Effectiveness of interventions to reduce carbon-emissions within secondary healthcare: Systematic review and narrative synthesis

Liz Shaw[1], Noreen Orr[1], Hassanat M. Lawal[1], Simon Briscoe[1], Xiaoyu Yan[2], Jo Thompson Coon[1], G.J. Melendez-Torres[1], Clara Martin-Pintado[1], Ruth Garside[1, 3]

[1]Exeter PRP Evidence Review Facility, College of Health and Community Sciences, South Cloisters, St Luke's Campus, Heavitree Road, University of Exeter, Devon, EX1 2LU.

[2]Environment and Sustainability Institute, University of Exeter, Penryn Campus, Penryn, Cornwall, TR10 9FE, UK

[3]European Centre for Environment and Human Health, Department of Public Health and Sports Science (Medical School) University of Exeter, Peter Lanyon, Penryn Campus, Penryn, Cornwall, TR10 9FE

Final Report

29.10.2024

Corresponding author:

Ruth Garside (R.Garside @exeter.ac.uk; 01392 725651; South Cloisters, St Luke's Campus, Heavitree Road, Exeter, Exeter, Devon, UK, EX1 2LU).

Conflicts of interests

None.

Funding

This is an independent report commissioned and funded by the NIHR Policy Research Programme [NIHR200695].

Jo Thompson Coon is supported by the National Institute for Health and Care Research Collaboration South West Peninsula. This report is independent research supported by the National Institute for Health Research Applied Research Collaboration South West Peninsula. The views expressed in this publication are those of the author(s) and not necessarily those of the National Institute for Health Research or the Department of Health and Social Care.

The opinions expressed in this publication are not necessarily those of the Exeter PRP Evidence Review Facility or the funders. Responsibility for the views expressed remains solely with the authors.

Data-sharing statement

Requests for access to data should be addressed to the corresponding author.

Funder involvement

This work is part of an ongoing programme of work funded by the NIHR Policy Research Programme. Throughout the review, stakeholders from the Greener NHS team within NHS England were consulted to understand the context of the issue under study, collaborated on the development of the research question(s) and protocol and development of the evidence and gap map.

Guarantor of the review: Professor Ruth Garside

DOI: 10.5281/zenodo.14169531

Contents

List of Tables

List of Figures

Abbreviations

CO_2	Carbon Dioxide
CO_2-eq	Carbon Dioxide equivalent
DHSC	Department of Health and Social Care
LCA	Life Cycle Assessment
NHS	National Health Service
NHSE	NHS England
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PRP	Policy Research Programme
UK	United Kingdom
USA	United States of America
PPE	Personal Protective Equipment

Guidance on the type of review and how to read this report

This is a technical report structured to foreground the findings of the narrative evidence synthesis. Thus, the report is divided into the following sections:

1. **Executive summary:** An executive summary providing an overview of the methods, key findings and implications for future research and clinical practice.
2. **Main report:** This provides a background to the systematic review, detailed methods, and results, before discussing the main findings of the review in the context of existing research and identifying potential implications for future policy, research, and practice.
3. **Appendices:** These provide the information necessary to support comprehension of the conduct and findings of the review.
4. **Supplementary Materials:** Supplementary Materials 1 provide an overview of all the studies included in the review. Supplementary Materials 2 provides additional information regarding how carbon emissions were calculated within each Life Cycle Assessment (LCA) study included in this review. Supplementary Materials 3 and 4 details the outcome measures and findings associated with LCA and non-LCA studies respectively which are included within this review.

Executive summary

What do we want to know?

The environmental footprint of healthcare services contributes between 1% and 5% towards the total global environmental impacts.(1, 2) In 2008, the Climate Change Act set national targets for the 100 percent reduction of carbon emissions in England of 1990 levels by 2050.(3) The National Health Service (NHS) has an important role in helping to achieve these targets, as the organisation accounts for 4% of England’s carbon-footprint.(4) Work focusing on identifying and delivering interventions to reduce carbon emissions within known carbon hotspots, such as NHS estates and facilities, travel and transport, supply chain, and certain medicines and medical and anaesthetic gases that have high global warming potential is already underway, alongside examining the effectiveness of different models of care delivery across all specialities.(4, 5) Evidence focusing on the effectiveness of interventions in reducing carbon emissions within secondary healthcare would be a useful complement to this work. An approach which also considers the patient pathway may be beneficial in identifying interventions which consider wider healthcare systems and thus have a meaningful impact on reducing carbon emissions.

We aimed to carry out a systematic review which examined the effectiveness of interventions in reducing the carbon footprint within specific medical specialities in secondary healthcare and explored where this evidence could inform the patient care pathway.

Research questions

What is the effectiveness of interventions for reducing the carbon footprint of medical interventions carried out in the following medical specialties within secondary healthcare:

- Cardiology
- Gastroenterology
- Ophthalmology
- Orthopaedics and trauma
- Renal
- Respiratory
- High volume low complexity surgery:
    - Ear, nose and throat
    - Gynaecology
    - Urology

We focused our research question on medical specialties with high levels of inpatient activity as these are likely to have the greatest impact on carbon emissions.

What we did

We carried out a systematic review of quantitative evidence evaluating the effectiveness of interventions intending to reduce carbon emissions within secondary healthcare in the specialities listed above. We searched a selection of bibliographic databases with coverage of both health care and environmental science journals, which we supplemented by inspecting the HealthcareLCA database, conducting forwards and backwards citation chasing on all studies which met our inclusion criteria, searching reference lists of topically relevant reviews, and searching Google Scholar and a selection of relevant websites.

Two reviewers independently carried out title/abstract and full-text screening using a list of pre-determined inclusion and exclusion criteria, with disagreements resolved through discussion. We extracted descriptive data regarding study sample, intervention/control group, carbon emission methodology, PROGRESS-PLUS criteria (related to equity) and environmental, patient and cost outcomes. We appraised the quality of studies using life cycle assessment (LCA) methods with a predetermined scoring system informed by Weidema's (1997) guidelines.

We synthesised the findings from LCA and non-LCA studies separately using narrative synthesis. Within each of these groups, studies were grouped into five broad intervention categories, 1) Accessing care, 2) Product level, 3) Care Delivery, 4) Setting and 5) Multiple components (detail regarding interventions included within each of these categories can be found in Table 3 of this report). We looked for, and tried to explain, patterns across studies within the same specialty which evaluated similar interventions. We also developed an evidence and gap map to highlight where evidence relevant to the aims of this review could inform a generic patient care pathway for each speciality and inform the future of research towards lower carbon pathways. To provide an accessible structure, the primary research evidence is mapped according to speciality, intervention and how each study may be used within the patient care pathway, from assessment and initial treatment, through to discharge from secondary care.

Input from the Greener NHS team at NHS England, LCA methods experts and patient and public representatives was incorporated throughout.

What did we find?

Eighty-nine studies (93 articles) met the eligibility criteria for inclusion.

Twenty-nine studies used life-cycle assessment (LCA) informed methods to calculate carbon emissions, 19 of these utilised a full LCA approach, comprising both:

1) an inventory analysis, evaluating the energy consumption, emissions and resources associated with an intervention throughout the life-cycle of the product, process or activity, and;
2) an impact assessment, converting inventory data from the life cycle assessment into a set of potential impacts on the environment (e.g. carbon emissions, eutrophication, ecosystem quality, non-renewable resources etc.).

Of the 33 studies conducted within the UK, one of these used full LCA methods. Urology (n=14), gastroenterology (n=13), oncology/radiation oncology (n=13) and renal (n=11) were the most common specialities represented.

Across different specialities, the majority of evidence was found in the first three stages of the patient care pathway (Initial assessment/diagnostic tests, initial treatment or follow-up). The exception to this was the renal specialty, where most of the evidence was within the 'Ongoing care' segment of the patient care pathway. There was limited evidence within the 'Discharge' segment of the care pathway across all specialities. Evidence relating to the wider health care setting was clustered within the gastroenterology (n=5) and radiology specialities (n=5). This evidence is displayed in an evidence and gap map.

Within the narrative synthesis, the number of studies in each broad intervention category was as follows: Accessing care: 29, Setting: 20, Product level: 17, Care delivery: 16 and Multiple components: 7.

The two largest groups of evidence were for studies evaluating telehealth (n=26) and reuseable equipment (n=13) interventions. Telehealth interventions were predominantly evaluated using non-LCA methods (n=23) and, whilst carbon-emissions favoured telemedicine interventions when compared to face-to-face care, these calculations often only considered patient-travel saved and did not account for carbon emissions associated with other parts of the delivery of the service, such as digital technology used or the energy use of building or clinic equipment for face to face appointments, or wider impact on the patient care pathway such as potential need to travel for additional primary care appointments. In general, the majority of patient and cost outcomes evaluated, favoured the telemedicine intervention, although most outcomes were based on descriptive or narrative analyses. Interventions comparing carbon emissions associated with the use of reuseable versus disposable surgical equipment represented the largest group of studies using LCA methods. For studies within the gastroenterology speciality, reuseable equipment was associated with reduced carbon-emissions. Within urology this finding was more uncertain, with three of the five studies finding disposable instruments to be associated with reduced carbon emissions. However, despite studies relating to this latter finding mainly being appraised as 'High' or 'Medium' quality, questions regarding the accuracy of use of characterization factors, quantity of materials used in disposable vs reuseable equipment packs and how carbon emissions were assigned to the reprocessing stage of reuseable equipment mean confidence in this finding is uncertain. In general, four of the five studies comparing reuseable and disposable urology equipment scored poorly on the quality appraisal item evaluating the reporting and potential influence of study funding and author conflicts of interest. Whilst waste management/reduction interventions were associated with reduced carbon emissions (n=12), interventions were highly heterogeneous with limited consideration of patient or cost outcomes. Eight non-LCA studies found reduced carbon emissions were associated with energy conservation interventions, such as turning equipment off when not in use or choosing imaging techniques with lower energy use, the majority of which were conducted within radiology/radiotherapy settings.

Key limitations to the evidence included within the review:

- A high degree of heterogeneity amongst types of intervention conducted within individual specialities, which made it challenging to identify interventions which were effective in reducing carbon emissions across different contexts.
- The number of studies including patient and cost outcomes alongside carbon emission calculations was also limited.
- Within studies drawing on an LCA approach, the lack of transparency in the reporting of methodological details raised issues of comparability and generalisability. Comparability was also hindered by the lack of consistency in how studies defined and reported the system boundaries for individual LCA studies.
- Carbon emission calculations used within non-LCA studies were typically narrow in scope, focusing on the "use and/or reuse" of products, with less consideration of other factors within the wider system which may also influence carbon emissions of the intervention under consideration, for example, energy used by both health services and patients.
- The extent to which carbon-emission calculations in non-LCA studies considered emissions associated with manufacture of equipment, vehicles or fuel, transport and/or waste management was also limited and dependant on the intervention in question.

- Comparisons between intervention/control groups in non-LCA studies made predominantly using non-statistical analysis.

What are the implications?

Research: Existing research relating to carbon emissions reflects a narrow range of all the possible interventions/specialties available. Further research needed to fill the gaps is highlighted in the evidence and gap map. Studies utilising full LCA methods were underrepresented. The uncertainty regarding the beneficial effects of reuseable equipment on carbon-emissions within urology underscores the importance of considering the full product pathway within an LCA approach and ensuring the system boundaries for the change being considered reflect all parts of the patient care pathway and product life-cycle. It also emphasises the importance of incorporating sensitivity analysis into LCAs and highlights the importance of considering mechanisms to reduce carbon emissions associated with the processes supporting the manufacture, transport and reprocessing of disposable and/or reuseable equipment as a target for future interventions.

Whilst LCAs may not always be appropriate or possible to conduct within health care settings, guidance for researchers examining the effectiveness of interventions intended to reduce carbon emissions using non-LCA study designs is needed to ensure all relevant factors relating to carbon-emissions from patient-care and emission pathways are considered.

Future primary research is needed which considers environmental outcomes alongside clinical/patient and cost outcomes to inform future policy and clinical practice.

Research evaluating telehealth interventions needs to ensure the digital carbon footprint is fully considered, alongside enduring the technology is used effectively to maximise patient outcomes and reduce costs across primary and secondary care.

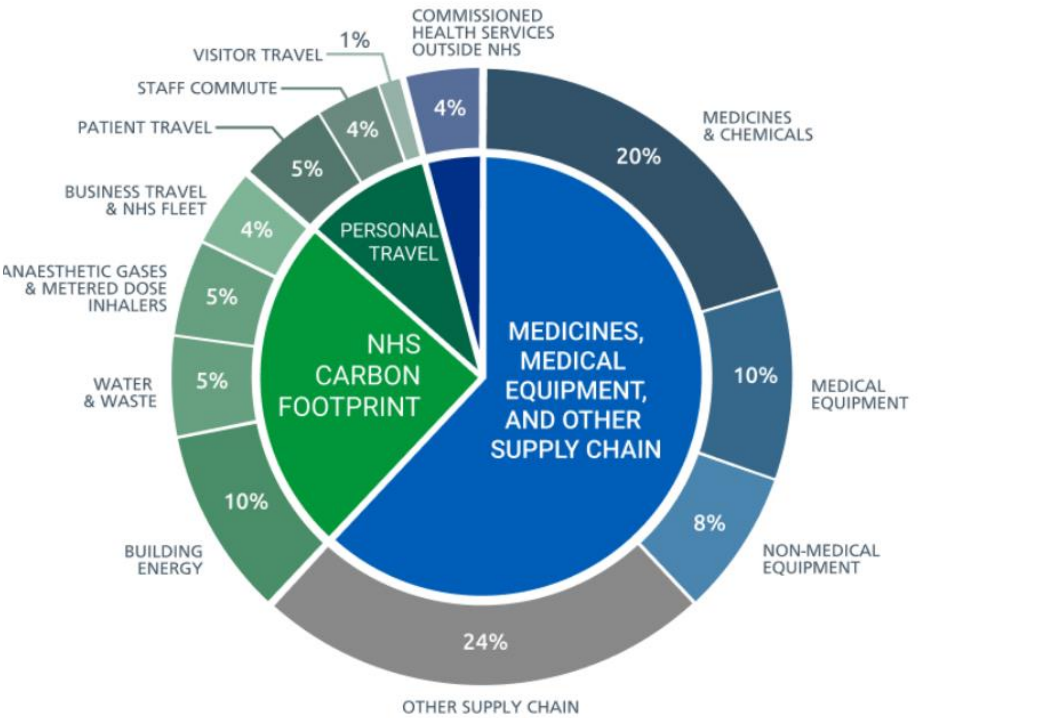
Practice: Patient and cost-outcomes were rarely considered alongside carbon emission calculations in the body of research evaluated. Hence, whilst there is tentative evidence to indicate that interventions which reduce the distance patients need to travel to access care is associated with reduced carbon emissions, the impact on patient clinical outcomes and patient satisfaction is inconclusive. There is also tentative evidence to indicate that reuseable surgical equipment is associated with reduced carbon emissions when compared with single-use within certain specialties. However, this is influenced by the composition of the instrument and how the reprocessing of reuseable units is carried out (e.g. number of units reprocessed at any one time and duration of reprocessing procedures) within specific local contexts.

Policy: The evidence and gap map provides a resource to identify where gaps in primary evidence exist on the patient care pathway both within and across different specialties, making it a useful tool to inform the commissioning of future research. The narrative synthesis considers the quality and quantity of evidence available to support the use of specific interventions to reduce carbon emissions within individual specialties. Our review highlights the larger groups of evidence available pertaining to the use of telehealth care and reuseable surgical equipment across different specialties and its methodological limitations which may influence the commissioning of future research and the implementation of interventions within secondary healthcare.

Part 1: Background

"The climate emergency is also a health emergency".(6) Climate change directly impacts the health of the human population through events such as earthquakes, flooding, heatwaves and drought, which increase the risk of injury, displacement, disruption of food supplies, infectious diseases and mental ill health.(1, 2, 6, 7) The impact on population health of these climate events, alongside indirect health consequences such as increased prevalence of respiratory conditions due to air pollution, places increased burden on health services.(8)

Whilst necessary for improving and maintaining human wellbeing, the environmental footprint of healthcare services contributes between 1% and 5% towards total global environmental impacts,(1, 2) with the National Health Service (NHS) accounting for 4% of England's carbon-footprint.(4) Sources of carbon emissions within the UK healthcare setting were calculated between 1990 to 2019, with the largest share of emissions being supply chains (62%), and other sources including delivery of care (24%), travel to and from NHS sites by staff, patients and visitors (10%) and private health and care services commissioned by the NHS (4%).(2) Figure 1 below provides a more detailed breakdown of sources of carbon emissions.(4)



(6)

Figure 1: Sources of carbon emissions by proportion of NHS Carbon Footprint plus (4)

Policy context

In 2008, the Climate Change Act set national targets for the 100 percent reduction of carbon emissions in England of 1990 levels by 2050.(3) Since 2010 the NHS has exceeded its commitments under the Act by reducing its carbon footprint by 30%,(6) through committing to NetZero targets.(4) The health and social care system in England achieved a reduction of 62% in carbon emissions between 1990 and 2020. NHS England (NHSE) have committed to achieve a reduction of 80% by 2028-2032 for emissions controllable by the NHS, creating a new national mandate for change.(4) Reducing the impact of the healthcare system on climate change has the potential to benefit population health, through improved air quality and diet, and increased activity levels.(9)

The NHS England Greener NHS, alongside the Primary Care and Medicines, policy teams have been working closely with patients, clinicians, and industry to minimise emissions from medicines and anaesthetic gases. Key focus areas include reducing waste, ensuring the right medicines are available to patients, and finding mechanisms to support shared, informed decision making.(4)

Work focusing on identifying and delivering interventions to reduce carbon emissions within known carbon hotspots, such as NHS estates and facilities, travel and transport, supply chain, and certain medicines and medical and anaesthetic gases that have high global warming potential is already underway, alongside examining the effectiveness of different models of care delivery across all specialities, to enable safe, patient-centred lower carbon care models.(4, 5)

Evidence focusing on the effectiveness of interventions to reduce carbon emissions within secondary healthcare would be a useful complement to the work. The type of care, how it is delivered, and the place care is delivered within underpins the carbon footprint of the NHS. An approach which considers how care is delivered across patient care pathways within individual specialities may help support the delivery of equitable and accessible high-quality care. Such an approach can also consider other wider NHS/health services policies and ensuring that all those that involved in the design and delivery of care are involved.

Existing evidence

Scoping of the evidence base indicates that there are several systematic reviews which examine different types of interventions to reduce carbon emissions which are summarised below.

Four systematic reviews focus on interventions to reduce carbon-emissions within operating theatres.(10-13) Papadopoulou et al. (2022) examine the environmental sustainability of minimally invasive surgery techniques (including robotic and laparoscopic surgery) and include studies from a variety of different specialities which examine different interventions such as cost-awareness campaigns and reusable instruments or report a LCA for a particular surgical procedure.(10) The number of studies evaluating/modelling the effect of an intervention in this review was limited (n=6), with gynaecology and gastroenterology being the main surgical specialties represented.(10) In the review conducted by Perry et al (2022), studies evaluated interventions focusing on recycling and waste management, waste reduction, reuse, reprocessing/LCA, energy and resource reduction and anaesthetic gases.(12) Searches were confined to the medical literature and carbon emission data were not routinely reported for all the included primary studies. Keil et al (2022) included LCAs which compared single-use and reusable healthcare products with similar functions.(11) Interventions focused on non-invasive medical devices, inhalers, invasive medical devices and protective equipment. The review synthesis predominantly focused on greenhouse gas emission data, rather than carbon-emissions, and did not consider the influence of individual specialities.(11) Finally, the review conducted by Siu et al (2016) compared the environmental impact of reusable vs disposable laparoscopic instruments.(13) Searches for this review were limited to sources from the medical field and the review authors did not conduct quality appraisal of the included studies or report carbon-emission outcomes.

Two systematic reviews explored the environmental impact of telemedicine interventions in place of face-to-face patient care.(14, 15) The review by Ravindrane and Patel (2022) encompassed renal medicine, head and neck cancer, vascular surgery and urology specialities.(14) Whilst the review reported the impact of this type of intervention on carbon-emissions, it did not consider variation in the use of telemedicine within different specialities.(14) Lange et al (2022) applied a transparency checklist for carbon footprint calculations within a systematic review of virtual care interventions.(15) Overall, the review highlighted a saving of 148kg carbon dioxide equivalents[1] per patient, but indicated the evidence was weak, with the reported carbon footprint being highly heterogeneous.(15) This review did not calculate contributions of individual specialities/pathways.(15) In addition, these existing systematic reviews do not consider the evidence relating to environmental impact of these interventions alongside impact on patient and financial outcomes.

Due to the lack of systematic reviews which consider carbon emissions associated with the patient pathway within individual specialties, further research is needed to identify and transform the most carbon intensive clinical pathways, while ensuring future models of care can be delivered in a cost-effective manner without increasing emissions or compromising patient care.

[1] a metric measure used to compare the emissions from various greenhouse gases on the basis of their global-warming potential, by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming potential.16. Explained ES. Glossary:Carbon dioxide equivalent 2024 [Available from: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Carbon_dioxide_equivalent.

Aim

To carry out a systematic review which examines the effectiveness of interventions in reducing the carbon footprint within medical specialities with high levels of inpatient activity in secondary healthcare.

Research questions

What is the effectiveness of interventions for reducing the carbon footprint of medical interventions carried out in the following medical specialties within secondary healthcare:

- Cardiology
- Gastroenterology
- Ophthalmology
- Orthopaedics and trauma
- Renal
- Respiratory
- High volume low complexity surgery, specifically:
    - Ear, nose, and throat
    - Gynaecology
    - Urology

We focused our research question on medical specialties with high levels of inpatient activity as these are likely to have the greatest impact on carbon emissions.

Methodology

Our review protocol was prospectively registered on the Open Repository Exeter.(17) The methods used to conduct and report the findings are consistent with the best practice approach for the conduct of systematic reviews and reporting of evidence synthesis.(18-20) Below, we summarise how we identified relevant primary studies, quality appraised these and synthesised their findings.

Search strategy

The search strategy was developed by an information specialist (SB) in consultation with the review team and stakeholders (for further information, see 'Stakeholder involvement' section below). Our overall approach combined searches of bibliographic databases with backward and forward citation searches of studies which met the inclusion criteria, web searches of topically relevant organisations, searches of Google Search, and checking the included studies of topically similar systematic reviews. In addition, we inspected the Healthcare LCA database for relevant studies.

Bibliographic databases

We searched a selection of bibliographic databases with coverage of both health care and environmental science journals, including the health care databases MEDLINE and Embase (both via Ovid), the environmental science database Environment Complete (via EBSCO) and the multidisciplinary Science Citation Index database (via Web of Science, Clarivate Analytics). Searches of MEDLINE and Embase combined search terms for carbon emissions with search terms for relevant specialties (see MEDLINE search in 1. Lenzen M, Malik A, Li M, Fry J, Weisz H, Pichler PP, et al. The environmental footprint of health care: a global assessment. Lancet Planet Health. 2020;4(7):e271-e9.

