11	Carbon Literacy Project	Advocacy for carbon literacy
12	National Institute for Health and Care Excellence (NICE)	Health promotion, health policy, global health, migration, systems thinking, developing education for sustainable healthcare, health inequity

B.2 Phase 2: Mapping the landscape

This phase of the study aimed to identify and map existing approaches for measuring and reducing the environmental impact of health research. It included the following tasks:

- Task 2.1: Desk research
- Task 2.2: Crowdsourcing
- Task 2.3: Analysis and review of the landscape.

The desk research involved a review of the academic and grey literature, as well as more informal sources such as blogs and websites (Task 2.1). These evidence sources were identified through a search strategy conducted in Google Scholar (see section B.9) designed to ensure the appropriate coverage of practices and initiatives across different types of health research and environmental impacts. The study team also obtained additional recommendations of sources through consultations with Wellcome and the expert group assembled for the study.

The evidence obtained was collated using an extraction template, which became the eventual table of initiatives. Targeted searches were conducted to identify additional sources to fill in any evidence gaps. These searches confirmed gaps within the areas of clinical trials and qualitative research interventions, with the research team unable to locate further interventions in these areas after a search of over two hours. In total, 14 search strings were used and 101 sources (academic and grey literature) extracted, which led to the identification of 42 initiatives.

While the desk research provided valuable information on the available tools to measure and reduce the environmental impact of health research, it is likely that a wide range of practices have not been documented as some initiatives are still in the process of being implemented. To widen the search strategy, we supplemented the desk research with stakeholder engagement through a crowdsourcing exercise to capture evidence that might not yet be documented or available online (Task 2.2). We drew on international networks (e.g. Transformative Innovation Policy Consortium (TIPC), African Academy of Sciences, LEAN, SELN and Lab Conscious), online searches of key stakeholders in the field, and any contacts shared by Wellcome and our expert group. We used a stratified sampling approach to cover a range of views, ensuring a varied mapping of global initiatives and practices across geographies, sectors and research types. The study team reached out to 99 stakeholders, which led to the identification of 27 additional initiatives.

As the final task for this phase of the study, we assessed and compared the findings from Tasks 2.1 and 2.2 and mapped the examples collected, ensuring that all the information was adequately captured and that duplicates were removed (Task 1.3). We analysed the range of initiatives identified to provide an overview of areas currently covered and gaps to be addressed (see section 2.2). If the study team came across an additional initiative either through Wellcome or a stakeholder during the remainder of the project, it was added to the list. Relevant analyses were also subsequently updated to reflect the new interventions. The final number of initiatives included is 146.

During the analysis, initiatives were classified by type. The categories for initiatives were devised iteratively by the study team as the analysis progressed.

We analysed the range of initiatives identified to provide an overview of areas

B.3 Phase 3: Case studies

This phase of the work drew on case studies to allow for deep dives into good practice examples of how sustainability measures have been implemented. It included the following tasks:

- Task 3.1: Review available documentation
- Task 3.2: Interviews.

Based on our mapping of the landscape in Phase 2 and engagement with Wellcome, experts and stakeholders, we selected seven promising examples to explore further as case studies.

For each case study, we reviewed the relevant available documentation obtained from our previous evidence review (Phase 2) and from additional searches (Task 3.1). We also conducted online interviews with relevant stakeholders associated with the case study (Task 3.2). Most interviews were recorded, with the consent of interviewees, and lasted approximately one hour. Some additional shorter interviews were conducted for the purpose of filling gaps and were not recorded. Case studies set out examples of practice in detail, covering learning from how they have been implemented, any barriers and enablers, and their impact so far. The total number of interviews conducted for case studies was 33.

B.4 Phase 4: Review of Wellcome processes and strategy

This phase of the work aimed to understand how Wellcome processes work and understand some of the practical challenges and considerations in implementing these initiatives from a funder perspective. It included the following tasks:

- Task 4.1: Desk research
- Task 4.2: Interviews with Wellcome staff.

Our approach involved desk research covering publicly available materials and any additional documentation shared by Wellcome and stakeholders (Task 4.1). We also conducted 11 in-person 45 minute interviews with key Wellcome staff to explore the feasibility of different sustainability initiatives in the Wellcome context (Task 4.2). These interviews were recorded with consent.

B.5 Phase 5: Reviewing the wider context

This phase of the work aimed to determine the feasibility of implementing sustainability initiatives in different contexts. It included the following tasks:

- Task 5.1: Focus groups with current Wellcome grant holders
- Task 5.2: Focus groups with non-researcher stakeholders.

In the discussions, we assessed how approaches could be implemented across the four health research categories of 1) lab-based research; 2) research in clinical settings; 3) computational research; and 4) qualitative and desk-based research. We explored factors specific to the different research categories, cross-cutting issues, and differences across geographies and research settings (e.g. sectors, organisation types).

We conducted eight online focus groups, each with a range of three to eight participants:

- Seven focus groups with current Wellcome grant holders (Task 5.1).
- One focus group with non-researcher stakeholders (e.g. research office staff members, research managers and administrators, university staff focused on sustainability) (Task 5.2).

Consent was obtained to record the discussions for note-taking purposes. The sample of award holders and non-research stakeholders were selected to ensure representation from different countries. In particular we aimed to ensure representation from LMICs, as our initial scoping indicated that these countries were less represented in the documented interventions. The sample also contained stakeholders identified in the crowdsourcing exercise.

We analysed the range of initiatives identified to provide an overview of areas

B.6 Phase 6: Developing findings

This phase of the work validated the findings obtained across Phases 1 to 5 of the study. It included the following tasks:

- Task 6.1: Triangulation of evidence
- Task 6.2: Workshop with Wellcome internal stakeholders.