2. Tennison I, Roschnik S, Ashby B, Boyd R, Hamilton I, Oreszczyn T, et al. Health care's response to climate change: a carbon footprint assessment of the NHS in England. Lancet Planet Health. 2021;5(2):e84-e92.

3. Climate Change Act, c. 27 (2008).

4. NHS England. Delivering a 'Net Zero' National Health Service. NHS England; 2022.

5. NHS Shared Business Services. Net Zero Carbon Reduction Plan. NHS SBS; 2022.

6. England N. Health and climate change 2024 [Available from: https://www.england.nhs.uk/greenernhs/national-ambition/national-commitments/#:~:text=The%20health%20impacts%20of%20climate,the%20public%20and%20the%20NHS.

7. The Lancet Respiratory M. Climate change crisis goes critical. Lancet Respir Med. 2023;11(3):213.

8. Physicians RCo. Breaking the fever: Sustainability and climate change in the NHS. London: RCP; 2017.

9. Mailloux NA, Henegan CP, Lsoto D, Patterson KP, West PC, Foley JA, et al. Climate Solutions Double as Health Interventions. Int J Environ Res Public Health. 2021;18(24).

10. Papadopoulou A, Kumar NS, Vanhoestenberghe A, Francis NK. Environmental sustainability in robotic and laparoscopic surgery: systematic review. Br J Surg. 2022;109(10):921-32.

11. Keil M, Viere T, Helms K, Rogowski W. The impact of switching from single-use to reusable healthcare products: a transparency checklist and systematic review of life-cycle assessments. European Journal of Public Health.

12. Perry H, Reeves N, Ansell J, Cornish J, Torkington J, Morris DS, et al. Innovations towards achieving environmentally sustainable operating theatres: A systematic review. Surgeon. 2023;21(3):141-51.

13. Siu J, Hill AG, MacCormick AD. Systematic review of reusable versus disposable laparoscopic instruments: costs and safety. ANZ J Surg. 2017;87(1-2):28-33.

14. Ravindrane R, Patel J. The environmental impacts of telemedicine in place of face-to-face patient care: a systematic review. Future Healthc J. 2022;9(1):28-33.

15. Lange O, Plath J, Dziggel TF, Karpa DF, Keil M, Becker T, et al. A Transparency Checklist for Carbon Footprint Calculations Applied within a Systematic Review of Virtual Care Interventions. Int J Environ Res Public Health. 2022;19(12).

16. Explained ES. Glossary: Carbon dioxide equivalent 2024 [Available from: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Carbon_dioxide_equivalent.

17. Shaw E. BS, Orr N., Nunns M., Boddy K., Turner M., Thompson Coon J., Melendez-Torres G.J. & Garside R. Effectiveness of interventions to reduce carbon-emissions within secondary healthcare: Systematic review and narrative synthesis 2023 [Available from: https://ore.exeter.ac.uk/repository/handle/10871/133658.

18. Zumsteg JM, Cooper JS, Noon MS. Systematic Review Checklist: A Standardized Technique for Assessing and Reporting Reviews of Life Cycle Assessment Data. J Ind Ecol. 2012;16(Suppl 1):S12-s21.

19. Centre for Reviews and Dissemination. CRD's guidance for undertaking reviews in health care 2009 [Available from: https://www.equator-network.org/reporting-guidelines/systematic-reviews-crds-guidance-for-undertaking-reviews-in-health-care/.

20. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. Systematic Reviews. 2021;10(1):89.

21. HealthcareLCA. Cumulative number of data sources within the HealthLCA database disaggregated by scale of analysis 2021.

22. Drew J, Christie SD, Tyedmers P, Smith-Forrester J, Rainham D. Operating in a Climate Crisis: A State-of-the-Science Review of Life Cycle Assessment within Surgical and Anesthetic Care. Environ Health Perspect. 2021;129(7):76001.

23. B.P. W. Guidelines for critical review of life cycle assessments: SPOLD; 1997 [Available from: https://lca-net.com/publications/show/guidelines-critical-review-life-cycle-assessments/.

24. Healthcare CfS. Integrating Sustainability into Quality Improvement to Creawte a More Ethical and Sustainable Healthcare System [Available from: https://sustainablehealthcare.org.uk/susqi.

25. Thomas J, Graziosi, S, Brunton J, Ghouze, Z, O'Driscoll, P, Bond, M & Koryakina, A. EPPI-Reviewer: advanced software for systematic reviews, maps and evidence synthesis. . EPPI-Reviewer: advanced software for systematic reviews, maps and evidence synthesis. 2022.

26. Centre DSFaE. EPPI-Mapper, Version 2.1.0.: PPI Centre, UCL Social Research Institute, University College London; 2022.

27. Betts A, Rogers, N., Beresford, T. & Saunders, H. A greener endoscopy unit for Royal Cornwall Hospital - Endoscopy team. 2022.

28. Bird N, Kirk, L., Wales J. & Hitchings, J. Changing the 3 montly blood test postage kits for patients on the renal transplant register.2022.

29. Burton L, Goggin, A., Tomkinson, A., Patterson, J. & Brennan, F. Sustainable ENT: Fractured Nose Manipulation- Local Anaesthetic Pathway. 2022.

30. Chan MN, A. Reducing carbon waste from pulse lavage systems used in joint replacement surgery, orthopaedic theatres. 2023.

31. Hardy A, Jones, P., Simpson, T., Gullapudi, V. R. L. & Wight, M. . Haemodialysis: optimising heat disinfect cycles and use of standby mode. 2022.

32. Kodumuri P, Jesudason, P., Houghton, J., Roberts, S., Williamson, I. & Revell, T. The upper “hand” of sustainability: Reducing the carbon footprint in hand surgery. 2022.

33. Kodumuri P, Jesudason EP, Lees V. Reducing the carbon footprint in carpal tunnel surgery inside the operating room with a lean and green model: a comparative study. The Journal of hand surgery, European volume. 2023:17531934231176952.

34. Langstaff A. Photobiomodulation therapy (PBM): using light therapy for oral mucositis, Palliative care team. 2023.

35. Lewis D, Tranter G, Axford AT. Use of videoconferencing in Wales to reduce carbon dioxide emissions, travel costs and time. J Telemed Telecare. 2009;15(3):137-8.

36. Materacki LB, L. . Scoping for change – adopting greener practice in endoscopy in Gloucestershire, Endoscopy team. 2023

37. Milne S. Retrofit of Heat Exchangers to Haemodialysis Machines - Case Study and How to Guide. 2023.

38. Milne S. Green nephrology: Retro-fit of heat exchangers to haemodialysis machines - case study and how-to guide. 2010.

39. Nielsen L, Bush, O. & Steinbach, I. Pioneering Early Mobilisation in a Cardiac Intensive Care unit: a Sustainable Healthcare Initiative. 2022.

40. Owens S, Harvey, N., Hillier, M., John-Cox, S. & Rao, I. Collaborative report of paper lite and contrast recycling projects, Endoscopy team. 2023.

41. Bond A, Jones A, Haynes R, Tam M, Denton E, Ballantyne M, et al. Tackling climate change close to home: mobile breast screening as a model. Journal of Health Services Research & Policy. 2009;14(3):165-7.

42. Chuter R, Stanford-Edwards C, Cummings J, Taylor C, Lowe G, Holden E, et al. Towards estimating the carbon footprint of external beam radiotherapy. Phys Medica. 2023;112:8.

43. Connor A, Lillywhite R, Cooke MW. The carbon footprints of home and in-center maintenance hemodialysis in the United Kingdom. Hemodialysis International. 2011a;15(1):39-51.

44. Connor A, Mortimer F, Higgins R. The follow-up of renal transplant recipients by telephone consultation: Three years experience from a single UK renal unit. Clinical Medicine, Journal of the Royal College of Physicians of London. 2011b;11(3):242-6.

45. Connor MJ, Miah S, Edison M, Brittain J, Kondjin Smith M, Hanna M, et al. Clinical, fiscal and environmental benefits of a specialist led virtual ureteric colic clinic: a report of a prospective study. BJU international. 2019.

46. Coombs NJ, Coombs JM, Vaidya UJ, Singer J, Bulsara M, Tobias JS, et al. Environmental and social benefits of the targeted intraoperative radiotherapy for breast cancer: Data from UK TARGIT-A trial centres and two UK NHS hospitals offering TARGIT IORT. BMJ Open. 2016;6(5):e010703.

47. Cooper D, Bhuskute N, Walsh G. Exploring the impact and acceptance of wearable sensor technology for pre-and postoperative rehabilitation in knee replacement patients: a UK-based pilot study. JBJS Open Access. 2022;7(2):e21.

48. Cooper DM, Bhuskute N, Hepworth C, Walsh G. The Economic Impact of a Pilot Digital Day-Case Pathway for Knee Arthroplasty in a U.K. Setting. JB & JS open access. 2023;8(1).

49. Curtis A, Parwaiz H, Winkworth C, Sweeting L, Pallant L, Davoudi K, et al. Remote Clinics During Coronavirus Disease 2019: Lessons for a Sustainable Future. Cureus. 2021;13(3):e14114.

50. de Preux L, Rizmie D. Beyond financial efficiency to support environmental sustainability in economic evaluations. Future Healthcare Journal. 2018;5(2):103-7.

51. Dorrian C, Ferguson J, Ah-See K, Barr C, Lalla K, van der Pol M, et al. Head and neck cancer assessment by flexible endoscopy and telemedicine. Journal of Telemedicine and Telecare. 2009;15(3):118-21.

52. King J, Poo SX, El-Sayed A, Kabir M, Hiner G, Olabinan O, et al. Towards NHS Zero: greener gastroenterology and the impact of virtual clinics on carbon emissions and patient outcomes. A multisite, observational, cross-sectional study. Frontline Gastroenterology. 2023;14(4):287-94.

53. Miah S, Dunford C, Edison M, Eldred-Evans D, Gan C, Shah TT, et al. A prospective clinical, cost and environmental analysis of a clinician-led virtual urology clinic. Ann R Coll Surg Engl. 2019;101(1):30-4.

54. Moussa G, Andreatta W, Ch'Ng SW, Ziaei H, Jalil A, Patton N, et al. Environmental effect of air versus gas tamponade in the management of rhegmatogenous retinal detachment VR surgery: A multicentre study of 3,239 patients. PLoS ONE. 2022;17(1 January):e0263009.

55. Moussa G, Ch'ng SW, Park DY, Ziaei H, Jalil A, Patton N, et al. Environmental effect of fluorinated gases in vitreoretinal surgery: a multicenter study of 4,877 patients. American journal of ophthalmology. 2021.

56. Natale J, Pascoe J, Horn C, Coode-Bate J, Dickinson A. Teleconsultation versus traditional clinical assessment of patients undergoing circumcision: A retrospective cohort study. Journal of Clinical Urology. 2022.

57. Phull M, Begum H, John JB, van Hove M, McGrath J, O'Flynn K, et al. Potential Carbon Savings with Day-case Compared to Inpatient Transurethral Resection of Bladder Tumour Surgery in England: A Retrospective Observational Study Using Administrative Data. European Urology Open Science. 2023;52:44-50.

58. Richards JD, Stoddart M, Bolland B. Virtual Arthroplasty Follow-Up: Better for the Trust, Patients, and the Planet. Cureus. 2022;14(11):e31978.

59. Rizan C, Bhutta MF. Environmental impact and life cycle financial cost of hybrid (reusable/single-use) instruments versus single-use equivalents in laparoscopic cholecystectomy. Surgical Endoscopy. 2022;36(6):4067-78.

60. Udayaraj UP, Watson O, Ben-Shlomo Y, Langdon M, Anderson K, Power A, et al. Establishing a tele-clinic service for kidney transplant recipients through a patient-codesigned quality improvement project. BMJ open quality. 2019;8(2):e000427.

61. Yong KK, He Y, Cheung HCA, Sriskandarajah R, Jenkins W, Goldin R, et al. Rationalising the use of specimen pots following colorectal polypectomy: a small step towards greener endoscopy. Frontline Gastroenterology. 2022.

62. Zander A, Niggebrugge A, Pencheon D, Lyratzopoulos G. Changes in travel-related carbon emissions associated with modernization of services for patients with acute myocardial infarction: A case study. Journal of Public Health. 2011;33(2):272-9.

63. Beswick DM, Vashi A, Song Y, Pham R, Holsinger FC, Rayl JD, et al. Consultation via telemedicine and access to operative care for patients with head and neck cancer in a Veterans Health Administration population. Head Neck-J Sci Spec Head Neck. 2016;38(6):925-9.

64. Field RR, Calderon M-DC, Ronilo SM, Ma M, Maxwell H, Mensah P, et al. Environmental and Economic Impact of Using a Higher Efficiency Ventilator and Vaporizer During Surgery Under General Anesthesia: A Randomized Controlled Prospective Cohort. Cureus. 2023;15(5):e39534.

65. Frick MA, Baniel CC, Qu V, Hui C, Brown E, Chang DT, et al. Effect of Radiation Schedule on Transportation-Related Carbon Emissions: A Case Study in Rectal Cancer. Advances in Radiation Oncology. 2023;8(5):101253.

66. Jiang CY, Strohbehn GW, Dedinsky RM, Raupp SM, Pannecouk BM, Yentz SE, et al. Teleoncology for Veterans: High Patient Satisfaction Coupled With Positive Financial and Environmental Impacts. JCO Oncology Practice. 2021;17(9):E1362-E74.

67. Kemble JP, Winoker JS, Patel SH, Su ZT, Matlaga BR, Potretzke AM, et al. Environmental impact of single-use and reusable flexible cystoscopes. BJU International. 2023;131(5):617-22.

68. Le NNT, Hernandez LV, Vakil N, Guda N, Patnode C, Jolliet O. Environmental and health outcomes of single-use versus reusable duodenoscopes. Gastrointestinal Endoscopy. 2022;96(6):1002-8.

69. Leapman MS, Thiel CL, Gordon IO, Nolte AC, Perecman A, Loeb S, et al. Environmental Impact of Prostate Magnetic Resonance Imaging and Transrectal Ultrasound Guided Prostate Biopsy. European Urology. 2023;83(5):463-71.

70. Meiklejohn DA, Khan ZH, Nunez KM, Imhof L, Osmani S, Benavidez AC, et al. Environmental Impact of Adult Tonsillectomy: Life Cycle Assessment and Cost Comparison of Techniques. The Laryngoscope. 2023.

71. Mojdehbakhsh RP, Rose S, Peterson M, Rice L, Spencer R. A quality improvement pathway to rapidly increase telemedicine services in a gynecologic oncology clinic during the COVID-19 pandemic with patient satisfaction scores and environmental impact. Gynecologic Oncology Reports. 2021;36:100708.

72. Patel KB, Gonzalez BD, Turner K, Alishahi Tabriz A, Rollison DE, Robinson E, et al. Estimated Carbon Emissions Savings With Shifts From In-Person Visits to Telemedicine for Patients With Cancer. JAMA network open. 2023;6(1):e2253788.

73. Sherman JD, Raibley LAt, Eckelman MJ. Life Cycle Assessment and Costing Methods for Device Procurement: Comparing Reusable and Single-Use Disposable Laryngoscopes. Anesthesia and analgesia. 2018;127(2):434-43.

74. Sillcox R, Blaustein M, Khandelwal S, Bryant MK, Zhu J, Chen JY. Telemedicine Use Decreases the Carbon Footprint of the Bariatric Surgery Preoperative Evaluation. Obesity Surgery. 2023a.

75. Sillcox R, Gitonga B, Meiklejohn DA, Wright AS, Oelschlager BK, Bryant MK, et al. The environmental impact of surgical telemedicine: life cycle assessment of virtual vs. in-person preoperative evaluations for benign foregut disease. Surgical Endoscopy and Other Interventional Techniques. 2023b.

76. Thiel CL, Eckelman M, Guido R, Huddleston M, Landis AE, Sherman J, et al. Environmental impacts of surgical procedures: Life cycle assessment of hysterectomy in the United States. Environmental Science and Technology. 2015;49(3):1779-86.

77. Thiel CL, Mehta N, Sejo CS, Qureshi L, Moyer M, Valentino V, et al. Telemedicine and the environment: life cycle environmental emissions from in-person and virtual clinic visits. Npj Digital Medicine. 2023;6(1).

78. Thiel CL, Woods NC, Bilec MM. Strategies to Reduce Greenhouse Gas Emissions from Laparoscopic Surgery. American journal of public health. 2018;108(S2):S158-S64.

79. Thota R, Gill DM, Brant JL, Yeatman TJ, Haslem DS. Telehealth Is a Sustainable Population Health Strategy to Lower Costs and Increase Quality of Health Care in Rural Utah. JCO oncology practice. 2020;16(7):e557-e62.

80. Vo LV, Mastrorilli V, Muto AJ, Emerson GG. Reuse of shipping materials in the intravitreal bevacizumab supply chain: feasibility, cost, and environmental impact. International Journal of Retina and Vitreous. 2023;9(1):34.

81. Woods DL, McAndrew T, Nevadunsky N, Hou JY, Goldberg G, Yi-Shin Kuo D, et al. Carbon footprint of robotically-assisted laparoscopy, laparoscopy and laparotomy: A comparison. International Journal of Medical Robotics and Computer Assisted Surgery. 2015;11(4):406-12.

82. Woolen SA, Becker AE, Martin AJ, Knoerl R, Lam V, Folsom J, et al. Ecodesign and Operational Strategies to Reduce the Carbon Footprint of MRI for Energy Cost Savings. Radiology. 2023;307(4):e230441.

83. Baboudjian M, Pradere B, Martin N, Gondran-Tellier B, Angerri O, Boucheron T, et al. Life Cycle Assessment of Reusable and Disposable Cystoscopes: A Path to Greener Urological Procedures. European Urology Focus. 2022.

84. Bendine G, Autin F, Fabre B, Bardin O, Rabasco F, Cabanel JM, et al. Haemodialysis therapy and sustainable growth: a corporate experience in France. Nephrology, dialysis, transplantation : official publication of the European Dialysis and Transplant Association - European Renal Association. 2020.

85. Chambrin C, de Souza S, Gariel C, Chassard D, Bouvet L. Association Between Anesthesia Provider Education and Carbon Footprint Related to the Use of Inhaled Halogenated Anesthetics. Anesthesia and Analgesia. 2023;136(1):101-10.

86. Filfilan A, Anract J, Chartier-Kastler E, Parra J, Vaessen C, de La Taille A, et al. Positive environmental impact of remote teleconsultation in urology during the COVID-19 pandemic in a highly populated area. Progres En Urologie. 2021;31(16):1133-8.

87. Rouviere N, Chkair S, Auger F, Alovisetti C, Bernard MJ, Cuvillon P, et al. Ecoresponsible actions in operating rooms: A health ecological and economic evaluation. International Journal of Surgery. 2022;101:106637.

88. Sanchez SA, Eckelman MJ, Sherman JD. Environmental and economic comparison of reusable and disposable blood pressure cuffs in multiple clinical settings. Resources, Conservation and Recycling. 2020;155:104643.

89. Arndt E-M, Jansen TR, Bojko J, Roos JJ, Babasiz M, Randau TM, et al. COVID-19 measures as an opportunity to reduce the environmental footprint in orthopaedic and trauma surgery. Frontiers in surgery. 2023;10:959639.

90. Buttner L, Posch H, Auer T, Jonczyk M, Fehrenbach U, Hamm B, et al. Switching off for future-Cost estimate and a simple approach to improving the ecological footprint of radiological departments. European Journal of Radiology Open. 2021;8:100320.

91. Klein H-M. A New Approach to the Improvement of Energy Efficiency in Radiology Practices. Ein neuer Ansatz zur Verbesserung der Energieeffizienz in radiologischen Versorgungseinheiten. 2023;195(5):416-25.

92. Leiden A, Cerdas F, Noriega D, Beyerlein J, Herrmann C. Life cycle assessment of a disposable and a reusable surgery instrument set for spinal fusion surgeries. Resources, Conservation and Recycling. 2020;156:104704.

93. Muschol J, Heinrich M, Heiss C, Hernandez AM, Knapp G, Repp H, et al. Economic and Environmental Impact of Digital Health App Video Consultations in Follow-up Care for Patients in Orthopedic and Trauma Surgery in Germany: Randomized Controlled Trial. J Med Internet Res. 2022;24(11):11.

94. Schulte A, Maga D, Thonemann N. Combining Life Cycle Assessment and Circularity Assessment to Analyze Environmental Impacts of the Medical Remanufacturing of Electrophysiology Catheters. Sustainability. 2021;13(2).

95. Andrew N, Barraclough KA, Long K, Fazio TN, Holt S, Kanhutu K, et al. Telehealth model of care for routine follow up of renal transplant recipients in a tertiary centre: A case study. Journal of telemedicine and telecare. 2020;26(4):232-8.

96. Davis NF, McGrath S, Quinlan M, Jack G, Lawrentschuk N, Bolton DM. Carbon footprint in flexible ureteroscopy: A comparative study on the environmental impact of reusable and single-use ureteroscopes. Journal of Endourology. 2018;32(3):214-7.

97. McAlister S, McGain F, Petersen M, Story D, Charlesworth K, Ison G, et al. The carbon footprint of hospital diagnostic imaging in Australia. The Lancet Regional Health - Western Pacific. 2022;24:100459.

98. Wombwell A, Holmes A, Grills R. Are single-use flexible cystoscopes environmentally sustainable? A lifecycle analysis. Journal of Clinical Urology. 2023.

99. Cheung R, Ito E, Lopez M, Rubinstein E, Keller H, Cheung F, et al. Evaluating the Short-term Environmental and Clinical Effects of a Radiation Oncology Department's Response to the COVID-19 Pandemic. International Journal of Radiation Oncology Biology Physics. 2023;115(1):39-47.

100. Forner D, Purcell C, Taylor V, Noel CW, Pan L, Rigby MH, et al. Carbon footprint reduction associated with a surgical outreach clinic. Journal of Otolaryngology-Head & Neck Surgery. 2021;50(1).

101. Lambert P, Musto G, Thiessen M, Czaykowski P, Decker K. Impact of Cancer-Related Virtual Visits on Travel Distance, Travel Time, and Carbon Dioxide (CO2) Emissions during the COVID-19 Pandemic in Manitoba, Canada. Curr Oncol. 2023;30(7):5973-83.

102. Tselapedi-Sekeitto B, Rocha T, Sowerby LJ, Rotenberg B, Biadsee A. Telemedicine as an environmental ally-The social, financial, and environmental impact of virtual care in the otolaryngology clinic. American Journal of Otolaryngology. 2023;44(2):103791.

103. Boberg L, Singh J, Montgomery A, Bentzer P. Environmental impact of single-use, reusable, and mixed trocar systems used for laparoscopic cholecystectomies. PLoS ONE. 2022;17(7 July):e0271601.

104. Holmner A, Ebi KL, Lazuardi L, Nilsson M. Carbon Footprint of Telemedicine Solutions - Unexplored Opportunity for Reducing Carbon Emissions in the Health Sector. Plos One. 2014;9(9).

105. Stripple H, Westman R, Holm D. Development and environmental improvements of plastics for hydrophilic catheters in medical care: an environmental evaluation. Journal of Cleaner Production. 2008;16(16):1764-76.

106. Croghan SM, Rohan P, Considine S, Salloum A, Smyth L, Ahmad I, et al. Time, cost and carbon-efficiency: a silver of COVID era virtual urology clinics? Annals of the Royal College of Surgeons of England. 2021;103(8):599-603.

107. Hogan D, Rauf H, Kinnear N, Hennessey DB. The Carbon Footprint of Single-Use Flexible Cystoscopes Compared with Reusable Cystoscopes. Journal of Endourology. 2022;36(11):1460-4.

108. McCarthy CJ, Gerstenmaier JF, O' Neill AC, McEvoy SH, Hegarty C, Heffernan EJ. "EcoRadiology"--pulling the plug on wasted energy in the radiology department. Academic radiology. 2014;21(12):1563-6.

109. Asghari M, Al-e-Hashem S. A green delivery-pickup problem for home hemodialysis machines; sharing economy in distributing scarce resources. Transportation Research Part E-Logistics and Transportation Review. 2020;134.

110. Vaidya JS, Vaidya UJ, Baum M, Bulsara MK, Joseph D, Tobias JS. Global adoption of single-shot targeted intraoperative radiotherapy (TARGIT-IORT) for breast cancer-better for patients, better for healthcare systems. Frontiers in Oncology. 2022;12:786515.

111. Chen M, Zhou R, Du C, Meng F, Wang Y, Wu L, et al. The carbon footprints of home and in-center peritoneal dialysis in China. International Urology and Nephrology. 2017;49(2):337-43.

112. Sørensen BL, Grüttner H. Comparative study on environmental impacts of reusable and single-use bronchoscopes. Am J Environ Prot. 2018;7(4):55-62.

113. Fuschi A, Pastore AL, Al Salhi Y, Martoccia A, De Nunzio C, Tema G, et al. The impact of radical prostatectomy on global climate: a prospective multicentre study comparing laparoscopic versus robotic surgery. Prostate Cancer and Prostatic Diseases. 2023.

114. McLachlan A, Aldridge C, Morgan M, Lund M, Gabriel R, Malez V. An NP-led pilot telehealth programme to facilitate guideline-directed medical therapy for heart failure with reduced ejection fraction during the COVID-19 pandemic. N Z Med J. 2021;134(1538):77-88.

115. Neves JAC, Roseira J, Queiros P, Sousa HT, Pellino G, Cunha MF. Targeted intervention to achieve waste reduction in gastrointestinal endoscopy. Gut. 2022.

116. Lopez-Munoz P, Martin-Cabezuelo R, Lorenzo-Zuniga V, Vilarino-Feltrer G, Tort-Ausina I, Vidaurre A, et al. Life cycle assessment of routinely used endoscopic instruments and simple intervention to reduce our environmental impact. Gut. 2023:E329544.

117. Heye T, Meyer MT, Merkle EM, Vosshenrich J. Turn It Off! A Simple Method to Save Energy and CO2 Emissions in a Hospital Setting with Focus on Radiology by Monitoring Nonproductive Energy-consuming Devices. Radiology. 2023;307(4):e230162.

118. Winklmair N, Kieselbach G, Bopp J, Amon M, Findl O. Potential environmental effect of reducing the variation of disposable materials used for cataract surgery. Journal of Cataract and Refractive Surgery. 2023;49(6):628-34.

119. de Ridder EF, Friedericy HJ, van der Eijk AC, Dankelman J, Jansen FW. A New Method to Improve the Environmental Sustainability of the Operating Room: Healthcare Sustainability Mode and Effect Analysis (HSMEA). Sustainability. 2022;14(21).

120. Rizan C, Bhutta MF. Re: The Carbon Footprint of Single-Use Flexible Cystoscopes Compared with Reusable Cystoscopes: Methodological Flaws Led to the Erroneous Conclusion That Single-Use Is "Better". J Endourol. 2022;36(11):1466-7.

121. Brighton & Sussex Medical School CfSH, and UK Health Alliance on , Change C. Green surgery: Reducing the environmental impact of surgical care (v1.1). London: UKHACC; 2023.

122. Hogan D, Hennessey DB. Response to Rizan et al.: "The Carbon Footprint of Single-Use Flexible Cystoscopes Compared with Reusable Cystoscopes"-Clarification of Methods Due to Apparent Misinterpretation. J Endourol. 2023;37(10):1145-6.

123. Rizan C, Steinbach I, Nicholson R, Lillywhite R, Reed M, Bhutta M. The Carbon Footprint of Surgical Operations: A Systematic Review. Annals of Surgery. 2020;Publish Ahead of Print.

Appendix A: Search strategies). Medical speciality terms included generic terms for each speciality (e.g. gastroenterology, cardiology, etc.), diseases within each speciality which are treated in secondary care settings, and procedures within each speciality which are carried out in secondary care settings. A different approach was used to search Environment Complete and the Science Citation Index which combined search terms for carbon emissions with generic terminology for hospital settings and secondary care (see Environment Complete search in Appendix A). This approach was informed by our scoping searches which suggested that potentially relevant studies published in environmental science journals typically use more generic terminology to describe medical settings than studies in medical and health care journals. A date limit of 2008 was applied across all databases which corresponds with the 2008 Climate Change Act, prior to which evidence shows there were very few studies on carbon emissions in health care systems compared to exponential growth since this date.(21) English language limits were applied where available.

The results of the bibliographic database searches were exported to Endnote 20 (Clarivate Analytics, Philadelphia, PA, USA) and de-duplicated using the automated de-duplication feature and manual checking.

Supplementary searches

We supplemented our bibliographic database searches by inspecting the HealthcareLCA database (https://healthcarelca.com/). This regularly updated resource indexes studies of life cycle assessments (LCA) of medical technologies and procedures, including carbon emissions, and can be filtered to identify studies relevant to specific medical specialties, including several specialties which are included in this review.

Forward and backward citation searches were conducted on all studies that met our inclusion criteria. Forward citation searching was carried out via the Science Citation Index (Web of Science, Clarivate Analytics) and Google Scholar (https://scholar.google.co.uk/), depending on which citation index indexed the relevant studies which were identified. We also checked the included studies of any topically relevant systematic reviews that we identified during our scoping and screening processes.

We searched Google Search to identify studies not indexed in bibliographic databases or citation indexes, such as hospital-led evaluations published in grey literature format. Finally, we searched a selection of websites for relevant studies, specifically:

- Centre for Sustainable Healthcare https://sustainablehealthcare.org.uk/
- Current Awareness Service for Health https://cash.libraryservices.nhs.uk/
- European Centre for Environmental and Human Health https://www.ecehh.org/
- Health Care Without Harm https://noharm-europe.org/

- IHSCM – Greener care special interest group https://ihm.org.uk/special-interest-groups/greener-care/
- Green Health Wales https://greenhealthwales.co.uk/
- Greener NHS https://www.england.nhs.uk/greenernhs/
- Sustainable Healthcare Networks Hub https://networks.sustainablehealthcare.org.uk/

Identification and selection of papers

The inclusion criteria and exclusion criteria applied to the studies identified through the search strategy are detailed in Table 1. As an initial calibration exercise to determine the clarity of our inclusion and exclusion criteria, four reviewers applied the criteria to a sample (n=100) of search results (LS, SB, NO, HL). Decisions were discussed in a group meeting to ensure consistent application of criteria. Inclusion and exclusion criteria were revised to enable more consistent reviewer interpretation and judgement and applied to a second sample of 100 studies. Once finalised, the revised inclusion and exclusion criteria were applied to the title and abstract of each identified citation independently by two reviewers (LS, SB, NO, HL), with disagreements resolved through discussion or referral to a third reviewer as required. The full text of each record was assessed for inclusion in the same way. Study selection was supported by Endnote v.20 software and a PRISMA-style flowchart produced, detailing study selection and reason for exclusion of each record retrieved at full text.

Table 1: Review inclusion criteria

PICO	Criteria
Population	Include: Procedures, processes, or pathways within the following specialties*: - Cardiology - Gastroenterology - Obstetrics - Oncology - Ophthalmology - Orthopaedics and trauma - Radiology - Renal - Respiratory - High volume low complexity surgery, including: o Ear, nose, and throat (ENT) o Gynaecology o Urology Exclude: Any procedures, processes or pathways within specialities not listed above.
Intervention	Include: Any intervention intended to reduce the environmental impact of a process, treatment, or pathway. Examples of eligible interventions include (but are not limited to): waste reduction, remote clinics, surgical techniques, technology/instruments, treatment pathways, manufacturing, imaging, tests, and medication. Exclude: Any intervention associated with a speciality not listed above.
Comparator	Any.
Outcomes	Include: Carbon-emission data must be included, estimated carbon-emissions based upon LCA also eligible. Exclude: Studies only reporting outcomes related to patient, clinical, safety and/or satisfaction.
Setting	Include: Healthcare delivered within secondary care, including travel to/from/between secondary sites and remote delivery of care.

	Exclude: Any treatment, pathway or process associated with the above listed specialties in primary or community healthcare settings e.g. General practice Community nursing care
Study design	Include: Any comparative study design, including (but not limited to): - Randomized controlled trials; - Controlled trials; - Prospective and retrospective cohort studies - Before and after studies - Interrupted time series - Modelling studies; - Life Cycle Assessments which compare different treatment/processes. Exclude: Life Cycle Assessments which provide only an estimate of carbon-emissions associated with a particular treatment/process but present no comparison between different treatment/process options, case studies, systematic, scoping, or narrative reviews, qualitative studies, conference abstracts.
Date	Include: Studies published since 2008.
Geographical limit	None.
Language restriction	Studies published in English only. This is a pragmatic decision based upon the number of studies included in this review, timeframe for delivery and resource available.

*The final list of specialities was agreed in consultation with the Greener NHS team at NHS England. The list is based on inpatient hospital data showing high volumes of activity with subsequent implications for carbon footprints.

Protocol deviations

Due to the high number of eligible studies identified by our search and screening strategy, we made the pragmatic decision to prioritise the studies using the most robust methods to evaluate the impact of interventions to reduce carbon emissions, for full data extraction and quality appraisal. This two-tier approach meant that the complete data extraction form, based upon the items pre-specified in our protocol, was applied to included studies which used LCA methodology, whilst an abbreviated version was applied to other study designs. This approach enabled the review team to prioritise resources to ensure that review findings pertaining to carbon emissions were based upon the strongest evidence and that the review remained deliverable within the timeframe available. Further detail on this approach is provided below.

Data extraction and quality appraisal

The review team developed and piloted a standardised data extraction form (LS, NO, SB, HL) on a sample of LCA studies (n=3) using Microsoft Excel. The revised form was used to collect information pertaining to population characteristics, interventions evaluated, study methods and outcomes. The full data extraction form was applied to LCA studies by one reviewer (LS, HL) and checked by a second (HL, SB, NO, JTC, RG, LS), with the same process applied to non-LCA studies using a shorter data extraction form. The data extracted from LCA and non-LCA studies can be viewed in Appendix B: Data extraction items for included studies.

We critically appraised the LCA studies using a predetermined scoring system which was informed by Weidema's (1997) guidelines for critical review of LCAs and additional work by Drew et al (2021).(22, 23) The scoring system comprised 16 appraisal criteria divided across the four stages of the LCA. LCAs should, in accordance with ISO standards, include goal and scope definition, inventory analysis, impact assessment and interpretation of results. Table 2 illustrates the critical appraisal items that were applied to each LCA study. We added the points for each criterion and calculated a total score out of 35 points for each study. Critical appraisal was completed by one of three reviewers (LS, HL & NO), checked by a second and consultation with a third to resolve any disagreements.

No formal guidelines were used to quality appraise non-LCA studies. Instead, the findings of individual non-LCA studies were considered alongside the study design and methods for calculating carbon-emissions; this was used to inform statements regarding the confidence which could be placed in their synthesised findings. This allowed us to prioritise the most methodologically robust evidence with respect to carbon emissions for synthesis and deliver the review within the timeframe available. This decision was also informed by the lack of validated quality appraisal tools to assess methods of carbon emission calculation in non-LCA studies, with highly heterogeneous study designs; issues identified within other systematic reviews on related topics.(15)

Table 2: Critical appraisal criteria applied to LCA studies

Criteria
Phase 1: Goal & scope (12 points)
Study goal is clearly stated, including the study's rationale (1), intended application, and/or intended audience (1)
Lifecycle assessment method is clearly stated (1)
Functional unit is clearly defined and measurable (1), justified (1), and consistent with the study's intended application (1)
The system to be studied is adequately described with clearly stated system boundaries (1), lifecycle stages (1), and appropriate justification of any omitted stages (1)
The system covers production (1), use/reuse (1) and disposal (1) of materials and energy (half mark if only for energy and vice versa)
Phase 2: Inventory analysis (7 points)
The data collection process is clearly explained, including the source(s) of foreground material weights and energy values (1); the source(s) of reference data (e.g. inventory database (1); and what data are included (e.g. production and disposal of unit processes (1)
Representativeness of the data is discussed (1), differences in electricity generating mix are accounted for (1), and the potential significance of exclusions or assumptions is addressed (1)
Allocation procedures, where necessary, are described and appropriately justified (1)
Phase 3: Impact assessment (6 points)
Impact categories (1), characterisation method (1), and software used (1) are documented transparently
Results are clearly reported in the context of the functional unit (1) (0.5 if graphically, 0 if only normalized results reported)
A contribution analysis is performed and clearly reported (1), and hotspots are identified (1)
Phase 4: Interpretation (10 points)
Conclusions are consistent with the goal and scope (1) and supported by the impact assessment results (1)
Results are contextualized through the use of sensitivity analysis (1) and uncertainty analysis (1)
Limitations are adequately discussed (1), and the potential impact of omissions or assumptions on the study's outcomes are described (1)
The assessment has been critically appraised (i.e. peer review if journal article or independent, external critical review if report/thesis; 1)
Source(s) of funding (1) and any potential conflict(s) of interest are disclosed (1), and are unlikely to be a source of bias (1)

* Numbers in brackets show points assigned for each item.

Synthesis of the evidence

Data summarising the population, intervention, methodological and quality characteristics of the included studies was summarised in tables and described narratively. To support the narrative synthesis, we first categorised included studies into five groups according to the broad type of intervention being evaluated. These are described below in Table 3.

Table 3: Broad intervention categories

Broad intervention category	Description
Accessing care	Interventions changing patient access to, or pathway through, secondary healthcare. Interventions within this category included: Telehealth or virtual care-based interventions and de-centralised care.
Product level	Interventions focused on the products used for patient care e.g. reuseable surgery equipment or type of equipment used.
Care delivery	Interventions targeting how treatment is delivered e.g. alterations to care regimens, care pathways or surgical procedures.
Setting	Interventions which focus on systems and/or processes supporting the delivery of patient care e.g. waste management or energy conservation initiatives
Multiple	Multi-component Interventions which encompassed two or more of the above.

Within each of these five categories, studies were separated into those based on LCA methodology versus those which were not. Narrative synthesis was then used to identify and explain, where possible, patterns in intervention effectiveness in reducing carbon emissions relating to groups of similar interventions within the same speciality, with reference to study quality (for LCAs) and/or methods used to calculate carbon emissions. Summary statements were produced within each intervention group with regard to what the evidence base could tell us regarding the impact of different types of intervention on reduction of carbon emissions, patient outcomes (e.g. patient safety, satisfaction) and service costs.(24)

Production of an evidence and gap map

We used EPPI-Reviewer and EPPI mapper software to present studies as an evidence and gap map to highlight where evidence could inform key points of a generic patient care pathway for each speciality (See Appendix C: Patient care pathway).(25, 26) This patient pathway includes 1) Initial assessment (including diagnostic tests) within secondary care, 2) Initial treatment, 3) Follow-up care, 3) Ongoing secondary care, 4) Discharge from secondary care and, 5) Setting. Definitions for each of these parts of the patient care pathway are as follows:

- Initial assessment: entry into the secondary care pathway, this includes the initial review (consultation) and diagnostic tests needed to get to the next part of the pathway i.e. treatment.

- Initial treatment: the primary treatment received following assessment and diagnostics, based on the diagnosis and management plan. Typically delivered once e.g. joint replacement operation.
- Routine follow up appointments: Routine follow-up following initial treatment.
- Ongoing secondary care: further treatment or treatment that is delivered as a course or regime for patients which require longer-term treatment e.g. haemodialysis.
- Discharge from secondary care: discharge of patients from secondary care.
- Systemic interventions: Interventions which influence the setting or environment patient care is delivered within. This part of the patient care pathway is for interventions targeting more systemic aspects of the care delivery system, including those which a) could influence more than one stage of the patient care pathway or b) sit outside of the pathway (e.g. interventions intended to reduce equipment packaging), but are still associated with the care patients receive.

To provide an accessible structure, the systematic review evidence was mapped according to speciality and the patient care pathway, from initial access of secondary care health services, through to discharge from secondary care. Each included study was assigned to a position on the pathway by one reviewer (LS) and checked by a second (NO). Disagreements were resolved through discussion. Due to the nature of the interventions evaluated by the included studies, a study may sit in multiple places in the evidence and gap map.

Within each segment of the grid, systematic review evidence is presented in bubbles according to broad intervention categories as described above, with the colour and size of the bubble indicating the type of intervention and amount of evidence available within that section of the grid. Filters allow map users to change the type of evidence displayed based upon key features of the included studies, including methods used (e.g. LCA or non-LCA), specific type of intervention (e.g. telehealth, reuseable equipment), and geographic location (e.g. UK vs non-UK).

We produced summaries of the number and type of studies at each stage of the care pathway for each speciality.

Stakeholder involvement

We have consulted with and worked closely alongside several stakeholder groups throughout the conduct of this review. Stakeholders included those requesting the review from NHSE, people with expertise in LCA methods or studies evaluating interventions to reduce carbon emissions within healthcare settings from the University of Exeter and members of PERSPEX patient and public involvement group. The method of engaging with and respective impact on the review process, of each of these stakeholder groups on the review process and outputs is summarised in Table 4.

Table 4: Impact of stakeholder involvement on review process

Stage of review	Method of stakeholder involvement	Impact on review
Research question & protocol development	12.01.23/07.03.23: 2x1hr face-to face meetings via MT with government policy stakeholders, communication via email.	Clarification regarding policy context for the review, aim, intended use and identifying focused research question. Identification of high-volume specialities which likely to be associated with highest carbon-emissions. Highlighted Healthcare LCA database and other websites as resources to include in search strategy and facilitated contact with individuals who maintain this resource. Approved inclusion criteria, with particular input regarding outcomes of interest. Approved search terms and search strategy.
	Email contact with individuals who maintain Healthcare LCA database.	Informing review search strategy.
	1x20min face-to-face meeting via MT with members of PERSPEX.	Discussion of research questions and aims of review highlighted importance of including interventions targeting waste management e.g. use of paper and incineration. Emphasised importance of consideration of patient outcomes, such as patient satisfaction and safety alongside carbon emission evidence. Identified need for plain language protocol to share with patient/public collaborators.
	13.9.23: 1x45min face-to-face meeting via MT with clinical/methods expert.	Sense check of protocol content and signposting to other potential experts regarding LCA methodology. Clarification of different ways carbon emissions can be measured and/or referred to in non-LCA studies and definition of these. Provided context of how carbon emissions evaluated within NHS settings and associated challenges. Provided thoughts on synthesis strategy to enable identification of key messages for individual specialties.
Screening	18.09.23: 1x1hr meeting via MT with government policy stakeholders, communication via email	Comment on summary of included studies as to whether these met expectations on type and range of evidence eligible for inclusion in review and if this aligned with their perception of the purpose of the review. Helped us resolve uncertainties regarding study eligibility at full-text screening.
Data extraction	22.09.23: 1x45min face-to-face meeting via MT with methods expert.	Discussed draft data extraction and quality appraisal forms.
	23.11.23: 1x45min face-to-face meeting via MT with XY, email communication.	Provided an introductory overview to LCA methodology and answered specific queries regarding key concepts such as differentiating LCA from inventory analysis, representativeness of data, sensitivity/uncertainty analysis. Reviewed content draft data extraction and quality appraisal forms which pertained to studies utilising LCA methods.
	14.12.23: 1x1hr face-to-face meeting via MT with government policy	Approved content of draft data extraction form. Particular request for details regarding research funding and conflict of interest. Decision to prioritise studies utilising LCA methodology for full data

	stakeholders, communication via email.	extraction and quality appraisal. Supported identifying key study characteristics to extract from non-LCA studies.
Quality appraisal	Communication via email with XY.	Resolved specific queries regarding key concepts relating to quality appraisal of LCA studies and identifying studies which, whilst adopting features and language from LCA study designs, were non-LCA studies.
Synthesis	14.12.23/23.01.24: 2x1hr face-to face meetings via MT with government policy stakeholders, communication via email. 06.03.24: 1x30min meeting via MT with members of PERSPEX. Communication via email.	Decision to prioritise evidence based on LCA study design, with shorter narrative overview of findings from non-LCA studies based on discussion. Broad intervention categories initially identified by MP, refined by Exeter PRP review team and agreed upon through discussion. Need for evidence and gap map identified through stakeholder need to see how evidence included in the review mapped onto patient care pathway. Provided feedback on preliminary findings of review and structure and accessibility of the evidence and gap map.
Write up	Communication via email with XY. Communication via email with government stakeholders.	Reviewed and provided feedback on draft internal report prior to it being sent to government stakeholders. Reviewed and provided feedback on draft report prior to it being finalised.
Dissemination	Communication via email with government stakeholders. 03.04.24: 1x30min meeting via MT with members of PERSPEX. Communication via email.	Government stakeholders and PERSPEX members involved in identifying key audiences for potential dissemination products and pathways for sharing these. Reviewed dissemination materials, including a plain language summary and briefing paper. Also provided feedback on structure of simplified patient care pathway on which evidence and gap map based and accessibility of draft evidence and gap map.

MP=Manraj Phull, XY=Xiaoyu Yan; LCA=Life Cycle Assessment, MT=Microsoft Teams, PERSPEX=Patient and Public Engagement Group, Faculty of Health and Life Sciences, University of Exeter

Results

This results section is structured as follows:

1. ***Summary of main findings:*** Presentation of the key findings from the narrative synthesis and how these relate to the research questions of this review.
2. ***Descriptive results:*** This section summarises the key features of the evidence, including characteristics of the participants/health systems, interventions, methods, and study quality.
3. ***Evidence and gap map:*** Studies within each speciality are displayed in an interactive evidence map along a simplified care pathway and accompanied by a summary of key messages.
4. ***Narrative synthesis:*** Studies are grouped into the five broad intervention categories described above: Accessing Care, Product Level, Care Delivery, Setting and Multiple Components. Within each category, studies are grouped according to study design (LCA vs non-LCA), speciality and intervention type. Key findings relating to the effectiveness of interventions in reducing carbon emissions, within the context of impact on service costs and patient care, are summarised with reference to study quality.