The RAND project team first mapped the evidence gathered through earlier phases and developed the findings presented in this report (Task 6.1). In a RAND facilitated workshop with 10 Wellcome internal stakeholders these were then refined based on feedback (Task 6.2).

B.7 Phase 7: Reporting and engagement

This phase of the work brought together the key findings of the study and presented them in this report. It included the following tasks:

- Task 7.1: Final analysis
- Task 7.2: Reporting.

The report was subject to a quality assurance process based on RAND's rigorous quality standards. The final report is accompanied by an Excel spreadsheet of initiatives with details on their characteristics.

B.8 Limitations

There are several limitations that should be taken into consideration in interpreting the findings of this study, and any related recommendations. This study cannot claim to have identified an exhaustive list of initiatives. For example, our targeted searches mainly aimed to locate gaps in research category type, but avoided filling gaps in sector type (e.g. private sector) to tailor to Wellcome's grant recipient affiliations. In screening the results of the Google Scholar searches, a cut-off was applied so that each search string screening was ceased once a set number of relevant articles had been identified. This means that more initiatives could potentially have been identified if the limit had been higher, and that the selection of initiatives may not be representative of the landscape as a whole. The search strings also did not include some terms (e.g. plurals) that could have picked up other relevant articles. However, the steps taken to supplement these searches with information gained from experts and a range of additional sources serve to mitigate these limitations.

B.9 Phase 9: Search strings

Table 11 provides the list of search strings developed to identify relevant literature (academic and grey literature). These search strings were used within Google scholar and complemented by targeted searches. In each search, researchers were instructed to only examine up until a certain number of eligible articles had been identified. For this reason, date ranges vary, as in each search the range was extended until an adequate number of relevant articles had been reached.

Table 11
Search strings

Search string	Years covered	Health research category	Broad impact category	Specific impact category	Number of hits
(laboratory OR lab OR 'lab-based' OR 'wet lab') AND waste AND (sustainability OR sustainable OR sustainably) AND ('health research' OR 'health science')	2018–2022	Lab-based research	Upstream activities (inputs)	Waste generated	17,300
('clinical trials' OR 'clinical studies' OR 'clinical research') AND waste AND (sustainability OR sustainable OR sustainably) AND ('health research' OR 'health science')	2010–2022	Research in clinical settings	Upstream activities (inputs)	Waste generated	10,200
('clinical trials' OR 'clinical studies' OR 'clinical research' OR 'medical research' OR 'medical science' OR 'biomedical research') AND ('infrastructure challenges' OR 'sustainable infrastructure*' OR 'sustainable equipment')	2010–2022	Research in clinical settings	Upstream activities (inputs)	Infrastructure and equipment	2,090
'Health research' AND (sustainable OR environment OR environmental OR environmentally OR 'eco friendly' OR reusable OR green OR 'net zero') AND ('big data' OR AI OR 'Artificial Intelligence' OR 'Machine Learning' OR Metadata OR 'Meta data' OR 'Big data analytics' OR 'data engineering' OR 'cloud computing' OR 'descriptive analytics' OR 'diagnostic analytics' OR 'predictive analytics' OR 'prescriptive analytics' OR 'user behaviour analytics')	2010–2022	Computational research	Other	Other	77,500

Table 11
Search strings

Search string	Years covered	Health research category	Broad impact category	Specific impact category	Number of hits
‘Health research’ AND (sustainable OR environment OR environmental OR environmentally OR ‘eco friendly’ OR reusable OR green OR ‘net zero’) AND (‘big data’ OR ‘AI’ OR ‘Artificial Intelligence’ OR ‘Machine Learning’ OR ‘Metadata’ OR ‘Meta data’ OR ‘Big data analytics’ OR ‘data engineering’ OR ‘cloud computing’ OR ‘descriptive analytics’ OR ‘diagnostic analytics’ OR ‘predictive analytics’ OR ‘prescriptive analytics’ OR ‘user behaviour analytics’)	2018–2022	Computational research	Other	Other	21,500
‘Health research’ AND (sustainable OR environment OR environmental OR environmentally OR ‘eco friendly’ OR reusable OR green OR ‘net zero’) AND (‘big data’ OR ‘meta data’ OR ‘cloud computing’)	2018–2022	Computational research	Other	Other	17,400
(‘energy consumption’ OR ‘energy use’ OR fuel) AND (‘health research’ OR ‘health science’) AND (laboratory OR lab OR ‘lab-based’ OR ‘wet lab’) AND (sustainability OR sustainable OR sustainably)	2012–2022	Lab-based research	Upstream activities (inputs)	Fuel and energy related activities	14,300
(emissions OR emission OR pollution OR carbon OR CO2 OR CH4 OR N20 OR HFCs OR PFCs OR SF6) AND (‘health research’ OR ‘health science’) AND (laboratory OR lab OR ‘lab-based’ OR ‘wet lab’) AND (sustainability OR sustainable OR sustainably	2012–2023	Lab-based research	Upstream activities (inputs)	Direct and indirect emissions (CO2, CH4, N20, HFCs, PFCs, SF6)	17,400
(infrastructure OR equipment) AND (laboratory OR lab OR ‘lab-based’ OR ‘wet lab’) AND (sustainability OR sustainable OR sustainably) AND (‘health research’ OR ‘health science’)	2017–2022	Lab-based research	Upstream activities (inputs)	Infrastructure and equipment	17,000