Summary of main findings

- Eighty-nine studies (93 articles) met the eligibility criteria for inclusion. The majority were published in peer-reviewed academic journals; 13 are non-peer reviewed project web reports as part of carbon-reduction initiatives at individual NHS Trusts. Thirty-three studies were conducted within the UK.
- Twenty-nine studies used life-cycle assessment (LCA) informed methods to calculate carbon emission, 19 of these utilised a full LCA approach comprising both:
    - an inventory analysis, evaluating the energy consumption, emissions and resource associated with an intervention throughout the life-cycle stage of the product, process or activity, and;
    - an impact assessment, converting inventory data from the life cycle assessment into a set of potential impacts on the environment (e.g. carbon emissions, eutrophication, ecosystem quality, non-renewable resources e.t.c.).

  Ten studies were critically appraised as 'High' quality, 14 as 'Medium' quality and five as 'Low' quality. Of the 33 studies conducted within the UK, one of these used full LCA methodology.
- We produced an evidence and gap map to present how the 89 included studies aligned with a simplified patient care pathway within each speciality. Urology (n=14), gastroenterology (n=13), oncology/radiation oncology (n=13) and renal (n=11) were the most common specialities represented, and gynaecology (n=3), ICU (n=2), obstetrics (n=1) and respiratory (n=1) were the least well represented. Across different specialities, the majority of evidence was found in the first three stages of the patient care pathway (Initial assessment/diagnostic tests, initial treatment or follow-up). The exception to this was the renal specialty, where most of the evidence was within the 'Ongoing care' segment of the patient care pathway. There was limited evidence within the 'Discharge' segment of the care pathway across all specialities. Evidence relating to the wider healthcare setting was clustered within the gastroenterology (n=5) and radiology specialities (n=5).

- All 89 included studies were classified into one of five broad intervention categories: 'Accessing care', 'Setting', 'Product level', 'Care delivery' and "Multiple components". Key findings from each category are as follows:
    - ***Accessing care (n=29):*** Studies represented a range of specialties, with urology (n=5), orthopaedics (n=4) and oncology/radiation oncology (n=6) the most common. Three studies were informed by LCA methodology; two were appraised as 'High' and one as 'Medium' quality. The most common type of intervention evaluated was ***telehealth***

(n=26), which was associated with reduced carbon emissions when compared to face-to-face care. However, most of the conclusions come from studies using a non-LCA based methodology (n=24) and were based on carbon-emission calculations which considered only patient-travel saved and did not account for carbon emissions associated with other parts of the system. This is reflected in the limited range of patient outcomes measured, of which patient travel distance and time saved were the most common. In general, the majority of patient and cost outcomes evaluated favoured the telemedicine intervention, although most outcomes were based on descriptive or narrative analyses.

- ***Setting (n=20):*** Four studies used LCA informed methodology, one appraised as 'High', two as 'Medium' and one as 'Low' quality. Overall, whilst ***waste management/reduction*** interventions were associated with reduced carbon emissions (n=12), interventions were highly heterogeneous with limited consideration of patient or cost outcomes. Seven non-LCA studies found reduced carbon emissions were associated with energy conservation interventions, the majority of which were conducted within radiology/radiotherapy settings.
- ***Product level (n=17):*** Thirteen LCA studies, appraised as predominantly 'High' or 'Medium' quality, used LCA or inventory analysis methods to explore carbon emissions associated with ***reuseable equipment***. Overall, reduced carbon-emissions were associated with reuseable equipment when compared to disposable options, although there is some uncertainty with respect to these findings within the urology speciality. Patient reported outcomes were limited. Two studies evaluated costs of reuseable equipment within gastroenterology settings, both concluding that reuseable/hybrid equipment cost less than disposable. One 'Medium' quality LCA study and three non-LCA studies evaluated interventions focusing on changing equipment type. Heterogeneity of interventions prevented meaningful synthesis.
- ***Care delivery (n=16):*** Five non-LCA studies evaluated the impact of ***altering the treatment regimen*** for patients undergoing cancer treatment. All studies indicated reduced carbon emissions were associated with treatment schedules which reduced the number of times patients were required to travel to hospital. Patient and cost outcomes were limited, with the majority calculated using narrative or descriptive statistics. Five non-LCA studies and one 'Medium' quality LCA study evaluated carbon emissions associated with changes to the patient treatment pathway. Three LCA studies (two of 'Medium', one of 'High' quality) and one non-LCA studies evaluated changes in surgical procedures.

- ***Multiple components (n=7):*** Heterogeneity across types of specialities and intervention precluded meaningful synthesis.

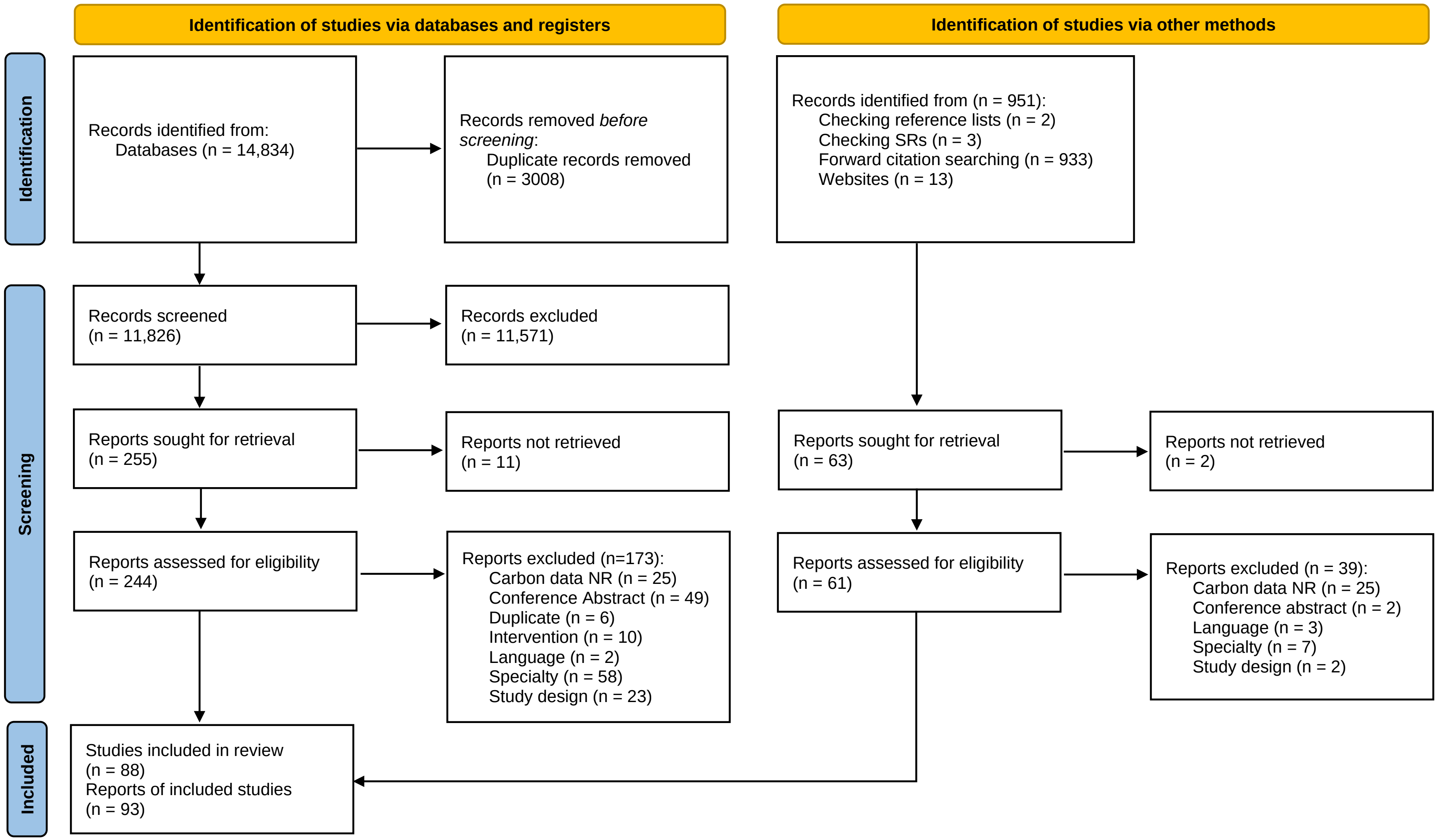
Descriptive results

Search results

The bibliographic database searches identified 14834 records. Following de-duplication, there were 11826 unique records. At title and abstract screening, 11571 records were excluded leaving 255 to screen at full text. A further 951 records were identified via alternative search methods, including forwards citation chasing (n=933), backwards citation chasing (n=2), website searches (n=13) and checking reference lists of relevant reviews (n=3), of which 63 were sought for retrieval. Of the 305 full texts which could be retrieved, 212 were excluded for the reasons listed in Figure 2. For a full list of reasons for exclusion at full text, please see Appendix D: List of excluded studies Eighty-nine studies (93 articles) met eligibility criteria for inclusion in this review and are described in Supplementary Materials 1.

Overview of included studies

Of the 89 studies (93 articles) which met eligibility criteria for this review, the majority were published in peer-reviewed academic journals, aside from 13 published as non-peer reviewed project web reports as part of carbon-reduction initiatives at individual NHS Trusts.(27-40)) Thirty-three studies were conducted within the UK,(27-62). Other countries included the USA (n=19),(63-82) France (n=6),(83-88) Germany (n=6),(89-94) Australia (n=4),(95-98) Canada (n=4),(99-102) Sweden (n=3),(103-105) Ireland (n=3),(106-108) multiple countries (n=2),(109, 110and one study was conducted within Austria,{Winklmair, 2023 #79) China,(111) Denmark,(112) Italy,(113) New Zealand,(114) Portugal,(115) Spain,(116) Switzerland (117)



From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71. For more information, visit: http://www.prisma-statement.org/

Figure 2: PRISMA diagram

Twenty-nine studies used LCA informed methods to calculate carbon emissions. Six studies conducted inventory analysis,(67, 75, 78, 98, 104, 118) or used methods informed by a LCA approach (n=3),(42, 43, 119) such as healthcare sustainability mode and effect analysis,(119) or component analysis.(43) Twenty studies used a full LCA approach.(59, 68-70, 73, 76, 77, 83, 87, 88, 92, 94, 96, 97, 103, 105, 107, 112, 113, 116) Of the 35 studies conducted within the UK, one used full LCA methodology.(59)

Of the studies which did not use LCA methods to calculate carbon emissions, 19 were based on an experimental study design, including three randomised controlled trials,(46, 64, 93) five controlled trials,(48, 65, 102, 107, 111) one feasibility study,(63) and 11 before and after studies.(27, 32-34, 36, 39, 60, 89, 99, 108, 114, 115) Nine were modelling studies.(28, 29, 31, 37, 38, 40, 50, 62, 109) The remaining 48 studies used observational methods, with the most common study designs being cross-sectional (n=9),(35, 44, 52, 71, 72, 86, 90, 100, 106) retrospective or prospective cohort (n=16),(45, 49, 51, 53, 56, 58, 61, 63, 66, 79, 80, 82, 84, 85, 110, 117) and database review (n=6).(41, 57, 74, 81, 95, 101) Further detail regarding the methods used in the studies based on LCA is provided as Supplementary Materials 2.

Studies were classified according to the five broad intervention categories: ‘Accessing care’ (n=29),(35, 41, 44, 45, 49, 51-53, 56, 58, 60, 63, 66, 71, 72, 74, 75, 77, 79, 86, 89, 93, 95, 100-102, 104, 106, 109, 114) ‘Setting’ (n=20),(27, 28, 32, 33, 37, 38, 40, 61, 80, 82, 85, 90, 91, 97, 108, 115-119) ‘Product level’ (n=17),(30, 54, 55, 59, 64, 67, 68, 73, 83, 88, 92, 94, 96, 98, 103, 105, 107, 112) ‘Care delivery’ (n=16),(29, 34, 39, 43, 46-48, 50, 57, 62, 65, 69, 70, 76, 81, 110, 111, 113) and ‘Multiple components’ (n=7).(31, 36, 42, 78, 84, 87, 99) Urology (n=14),(45, 53, 56, 57, 67, 69, 83, 86, 96, 98, 105-107, 113) Gastroenterology (n=12),(27, 36, 40, 52, 59, 61, 68, 73-75, 103, 115, 116) and Oncology/Radiation oncology (n=13) were the most common specialities represented.(34, 35, 46, 63, 65, 66, 72, 79, 81, 99-101, 110) The most common intervention evaluated was telemedicine (n=27),(35, 44, 45, 49, 51-53, 56, 58, 60, 63, 66, 71, 72, 74, 75, 77, 79, 86, 89, 93, 95, 101, 102, 104, 106, 114) which included three studies using LCA methods.(75, 77, 104). LCA methods were most commonly used to evaluate interventions within the ‘Product level’ category, specifically interventions comparing carbon emissions associated with reuseable versus single use equipment (n=13),(59, 67, 68, 73, 83, 88, 92, 94, 96, 98, 103, 107, 112) with the highest number in urology product-level interventions (n=6).(67, 83, 96, 98, 105, 107) Further detail regarding interventions evaluated by the studies using LCA methods is provided in Appendix E: Description of interventions evaluated by LCA studies.

An overview of the quality of all the studies using or informed by LCA methods is provided in the next section.

Quality of the evidence

The critical appraisal scores ranged from 11.5 to 34 (see Table 5). The majority of the studies had a clear aim or rationale and were clear on the paper's intended application and/or audience. All but three studies stated the lifecycle assessment method clearly.(42, 87, 107) However, only eight studies explicitly reported that they had conducted the study in accordance with ISO standards (ISO 14040 series).(59, 69, 73, 77, 94, 97, 103, 113) Not all studies were classified as full LCAs with some stating that the study was a 'simplified' LCA,(99, 107) others were inventory analyses as they did not consider environmental impacts beyond carbon emissions.(42, 67, 69, 75, 96-98, 107, 113, 118) Only six studies reported full details on the functional unit,(83, 88, 94, 103-105) while nine did not report any details at all.(67, 78, 96, 98, 107, 113, 116, 118, 119) Fifteen studies reported details on the systems studied and defined the system boundaries, often described as 'cradle to grave'.(44, 59, 67, 69, 75, 77, 83, 88, 94, 97, 104, 105, 113, 116) Just over a third of the studies fully reported details on the system covered - production, use/reuse and disposal of materials and energy.(43, 69, 70, 75, 77, 94, 97, 104, 105, 113) More than half the studies (n =17) fully explained the data collection process, the data included, and the source(s) of reference data which was most commonly the Ecoinvent database.(43, 59, 67-70, 73, 75-77, 94, 97, 103, 104, 112, 113, 116) Authors could report obtaining detailed data from manufacturers (e.g. (107)) and others noted a lack of data on the material composition of devices (e.g. (68, 83)). Allocation was not always necessary,(42, 75, 77, 96, 104, 118) but where environmental exchanges had to be allocated to different products, a number of studies described and justified the allocation.(43, 59, 73, 76, 78, 88, 94, 98, 103, 116, 119) Only five studies scored highly on reporting impact assessment.(59, 76, 83, 94, 113) Some reported the tools used for assessing environmental impacts: (i) the US EPA's impact assessment model, TRACI (Tool for the Reduction and Assessment of Chemical and other Environmental Impacts);(64, 64,(69Meiklejohn, 2023 #48, 73, 76-78, 88); (ii) ReCiPe Midpoint Hierarchist model;(59, 68, 92, 97) and (iii) the Eco-Indicator 99 tool.(105) Only three studies used both uncertainty analyses and sensitivity analyses to contextualise their results.(77, 103, 104) For the majority of studies (n = 23), their conclusions were consistent with their goals and supported by their results. Three studies did not disclose a potential conflict of interest or include a funding declaration.(43, 70, 78) Five studies made a funding declaration but asserted that receiving funding from manufacturing companies such as Amu A/S and Neo Medical S. A. had not influenced the results of studies.(59, 83, 92, 105, 112) One study reported a research agreement with an industry partner (Vanguard AG, Germany) who provided primary data for the ‘medical remanufacturing route’ and the ‘bill of materials’ for the catheter under investigation.(94)

Table 5: Quality appraisal

Author, Date	Study goal clearly stated, study's rationale (1), intended application, and/or intended audience (1)	Life cycle assessment method clearly stated (1)	Functional unit clearly defined and measurable (1), justified (1), and consistent with study's intended application (1)	System adequately described with clearly stated boundaries (1), lifecycle stages (1), and justification of omitted stages (1)	The system covers production (1), use/reuse (1) and disposal (1) of materials and energy	Data collection process clearly explained, including source(s) foreground material weights/energy values (1); source(s) reference data (1); what data included (1)	Representativeness of data discussed (1), differences in electricity generating mix accounted for (1), and potential significance of exclusions/assumptions addressed (1)	Allocation procedures, where necessary, are described and appropriately justified (1)	Impact categories (1), characterization method (1), and software used (1) are documented transparently	Results are clearly reported in the context of the functional unit (1) (0.5 if graphically, 0 if only normalized results reported)	A contribution analysis is performed and clearly reported (1), and hotspots are identified (1)	Conclusions consistent with goal and scope (1) and supported by impact assessment (1)	Results are contextualised through the use of sensitivity analysis (1) and uncertainty analysis (1)	Limitations adequately discussed (1), and potential impact of omissions/assumptions on study's outcomes described (1)	Assessment has been critically appraised (1)	Source(s) of funding (1) and potential COI disclosed (1), and unlikely to be source of bias (1)	Overall rating
Baboudjian 2023(83)	2	1	3	3	1.5	1	2	0	2	0	2	2	1	2	1	2	25.5
Boberg 2022(103)	2	1	3	3	2	3	2	1	2	1	2	2	2	2	1	3	32
Chuter 2023(42)	2	0	2	2	0.5	2	1	NA	NA	1	2	2	NA	1	1	3	19.5
Connor 2011a*(43)	2	1	1	3	3	3	3	1	0	0	2	2	0	2	1	0	24
Davis 2018(96)	2	1	0	1	3	2	1	NA	0	0.5	2	0	0	0	1	1	14.5
de Ridder 2022**(119)	2	1	0	2	1	2	0.5	1	NA	0	2	2	0	1	1	3	18.5
Fuschi 2023(113)	1	1	0	3	3	3	0	0	3	0.5	0	1	0	0	1	1	17.5
Hogan 2022(107)	1	0	0	2	1.5	2	1	1	NA	0	2	2	0	2	1	1	16.5
Holmner 2013(104)	2	1	3	3	3	3	2	NA	0	1	0	1	2	2	1	3	27
Kemble 2023(67)	2	1	0	3	2	3	0.5	0	0	1	2	1	0	2	1	3	19.5
Le 2022 (68)	1	1	2	2	3	3	1	0	2	1	2	2	1	2	1	0	24
Leapman 2023(69)	2	1	2	3	3	3	1	0	0	1	2	2	1	2	1	1	25
Leiden 2020(92)	2	1	2	2	1.5	2	2	0	2	0.5	2	2	1	0	1	1	22
López-Muñoz 2023(116)	2	1	0	3	1.5	3	2	1	1	0	2	2	0	2	1	3	24.5
McAlister 2022(97)	2	1	2	3	3	3	3	0	0	2	2	2	0	2	1	3	29
Meiklejohn 2023(70)	2	1	2	2	3	3	1	0	2	1	2	2	1	1	1	0	24
Rizan 2022(59)	2	1	2	3	3	3	2	1	3	1	2	2	1	2	1	1	30

Author, Date	Study goal clearly stated, study's rationale (1), intended application, and/or intended audience (1)	Life cycle assessment method clearly stated (1)	Functional unit clearly defined and measurable (1), justified (1), and consistent with study's intended application (1)	System adequately described with clearly stated boundaries (1), lifecycle stages (1), and justification of omitted stages (1)	The system covers production (1), use/reuse (1) and disposal (1) of materials and energy	Data collection process clearly explained, including source(s) foreground material weights/energy values (1); source(s) reference data (1); what data included (1)	Representativeness of data discussed (1), differences in electricity generating mix accounted for (1), and potential significance of exclusions/assumptions addressed (1)	Allocation procedures, where necessary, are described and appropriately justified (1)	Impact categories (1), characterization method (1), and software used (1) are documented transparently	Results are clearly reported in the context of the functional unit (1) (0.5 if graphically, 0 if only normalized results reported)	A contribution analysis is performed and clearly reported (1), and hotspots are identified (1)	Conclusions consistent with goal and scope (1) and supported by impact assessment (1)	Results are contextualised through the use of sensitivity analysis (1) and uncertainty analysis (1)	Limitations adequately discussed (1), and potential impact of omissions/assumptions on study's outcomes described (1)	Assessment has been critically appraised (1)	Source(s) of funding (1) and potential COI disclosed (1), and unlikely to be source of bias (1)	Overall rating
Rouviere 2022(87)	2	0.5	1	1	0	0	0	0	1	0	0	1	0	1	1	3	11.5
Sanchez 2020(88)	2	1	3	3	1.5	2.5	3	1	2	1	2	2	1	2	1	3	31
Schulte 2021(94)	2	1	3	3	3	3	3	1	3	1	2	2	1	2	1	3	34
Sherman 2018(73)	2	1	2	2	2	3	2	1	2	1	2	2	1	0	1	3	27
Sillcox 2023b(75)	1	1	2	3	3	3	2	NA	0	1	1	2	1	2	1	1	24
Sorensen 2018(112)	2	1	2	2	2	3	1	0	1	0.5	1	2	1	2	1	2	23.5
Stripple 2008(105)	2	1	3	3	2	1	1	0	2	0.5	0	2	1	0	1	1	20.5
Thiel 2015(76)	3	1	2	2	2.5	3	2	1	3	1	1	2	1	2	1	3	31.5
Thiel 2018(78)	2	1	0	0	1.5	2	1	1	0	0	2	2	0	0	1	0	13.5
Thiel 2023(77)	2	1	2	3	3	3	0.5	NA	2	1	2	2	2	1	1	3	28.5
Winklmair 2023(118)	2	1	0	2	0.5	2	1	NA	0	0	0	2	0	1	1	2	14.5
Wombwell 2023(98)	2	1	0	2	1.5	2	0.5	1	0	0	1	2	0	2	1	3	19

*Component analysis, **Healthcare Sustainability Mode and Effect Analysis. Top score – 35. High –>26 (Green) Medium – > 17.5(Blue) Low – 17.5 (Amber). COI=Conflict of Interest, Inventory analysis (pink),

Evidence and gap map

This evidence and gap map (EGM) provides a brief description of where primary research exists across the patient pathway for 13 specialities in secondary healthcare. Further detail regarding intervention findings specific to individual specialties can be found in Appendix F.

Urology

In urology, there are six intervention studies that are categorised as 'accessing care', five of which relate to 'initial assessment and /or diagnostic test',(45, 56, 69, 86, 106), five to 'follow-up care',(45, 53, 69, 86, 106) and one to 'discharge from secondary care'.(53) There are seven product level studies with four in 'initial assessment and /or diagnostic test',(67, 83, 98, 107) and three in ''initial treatment'.(96, 105, 113) There is one intervention study categorised as 'care delivery' and is in the 'initial treatment' part of the care pathway.(57)

Gastroenterology

In gastroenterology, there are three 'accessing care' intervention studies in 'initial assessment and/or diagnostic test',(52, 74, 75) and one in 'follow-up care' parts of the care pathway.(52), There are also four product level studies, two of which are in 'initial assessment and/or diagnostic test',(68, 73) and two in 'initial treatment'.(59, 103) Within this speciality, there are four 'setting' studies (i.e. with a focus on waste management or energy conservation), three of which relate to 'initial assessment and /or diagnostic test',(61, 115, 116) and two in 'systemic intervention' (See Methods).(27, 115) There are also two multicomponent studies in the ''systemic intervention' part of the care pathway.(36, 40)

Oncology

Within the cancer speciality, 'accessing care' intervention studies dominate across the care pathway, with seven in 'initial assessment and /or diagnostic test',(35, 51, 63, 66, 72, 79, 100) six in 'follow-up care',(35, 63, 66, 72, 100, 101) two in 'ongoing care',(35, 79) and one in 'discharge from secondary care'.(35) There are also five 'care delivery' studies that are split across 'initial treatment' (n =1),(81) and 'ongoing secondary care' (n = 4).(34, 46, 65, 110)

Ophthalmology

Ophthalmology has only four studies, two product level studies in the 'initial treatment' part of the care pathway,(54, 55) and two 'setting' studies in the 'systemic intervention' category of the care pathway.(80, 118)

Respiratory

There is only one product level study in the respiratory speciality, relating to the 'initial assessment and /or diagnostic test' part of the care pathway.(112)

Renal

Almost all the studies within the renal speciality are found within 'ongoing secondary care': four are 'accessing care' intervention studies,(43, 60, 95, 109) two are 'care delivery' studies,(44, 50, 111) three are multicomponent studies,(31, 37, 84) and four are 'setting' studies.(28, 37, 38, 84). One 'setting' study fits within the 'follow-up' care part of the care pathway.(28)

Cardiac

There are four studies in the cardiac speciality; two 'accessing care' intervention studies (one in 'follow-up care',(39) and one in 'ongoing secondary care'(114)), one care delivery study in 'initial treatment',(62) and one product level study in 'initial assessment and/or diagnostic test'.(94)

ENT

There are four studies in the ENT speciality; three accessing care intervention studies and one care delivery study, split across the 'initial assessment and/or diagnostic test',(51, 102) and 'initial treatment' parts of the clinical pathway.(29, 70)

Orthopaedic and/or trauma

Eight of the studies within the orthopaedics/or trauma speciality are accessing care intervention studies spread across three parts of the care pathway, 'initial assessment and/or diagnostic test' (n = 1),(89) 'initial treatment' (n = 2),(48, 49) and 'follow-up care' (n = 5).(47, 48, 58, 89, 93) The remaining studies are two multicomponent studies, one in' initial treatment',(32) and one in 'systemic interventions',(33) and two product level studies found in 'initial treatment'.(30, 92)

Radiology

With radiology, there are three 'accessing care' intervention studies (two in 'initial assessment and/or diagnostic test',(41, 66) and one in 'follow-up care'(66)); there are five 'care delivery' studies, one in 'follow-up care',(42) and four in 'ongoing secondary care'.(34, 42, 46, 65) There are four 'setting' studies (one in 'initial assessment and/or diagnostic test',(90) and four in the 'systemic interventions' part of the care pathway (82, 90, 108, 117)). There is one multicomponent study in 'initial assessment and/or diagnostic test' and in 'systemic interventions',(91) and one product level study ('initial assessment and/or diagnostic test'.(97)

Obstetrics

There are only four studies in the obstetrics pathway, one 'accessing care' study in 'follow-up care',(71) one 'care delivery' study in 'initial treatment',(76) and two multicomponent studies in 'initial treatment'.(78, 119)

ICU

There is one product level study based in ICU and it is in the first four parts of the care pathway.(88)

Multiple

The 'multiple' speciality has two 'accessing care' intervention studies, each sitting within the 'initial assessment and/or diagnostic test', 'initial treatment' and 'follow-up care' parts of the care pathway.(77, 104) It also has three multi component studies, two of which are in 'initial treatment',(64, 87) and the other in 'systemic interventions'.(85)

Narrative synthesis

This section presents the narrative synthesis of all included studies, grouped into five broad intervention categories: Accessing care (n=29), Setting (n=20), Product level (n=17), Care delivery (n=16) and Multiple (n=7). Key findings relating to similar interventions within each speciality are explored with respect to key outcomes such as carbon emissions, patient outcomes and service costs. A summary providing an overview of findings from each intervention category is provided at the end of each section. Tables providing an overview of study methods and findings relating to carbon emissions, patient outcomes and service costs for non-LCA studies can be found in Appendices G to K. Please see Supplementary Materials 3 and 4 for detail regarding specific outcomes from individual studies.

Accessing care

Summary: accessing care

Twenty-nine studies evaluated the effectiveness of interventions which changed how patients accessed care. Interventions within this category included telehealth or remote care interventions (n=26),(35, 44, 45, 49, 51-53, 56, 58, 60, 63, 66, 71, 72, 74, 75, 77, 79, 86, 89, 93, 95, 101, 102, 104, 106, 114) and de-centralized care (n=3),(41, 100, 109) Three of the studies within this intervention category were LCAs evaluating telehealth interventions.(75, 77, 104)

LCA studies: Whilst the reductions in carbon emissions associated with the use of telemedicine or virtual appointments is consistent across the three 'Moderate' to 'High' quality studies represented, the lack of duplication of these findings within specialities and heterogeneity of intervention content and delivery limits confidence in the reliability of these findings and how widely they can be generalised. There was limited evidence regarding the impact of such interventions on patient outcomes or service costs.

Non-LCA studies: All 24 studies which compared telehealth interventions to face-to-face care reported reduced carbon-emissions within the telehealth intervention group. However, most of these conclusions were based on carbon-emission calculations which considered only patient-travel saved and did not account for carbon emissions associated with other parts of the system e.g. energy associated with infrastructure use within patient homes and healthcare facilities where staff are based, or emissions associated with the extraction, manufacture, transport and/or disposal of relevant materials e.g car/petrol production. This is reflected in the limited range of patient outcomes measured, of which patient travel distance and time saved were the most common. Sixteen studies evaluated cost outcomes. In general, the majority of patient and cost outcomes favoured the telemedicine intervention, although most outcomes were analysed descriptively or narratively. Three studies reported that interventions aiming to de-centralise care demonstrated reduced carbon emissions when compared to standard care, with carbon emission calculations predominantly based on travel saved. Specialities represented included renal,(109) oncology,(100) and radiology.(41)

LCAs

Three studies stated that they used LCA methods to evaluate an intervention which changed access to care. One study appraised as 'Medium' quality was conducted within gastroenterology,(75) and two studies appraised as 'High' quality were relevant to multiple specialties.(77, 104) The carbon emission findings and other outcomes reported are summarised in Table 6 below.

Three studies evaluated the effectiveness of telehealth or virtual care interventions and indicated a reduction in carbon emissions following intervention implementation.(75, 77, 104) One 'High' quality study completed a full impact assessment, which indicated a significant difference between intervention and face-to-face control groups in favour of the virtual care intervention for the following impact categories: Ozone depletion, smog, acidification, eutrophication, carcinogenics, non-carcinogenics, respiratory effects, ecotoxicity and fossil fuels.(77) Patient outcomes were limited to the non-statistical comparison of distance travelled (n=2),(75, 104) or number of cancellations (n=1) between groups,(75) both of which favoured the telemedicine intervention or showed no difference.

Non-LCA studies

Telemedicine

Twenty-four studies using a non-LCA approach to evaluate interventions which focused on the remote delivery of services through telemedicine or video conferencing in comparison to face-to-face care.(35, 44, 45, 49, 51-53, 56, 58, 60, 63, 66, 71, 72, 74, 79, 86, 89, 93, 95, 101, 102, 106, 114). Six observational studies were conducted within oncology/radiation oncology services,(35, 63, 66, 72, 79, 101) five observational studies were conducted within urology services,(45, 53, 56, 86, 106) four studies were conducted within the orthopaedics and/or trauma speciality (two observational,(49, 58) and two using an experimental comparative study design(89, 93)) three observational studies were conducted within the renal speciality,(44, 60, 95) two observational studies were conducted within gastroenterology,(52, 74) two studies were conducted within ENT services (one observational,(51) the other a prospective comparative study(102)), one before and after study was conducted within cardiology,(114) and one observational study was carried out within gynaecological services.(71) All of the studies reported reduced carbon-emissions within the telehealth intervention group. However, most carbon-emission calculations considered only patient-travel saved and did not account for carbon emissions associated with other parts of the system. For example, energy associated with infrastructure use within patient homes and healthcare facilities where staff are based, or emissions associated with the extraction, manufacture, transport and/or disposal of relevant materials e.g car/petrol production were not often considered. This is reflected in the limited range of patient outcomes measured, of which patient travel distance (n=12),(44, 45, 53, 60, 66, 71, 72, 74, 79, 95, 101, 106) and time saved (n=9) were the most common.(63, 66, 86, 89, 93, 95, 101, 102, 106) Patient satisfaction (n=3),(49, 95, 102) safety (e.g. adverse events) (n=3),(49, 52, 74) and acceptability (i.e. attendance) (n=5) were poorly reported.(52, 56, 60, 74, 93) The retrospective nature of these studies meant that whilst some data for these key outcomes was reported for the intervention group, complementary comparative data for the control group was often absent.

Overall, the results for most patient outcomes measured favoured the telehealth intervention group. Sixteen studies considered costs to patients (n=10),(49, 58, 63, 66, 79, 86, 93, 95, 101, 106) and/or services (n=6).(45)((35, 51, 53, 56, 60) Findings were mainly based on narrative/descriptive cost-calculations (i.e. were not formal cost-effective studies and did not use statistical tests to establish if there was a significant difference between groups), indicating telehealth interventions were associated with reduced costs for both patients and services compared to face-to-face care. The exception to this was a study by Dorrian et al (2009), which indicated face-to-face care cost less than consultants supervising patient examination via videoconferencing software.(51) In this study, authors indicated that the threshold at which tele-ENT became cheaper than travel was not met within the pilot study.

As indicated above, most studies within this category used observational study designs, thus findings may be more susceptible to bias than findings arising from experimental studies using comparative study designs.

De-centralised care

Three studies evaluated interventions aiming to decentralise care, including an outreach clinic for head and neck cancer patients,(100) a breast cancer screening clinic,(41) or delivery systems for home haemodialysis equipment.(109) Study designs were a retrospective database review, cross-sectional survey and two modelling studies. Carbon emission reduction calculations were predominantly based upon emissions associated with travel and were in favour of the care pathway intervention across all three studies. The only other patient outcome measured was distance to travel to point of care, which was reduced by the care pathway intervention in one study.(41) Cost outcomes were measured in one study, which indicated that an intervention facilitating direct sharing of equipment between users reduced costs when compared to delivery via a central depot.(109)

Further detail regarding the non-LCA studies evaluating interventions within the ‘Accessing Care’ category can be found in Appendix G.

Table 6: Accessing care – outcomes from LCA studies

Study, speciality: Study design (Comparison)	**Carbon emission findings**	**Other Outcomes**											
		Patient travel saved	**Cancellations**	**Ozone depletion**	**Smog**	**Acidification**	**Eutrophication**	**Carcinogenics**	**Non-carcinogenics**	**Respiratory effects**	**Ecotoxicity**	**Fossil fuel depletion**	**Costs**
	Telehealth												
Holmner 2014, Hand and plastic surgery: Inventory analysis (C1: Telerehab vs C2: Face-to-face)(104)	***Favours C1 (telemedicine):*** Hand/plastic surgery clinic: carbon cost of 238 telemedicine appointments=602 kgCO_2e (average of 1.4–2.8% of carbon costs of travelling to/from clinic by car or subsidized taxi services, and total avoided travel distance of 82,310 km for patients. Based on upper+lower bound scenarios, 1xtelerehabilitation visit generated 0.4–0.9% and 3.2–6.4% of carbon costs for 1xface-to-face appointment. Similar numbers obtained in speech therapy clinic. Summary: telerehabilitation activities of two clinics cut carbon emissions by 15–250 times for telemedicine work model compared vs traditional care. Based on the upper and lower bound scenarios, 1x1hr telemedicine appointment estimated to generate 1.86 and 8.43 kgCO_2e, respectively. Telerehabilitation carbon cost-effective if patient travels min.3.6km by car for 1x1hr appointment (using Lenzen estimate)[a] or 7.2 km (based on the Leduc estimate).[b] Corresponding values for the upper bound videoconference scenario: 16 km and 32 km, respectively. Sensitivity analysis show technology used, meeting duration, bandwidth, use rate/expected life equipment impact carbon emissions for telemedicine	C1> C2 [N]											
Sillcox 2023b, GE: Inventory analysis (C1: Telerehab vs C2: Face-to-face)(75)	***Favours C1 (telemedicine):*** In-person visits: 145 patient travel distances recorded (median [IQR] distance travel distance of 29.5 [13.7, 85.1] miles)= 38.22–39.61 kgCO_2-eq emitted. Telemedicine visits: Mean (SD) visit time=40.6 (17.1) min. Telemedicine GHG emissions ranged from 2.26 to 2.99 kgCO_2-eq depending on device used. In-person visit=25 times more GHG emissions compared to telemedicine visit ($p<0.001$)	C1> C2 [N]	><										

Study, speciality: Study design (Comparison)	Carbon emission findings	Other Outcomes											
		Patient travel saved	Cancellations	Ozone depletion	Smog	Acidification	Eutrophication	Carcinogenics	Non-carcinogenics	Respiratory effects	Ecotoxicity	Fossil fuel depletion	Costs
Thiel 2023, Multiple: LCA (C1: Virtual Care vs C2: Face-to-face)(77)	***Favours C1 (virtual care):*** VC system reduced 2021 GHG emissions by nearly 17,000 metric tons vs in-person treatment, equivalent of over 2100 homes energy use/yr or CO_2 sequestered by nearly 20,000 acres of US forest in one year.25 Departments with largest growth of telemedicine: psychiatry (88% visits virtual in 2021), medical specialties (73%), pain management (68%), GI surgery (63%), and cancer (47%). Specialties with smaller increases in telemedicine: ophthalmology (1% of visits were virtual in 2021), plastic surgery (7%), orthopaedics (11%), and otolaryngology (18%). Emissions/patient ranged by department and visit type. In-person visits: primary care and paediatrics emitted least per visit (7.33 kg CO_2e/visit). Orthopaedics: largest per visit emissions (63.8 kg CO_2e/in-person visit). Per visit, virtual medicine emits <1% GHGs of in person visit, [range of 0.02 to 0.08kg CO_2e/visit, depending on department]. Assumed mode of patient travel has largest impact on model. When modelled all patient travel as occurring via passenger car, in-person visit emissions increased 77%, from 25,700 metric tons to 45,400 metric tons. For in-person visits, energy sources had little influence on emissions outcomes. Solar power reduced modelled emissions slightly and US average grid mix increased emissions slightly. Changing assumed energy intensity of clinics for in-person visits, or for in-person visits avoided by virtual visits, did not change outcomes. Transportation of patients dominates SHC's per-visit emissions. For VC specifically, changes to energy sources did impact modelled emissions, with solar reducing virtual visit emissions nearly 70% and US grid mix leading to 20% increase in estimated telehealth emissions. A maximum supply list, though unrealistic for most clinical visits, increased total GHG emissions from all in person 2021 visits by about 1.1% or 277,000 kg CO_2e. Modes of transportation change study results, with large caveat that access to various modes of transit are limited e.g. aircraft useless for short-distance travel, bike useless for long-distance, an appropriate bus route may not be accessible, or car may be unaffordable. Therefore, analysis speaks only to theoretical changes to emissions rather than practical changes			C1 > C2 (S)	C1 > C2 (S)	C1 > C2 (S)	C1 > C2 (S)	C1 > C2 (S)	C1> C2 (S)	C1> C2 (S)	C1 > C2 (S)	C1> C2 (S)	

Green shaded cell=Study appraised as 'High' quality, Blue shaded cell=Study appraised as "Medium" quality,C1 > C2 - Analysis favoured Comparator 1 over C2, [N] - supported by narrative write up (no formal statistics), [S] – calculated using formal statistics, [a]Lenzen M (1999) Total requirements of energy and greenhouse gases for Australian transport. Transportation Research Part D-Transport and Environment 4: 265–290, [b]Leduc G, Mongelli I, Uihlein A, Nemry F (2010) How can our cars become less polluting? An assessment of the environmental improvement potential of cars. Transport Policy 17: 409–419, [c]No negative impact of intervention, [d]Incomplete impact assessment, [e]Component Analysis Study. C=Comparator, CA=Component Analysis, GE=Gastroenterology, GHG=Greenhouse Gas, GI=Gastrointestinal, HHD=Home Haemodialysis, HVAC=heating, ventilation, and air conditioning, kg CO2 eq=kg Carbon Dioxide equivalents, ICHD=In-Centre Haemodialysis, IQR=Interquartile Range, kWh=Kilowatt hours, MRI=Magnetic Resonance Imaging, SD=Standard Deviation, TRUS= Transrectal Ultrasound, VC=Virtual Care

Setting

Summary: Setting

Twenty studies evaluated interventions which focused on changing behaviours within the wider healthcare delivery system. Interventions could be separated into two categories; waste management (n=12),(27, 28, 32, 33, 40, 61, 80, 85, 115, 116, 118, 119) and energy conservation (n=8).(37, 38, 82, 90, 91, 97, 108, 117) Four of these studies were informed by LCA methods, and are described further below.(97, 116, 118, 119)

LCA studies: Three studies drawing on LCA methods, appraised as "Medium" or "Low" quality reported reductions in carbon emissions achieved through waste reduction interventions. Interventions were highly heterogeneous and no other outcomes aside from waste reduction were measured. One inventory analysis appraised as 'High' quality, indicated CT and MRI scans were associated with highest carbon emissions.

Non-LCA studies: Nine studies indicated carbon emissions were reduced following a waste management intervention, although calculations were often based on a narrow range of processes/stages within the systems being evaluated. Only four studies evaluated patient satisfaction,(28, 40) and/or patient clinical outcomes,(27, 28, 115) with seven studies reporting on service cost.(27, 28, 32, 33, 40, 85, 115) All other outcomes favoured the waste management intervention being evaluated. The quantity of data available for synthesis was limited by the number of studies providing data on each outcome for each comparator. Seven studies used a non-LCA approach to evaluate energy conservation interventions. The majority of these were conducted within radiology/radiotherapy settings (n=5),(82, 90, 91, 108, 117) four focusing on reducing energy associated with equipment when not in use,(82, 90, 108, 117) and one evaluating the construction and operation of an energy optimised medical centre.(91) The majority of studies found reduced carbon emissions associated with the intervention. Two related studies modelled the potential environmental and cost impacts associated with retrofitting heat exchangers to haemodialysis machines and reporting findings which favoured the intervention condition.(37, 38)

LCAs

Details regarding findings for carbon emissions and other outcomes are reported in Table 7, with further information regarding study design and participants reported in Appendix H and Supplementary Materials 3.

Waste management

Two studies undertook an inventory analysis approach to establish the impact of waste management interventions on carbon emissions,(116, 118) with a further study undertaking a 'Healthcare Sustainability Mode and Effect Analysis.(119) Two were appraised as "Medium" quality,(116, 119) and one as "Low" quality.(118) Overall, reductions in carbon emissions were achieved through waste reduction interventions which included a waste reduction decision tool for use in the operating room (OR),(119) maximising recycling of components of surgical instruments,(116) and increasing recycling of different parts of packaging of instruments used during cataract surgery.(118) No other outcomes aside from waste reduction were measured.

Energy conservation

One study, using an inventory analysis approach and appraised as 'High' quality, compared carbon emissions associated with different types of scan types,(97) and reported that highest carbon emissions were attributable to CT and MRI scans (when compared to X-ray, mobile x-ray and ultrasound). MRI had the highest mean power consumption and time spent per scan, spending 67% of its time in standby mode.

Table 7: Setting LCA studies – overview of main findings

Study: Speciality (Study design)	Name of Interventions (C1 vs C2 etc…)	Carbon emission findings (based on summary of reported findings for each study)	Summary findings: other outcomes					
			Time spent standby mode	Time/scan	Power consumption	Waste incineration	Waste reduction	Staff satisfaction
McAlister 2022: Radiology/Radiotherapy (Inventory analysis)[a] (97)	Image type C1: CXR vs C2: Ultrasound vs C3: MCXR vs C4: CT vs C5: MRI	***C4 (CT) and C5 (MRI) largest environmental impact:*** ALCA: MRI and CT had highest emissions=17¢5 and 9¢2 kg CO2e per scan respectively. Majority of impact (MRI - 94%, CT - 91%) resulting from electricity use. MRI-impact of consumables came predominantly from cotton drawsheets (0¢7kg CO2e, or 4% total impact). For CT: originated primarily from contrast tubing, cotton sheet and pillowcase (both 0¢4 kg CO2e, 4%) and contrast tubing (0¢3 kg CO2e, 3%). US and CXR had similar carbon impacts (0¢76 and 0¢53 kg CO2e respectively). Whilst dominant emissions source for US (as for MRI and CT) is electricity (87%), for CXR=washing/drying of cotton sheet and pillowcase (0¢67 kg CO2e, 88%), with electricity only contributing 0¢02 kg CO2e, or 3% of total impact. CLCA: Carbon emissions for MRI, CT and US were 84-94% lower compared to ALCA, due to exclusion of standby power in calculated impact. MRI and CT remained imaging modalities with largest impacts (1¢1 and 1¢09 kg CO2e respectively). For CXR, impact fell only slightly from 0¢8 to 0¢6 kg CO2e compared to ALCA, as main source of impact (sheet/pillowcase laundering) remained same	All imaging devices spent more time in standby mode vs active mode (range 67% MRI time in standby to 99.6% for X-ray)	C1< C3< C4 <C2< C5	MRI highest mean power consumption/minute of operation in active and standby, had lower attributional power consumption vs CT due to CT scanner being in standby longer than MRI scanner (92% time vs 67%) so each active minute of CT scanner having greater number standby min.[b]			
De Ridder 2022: Obstetrics [HSMEA](119)	C1: Waste reduction decision tool C2: Usual care	***Favours C1 (Decision tool):*** Sustainable solutions in preparation room and OR for C-section: waste reduction of 600g (-22%) and a carbon footprint reduction of 2.5 kg CO2 eq (-22%). Of total CO2 footprint reduction, 98% attributable to revision of custom pack, 2% from paper/plastic recycling					C2>C2 (N)	NCD
López-Muñoz 2023: GE (Inventory Analysis)(116)	C1: Recycling (Green mark intervention) C2: Biowaste	***Favours C1 (Green mark intervention):*** Reduction of 34.3% of emissions (95% CI 28.1% to 40.3%). GHG emissions reached up to 67.74kg CO2 -eq during our one-week prospective study. Sustainability intervention could reduce environmental impact up to 27.44% (18.26 kg CO2 -eq). This allows recycling of 61.7% of the instrument total weight (4.69kg)				C1> C2 (N)		

Study: Speciality (Study design)	Name of Interventions (C1 vs C2 etc…)	Carbon emission findings (based on summary of reported findings for each study)	Summary findings: other outcomes					
			Time spent standby mode	Time/scan	Power consumption	Waste incineration	Waste reduction	Staff satisfaction
Winklmair 2023: Ophthalmology (Inventory Analysis)(118)	C1: Recycling components of cataract package vs C2: Incineration	***Favours C1 (Recycling):*** Cataract packages of 3 hospitals contained average 0.74kg materials=2.3kg CO, eq/package. (not including: phaco cassettes, tubing, infusions with cutlery, other cataract package external disposables). GWP for all cataract packages sold in 2021 with an 100% assumed waste incineration rate for all products was 209 380 kgCO; eq. (2.4kg CO, eq/cataract package). With assumed recycling rate of 100% of all technically recyclable materials (ie., packaging materials not contaminated in OR), carbon footprint was 195804 kg CO; eq. (2.2kg CO; eq/cataract package). Difference in CO, effect between cataract packages with 100% incineration and those with 100% recyclable materials was, therefore, approximately 6.5% (13576kg CO, eq.)						