Table 11
Search strings

Search string	Years covered	Health research category	Broad impact category	Specific impact category	Number of hits
(sustainability OR sustainable OR sustainably) AND ('health research' OR 'health science') (chemicals OR toxins OR toxic OR contamination OR poisonous OR hazardous) AND (laboratory OR lab OR 'lab-based' OR 'wet lab') AND (sustainability OR sustainable OR sustainably) AND ('health research' OR 'health science')	2015–2022	Lab-based research	Other	Release of chemicals, organisms or detrimental/ uncommon materials into the environment	18,100
(emissions OR emission OR carbon OR pollution OR CO2 OR CH4 OR N20 OR HFCs OR PFCs OR SF6) AND ('clinical research' OR 'medical research') AND ('health research' OR 'health science') AND (sustainability OR sustainable OR sustainably)	2015–2022	Research in clinical settings	Other	Direct and indirect emissions (CO2, CH4, N20, HFCs, PFCs, SF6)	9,110
(chemicals OR toxins OR toxic OR contamination OR poisonous OR hazardous) AND ('clinical research' OR 'medical research') AND ('health research' OR 'health science') AND (sustainability OR sustainable OR sustainably)	2015–2023	Research in clinical settings	Other	Release of chemicals, organisms or detrimental/ uncommon materials into the environment	11,700
('carbon footprint' OR 'carbon emissions' OR 'carbon emission') AND (conference OR seminar OR 'annual meeting') AND (health OR 'health research')	2015–2023	Cross-cutting issues	Other	Direct and indirect emissions (CO2, CH4, N20, HFCs, PFCs, SF6)	17,100

Table 11
Search strings

Search string	Years covered	Health research category	Broad impact category	Specific impact category	Number of hits
(‘carbon footprint’ OR ‘carbon emissions’ OR ‘carbon emission’) AND (conference OR seminar OR ‘annual meeting’) AND (‘health research’ OR ‘medical research’))	2015–2023	Cross-cutting issues	Other	Direct and indirect emissions (CO2, CH4, N20, HFCs, PFCs, SF6)	7,980

Endpoints

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1 UK Medical Research Council has encouraged its facilities to achieve the gold level of LEAF by 2025, and the National Environmental Research Council has required LEAF to be implemented internally.

2 Dobbelaere, J., J.B. Heidelberger and N. Borgermann. 2022. 'Achieving Sustainable Transformation in Science – Green Grassroots Groups Need Nurturing from the Top.' Journal of Cell Science 135(17): jcs259645.

3 Laboratories for the 21st Century/U.S. Department of Energy. Laboratories for the 21st Century: An Introduction to Low-Energy Design. 2008. As of 30 June 2023: https://www.nrel.gov/docs/fy08osti/29413.pdf

4 Urbina, M.A., A.J.R. Watts and E.E. Reardon. 2015. 'Labs Should Cut Plastic Waste Too.' Nature 528(7583): 479–479.

5 Dobbelaere, J., J.B. Heidelberger and N. Borgermann. 2022. 'Achieving Sustainable Transformation in Science – Green Grassroots Groups Need Nurturing from the Top.' Journal of Cell Science 135(17): jcs259645.

6 Borgermann, N., Schmidt, A. and Dobbelaere, J. 2022. 'Preaching water while drinking wine: why universities must boost climate action now.' One Earth 5: 18–21.

7 Urbina, M.A., A.J.R. Watts and E.E. Reardon. 2015. 'Labs Should Cut Plastic Waste Too.' Nature 528(7583): 479–479.

8 Energy Star Portfolio Manager. 2021. US Energy Use Intensity by Property Type. Technical Reference. https://portfoliomanager.energystar.gov/pdf/reference/US%20National%20Median%20Table.pdf; see RSC report for more laboratory-related statistics: Royal Society of Chemistry (RSC). 2022. Sustainable laboratories: A community-wide movement toward sustainable laboratory practices. As of 30 June 2023: https://www.rsc.org/globalassets/22-new-perspectives/sustainability/sustainable-labs/sustainable-laboratories-report.pdf

9 Lyle, K. et al. 2009. 'Carbon Cost of Pragmatic Randomised Controlled Trials: Retrospective Analysis of Sample of Trials.' British Medical Journal 339: b4187.

10 Budennyy, S.A. et al. 2023. 'Eco2ai: carbon emissions tracking of machine learning models as the first step towards sustainable AI'. Doklady Mathematics: 1-11. Moscow: Pleiades Publishing.

11 Grealey, J. et al. 2022. 'The Carbon Footprint of Bioinformatics.' Molecular Biology and Evolution 39(3): msac034.

12 Samuel, G. and A.M. Lucassen. 2022. 'The Environmental Sustainability of Data-Driven Health Research: A Scoping Review.' Digital Health 8: 20552076221111296.

13 Kings College London. 2022. Addressing the Environmental Impact of (Digital) Health Research. As of 30 June 2023: https://kclpure.kcl.ac.uk/portal/files/179062600/Summary_Report_of_funding_body_sustainability_workshop_J%20uly_2022.pdf

14 All European Academies (ALLEA). 2022. Towards Climate Sustainability of the Academic System in Europe and beyond. As of 30 June 2023: https://allea.org/portfolio-item/towards-climate-sustainability-of-the-academic-system-in-europe-and-beyond/

15 Dobbelaere, J., J.B. Heidelberger and N. Borgermann. 2022. 'Achieving Sustainable Transformation in Science – Green Grassroots Groups Need Nurturing from the Top.' Journal of Cell Science 135(17): jcs259645.

16 The Academy of Medical Sciences. 2023. Enabling greener biomedical research. As of 30 June 2023: https://acmedsci.ac.uk/file-download/47605694

17 Kings College London. 2022. Addressing the Environmental Impact of (Digital) Health Research. As of 30 June 2023: https://kclpure.kcl.ac.uk/portal/files/179062600/Summary_Report_of_funding_body_sustainability_workshop_J%20uly_2022.pdf

18 Modified from the following after desk research and expert consultation: Pang et al. 2003. Knowledge for better health: A conceptual framework and foundation for health research systems. Policy and Practice. As of 30 June 2023: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2572351/pdf/14758408.pdf

19 'Green chemistry (GC) is defined as the design of chemical products and processes to reduce or eliminate the use and generation of hazardous substances'. From: Sanchez M.E.C. et al. 2002. 'Green chemistry approaches to the synthesis of pyrazoline steroid derivatives and their theoretical DFT characterization.' Green Chemistry and Computational Chemistry. As of 30 June 2023: https://www.sciencedirect.com/topics/chemistry/green-chemistry

20 World Resources Institute. n.d. The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard. As of 30 June 2023: https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf

21 See Annex B for further information on methodology

22 Interviews with Wellcome staff.

23 Interviews with Wellcome staff.

24 https://www.universitiesuk.ac.uk/topics/climate-and-sustainability/accelerating-uk-tertiary-education

25 Focus groups, Green Algorithms Case Study, Sustainable Healthcare Coalition Case Study.

26 Focus groups.

27 The Academy of Medical Sciences. 2023. Enabling greener biomedical research. As of 30 June 2023: https://acmedsci.ac.uk/file-download/47605694

28 Focus groups.

29 Currently, the following assessments of sustainability criteria have been implemented in UK health research funding bodies: the Biotechnology and Biological Sciences Research Council (BBSRC) has included unweighted sustainability criteria in a funding call out; the Natural Environment Research Council (NERC) has implemented a pilot that required researchers to consider the environmental impact of their work; Wellcome asks for a calculation of carbon footprint as part of application; The Health Foundation asks applicants if they have an environmental policy and to explain the environmental impact of their proposal, which is not assessed but used to informed future assessed criterion; the European Commission Marie Skłodowska-Curie Actions (MSCA) assess how beneficiaries align with the MSCA green charter and will consider mandatory regulation, see MacFarlane, M. and G. Samuel. 2022. Addressing the Environmental Impact of (Digital) Health Research Conversations with UK funders Summary Report: 11–12.

30 Focus groups.

31 LEAF Case study

32 Another study concerning the methodology for measurement of artificial intelligence (AI) impact involving the Turing Institute has also received NIHR funding, but we were unable to locate the research award page (See MacFarlane, M. and G. Samuel. 2022. Addressing the Environmental Impact of (Digital) Health Research Conversations with UK funders Summary Report: 12).

33 Focus groups.

34 Focus groups. Green Algorithms case study. Sustainable Healthcare Coalition case study. LEAF case study.

35 Focus groups. Green Algorithms case study. Sustainable Healthcare Coalition case study. LEAF case study.

36 See, for example, the R&D people and culture strategy: https://www.gov.uk/government/publications/research-and-development-rd-people-and-culture-strategy; and the decision to emphasise research culture in the Research Excellence Framework 2028: https://www.ukri.org/publications/ref2028-initial-decisions-and-issues-for-further-consultation/

37 Samuel, G. and C. Richie. 2023. 'Reimagining research ethics to include environmental sustainability: A principled approach, including a case study of data-driven health research.' Journal of Medical Ethics 49: 428–433.

38 Resources for sustainable laboratory practice': https://www.rsc.org/policy-evidence-campaigns/environmental-sustainability/sustainability-reports-surveys-and-campaigns/sustainable-laboratories/resources-for-adopting-sustainable-lab-practices/.

39 The inclusion of clinical and digital labs is upcoming.

40 Universities UK. 2023. 'LEAF – A new standard in Sustainable Science'. Universities UK. As of 3 July 2023: https://www.universitiesuk.ac.uk/topics/international/international-staff-and-students/leaf-new-standard-sustainable-science

41 Environmental Sustainability Team. 2022. 'LEAF Workshop.' University of Manchester. As of 3 July 2023: https://documents.manchester.ac.uk/display.aspx?DocID=59386; Bennett, M. 2022. 'How Can We Improve Sustainability in the Lab? An Introduction to UCL's LEAF Programme.' FEBS. As of 3 July 2023: https://network.febs.org/posts/how-can-we-improve-sustainability-in-the-lab-an-introduction-to-ucl-s-leaf-programme

42 Environmental Sustainability Team. 2022. 'LEAF Workshop.' University of Manchester. As of 3 July 2023: https://documents.manchester.ac.uk/display.aspx?DocID=59386

43 UCL. 2022. 'Take part in LEAF'. Sustainable UCL. As of 3 July 2023: https://www.ucl.ac.uk/sustainable/case-studies/2020/aug/take-part-leaf; Interview 1a.

44 Environmental Sustainability Team. 2022. 'LEAF Workshop.' University of Manchester. As of 3 July 2023: https://documents.manchester.ac.uk/display.aspx?DocID=59386; University of Exeter. 'LEAF User Guide.' University of Exeter. As of 3 July 2023: https://www.exeter.ac.uk/media/universityofexeter/campusservices/sustainability/images/Get_Started_-_LEAF_User_Guide.pdf. These areas do not cover all sustainability categories measured by the standard, but LEAF is currently developing additional calculators for some.