Green shaded cell=Study appraised as 'High' quality, Blue shaded cell=Study appraised as "Medium" quality, Orange shaded cell=Study appraised as "Low" quality, [a]Stated as LCA, but incomplete impact assessment, [b]ALCA power consumption higher than both mean power consumption and CLCA power consumption due to high proportion of time spent in standby for all modalities.CI=Confidence Interval. C=Comparator, CT=Computerised Tomography, CXR=Chest X-Ray, GE=Gastroenterology, ALCA=Attributional Life Cycle Assessment, CLCA=Consequential Life Cycle Assessment, LCA=Life Cycle Assessment, MRI=Magnetic Resonance Imaging, MCXR=Mobile Chest X-Ray, NCD=No Comparative Data, C1>C2 = favours C1, (N)=Narrative synthesis

Non-LCA

Waste management

Nine studies used a non-LCA approach to evaluate various waste management interventions. Four were conducted within gastroenterology settings,(27, 40, 61, 115) one within renal,(28) one across multiple settings,(85) two within orthopaedics/trauma,(32, 33) and one within ophthalmology.(80) Overall, carbon emissions were reduced as a result of waste management interventions, although calculations were often based on a narrow range of processes/stages within the systems being evaluated. A heterogeneous range of other outcomes were measured. Only four studies evaluated patient satisfaction,(28, 40) and/or patient clinical outcomes.(27, 28, 115) The quantity of data available for synthesis was limited by the number of studies providing data on each outcome for each comparator. Seven studies reported on service costs.(27, 28, 32, 33, 40, 85, 115) All other outcomes favoured the waste management intervention being evaluated.

Energy Conservation

Seven studies used a non-LCA approach to evaluate energy conservation interventions. The majority of these were conducted within radiology/radiotherapy settings (n=5),(82, 90, 91, 108, 117) and two studies were conducted within a renal setting.(37, 38)

Of the five studies conducted within a radiology setting, four focused on reducing energy associated with equipment when not in use,(82, 90, 108, 117) Two of these four studies used a modelling approach,(82, 90) and two used a before and after.(108, 117) Both modelling studies and one experimental study demonstrated the actual or potential reductions to carbon-emissions associated with switching equipment (such as monitors, air conditioners and MRI scanners) off completely, or using standby mode when not in use during late or overnight shifts. The intervention which focused on providing the results of a one week energy audit at a department meeting was not effective in reducing the number of desktop computers left on overnight,(108) which may indicate that provision of information alone is insufficient to change staff behaviour. One retrospective comparative study compared the energy use across the building and operation of two radiological facilities using different energy-friendly and/or regenerative technology and the carbon emission savings associated with each condition are reported in Appendix H.(91) All five studies calculated potential or actual energy and costs saved, which favoured the intervention.

Two studies modelled the potential environmental and cost impacts associated with retrofitting heat exchangers to haemodialysis machines,(37, 38) reporting findings which favoured the intervention condition.

Product Level

Summary: Product level

Eighteen studies evaluated interventions at the product level. Specialties represented by these studies include urology (n=6),(67, 83, 96, 98, 105, 107) gastroenterology (n=5),(59, 61, 68, 73, 103) ophthalmology (n=1),(54, 55) cardiology (n=1),(94) ICU (n=1),(88) respiratory (n=1),(112) orthopaedic and/or trauma (n=2),(30, 92) and multiple specialties (n=1).(64) Fourteen of these studies used LCA informed methodology.(59, 67, 68, 73, 83, 88, 92, 94, 96, 98, 103, 105, 107, 112)

LCA studies: Thirteen studies, appraised as predominantly "High" or "Medium" quality, used LCA or inventory analysis methods to explore carbon emissions associated with reuseable equipment. Overall, reduced carbon emissions were associated with the use of reuseable equipment when compared to single-use within gastroenterology specialities. Findings from urology specialties relating to reuseable equipment were more mixed. Studies finding in favour of reuseable equipment in terms of carbon emissions reported reduced impact (or little difference) in the majority of other environmental impact categories; and vice versa for studies reporting reduced carbon emissions associated with disposable equipment. Two studies evaluated costs of reuseable equipment within gastroenterology settings, both concluding reuseable/hybrid equipment cost less than disposable.(73, 103) Patient reported outcomes were not measured.

Non-LCA studies: Heterogeneity in speciality and intervention type precluded meaningful analysis.

LCAs

The findings relating to carbon emissions and other impact categories for the fourteen LCA or inventory analysis studies are described narratively below within two sub-categories: reuseable equipment and equipment composition. A summary of this information can be found in Table 8, with further information on outcomes from other impact categories within Appendix I.

Reuseable equipment

Thirteen studies appraised as predominantly "High" or "Medium" quality used LCA or inventory analysis methods to explore carbon emissions associated with reuseable equipment. Five were conducted within urology,(67, 83, 96, 98, 107) four within gastroenterology,(59, 68, 73, 103) one within cardiology,(94) one within respiratory,(112) one within orthopaedics and/or trauma,(92) and one across multiple settings, including ICU.(88) Overall, reduced carbon emissions were associated with the use of reuseable equipment when compared to single-use within the four studies conducted in the gastroenterology speciality and single studies conducted in cardiac,(94) and multiple(88) settings. However, findings across studies were inconsistent for equipment used within urology settings. One study calculating carbon emissions associated with ureteroscopes indicating environmental costs between single and reuseable devices were comparable.(96) Three studies calculating carbon emissions associated with cystoscopes,(83, 98, 107) indicated single-use equipment were associated with reduced carbon emissions when compared to reuseable. In contrast, another study indicated that reuseable cystoscopes were associated with reduced carbon emissions.(67) Reduced carbon emissions associated with single use equipment were also highlighted in a study evaluating reuseable bronchoscopes,(112) and reuseable surgical instrument sets within spinal fusion surgery.(92) Authors of the former study were funded by a manufacturer of a single use bronchoscope.(112)

Queries have been raised by experts in LCA methods regarding the methods used in four of the above studies to calculate carbon emissions associated with reuseable equipment.(83, 92, 107, 112) Specific concerns relate to lack of clarity regarding, or inappropriate, selection of characterisation factors, unequal comparisons between the quantities of materials in reuseable versus disposable groups and overestimation of carbon-emissions associated with reprocessing of reuseable equipment.(59) Variations in carbon-emission findings associated with different equipment types may be greatly impacted by the assumptions made regarding composition of equipment, electricity mix and variations in how reprocessing of reuseable equipment is conducted across different sites.(92, 107) The carbon emissions associated with the systems required to support these process may not always be appropriately factored into LCA methodology. Thus, the current evidence base, particularly within urology, makes it difficult to determine whether reuseable or single-use equipment is associated with reduced carbon emissions.

Findings from other impact categories reflected the direction of carbon emission findings reported in individual studies. In general, studies reporting in favour of reuseable equipment in terms of carbon emissions noted reduced impact (or little difference) in the majority of other environmental impact categories; and vice versa for studies reporting reduced carbon emissions associated with disposable equipment.

Two studies evaluated the impact of reuseable vs disposable equipment on costs within gastroenterology settings, both concluding that reuseable or hybrid equipment cost less than disposable.(73, 103)

Equipment composition

One LCA appraised as "Medium" quality evaluated carbon emissions associated with catheters composed of three different types of plastic (TPU vs PVC vs Polyolefin based elastomer), with lowest carbon emissions associated with the polyolefin-based catheter.(105) Across other environmental impact categories, the polyolefin-based catheter had lower environmental impacts compared to TPU and approximately equivalent impact compared to PVC, depending on the model used.

Non-LCA studies

Equipment type

Four studies, representing three speciality groups (orthopaedic and trauma,(30) multiple,(64) and ophthalmology(54, 55)) evaluated carbon emissions associated with different types of equipment. Different types of equipment evaluated included pulse lavage equipment used during joint replacement surgery,(30) anaesthesia machines,(64) different types of anaesthetic gas,(54) and gas cannisters.(55) Due to the heterogeneity between specialities and intervention type, no meaningful comparison can be made across the studies in this category. Please see Appendix I for a description of these studies, carbon emission findings and other outcomes measured.

Table 8: Product-level LCA studies - overview of main findings

Study, Speciality: Study Design	Name of Interventions compared (C1 vs C2 etc…)	Carbon emission findings (based on summary of reported findings for each study)	Summary other impact categories
		Reuseable Equipment	
Baboudjian 2022, Urology; LCA(83)	C1: Reuseable flexible cystoscopes vs C2: Single-use cystoscope	***Favours C2 (Single-use):*** Use of Single-use aScope would allow a reduction of at least 33% on the climate change category (i.e., 33% reduction in CO2 emissions) compared with just disinfection reprocessing of reusable cystoscopes. For both devices main emissions generated during initial manufacture of materials and assembly of the device, regardless of impact category assessed	***Four impact categories: 2 Favoured SU:*** Mineral resource depletion Acidification. ***2 No difference:*** Ecotoxicity, Eutrophication
Hogan 2022, Urology; Prospective single-centre cohort study: controlled trial/Simplified LCA[a,b] (107)	C1: Reusable vs C2: Disposable flexible cystoscopes	***Favours C2 (Single-use):*** SU cystoscope weighs 158 g in total (146.31 g plastic, 6.32 g steel, 2.84 g electronics, and 2.53 g of rubber), giving manufacturing carbon footprint of 1.34 kg of CO_2/cystoscope. Solid waste disposed via incineration after SU flexible cystoscopy produced median 0.61 kg of CO_2 (IQR 0.50-0.64), waste to landfill producing 0.11 kg of CO_2 (IQR 0) per case. Sterilization of SU endoscopes produces 0.3 kg of CO_2 (IQR 0) per endoscope[c] Transport of each SU cystoscope from manufacturing factory in Malaysia produced 0.049 kg of CO_2. Total median carbon footprint: 2.41 kg CO_2 (IQR 2.40-2.44) per case for the SU flexible cystoscope. Manufacturing production of CO_2 of a reusable cystoscope based on weight 1.3 kg for Olympus cystoscope=14.94 kg of CO_2/cystoscope. Each reuseable cystoscope performs approx. 1120 cystoscopies/lifetime=0.013 kg of CO_2 (IQR 0) per case. Solid waste disposal by incineration after reusable flexible cystoscopy=median of 0.52 kg of CO_2 (IQR 0.51-0.60). Waste to landfill=0.22 kg of CO_2 (IQR 0) per case. Sterilization performed within the department using Olympus ETD-DoubleTM can reprocess up to three cystoscopes per cycle, consuming 10.5 kW of electricity, equating to 10.5 kg of CO_2 per cycle (3.5 kg of CO_2 (IQR 0) per case).[c] Total median carbon footprint significantly higher at 4.23 kg of CO_2 (IQR 4.22-4.24) per case for reusable flexible cystoscope ($p<0.0001$)	***One impact category: Favoured disposable*** - Solid Waste produced
Kemble 2023, Urology; Inventory Analysis(67)	C1: SU vs C2: Reusable cystoscopes	***Favours C2 (Reuseable):*** A fleet of 16 reusable cystoscopes in service for up to 135 months averaged 207 cases between repairs and 3920 cases per lifecycle. Based on manufacturing carbon footprint of 11.49 kg CO2/kg device for reusable flexible endoscopes and 8.54 kg CO2/kg device for SU endoscopes, per-case manufacturing cost was 1.37 kg CO2 for SU devices and 0.0017 kg CO2 for reusable devices. Solid mass of SU and reusable devices was 0.16 and 0.57 kg, respectively. For reusable devices, energy consumption of reusable device reprocessing using automated endoscope reprocessor=0.20 kg CO2, and per-case costs of device repackaging and repair were 0.005 and 0.02 kg CO2, respectively. Total estimated per-case carbon footprint of SU and reusable devices was 2.40 and 0.53 kg CO2, respectively, favouring reusable devices. Impact of reusable scopes estimated to be considerably less than SU scopes at all calculated case volumes	NA

Study, Speciality: Study Design	Name of Interventions compared (C1 vs C2 etc…)	Carbon emission findings (based on summary of reported findings for each study)	Summary other impact categories
Wombwell 2023, Urology; Inventory analysis(98)	C1: SU Ambu® aScope™ 4 Cysto System (Ambu®) vs C2: Reusable Olympus CYF-VH flexible video-cystoscope	***Favours C2 (Single-Use):*** Although basic manufacturing carbon footprint cost/use between Ambu® (reuseable) and Olympus (SU) cystoscopes vastly different (1.18 vs 0.02 kg CO2), once cleaning of reusable cystoscope considered, carbon footprint of SU cystoscope is ultimately lower than the reusable cystoscope (1.43 vs 2.22 kg CO2). SU cystoscopes have 36% lower carbon footprint, compared with their reusable counterpart	NA
Davis 2018, Urology; Inventory analysis[d](96)	C1: Reuseable flexible ureteroscopes vs Comparator 2: disposable flexible ureteroscopes	***No significant difference:*** Main finding – environmental costs of single-use and reusable flexible ureteroscopes are comparable. Total carbon footprint of lifecycle of both flexible ureteroscopes was <5kg COZ/case**.** SU scopes: Manufacturing cost 11.49kg of CO2, manufacturing carbon footprint 3.45kg of CO2 per 1kg ureteroscope. Sterilization: 0.3kg of CO2. Solid wast4e generated from disposal: 0.3 or 0.3kg [print error?] of CO2. Total carbon footprint of LCA: 4.43kg of CO2/endourologic case. Reuseable scope (1kg): Manufacturing carbon footprint: 11.49kg of CO2. Manufacturing costs/aScope: 0.06kg of CO2 (i.e. 1kg/180). Washing/sterilization: 7.89kg of CO2 for simultaneous washing and sterilization of 2 ureteroscopes or 3.94kg and 82.5L of water per ureteroscope. Repackaging costs negligible. Solid waste: 0.06kg of CO2 (i.e. 11.49kg of CO2/180). Cost of repair: 5kg of CO2, 0.31KG OF co2 per case (5kg of CO2/16). Total carbon footprint of lifecycle: 4.47kg of CO2/case	NA
Boberg 2022, GE; LCA(103)	C1: SU trocar system vs C2: Reusable trocar system vs C3: Mixed trocar systems for laparoscopic cholecystectomies	**Favours C2 (Reuseable):** SU trocar system's impact on climate change was 379% higher than RU system's impact and 12% higher than the mixed system's impact [median difference of 446 kg CO2eq (413–483) and 55 kg CO2eq (25–87), respectively. Similar environmental impact of the mixed and single-use trocar systems could be explained by the higher plastic weight of the single-use trocar used in the mixed system compared to the trocars used in the single-use system. Differences regarding effects on climate change robust in sensitivity analyses	***Comparison: SU vs RU*** - Resources, Ecosystem quality, Human health, **findings favour RU**. ***Comparison: SU vs Mixed*** - Resources, Ecosystem quality findings=**No significant difference**. Human health=**favours mixed**. ***Cost:*** RU and mixed trocar systems approx. half as expensive as SU
Le 2022, GE; LCA(68)	C1: Reuseable duodenoscope vs C2: Reuseable duodenoscopes with disposable endcaps vs C3: SU duodenoscopes	***Favours C1 (Reuseable):*** SD releases 36.3-71.5 kg CO2eq, which is 24-47 times > an RD (1.53 kg CO2 eq) or an RD with a disposable endcap (1.54 kg CO2 equivalent). Most climate change impact of SDs comes from manufacturing= 91-96% GHG emission. Second-highest contributor is disposal of SD=1.8 kg CO2 eq/procedure and accounts for 3-5% GHG emission. RDs: top contributor to GHG emission: electricity use during procedure (62%), RD cleaning and disinfection (26%). RDs with disposable endcaps perform similarly to traditional RDs in all categories, with the advantage of potentially reducing infections	***SU performs most poorly****:* Non-renewable resource, Ecosystem quality, Human Health. ***No sig. difference C1 vs C2:*** Non-renewable resource use, Ecosystem quality. ***Favours C2:*** Human health.

Study, Speciality: Study Design	Name of Interventions compared (C1 vs C2 etc…)	Carbon emission findings (based on summary of reported findings for each study)	Summary other impact categories
Rizan 2022, GE; LCA(59)	C1: SU vs C2: Hybrid surgical instruments used for Laparoscopic cholecystectomy (laparoscopic clip appliers, laparoscopic scissors, and ports)	***Favours C2 (Hybrid instruments):*** Carbon footprint/operation of laparoscopic hybrid instrument vs SU equivalent was 17% for clip applier (445g vs 255g CO2e), 33% scissors (378g vs 1139g CO2e), and 27% for four ports (933g CO2e vs 3495g CO2e/operation). When combined, carbon footprint of hybrid versions of all 3 instrument types 24% of SU equivalents (1756g CO2e vs 7194g CO2e), saving 5.4kg CO2e (normalised results: normal activities of global average person over 6h). Hotspot analysis: majority carbon footprint of hybrid instruments due to SU components (mean 62%, range 43–79%), followed by decontamination of reusable components (mean: 37%, range 21–56%). For all hybrid instruments, carbon footprint lower than SU equivalents when reusable component used more than twice. Impact on carbon plateaued at around 10 uses of reusable components, with little additional gain (<1%) after using laparoscopic scissors 60 times, ports 70 times, and clip appliers 100 times. However, continued use of these saves additional carbon burden obtaining new instruments. When packaged and decontaminated separately, carbon footprint of hybrid laparoscopic clip applier increased 3.7-fold to 1650g CO2e per use. There were small accompanying increases for laparoscopic scissors (to 394g CO2e per use, 4% increase) and ports (999g CO2e per use, 7% increase), due to greater proportional weight in instrument set. Nevertheless, in this alternative model, carbon footprint of all hybrid instruments lower than SU equivalents (36% less for laparoscopic clip appliers, 65% less for laparoscopic scissors, and 71% less for ports). Carbon footprint of decontamination process 54% higher when Australian electricity modelled, which increased carbon footprint of hybrid instruments by 11–30% but this lower (63–77%) than SU equivalents. Shipping instead of air-freight for international transport of SU instruments reduced carbon footprint by 22–33% relative to baseline SU items, but hybrid baseline instruments remained lower than shipped SU equivalents: by 74% the clip applier, 55% scissors, 65% ports. Using 3xhybrid 5mm ports and 1x1 mm port (635g CO2e/ operation) resulted in 32% carbon footprint reduction relative to base scenario hybrid port setup. Use of SU ports with this alternative port configuration associated with six-fold increase in carbon footprint vs hybrid use (3613g CO2e), constituting 3% increase relative to base scenario SU port setup. Under consequential approach to LCA, carbon footprint of hybrid laparoscopic clip applier was 198g CO2e (7% of SU equivalent of 2559g CO2e), scissors 299g CO2e (26% of SU equivalent of 1139g CO2e), and for four hybrid ports was 614g CO2e (18% SU equivalent of 3495 g CO2e). When combined under the consequentialist approach carbon footprint of hybrid versions of all 3 instrument types for operation= 15% that SU equivalents (1110g vs 7194g CO2e), saving 6083g CO2e	***20 impact categories, 15 favour hybrid:*** Stratospheric ozone depletion, ozone formation: human health, ozone formation: terrestrial ecosystems, fine particulate matter, mineral resource depletion, acidification, freshwater eutrophication, land use, fossil fuel scarcity, water consumption, human carcinogenic toxicity, human non-carcinogenic toxicity. Endpoint: resources, Endpoint: Ecosystem quality, ***4 favour SU*** (2 based on incomplete data): Ionising radiation, freshwater ecotoxicity, marine water ecotoxicity, marine eutrophication. For human health endpoint category: combination of hybrid laparoscopic clip appliers, scissors, and ports for single laparoscopic cholecystectomy saved estimated 1.13 e−5 DALYs.