45 Environmental Sustainability Team. 2022. 'LEAF Workshop.' University of Manchester. As of 3 July 2023: https://documents.manchester.ac.uk/display.aspx?DocID=59386

46 UCL. 2023. 'On-off Stickers.' University College London. As of 3 July 2023: https://www.ucl.ac.uk/sustainable/sites/sustainable/files/ucl_on_off_stickers.pdf; UCL. 2023.. 'Fume Cupboard sticker.' University College London. As of 3 July 2023: https://www.ucl.ac.uk/sustainable/sites/sustainable/files/fumecupboard_sticker.pdf; UCL. 2023. 'Leaving the lab checklist.' University College London. As of 3 July 2023: https://www.ucl.ac.uk/sustainable/sites/sustainable/files/leaving_the_lab_check_list_ucl.pdf

47 UCL. 2022. 'LEAF - Laboratory Efficiency Assessment Framework.' Sustainable UCL. As of 3 July 2023: https://www.ucl.ac.uk/sustainable/make-your-lab-sustainable-leaf

48 Interview 1a.

49 Green Labs NL. 2023. 'LEAF in Dutch Institutes Pilot.' Green Labs NL. As of 3 July 2023: https://www.greenlabs-nl.eu/leaf-project/

50 Interview 1a.

51 UCL. 2022. 'LEAF Impact.' Sustainable UCL. As of 3 July 2023: https://www.ucl.ac.uk/sustainable/leaf/leaf-impact. Interview 1a mentioned that these figures contained a 'huge' standard deviation due to the varying sizes and levels of use of laboratories.

52 UCL. 2022. 'LEAF Impact.' Sustainable UCL. As of 3 July 2023: https://www.ucl.ac.uk/sustainable/leaf/leaf-impact

53 LEAF is in the following countries: Denmark, Germany, England, Northern Ireland, Wales, Scotland, Ireland, Spain, Portugal, Australia, Austria, Switzerland, Israel, France, Belgium and the Netherlands. The European Molecular Biology Laboratory (EMBL), an intergovernmental organisation based in Heidelberg, Germany, is also implementing the standard.

54 Bennett, M. 2022. 'How Can We Improve Sustainability in the Lab? An Introduction to UCL's LEAF Programme.' FEBS. As of 3 July 2023: https://network.febs.org/posts/how-can-we-improve-sustainability-in-the-lab-an-introduction-to-ucl-s-leaf-programme

55 Bennett, M. 2022. 'Green Labs Go Global with LEAF.' Science and Engineering South. As of 3 July 2023: https://www.ses.ac.uk/green-labs-go-global-with-leaf/

56 MRC. 2022. 'Strategic Delivery Plan 2022-2025.' UK Research and Innovation. As of 3 July 2023: https://www.ukri.org/wp-content/uploads/2022/09/MRC-200922-MRCStratrgicDeliveryPlan.pdf; UKRI. 2021. 'MRC Announces Membership of Laboratory Efficiency Framework.' UK Research and Innovation. As of 3 July 2023: https://www.ukri.org/news/mrc-announces-membership-of-laboratory-efficiency-framework/

57 NTDC. 2019. 'The NTDC Supports LEAF Project.' National Technician Development Centre. As of 3 July 2023: https://drive.google.com/file/d/1yTArPEwzfNvi6Yo2OqPHH_JiWwjRzkRP/view?usp=share_link

58 Universities UK. 2023. 'LEAF – A new standard in Sustainable Science.' Universities UK. As of 3 July 2023: https://www.universitiesuk.ac.uk/latest/insights-and-analysis/leaf-new-standard-sustainable-science

59 Bennett, M. 2022. 'How Can We Improve Sustainability in the Lab? An Introduction to UCL's LEAF Programme.' FEBS. As of 3 July 2023: https://network.febs.org/posts/how-can-we-improve-sustainability-in-the-lab-an-introduction-to-ucl-s-leaf-programme

60 Rae, C.L., M. Farley, K.J. Jeffery and A.E. Urai. 2022. 'Climate Crisis and Ecological Emergency: Why They Concern (Neuro)Scientists, and What We Can Do.' Brain and Neuroscience Advances 6 (January). As of 3 July 2023: https://journals.sagepub.com/doi/10.1177/23982128221075430. Note: one of the authors of this article is the principal administrator of LEAF.

61 Further examples include: 'Have you calibrated your scales and pipettes in the past 12 months?' for those seeking bronze level status, asking for labs to normalise the sharing of negative results, and determining whether existing data from public sources could be used to satisfy part of the aims of the experiment (Interview 1a).

62 Marshall-Cook, J. and M. Farley. n.d. Sustainable Science and the Laboratory Efficiency Assessment Framework (LEAF).

63 Marshall-Cook, J. and M. Farley. n.d. Sustainable Science and the Laboratory Efficiency Assessment Framework (LEAF).

64 Marshall-Cook, J. and M. Farley. n.d. Sustainable Science and the Laboratory Efficiency Assessment Framework (LEAF).

65 Interviews 2f, 1b, 1c.

66 Interviews 1b, 1c.

67 Interviews 2c, 2f.

68 Interviews 1b, 1e.

69 Interview 2c.

70 Charity in UK context.

71 My Green Lab. n.d. 'Strategic Plan 2021–2023.' My Green Lab. As of 3 July 2023: https://www.mygreenlab.org/uploads/2/1/9/4/21945752/my_green_lab_strategic_plan-final_-_public.pdf

72 Davar, Z. 2017. 'Company Profile: My Green Lab.' Cleantech Rising (blog). As of 3 July 2023: https://medium.com/cleantech-rising/company-profile-my-green-lab-5a047639354b

73 My Green Lab. 2023. 'My Green Lab Certification.' My Green Lab. As of 3 July 2023: https://www.mygreenlab.org/green-lab-certification.html/#certificationprocess

74 MGL plans to consider facilities, procurement, and environment, health and safety staff as lab staff in a future version of the standard.

75 My Green Lab. 2023. 'My Green Lab Certification.' My Green Lab. As of 3 July 2023: https://www.mygreenlab.org/green-lab-certification.html

76 Interview 2a.

77 Answer options are: 'always', 'frequently', 'sometimes', 'never', 'I don't know' and 'this does not apply'.

78 Interview 2b.

79 Noonan, David. 2018. 'The 25% Revolution-How Big Does a Minority Have to Be to Reshape Society?' Scientific American. As of 3 July 2023: https://www.scientificamerican.com/article/the-25-revolution-how-big-does-a-minority-have-to-be-to-reshape-society/

80 Interview 2a.

81 IT labs are not covered, although some parts of the assessment apply to them (i.e. energy, plug load, community, employee travel/commuting and recycling). MGL is considering extending certification to IT labs in the future. Interview 2a.

82 My Green Lab. n.d. 'Green lab certificate sample feedback report.' As of 3 July 2023: https://www.mygreenlab.org/uploads/2/1/9/4/21945752/my_green_lab_cert_sample_feedback_report.pdf

83 Interview 2a.

84 Interview 2a.

85 Interview 2a.

86 Interview 2a.

87 As of writing, MGL certified labs are now located in the following countries: Argentina, Australia, Austria, Belgium, Brazil, Canada, Chile, China, Denmark, Egypt, Finland, France, Germany, Hungary, India, Indonesia, Ireland, Israel, Italy, Japan, Luxembourg, Malaysia, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Russia, Saudi Arabia, Singapore, Slovenia, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, the United Arab Emirates, United Kingdom, United States.

88 Interview 2a.

89 Windsor, M. 2023. 'What's new with the planet's greenest university research enterprise?' UAB.edu. As of 3 July 2023: https://www.uab.edu/reporter/campus/sustainability/item/9951-what-s-new-with-the-planet-s-greenest-university-research-enterprise

90 Interview 2a.

91 These are: 1) turning off equipment: >1 kWh/day (this assumes turning off two water baths overnight); 2) adjusting set points on ultra-low temperature freezers: 8 kWh/day/freezer; and 3) closing fume hood sashes: 20 kWh/day/fume hood. From Paradise, A. 2021. Asking Why: Cultivating Eco-Consciousness in Research Labs. As of 3 July 2023: https://books.openedition.org/obp/20753?lang=en#notes

92 Interview 2a.

93 Interview 2a.

94 Interview 2a.

95 Interview 2a.

96 My Green Lab. 2021. 'Green Lab Certification Named Key Player in the UN Climate Change's Race to Zero.' My Green Lab. As of 3 July 2023: https://www.mygreenlab.org/blog-beaker/green-lab-certification-named-key-player-in-the-un-climate-changes-race-to-zero

97 My Green Lab. 2021. 'Green Labs Go Global: 2021 Year in Review.' My Green Lab. As of 3 July 2023: https://www.mygreenlab.org/blog-beaker/green-labs-go-global-2021-year-in-review

98 Interview 2b.

99 Interview 2d, 2e.

100 Interview 2c.

101 Interview 2d, 2e.

102 Interview 2a.

103 Interview 2a.

104 NIHR. 2019. 'NIHR Carbon Reduction Guidelines.' Nihr.ac.uk. As of 3 July 2023: https://www.nihr.ac.uk/documents/the-nihr-carbon-reduction-guidelines/21685

105 NIHR. 2019. 'NIHR Carbon Reduction Guidelines.' Nihr.ac.uk. As of 3 July 2023: https://www.nihr.ac.uk/documents/the-nihr-carbon-reduction-guidelines/21685

106 NIHR Funding Application Form (Internal documentation)

107 Lyle K, L. Dent, S. Bailey, L. Kerridge, I. Roberts, R. Milne et al. 2009. 'Carbon cost of pragmatic randomised controlled trials: Retrospective analysis of sample of trials.' British Medical Journal 339.

108 Interview 5c

109 Interview 5c; Sustainable Trials Study Group. 2007. 'Towards sustainable clinical trials.' British Medical Journal 334: 671. As of 3 July 2023: https://doi.org/10.1136/bmj.39140.623137.BE

110 Lyle K, L. Dent, S. Bailey, L. Kerridge, I. Roberts, R. Milne et al. 2009. 'Carbon cost of pragmatic randomised controlled trials: Retrospective analysis of sample of trials.' British Medical Journal 339.

111 Interview 5c

112 NIHR. 2019. 'NIHR Carbon Reduction Guidelines.' Nihr.ac.uk. As of 3 July 2023: https://www.nihr.ac.uk/documents/the-nihr-carbon-reduction-guidelines/21685

113 Interview 5c

114 Interview 5c

115 Interview 5c

116 Interview 5a

117 Interview 5c

118 Interview 5c

119 For example: Adshead, F. et al. 2021. 'A strategy to reduce the carbon footprint of clinical trials.' The Lancet 398(10297): 281–282.

120 For example: Samuel, G. and C. Richie. 2023. 'Reimagining research ethics to include environmental sustainability: A principled approach, including a case study of data-driven health research.' Journal of Medical Ethics 49: 428–433.

121 Interview 5b

122 Adshead, F. et al. 2021. 'A strategy to reduce the carbon footprint of clinical trials.' The Lancet 398(10297): 281–282.