Study, Speciality: Study Design	Name of Interventions compared (C1 vs C2 etc…)	Carbon emission findings (based on summary of reported findings for each study)	Summary other impact categories
Sherman 2018, GE; LCA(73)	C1: Reusable vs SU/disposable laryngoscopes	***Favours C1 (Reuseable):*** Life cycle emissions from reusables largely due to reprocessing and thus depend on the level of cleaning utilized. Overall, majority of life cycle emissions that SUD components generate created during initial material manufacturing and device assembly. Reusable laryngoscopes produce far fewer environmental emissions. Most favourable scenario: reusable stainless-steel handle treated to HLD standards. LLD of reusable handle produces 40% more GHG emissions (0.08 kg CO2-eq per use) and STZ nearly 400% more (0.23kg CO2-eq) than HLD (0.06kg CO2-eq). SUD generates approx. 25x more GHG emissions (1.41kg CO2-eq and 1.60kg CO2-eq for the plastic and metal SUD handles, respectively) than reusable handle treated with HLD. Most favourable scenario across all emissions categories: reusable steel tongue blade treated to the minimum HLD standards. Like results for handles, sterilizing reusable blades increases GHG emissions by nearly 400% (0.22kg CO2-eq) compared to HLD (0.06kg CO2-eq/use). SUD options for blades generate 6–8x as much GHG emissions/use as reusable HLD option depending on whether SUD blade is made of plastic (0.38kg CO2-eq) or metal (0.44kg CO2-eq). Even if treated with STZ, reusable device generates 40%–50% fewer GHG emissions than SUD alternatives. The SUD tongue blades were the overall worst option under all scenarios, and metal was worse than plastic. SU handles become environmentally preferable if reusable device lifetime falls below 5 and 4 uses for plastic and metal SUDs, respectively. SU plastic blades become environmentally preferable if multi-use device lifetime falls below 5 uses, and for SUD metal blades its 3 uses of the reusable. The total recycling scenario demonstrated marginal reductions in GHG emissions over the standard waste disposal scenario for SUDs and had no significant impact on reusable device emissions	***9 Impact categories - All favour RU:*** Ozone depletion, smog, fine particulate matter, ecotoxicity, marine water ecotoxicity, acidification, marine eutrophication, human carcinogenic toxicity, human non-carcinogenic toxicity, ***Cost: Favours RU.***
Schulte 2021, Cardiac; LCA(94)	Comparison 1: newly-manufactured catheter vs Comparison 2: remanufactured catheter	***Favours C2 (Remanufactured):*** Using remanufactured medical catheter has lower impact on global warming (0.87 kg CO2-eq./catheter) than virgin production route. (1.75 kg CO2-eq./catheter). Production/processing of plastics for producing virgin catheter is most contributing to the GWI of using a newly-manufactured catheter for SU (59.4%). Carbon footprint of plastic production/processing for a newly-manufactured catheter (1.04 kg CO2-eq./catheter) greater than GWI of entire medical remanufacturing process (0.87 kg CO2-eq./catheter). In medical remanufacturing route, electricity consumption contributes most to GWI (34.5%), followed by waste treatment (32.0%) and packaging materials (18.2%). GWI of treatment similar for medical remanufacturing (0.28 kg CO2-eq./catheter) and new production (0.30 kg CO2-eq./catheter) because loss rate of collected but not-remanufactured catheters in medical remanufacturing process (47.9%). Approx. 2xcatheters must be collected for each remanufactured catheter	***15 impact categories. 12 favour RU:*** Ozone depletion, ionising radiation, ozone formation: Terrestrial ecosystems, freshwater ecotoxicity, acidification, marine eutrophication, eutrophication: terrestrial, human non-carcinogenic toxicity, resource use: energy carriers, resource use: metals and minerals, respiratory inorganics. ***2 favour virgin***: Freshwater eutrophication, land use. **1 no difference:** Waste consumption

Study, Speciality: Study Design	Name of Interventions compared (C1 vs C2 etc…)	Carbon emission findings (based on summary of reported findings for each study)	Summary other impact categories
Sanchez 2020, Multiple, including ICU; LCA(88)	C1: Reuseable vs C2: Disposable blood pressure cuffs	***Favours C1 (Reuseable):*** BP cuffs dominated by production of cuff materials (mostly plastics), including GHG emissions from extraction of raw materials e.g. oil and gas, from chemical and manufacturing plants, and from power plants that generate electricity to support these activities, also from transport of materials in supply chain and to final point of use. Incineration waste management scenario adds emissions from combustion of the disposable cuff materials and packaging. Emissions from production of reusable cuffs negligible when scaled to 1xday of use, based on expected lifetime of 3 yrs. Reusable cuff impacts dominated by manufacturing of chemical wipes used for LLD, even though only ¼ of one wipe assumed to be used during each cleaning. Transportation and packaging impacts of reusable cuffs negligible across all use and cleaning scenarios. In out-patient settings, life cycle GHG emissions of reusable cuff options are consistently and substantially lower than those for the disposable cuffs. For the Office/Clinic room where the disposable cuff is only used once+discarded, difference in GHG emissions between cuff options is approx. factor of 40 when shared reusable cuff cleaned after each encounter and disposed via incineration. For Ambulatory Procedure where BP measurements are taken in three locations, shared reusable cuffs more favourable by factor of 13–14 when stationary. If patients given dedicated reusable BP cuffs cleaned at end of day, results show factor of ~40 difference. In Regular Ward setting assuming LOS=5 days, emissions associated with production of disposable cuffs are spread out over longer use period, so only a factor of 2–3 difference favouring shared reusable cuff cleaned after each patient encounter. Alternatively, if reusable BP cuffs are dedicated, they are even more favourable since only 20 cleanings per day are required vs. 80 cleanings if shared. In ICU, each patient assumed to have dedicated reusable/disposable BP cuff. If reusable cuffs are cleaned only at the end of five-day patient encounter and disposable cuffs discarded at that same time, difference in life cycle GHG emissions between the cuff types is approx. factor of 30 favouring reusables. If both cuffs cleaned daily advantage of reusable=factor of 7-8	***9 Impact categories - all favour RU:*** Ozone depletion, smog, fine particulate matter, ecotoxicity, acidification, eutrophication, fossil resource scarcity, human non/carcinogenic toxicity, Cost: Favours RU
Sorensen 2018 , Respiratory; LCA[e](112)	C1: SU flexible device for bronchoscopy (the Ambu® aScopeTM 4 broncho) vs C2: Reuseable bronchoscope	***Favours C1 (Single-Use) or No difference:*** Using one set of protective wear per operation and the materials for cleaning and disinfection determine that reusable scopes have higher emissions of CO2-eq. Cleaning two or more reusable scopes per set of PPE makes the impacts comparable. Other aspects that may impaAmbu® aScopeTM 4 broncho, gives credit of 6% energy when incinerated but adds extra 21% emission of CO2-equivalents. Numbers similar for RB. Consequence for regions where incineration with energy recovery is not available is CO2-equivalent emissions will be 21% lower for aScope. In the same way, the numbers can be interpreted for RBs. Recycling of packaging materials from the Ambu ® aScopeTM 4 broncho gives 1% crediting for CO2-equivalent emissions. Due to assumption none of PPE or auxiliary materials used for cleaning of RBs is recycled, there will be no crediting to consider. Result of the assessment highly depends on use of PPE and cleaning procedures	***2 impact categories - both favour SU***: Loss of scarce resources, resource use: energy carriers

Study, Speciality: Study Design	Name of Interventions compared (C1 vs C2 etc…)	Carbon emission findings (based on summary of reported findings for each study)	Summary other impact categories
Leiden 2020, Orthopaedics and/or Trauma; LCA(92)	C1: Reuseable vs C2: Disposable surgery instrument set for spinal fusion surgery	***Favours C2 (Disposable):*** Application of disposable set of instruments=environmental advantage of approx. 45–85% against reusable set in all impact categories. Main environmental impact of disposable set generated in production phase-this share always higher compared to reusable set. Major environmental impacts result from sterilization of reusable set, mainly due to energy use for washing and steam sterilization. Transportation and disposal processes have minor impacts in both cases. Sensitivity analysis results: increasing no. surgeries/yr, has negligible effect on entire environmental impact. But changing logistics principle (from loaner to consignment system) and consequently dividing no. sterilization cycles in halves=serious reduction of environmental impacts. External 60 Co sterilization further reduces environmental impact, but environmental impact still higher than for disposable set. Further required transport increases environmental impact and impact for washing and disinfection within hospital remains same	Aggregated single-score indicator depicts overall benefit of 75 % for SU.
Stripple 2008, Urology; LCA(105)	C1: TPU catheter vs C2: PVC catheter vs C3: Polyolefin-based elastomer catheter	***Favours C3 (Polyolefin-based catheter):*** Fossil CO_2 emissions: TPU has highest CO_2 emissions and new polyolefin-based elastomer the lowest emissions. Regarding total energy use or CO_2, NO_x or SO_2 emissions, polyolefin-based elastomer catheter shows lowest environmental impact, followed by PVC catheter and the TPU catheter having the highest environmental impact	***Eco-indicator 99 model - summary findings:*** Compared to TPU, new polyolefin-based elastomer shows lower environmental impact in all categories except ecotoxic emissions and extraction of minerals. Compared to PVC, polyolefin-based elastomer shows a lower impact in six of nine categories. C***M2 model - summary findings***: New material shows an overall low environmental impact. Compared to TPU, polyolefin-based elastomer has a lower or equivalent environmental impact in all impact categories. Compared to PVC, its impact is lower in five out of 10 impact categories. ***EPS 2000 model- summary findings:*** Results show highest environmental impact for TPU catheter, while the polyolefin-based elastomer and the PVC catheters show almost equivalent environmental impact, with a small favour towards the PVC catheter. However, these final scores based on weighted values

Green shaded cell=Study appraised as 'High' quality, Blue shaded cell=Study appraised as "Medium" quality, [a]Incorporates simplistic LCA methods, [b]Results queried by Rizan et al (2022)– see Discussion of this report, [c]Davis, McGrath, Quinlan et al. Carbon footprint in flexible ureteroscopy: A comparative study on the environmental impact of reuseable and Single-use ureteroscopes. J Endourol. 2018; 32(3): 214-217, [d]Stated as LCA but incomplete impact assessment, [e]Using one set of protective wear/operation and materials for cleaning and disinfection determine reusable scopes have higher values of resource consumption. Cleaning two or more reusable scopes per set of PPE makes the impacts fairly comparable. BP=Blood Pressure, C=Comparator, CO2=Carbon Dioxide, GHG=Greenhouse Gases, IQR=Interquartile Range, PVC=Polyvinyl Chloride, RU=Reuseable, SU=Single Use

Care Delivery

Summary:

Sixteen studies evaluated interventions which changed some aspect of how condition specific treatment or care was delivered. Six studies focused on changes to treatment modalities or regimens,(30, 34, 44, 46, 50, 65, 110) six evaluated alterations to the treatment/clinical pathway,(29, 39, 47, 48, 57, 62, 69) and four studies evaluated changes to the surgical equipment or approach used.(70, 76, 81, 113) Specialities represented included oncology/radiation oncology (n=5),(34, 46, 65, 81, 110) renal (n=2),(43, 111) urology (n=1),(113) orthopaedic and/or trauma (n=1),(33) ENT (n=1),(70) and gynaecology (n=1).(76) Five studies were informed by LCA methods, and are described further below.(43, 50, 69, 70, 76, 113)

LCA studies:

One component analysis study appraised as "Medium" quality reported that home haemodialysis (HHD) using standard machines, three nights a week for seven hours was most effective in terms of patient health benefits, carbon reductions and financial costs.(43, 50) This finding was supported by one controlled trial concluding that home haemodialysis was associated with reduced carbon emissions when compared to in-centre haemodialysis.(111) Due to the variation in types of intervention and speciality, no meaningful comparisons can be made across the remaining LCA studies.

Non-LCA studies: Four studies evaluated the impact of altering the treatment regimen for patients undergoing cancer treatment.(34, 46, 65, 110) All studies indicated reduced carbon emissions were associated with treatment schedules which reduced the number of times patients were required to travel to hospital. Two studies considered patient clinical,(34, 110) safety,(34) and/or accessibility outcomes,(110) with one study considering service costs.(110) These outcomes were presented using narrative or descriptive statistics and were all in favour of the intervention. Four studies indicated that interventions which changed the patient care pathway were associated with reduced carbon emissions within orthopaedics and/or trauma,(47, 48) cardiology,(39) Urology,(57) and ENT specialties.(29) Carbon emission calculations were mainly based on the materials consumed as result of providing care and/or travel. Changes to the care pathway for patients needing urgent cardiac treatment which required care to be provided in more specialist centres were associated with higher carbon-emissions.(62) Three studies indicated that care pathway interventions were associated with reduced service costs.(29, 47, 48{Nielsen, 2022 #103)} Patient outcomes were poorly reported. One retrospective database review study comparing surgical approaches to staging procedure for endometrial cancer, found robot-assisted laparoscopy had the highest carbon footprint, with laparotomy the lowest. Laparotomy was also found to have the lowest energy consumption and was associated with the lowest environmental energy use.(81)

LCAs

Treatment pathway

One LCA appraised as 'Medium' quality was conducted within urology,(69) and evaluated an intervention examining how different combinations of prostate Magenetic Resonance Imaging (MRI) and transrectal ultrasound guided prostate biopsy sampling could affect carbon emissions, indicated that systematic biopsy without the use of MRI produced the least carbon emissions of the four comparators being evaluated.(69) No other outcomes were evaluated within this study.

Treatment regimen

One component analysis study appraised as "Medium" quality evaluated the environmental impact and cost-effectiveness of different haemodialysis regimens and place of delivery.(43, 50) In this study, the authors highlighted the tension between reducing carbon emissions through provision of home haemodialysis (HHD) by reducing patient travel and increasing carbon emissions through increasing frequency and number of HHD treatments. They indicated that HHD using standard machines, three nights a week for seven hours was most effective in terms of patient health benefits, carbon reductions and financial costs.

Surgical procedure

One inventory analysis appraised as "Medium" quality,(113) and two studies using LCA methods (quality appraised as "High",(76) and "Medium"(70)) evaluated the impact of altering the types of surgical procedure used on environmental outcomes. These interventions included comparing robotic and laparoscopic surgical techniques for radical prostatectomy,(113) different methods for conducting tonsillectomy,(70) and different methods for undertaking hysterectomies.(76) Due to the variation in types of intervention and speciality, no meaningful comparisons could be made across these studies. Instead, the findings from the individual studies are summarised below in Table 9, with further detail in Appendix J.

Table 9: Care delivery - summary of findings from LCA studies

Study, Speciality: Design (Comparators)	Carbon emission findings (based on summary of reported findings for each study)	Summary of other impacts											
		Ozone depletion	Smog	Respiratory/ Fine particulate matter	Ecotoxicity	Acidification	Eutrophication	Human carcinogenic toxicity	Human non-carcinogenic toxicity	Reuseable equipment	Operating time	Energy demand	Cost
Connor 2011a[e]; de Preux 2018*, Renal: CA (Home vs In hospital maintenance HD- Diff treatment regimens (Place of treatment/ Machine type/ freq. treatments/ duration treatments (h)): C1: ICHD Standard 3d/wk, 4h vs C2: HHD Standard 4d/wk, 4.5h vs C3: HHD Standard 5d/wk, 4hr vs C4: HHD Standard 6d/wk, 2h vs C5: HHD Standard 6 nights/wk, 7h vs C6: HHD Standard 3 nights/wk, 7h vs C7: HHD NxStage 5.5/wk, 3h vs C8: HHD NxStage 6 nights/wk, 7h)(43, 50)	Most common form of dialysis in UK (3xwk ICHD,7)=carbon footprint of 3818 kg CO2 Eq/patient/yr, with majority of emissions arising within medical equipment (37%), building energy use (21%) and patient travel (20%). Delivery of HHD using standard HD machines=release of 3901-7197kg CO2 Eq/pt/yr depending on regime. Regime choice may have 2-fold impact on carbon footprint. Following reduction in patient travel emissions, clinically beneficial increase in dialysis treatment times (beyond 3xwk ICHD) achieved without associated increase in overall carbon footprint through provision of HHD. 3xwk nocturnal HHD offers 9hrs more dialysis/wk than ICHD, with comparable carbon footprints (3901 and 3818kg CO2 Eq respectively). Provision of 6x2hr HHD treatments/wk=5210kg CO2eq— 43818kg attributable to delivery of same total wkly treatment time by 3xwk ICHD. Emissions from medical equipment supply chains=37% of the emissions associated with ICHD. Re-use of dialyzers over 10 treatments reduces carbon footprint of 3xwk ICHD by 9.7%, from 3818 to 3448kg CO2 Eq/pt/yr. Substantial carbon saving derives from reductions in supply chain emissions of the dialyzers (290kg CO2 Eq) and associated packaging (4kg CO2 Eq), and from reductions in waste management emissions (primarily reduction of kg CO2 Eq in incineration emissions). Electricity consumption contributes significantly to carbon footprint of provision of HD using standard machines, representing 21% and 48% of emissions associated with ICHD and 6 nightly nocturnal HD, respectively. Newer HD technologies may offer solution. Provision of 3hr treatments/5.5 days/wk using NxStage equipment= carbon footprint of 1844kg CO2 Eq—<half that of 3xwk ICHD. 6 nightly nocturnal HHD using NxStage equipment results in 2131kg CO2 Eq—<1/3 emissions of comparable HHD regime using standard HD machine. Emissions attributable to patient undertaking 5.5wkly dialysis but never travelling (1841kg CO2 Eq) almost identical to those of a patient undertaking 5.5xwk dialysis and travelling in line with the assumptions made in study (1844kg CO2 Eq). Summary: As a result of reduction in patient travel emissions, clinically beneficial increase in dialysis treatment times (beyond that of 3xwk ICHD) can be achieved without associated increase in carbon footprint through provision of HHD. 3xwk nocturnal HHD offers 9 hrs more dialysis/week than ICHD, yet 2 regimes have comparable carbon footprints (3901 and 3818 kg CO2 Eq respectively). However, production of medical equipment is carbon intensive, and reduction in patient travel emissions is soon offset by increase in the frequency of HD treatments - provision of 6x2- hour HHD treatments/wk=carbon footprint of 5210 kg CO2eq— considerably 43818 kg attributable to the delivery of the same total weekly treatment time by 3xwk ICHD. Authors suggest rising uptake of HHD, in current form and using standard machines, likely to increase, rather than decrease, carbon footprint of HD programs												C6 **

Study, Speciality: Design (Comparators)	Carbon emission findings (based on summary of reported findings for each study)	Summary of other impacts											
		Ozone depletion	Smog	Respiratory/ Fine particulate matter	Ecotoxicity	Acidification	Eutrophication	Human carcinogenic toxicity	Human non-carcinogenic toxicity	Reuseable equipment	Operating time	Energy demand	Cost
Fuschi 2023, Urology; Inventory analysis(113)	***Favours C2 (Robot assisted):*** CO_2 emissions resulting from production, disposal, and sterilization of instruments overall higher for the instruments used in laparoscopic procedure (12946.73g) compared to robot-assisted procedure (9506.18g), with majority of the emissions coming from plastic (9083.30 g vs. 6481.80g) and from composite fibre components (3019.63g vs. 2157.63g), the robot-assisted procedure had higher emissions from metal components (866.76g vs. 839.80g). Total CO_2 emissions from energy consumption=37807.23g for robotic procedure and 46728.24g for laparoscopic procedure. Total CO_2 emissions for robot-assisted procedure=47313.414g per procedure, of which 9506.18g derived from instrument production, disposal, and sterilization; whereas 37807.23g from energy consumption. Total laparoscopic CO_2 emissions= 59674.96g, with 12946.72g being derived from instrument use and 46728.24 from energy consumption. Significant differences with lower CO_2 production obtained with robotic approach than laparoscopic, considering total CO_2 emissions, CO_2 derived from production, disposal and sterilization, and energy consumption												
Leapman 2023, Urology: LCAd (Different treatment pathways: C1; Bi-parametric prostate MRI with targeted and systemic biopsies vs C2: mpMRI with targeted biopsy cores only vs C3: Systematic biopsy without MRI vs C4: mpMRI with systematic biopsy)(69)	***Favoured C3 (Systematic biopsy without MRI): bpMRI with targeted and systematic biopsies would result in 70.5 kgCO2e, a 10.7% reduction relative to mpMRI. Variation in emissions by biopsy strategy. A strategy of a 12-core systematic biopsy without prostate MRI generated fewest emissions (36.2 kg CO2e), majority of which (33.0 kg CO2e, 91.3%) contributed by biopsy procedure itself and 3.2 kg CO2e (8.7%) from pathology analysis. Incorporation of prostate MRI increased estimated CO2e, primarily due to MRI step, and smaller contributions from additional biopsy core acquisition and processing. MRI with systematic biopsy sampling resulted in 78.9 kgCO2e, while approach of obtaining 2-5 MRI-fusion cores alone without systematic biopsy=6.2 kgCO2e***												

Study, Speciality: Design (Comparators)	Carbon emission findings (based on summary of reported findings for each study)	Summary of other impacts											
		Ozone depletion	Smog	Respiratory/ Fine particulate matter	Ecotoxicity	Acidification	Eutrophication	Human carcinogenic toxicity	Human non-carcinogenic toxicity	Reuseable equipment	Operating time	Energy demand	Cost
Meiklejohn 2023, ENT: LCA (C1: ME vs C2: Coblation vs C3: Cold excision without cautery)(70)	***No sig. difference between comparators:*** Life cycle impacts: Absolute values for GHG emissions for cold, ME, and coblation were 157.6, 184.5, and 204.7 kgCO2-eq per surgery, respectively. No statistically significant differences between techniques (all processes within the system boundaries included). Medications used for anaesthesia contributed most to GHG emissions, regardless of surgery technique. Subgroup analysis of the disposable items that differed between technique demonstrated a statistically significant difference in the GHG emissions attributable to disposable surgical items among the three different tonsillectomy techniques (χ2ð2) = 9.4168, $p = 0.009$). A post hoc pairwise comparison based on the Wilcoxon rank sum test revealed that a statistically significant difference ($p < 0.05$) was observed between ME and cold technique, and between coblation and cold technique, with cold having reduced impact in both comparisons	C3[a]		C3[a,b]	><[a]	C3[a]	C3[a]	C3[a]	C3[a]	><	><		C3 [N]
Thiel 2015, Gyn: LCA (Type of hysterectomy - C1: Abdominal vs C2: Vaginal vs C3: Laparoscopic vs C4: Robotic)(76)	***Favours C1 and C2 (Abdominal/Vaginal)[c]:*** Robotic hysterectomy largest environmental footprint over other hysterectomy types in every impact category analysed. Upper range of laparoscopic hysterectomy's 90% confidence interval overlaps with average impacts robotic hysterectomies in every category. Error bars in GHG emissions largely influenced by anaesthetic choice, which varies based on anaesthesiologist preference and is not indicative of type of hysterectomy performed. Without anaesthetics, abdominal and vaginal hysterectomies emit significantly less greenhouse gases, with narrower confidence intervals, than laparoscopic and robotic hysterectomies. On average, anaesthetic gases contributed to a third of the greenhouse gas emissions of robotic and laparoscopic hysterectomies and two-thirds of abdominal and vaginal hysterectomies. For abdominal and vaginal hysterectomy, anaesthetic use contributed to 98% of the ozone depletion potential. GHG emissions for vaginal hysterectomy from anaesthetics varied drastically between cases, from 0.001 kg CO2-eq/case to 505 kg CO2-eq/case	C2 +C 3	C1 HI[d]	C2+ C3	C1 HI[d]	C2 +C 3	C1 HI[d]	C1 HI[d]	C1 HI[d]	><		C2 +C 3	

Blue shaded cell=Appraised 'Medium' quality, Green shaded cell=appraised as 'High' quality. *Component analysis, ** most effective (health benefits+ carbon/ financial costs) [a]In relation to disposable instruments, [b]No significant difference observed between ME and Coblation technique for any impact category, [c]Without anaesthetics [d]Significant overlap with laparoscopic, abdominal, and vaginal. C=Comparator, GHG=Greenhouse Gas, HI=Highest impact, ME=Monopolar Electrocautery

Non-LCA

Treatment regimen

Seven studies using non-LCA methodology explored the impact of different treatment regimens/schedules on carbon emissions within an oncology/radiation oncology (n=4),(34, 46, 65, 110) or renal setting (n=1).(111)

Four studies evaluated the impact of altering the treatment regimen for patients undergoing cancer treatment.(34, 46, 65, 110) Study designs include a randomised controlled trial (RCT),(46) a controlled-trial,(65) a before and after trial,(34) and a retrospective cohort.(110) All studies indicated reduced carbon emissions were associated with treatment schedules which reduced the number of times patients were required to travel to hospital. Other outcomes measured in these studies which reflect this finding included savings to patient travel time (n=2),(46, 65), distance (n=3),(46, 65, 110) or costs (n=1).(65) Two studies considered patient clinical,(34, 110) safety,(34) and/or accessibility outcomes,(110) with one study considering service costs.(110) These outcomes were presented using narrative or descriptive statistics and most were in favour of the intervention.