123 Interview 5a.

124 Interview 5b
125 Interview 5c
126 Interview 5c
127 Interview 5b
128 Interview 5c
129 Interview 5b
130 Adshead, F. et al. 2021. 'A strategy to reduce the carbon footprint of clinical trials.' The Lancet 398(10297): 281–282.
131 Interview 5b
132 Interview 5b
133 Interview 5a
134 Interview 5c
135 Interview 5c
136 Interview 5c
137 Interview 5c
138 Interview 5c
139 Sustainable Healthcare Coalition. 2023. 'What we are.' Shcoalition.org. As of 4 July 2023: https://shcoalition.org/what-we-are/
140 Sustainable Healthcare Coalition. 2023. 'Making clinical trials sustainable.' Shcoalition.org. As of 4 July 2023: https://shcoalition.org/clinical-trials/
141 Interview 4a.
142 Interview 4b.
143 Committees Parliament. 2015, March. 'Written evidence submitted by the Coalition for Sustainable Pharmaceuticals and Medical Devices.' Committees.parliament.uk. As of 4 July 2023: https://committees.parliament.uk/writtenevidence/56683/html/#:~:text=The%20Coalition%20for%20Sustainable%20Pharmaceuticals%20and%20Medical%20Devices,NHS.%20Further%20information%20can%20be%20found%20here%3A%20www.sduhealth.org.uk%2Fcspm
144 Sustainable Healthcare Coalition. 2023. 'What we are.' Shcoalition.org. As of 4 July 2023: https://shcoalition.org/what-we-are/
145 Interview 4a.
146 Sustainable Healthcare Coalition. 2023. 'What we are.' Shcoalition.org. As of 3 July 2023: https://shcoalition.org/what-we-are/
147 Interview 4a.
148 Interview 4b.
149 Adshead, F. et al. 2021. 'A strategy to reduce the carbon footprint of clinical trials.' The Lancet 398(10297): 281–282.
150 Interview 4b.
151 Interview 4b.
152 Interview 4a.
153 Interview 4a.
154 Interview 4a.
155 Interview 4b.
156 Interview 4c.
157 Interview 4c.
158 Interview 4b.
159 Interview 4c.
160 Interview 4a.

161 Interview 4b.

162 Interview 4a.

163 Interview 4b.

164 Lannelongue, L., J. Grealey and M. Inouye. 2021. 'Green algorithms: Quantifying the carbon footprint of computation.' Advanced Science 8(12): 2100707. As of 4 July 2023: https://doi.org/10.1002/advs.202100707

165 Interview 7a.

166 Strubell, E., A. Ganesh and A. McCallum. 2019. 'Energy and policy considerations for deep learning in NLP.' arXiv preprint arXiv 1906.02243.

167 Lannelongue, L., J. Grealey and M. Inouye. 2021. 'Green algorithms: Quantifying the carbon footprint of computation.' Advanced Science 8(12): p. 2100707. As of 4 July 2023: https://doi.org/10.1002/advs.202100707

168 Interview 7a.

169 Interview 7a.

170 Patterson, D. et al. 2021. 'Carbon Emissions and Large Neural Network Training.' arXiv:2104.10350. As of 4 July 2023: https://arxiv.org/abs/2104.10350

171 Interview 7a.

172 Patterson, D. et al. 2021. 'Carbon emissions and Large Neural Network Training.' arXiv:2104.10350. As of 4 July 2023: https://arxiv.org/abs/2104.10350

173 Carbon intensity 'refers to how many grams of carbon dioxide (CO2) are released to produce a kilowatt hour (kWh) of electricity.' From: National Grid. 2023. 'What is carbon intensity'. As of 4 July 2023: https://www.nationalgrid.com/stories/energy-explained/what-is-carbon-intensity#:~:text=Carbon%20intensity%20is%20a%20measure,generated%20creates%20CO2%20emissions

174 Lannelongue, L., J. Grealey and M. Inouye. 2021. 'Green algorithms: Quantifying the carbon footprint of computation.' Advanced Science 8(12): p. 2100707. As of 4 July 2023: https://doi.org/10.1002/advs.202100707

175 Interview 7a.

176 Interview 7a.

177 Institute of Radio Astronomy and Astrophysics. n.d. Homepage. Irya.unam.mx. As of 4 July 2023: https://www.irya.unam.mx/web/en/

178 Interview 7a.

179 Interview 7b.

180 Interview 7a.

181 Carbon Literacy Project. n.d. 'Introduction to Carbon Literacy.' As of 4 July 2023: https://carbonliteracy.com/wp-content/uploads/2020/03/Introduction-to-Carbon-Literacy-Pack-v2.pdf

182 Interview 6a.

183 The case study will focus on organisations, although the project can also work with individuals and offer training to become a trainer for the programme or a carbon literacy training organisation.

184 Interview 6a.

185 Interview 6a.

186 Carbon Literacy Project. n.d. 'Organisation.' Carbonliteracy.com. As of 4 July 2023: https://carbonliteracy.com/organisation/

187 Interview 6a.

188 Carbon Literacy Project. n.d. 'About us.' Carbonliteracy.com. As of 4 July 2023: https://carbonliteracy.com/about-us/

189 Interview 6a.

190 Interview 6a.

191 NHS England. 2023. 'Greener NHS.' England.nhs.uk. As of 4 July 2023: https://www.england.nhs.uk/greenernhs/

192 Carbon Literacy Project. 2023. 'About us.' Carbonliteracy.com. As of 4 July 2023: https://carbonliteracy.com/about-us/

193 Interview 6a. The website indicates that 224,000 CO2e has been saved, but this is an average figure that has been extrapolated from a subset of learners to all certified learners. See Carbon Literacy Project. 2023. 'About us.' Carbonliteracy.com. As of 4 July 2023: https://carbonliteracy.com/about-us/

194 Studies including evaluations of carbon literacy training (including carbon literacy for labs) are available here: Carbon Literacy Project. 2023. 'Research.' Carbonliteracy.com. As of 4 July 2023: https://carbonliteracy.com/about-us/research/

195 Astbury, J. and K. Tate. 2012. 'Manchester Carbon Literacy Evaluation: Report Highlights.' The University of Manchester. As of 4 July 2023: https://carbonliteracy.com/wp-content/uploads/2018/09/MCL-Evaluation-Report-Highlights-27.11.12.pdf

196 Interview 6a.

197 Interview 6b.

198 Interview 6a.

199 Astbury, J. and K. Tate. 2012. 'Manchester Carbon Literacy Evaluation: Report Highlights.' The University of Manchester. As of 4 July 2023: https://carbonliteracy.com/wp-content/uploads/2018/09/MCL-Evaluation-Report-Highlights-27.11.12.pdf

200 Interview 6b.

201 Interview 6a.

202 Interview 6a.

203 Interview 6a.

204 Interview 6b.

205 Youtube. 2021. 'ARCHER2: Farewell to Archer.' Youtube.com. As of 4 July 2023: https://www.youtube.com/watch?v=SmM4ffwXlVo

206 Youtube. 2021. 'ARCHER2 – the UK's new supercomputer.' Youtube.com. As of 4 July 2023: https://www.youtube.com/watch?v=NEgbVNIo560; EPCC. 2023. 'Prof Mark Parsons.' Eppc.ed.ac.uk. As of 4 July 2023: https://www.epcc.ed.ac.uk/about-us/our-team/prof-mark-parsons

207 Zhang, Y. et al. 2022. 'Cooling technologies for data centres and telecommunication base stations: A comprehensive review.' Journal of Cleaner Production 334: 130280.

208 'Scope 3 includes all other indirect emissions that occur in the upstream and downstream activities of an organisation.' From Carbon Trust. 2023. 'Briefing: What are Scope 3 emissions.' Carbontrust.com. As of 4 July 2023: https://www.carbontrust.com/our-work-and-impact/guides-reports-and-tools/briefing-what-are-scope-3-emissions

209 Woodward, L., P. Townsend and M.N. Juckes. 2022. 'Net zero DRI scoping interim report: Stakeholder feedback.' Report on meeting held July 21st, 2022. Centre for Environmental Data Analysis. As of 4 July 2023: https://doi.org/10.5281/zenodo.6962305

210 Definition from UKRI website: 'The building blocks of the digital research infrastructure system include: large-scale computer facilities, including high-throughout, high-performance, and cloud computing; data storage facilities, repositories, stewardship and security; software and shared code libraries; mechanisms for access, such as networks and user authentication systems…' UKRI. 2022. 'Digital research Infrastructure.' Ukri.org. As of 4 July 2023: https://www.ukri.org/what-we-offer/creating-world-class-research-and-innovation-infrastructure/digital-research-infrastructure/

211 UKRI. 2020. 'UKRI Environmental Sustainability Strategy.' Ukri.org. As of 4 July 2023: https://www.ukri.org/wp-content/uploads/2020/10/UKRI-050920-SustainabilityStrategy.pdf

212 UKRI. 2020. 'UKRI Environmental Sustainability Strategy.' Ukri.org. As of 4 July 2023: https://www.ukri.org/wp-content/uploads/2020/10/UKRI-050920-SustainabilityStrategy.pdf

213 Zenodo. 2022. 'Introduction presentation for the UKRI Net Zero Digital Research Infrastructure project open meeting.' Zenodo.org. As of 4 July 2023: https://zenodo.org/record/5846588#.Y-P1zHbP2UI

214 Zenodo. 2022. 'Introduction presentation for the UKRI Net Zero Digital Research Infrastructure project open meeting.' Zenodo.org. As of 4 July 2023: https://zenodo.org/record/5846588#.Y-P1zHbP2UI

215 CEDA. 2023. 'UKRI Net Zero Digital Research Infrastructure Scoping Project.' As of 4 July 2023: https://net-zero-dri.ceda.ac.uk/

216 Zenodo. 2022. 'Introduction presentation for the UKRI Net Zero Digital Research Infrastructure project open meeting.' Zenodo.org. As of 4 July 2023: https://zenodo.org/record/5846588#.Y-P1zHbP2UI

217 CEDA. 2023. 'UKRI Net Zero Digital Research Infrastructure Scoping Project.' As of 4 July 2023: https://net-zero-dri.ceda.ac.uk/

218 CEDA. 2022. 'Partnering up to reach net zero computing.' Ceda.ac.uk. As of 4 July 2023: https://net-zero-dri.ceda.ac.uk/news/project-partners/

219 CEDA. 2023. 'Sandpit event.' Ceda.ac.uk. As of 4 July 2023: https://net-zero-dri.ceda.ac.uk/sandpit/

220 Interviews 8a, 8b.

221 Interview 8b.

222 Woodward, L., P. Townsend and M.N. Juckes. 2022. 'Net zero DRI scoping interim report: Stakeholder feedback.' Report on meeting held July 21st, 2022. Centre for Environmental Data Analysis. As of 4 July 2023: https://doi.org/10.5281/zenodo.6962305

223 Woodward, L., P. Townsend and M.N. Juckes. 2022. 'Net zero DRI scoping interim report: Stakeholder feedback.' Report on meeting held July 21st, 2022. Centre for Environmental Data Analysis. As of 4 July 2023: https://doi.org/10.5281/zenodo.6962305

224 Woodward, L., Townsend, P., and Juckes, M.N., 2022: Net zero DRI scoping interim report: stakeholder feedback (report on meeting held July 21st, 2022), Centre for Environmental Data Analysis, DOI: 10.5281/zenodo.6962305, 2022.

225 Woodward, L., Townsend, P., and Juckes, M.N., 2022: Net zero DRI scoping interim report: stakeholder feedback (report on meeting held July 21st, 2022), Centre for Environmental Data Analysis, DOI: 10.5

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