One controlled trial evaluated the carbon emissions associated with In-centre haemodialysis versus home haemodialysis, concluding that the former was associated with reduced carbon emissions.(111)

Treatment pathway

Five non-LCA studies evaluated the effectiveness of changes to treatment/clinical pathways in reducing carbon emissions, one controlled trial was conducted within orthopaedics and/or trauma,(47, 48) one before and after,(39) and one modelling study within cardiology,(62) and one study each in urology,(57) and ENT,(29) utilising retrospective database review and modelling study designs respectively. Details regarding the care pathways evaluated can be found in Appendix J. Care pathway interventions were associated with reductions in carbon emissions across four studies, mainly attributed to reduced number of face-to-face visits,(47, 48) reduced hospital length of stay (LOS),(39) or reduced patient travel.(29) However, where changes to the care pathway required patients to travel via ambulance to specialist care centres, carbon emissions increased.(62) Carbon emission calculations were mainly based on the materials consumed as the result of providing care and/or travel,(47, 48, 62) with two studies considering energy consumption involved in delivering care,(29, 57) and/or waste disposal.(57) No studies considered carbon emissions associated with extraction/product manufacture or material transport. Comparisons between intervention and control groups for outcomes relevant to service use were mainly based on descriptive/narrative analysis and included number of face-to-face visits (n=1),(47) hospital length of stay (LOS)(n=3),(39, 48, 57) and number of physiotherapist appointments (n=1).(48) Outcomes favoured care pathway intervention over standard care pathways. Three studies indicated that care pathway interventions were associated with reduced service costs.(29, 39, 48) Only one study, which evaluated the impact of a day-case pathway vs inpatient care for patients undergoing transurethral bladder tumour surgery evaluated any patient focused outcomes, with analysis based on descriptive/narrative statistics indicating that the day-case pathway reduced number of patient readmissions.(57)

Surgical procedure

One retrospective data base review study compared different surgical procedures for patients undergoing a staging procedure for endometrial cancer (robotically-assisted laparoscopy, laparoscopy and laparotomy).(81) Robot-assisted laparoscopy was found to have the highest carbon footprint, and laparotomy the lowest. Laparotomy was also found to have the lowest energy consumption and was associated with the lowest environmental energy use.(81)

Multiple components

Seven studies evaluated interventions which included multiple components, representing two or more of the other four categories described above. Specialties represented included renal (n=2),(31, 84) gastroenterology (n=1),(36) oncology/radiation oncology (n=1),(99) radiology (n=1),(42) gynaecology (n=1),(78) and multiple (n=1).(87) Three studies drew on LCA methods; two inventory analysis were appraised as “Low” quality,(78, 87) and one inventory analysis appraised as “Medium” quality.(42) Heterogeneity across types of speciality and intervention precluded meaningful synthesis. An overview of the study characteristics and main findings relating to carbon emissions and other outcomes is provided in Appendix K.

Discussion

This systematic review aimed to examine the effectiveness of interventions in reducing the carbon footprint within medical specialities in secondary healthcare. Eighty-nine studies met the eligibility criteria. We presented the evidence in an evidence and gap map, structured according to a secondary healthcare patient care pathway. Urology (n=14), gastroenterology (n=13). oncology/radiation oncology (n=13) and renal (n=11) were the most common specialities represented, and gynaecology (n=3), ICU (n=2), obstetrics (n=1) and respiratory (n=1) being the least well represented. Across different specialities, the majority of evidence was found in the first three stages of the patient care pathway (Initial assessment/diagnostic tests, initial treatment or follow-up). The exception to this was the renal specialty, where most of the evidence was within the 'Ongoing care' segment of the patient care pathway. There was limited evidence within the 'Discharge' segment of the care pathway across all specialities. Evidence relating to the wider healthcare setting was clustered within the gastroenterology (n=5) and radiology specialities (n=5).

Interventions evaluated by the included studies were classified into one of five broad categories: 'Accessing care' (n=30), 'Setting' (n=20), 'Product level' (n=17), 'Care delivery' (n=16) and 'Multiple components' (n=7). The two largest groups of evidence were for studies evaluating telehealth (n=26) and reuseable equipment (n=13) interventions. Telehealth interventions were predominantly evaluated using non-LCA methodology (n=23) and, whilst carbon-emissions favoured telemedicine interventions when compared to face-to-face care, these calculations often only considered patient-travel saved and did not account for carbon emissions associated with use of digital pathway or other parts of the patient care pathway, such as the impact on primary care. In general, the majority of patient and cost outcomes evaluated, favoured the telemedicine intervention, although most outcomes were based on descriptive or narrative analyses. These findings were reflected in the systematic review by Ravindrane et al (2022) which explored the environmental impact of telemedicine instead of face-to-face care in healthcare. They highlighted that the benefit of telemedicine in terms of carbon emission reduction was dependent on energy consumption of the telemedicine systems, number of patients, mode of transport used, and distance of travel avoided and indicated that improvements to modelling used within studies were needed, including use of sensitivity analysis and transparent reporting of assumptions used.(14) Lange et al (2022) also highlighted the poor methodological quality of carbon emission methodology used in their review of telemedicine interventions within healthcare.(15)

Interventions comparing carbon emissions associated with the use of reuseable versus disposable surgical equipment represented the largest group of studies utilising LCA methods. For studies within the gastroenterology speciality, reuseable equipment was associated with reduced carbon-emissions. Within urology this finding was reversed, with disposable instruments found to be associated with reduced carbon emissions. However, despite the quality of these studies being appraised as mainly 'High' or 'Medium' within this review, questions regarding the accuracy of use of characterization factors, quantity of materials used in disposable vs reuseable equipment packs and how carbon emissions were assigned to the reprocessing stage of reuseable equipment mean confidence in this finding is uncertain.(120, 121) The latter finding contrasts with findings from two other systematic reviews, which indicate reuseable devices are associated with improved environmental outcomes,(13, 22) although limitations to the evidence base include methodological heterogeneity and lack of background life cycle inventory data for surgical inputs,(22) and lack of cost-comparison studies.(13) The uncertainty regarding the beneficial effects of reuseable equipment on carbon-emissions within urology arising from this review, underscores the importance of considering the full product pathway within an LCA approach and ensuring the system boundaries for the change being considered reflect all parts of the patient care pathway and product life-cycle. The composition of products evaluated and processes associated with (for example) transport, reprocessing of reuseable devices and waste disposal are highly context dependent, with alterations to these processes potentially having a huge impact on estimated carbon emission calculations.(92, 122) Thus, it can be challenging to generalise findings across LCA studies, even when conducted in similar countries/health systems for the same type of intervention, and emphasises the importance of incorporating sensitivity analysis into LCAs. It also highlights the importance of considering how to reduce carbon emissions associated with the processes supporting the manufacture, transport and reprocessing of disposable and/or reuseable equipment as a target for future interventions. This is an alternative focus to comparing emissions associated with disposable versus reuseable equipment and promotes addressing carbon emissions associated with known "hot spots" in the lifecycle of both types of product, such as manufacturing for disposable products and reprocessing for reuseable products, and may complement recommendations from the Green Surgery and MedTech Circular Economy reports to, amongst other actions, pursue use of reuseable equipment to reduce carbon emissions and overcome challenges within supply chains, resource scarcity, healthcare disparities and waste production.(121)

Finally, whilst waste management/reduction interventions were associated with reduced carbon emissions (n=12), interventions were highly heterogeneous with limited consideration of patient or cost outcomes. Eight non-LCA studies found reduced carbon emissions were associated with energy conservation interventions, the majority of which were conducted within radiology/radiotherapy settings and focused on the impact (or potential impact) of turning machines off when not in use.

Strengths and limitations

We have conducted a comprehensive systematic review of the literature which identifies and synthesises comparative studies evaluating interventions to reduce carbon emissions across nine specialties within secondary healthcare. We grouped these studies by broad intervention category to enable identification of carbon emission, patient, and cost outcomes relevant to specific interventions within each speciality, separating out evidence from studies which used LCA methods to calculate carbon-emissions to highlight findings supported by the most methodologically robust evidence base. Unfortunately, there was a high degree of heterogeneity between types of intervention conducted within individual specialities, which made it challenging to identify interventions which were effective in reducing carbon emissions within similar, and across different, contexts. The number of studies including patient and cost outcomes alongside carbon emission calculations was also limited. This may reflect our inclusion criteria, which required studies to measure carbon emissions. Thus, unless related to one of our included studies, studies purely focused on patient outcomes or service costs would have been excluded. The paucity of studies reporting patient clinical outcomes and satisfaction from both intervention and control groups may also reflect that studies using a before and after design or conducting a retrospective database review relied on data recorded on electronic databases where these outcomes may not be routinely recorded. Our inclusion criteria also required that included studies referenced a particular speciality, which may have resulted in the exclusion of otherwise relevant interventions, particularly within the "Systemic interventions" section of the care pathway.

Within studies drawing on an LCA approach, the lack of transparency in the reporting of methodological details raised issues of comparability and generalisability. The variability amongst LCA studies may be explained by data collection and calculation procedures, along with the researchers' assumptions and choices of background inventory databases. Although the Ecoinvent database was most commonly reported, there was a wide variety of secondary sources used by researchers, many of which were originally compiled for other purposes, ranging from government documents to other research papers and conference proceedings. In some instances, researchers reported using manufacturer details in order to calculate raw material composition of devices (e.g. Hogan et al (2022),(107) Kemble et al (2023),(67) Rizan et al (2022)(59)), while others could not access such data and based their calculations on available data for similar devices (e.g. Le et al (2022)(68)). In addition, comparability was hindered by the lack of consistency in how studies defined and reported the system boundaries for the individual LCA studies. The difficulty in generalising results from the LCA was that the data could be specific to a particular context or intervention. The geographical setting of a study was important, particularly in relation to calculating electricity supply. Studies undertaken in the US, for example, assumed US electricity supply with sources derived largely from fossil fuel (e.g. Leapman et al (2023)(69)) and results based on these assumptions were not likely to apply to other countries with cleaner energy sources such as Sweden (e.g. Holmner et al (2014)(104)).

Carbon emission calculations used within non-LCA studies were typically narrow in scope, focusing on the use and/or reuse of products, with less consideration of other factors within the wider system which may also influence carbon emissions of the intervention, for example, energy used by both health services and patients. The extent to which carbon-emission calculations in non-LCA studies considered emissions associated with manufacture of equipment, vehicles or fuel, transport and/or waste management was also limited and dependant on the intervention in question. These issues were particularly evident for interventions such as telemedicine or remote delivery of care, where carbon-emission calculations were typically based on non-statistical comparisons of patient travel distance saved because of reduced number of visits to hospital, with less consideration of factors such as staff and patient energy use via heating, lighting and/or internet access. For studies focusing on waste management/recycling initiatives as part of local initiatives to reduce carbon emissions within specific NHS trusts, carbon-emission calculations rarely considered emissions associated with the transport and recycling of waste which would otherwise have been destroyed. However, where comparable interventions existed between the two groups of evidence, findings from non-LCA studies generally reflected those in LCA studies.

We have presented all included studies within an interactive evidence and gap map, which displays the evidence relative to the patient care pathway for each speciality. This will enable evidence users to locate evidence relevant to their interests and requirements and highlights where groups of evidence and gaps exist. The smaller quantity of evidence relating to the "Discharge" part of the patient care pathway is likely influenced by the inclusion criteria for this review, which focused on interventions led by secondary healthcare. Thus, interventions such as self-management or ongoing support within the community would not have been captured in the evidence and gap map.

Implications for policy, practice, and future research

Research

- Existing research relating to carbon emissions reflects a narrow range of all the possible interventions/specialties available. Further research is needed to fill the gaps highlighted in the evidence and gap map, particularly evidence relating to the ongoing care or discharge of patients or relating to obstetric, respiratory and ICU specialties.

- Evidence generated using LCA methods is regarded as most robust for calculating carbon emissions associated with interventions, yet studies using these methods are under-represented in the evidence base. Many of the studies stating they used full LCA methods were in fact inventory analyses. This may reflect the methodological challenges and specific skillset required to conduct this type of study. Future research needs to ensure individuals conducting LCA studies have the support and resources required to carry out this research within healthcare settings and report the conduct and findings in a way which maintains transparency on methodological and system boundaries.
- Studies based on LCA methodology may not always be appropriate, necessary, or possible to action within healthcare settings, particularly when it is reasonable to assume a change in carbon emissions between intervention and/or control is associated with a particular material or process within the care pathway (for example, patient transport saved for telehealth interventions). However, the carbon-emission calculations used in these studies should reflect all relevant parts of both the patient-care and carbon-emission pathways associated with the intervention. It may be useful to develop guidelines to support researchers to consider which factors they need to consider within individual speciality/intervention groups. Such guidelines in turn could be used by systematic reviews to appraise the quality of studies using non-LCA methods.
- Closely tied to this, is the need to consider patient clinical and satisfaction outcomes alongside carbon-emission outcomes. This was a key issue raised by our PPIE collaborators and would ensure that carbon emissions associated with all stages of the patient care pathway are considered (e.g. visits to primary care clinician to manage complication) and ensure that patient health is not adversely affected by the intervention implemented.
- Comparisons between intervention and control groups should be supported through statistical analysis to increase confidence in the reported direction of research findings.
- There is the opportunity to integrate patient and public involvement into the development and implementation of new interventions and/or carry out qualitative research to gather patient views of interventions, supported by a higher number of effectiveness studies with a paucity of patient satisfaction data, such as telehealth.
- There is a need to review existing research which evaluates carbon emissions, patient health outcomes and cost implications associated with interventions which support patients transition between secondary and primary care.
- Regarding interventions with a telehealth component, future research needs to ensure the digital carbon footprint is fully considered, alongside ensuring the technology is used

effectively to maximise patient outcomes and reduce cost across primary and secondary care.

Practice

- There is tentative evidence to indicate that interventions which reduce the distance patients' need to travel to access care is associated with reduced carbon emissions. However, the impact on patient clinical outcomes and patient satisfaction is inconclusive and further research which addresses the methodological limitations highlighted above is required to increase confidence in reported findings.
- There is tentative evidence to indicate that reuseable surgical equipment is associated with reduced carbon emissions when compared with single-use within certain specialties. However, this is influenced by the composition of the instrument and how the reprocessing of reuseable units is carried out (e.g. number of units reprocessed at any one time and duration of reprocessing procedures).

Policy

- Our evidence and gap map provides a resource to identify where gaps in primary evidence exist on the patient care pathway both within and across different specialties, making it a useful tool to inform commissioning of future research.
- The narrative synthesis considers the quality and quantity of evidence available to support the use of specific interventions to reduce carbon emissions within individual specialties. Our review highlights the larger groups of evidence available pertaining to the use of telehealth care and reuseable surgical equipment across different specialties, and its methodological limitations which may influence the commissioning of future research and implementation of interventions within secondary healthcare.

Conclusions

This systematic review synthesises quantitative evidence evaluating the effectiveness of interventions intended to reduce carbon emissions within high-volume specialities delivered within secondary healthcare. It highlights a highly heterogeneous evidence base, and the methodological limitations associated with studies based on LCA and non-LCA methods. Whilst we identified several large clusters of studies evaluating similar interventions within the same speciality, future research needs to address these methodological limitations to support confident decision making within policy commissioning and clinical practice. Our evidence and gap map displays the included evidence according to individual speciality along the patient pathway, enabling evidence users to identify research which meets their requirements as well as identifying potential gaps where further research may be required.

Acknowledgements

Thank you to Jenny Lowe for support with full-text retrieval and Sue Whiffin for administrative support and proof-reading. Thank you to Drs David Pencheon and Sian de Bell for your methods and/or clinical expertise. Thank you to PERSPEX patient and public engagement group for your time and expertise. Thank you to the Greener NHS team for your input throughout this review.

References

1. Lenzen M, Malik A, Li M, Fry J, Weisz H, Pichler PP, et al. The environmental footprint of health care: a global assessment. Lancet Planet Health. 2020;4(7):e271-e9.

2. Tennison I, Roschnik S, Ashby B, Boyd R, Hamilton I, Oreszczyn T, et al. Health care's response to climate change: a carbon footprint assessment of the NHS in England. Lancet Planet Health. 2021;5(2):e84-e92.

3. Climate Change Act, c. 27 (2008).

4. NHS England. Delivering a 'Net Zero' National Health Service. NHS England; 2022.

5. NHS Shared Business Services. Net Zero Carbon Reduction Plan. NHS SBS; 2022.

6. England N. Health and climate change 2024 [Available from: https://www.england.nhs.uk/greenernhs/national-ambition/national-commitments/#:~:text=The%20health%20impacts%20of%20climate,the%20public%20and%20the%20NHS.

7. The Lancet Respiratory M. Climate change crisis goes critical. Lancet Respir Med. 2023;11(3):213.

8. Physicians RCo. Breaking the fever: Sustainability and climate change in the NHS. London: RCP; 2017.

9. Mailloux NA, Henegan CP, Lsoto D, Patterson KP, West PC, Foley JA, et al. Climate Solutions Double as Health Interventions. Int J Environ Res Public Health. 2021;18(24).

10. Papadopoulou A, Kumar NS, Vanhoestenberghe A, Francis NK. Environmental sustainability in robotic and laparoscopic surgery: systematic review. Br J Surg. 2022;109(10):921-32.

11. Keil M, Viere T, Helms K, Rogowski W. The impact of switching from single-use to reusable healthcare products: a transparency checklist and systematic review of life-cycle assessments. European Journal of Public Health.

12. Perry H, Reeves N, Ansell J, Cornish J, Torkington J, Morris DS, et al. Innovations towards achieving environmentally sustainable operating theatres: A systematic review. Surgeon. 2023;21(3):141-51.

13. Siu J, Hill AG, MacCormick AD. Systematic review of reusable versus disposable laparoscopic instruments: costs and safety. ANZ J Surg. 2017;87(1-2):28-33.

14. Ravindrane R, Patel J. The environmental impacts of telemedicine in place of face-to-face patient care: a systematic review. Future Healthc J. 2022;9(1):28-33.

15. Lange O, Plath J, Dziggel TF, Karpa DF, Keil M, Becker T, et al. A Transparency Checklist for Carbon Footprint Calculations Applied within a Systematic Review of Virtual Care Interventions. Int J Environ Res Public Health. 2022;19(12).

16. Explained ES. Glossary: Carbon dioxide equivalent 2024 [Available from: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Carbon_dioxide_equivalent.

17. Shaw E. BS, Orr N., Nunns M., Boddy K., Turner M., Thompson Coon J., Melendez-Torres G.J. & Garside R. Effectiveness of interventions to reduce carbon-emissions within secondary healthcare: Systematic review and narrative synthesis 2023 [Available from: https://ore.exeter.ac.uk/repository/handle/10871/133658.

18. Zumsteg JM, Cooper JS, Noon MS. Systematic Review Checklist: A Standardized Technique for Assessing and Reporting Reviews of Life Cycle Assessment Data. J Ind Ecol. 2012;16(Suppl 1):S12-s21.

19. Centre for Reviews and Dissemination. CRD's guidance for undertaking reviews in health care 2009 [Available from: https://www.equator-network.org/reporting-guidelines/systematic-reviews-crds-guidance-for-undertaking-reviews-in-health-care/.

20. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. Systematic Reviews. 2021;10(1):89.

21. HealthcareLCA. Cumulative number of data sources within the HealthLCA database disaggregated by scale of analysis 2021.

22. Drew J, Christie SD, Tyedmers P, Smith-Forrester J, Rainham D. Operating in a Climate Crisis: A State-of-the-Science Review of Life Cycle Assessment within Surgical and Anesthetic Care. Environ Health Perspect. 2021;129(7):76001.

23. B.P. W. Guidelines for critical review of life cycle assessments: SPOLD; 1997 [Available from: https://lca-net.com/publications/show/guidelines-critical-review-life-cycle-assessments/.

24. Healthcare CfS. Integrating Sustainability into Quality Improvement to Creawte a More Ethical and Sustainable Healthcare System [Available from: https://sustainablehealthcare.org.uk/susqi.

25. Thomas J, Graziosi, S, Brunton J, Ghouze, Z, O'Driscoll, P, Bond, M & Koryakina, A. EPPI-Reviewer: advanced software for systematic reviews, maps and evidence synthesis. . EPPI-Reviewer: advanced software for systematic reviews, maps and evidence synthesis. 2022.

26. Centre DSFaE. EPPI-Mapper, Version 2.1.0.: PPI Centre, UCL Social Research Institute, University College London; 2022.

27. Betts A, Rogers, N., Beresford, T. & Saunders, H. A greener endoscopy unit for Royal Cornwall Hospital - Endoscopy team. 2022.

28. Bird N, Kirk, L., Wales J. & Hitchings, J. Changing the 3 montly blood test postage kits for patients on the renal transplant register.2022.

29. Burton L, Goggin, A., Tomkinson, A., Patterson, J. & Brennan, F. Sustainable ENT: Fractured Nose Manipulation- Local Anaesthetic Pathway. 2022.

30. Chan MN, A. Reducing carbon waste from pulse lavage systems used in joint replacement surgery, orthopaedic theatres. 2023.

31. Hardy A, Jones, P., Simpson, T., Gullapudi, V. R. L. & Wight, M. . Haemodialysis: optimising heat disinfect cycles and use of standby mode. 2022.

32. Kodumuri P, Jesudason, P., Houghton, J., Roberts, S., Williamson, I. & Revell, T. The upper “hand” of sustainability: Reducing the carbon footprint in hand surgery. 2022.

33. Kodumuri P, Jesudason EP, Lees V. Reducing the carbon footprint in carpal tunnel surgery inside the operating room with a lean and green model: a comparative study. The Journal of hand surgery, European volume. 2023:17531934231176952.

34. Langstaff A. Photobiomodulation therapy (PBM): using light therapy for oral mucositis, Palliative care team. 2023.

35. Lewis D, Tranter G, Axford AT. Use of videoconferencing in Wales to reduce carbon dioxide emissions, travel costs and time. J Telemed Telecare. 2009;15(3):137-8.

36. Materacki LB, L. . Scoping for change – adopting greener practice in endoscopy in Gloucestershire, Endoscopy team. 2023

37. Milne S. Retrofit of Heat Exchangers to Haemodialysis Machines - Case Study and How to Guide. 2023.

38. Milne S. Green nephrology: Retro-fit of heat exchangers to haemodialysis machines - case study and how-to guide. 2010.

39. Nielsen L, Bush, O. & Steinbach, I. Pioneering Early Mobilisation in a Cardiac Intensive Care unit: a Sustainable Healthcare Initiative. 2022.

40. Owens S, Harvey, N., Hillier, M., John-Cox, S. & Rao, I. Collaborative report of paper lite and contrast recycling projects, Endoscopy team. 2023.

41. Bond A, Jones A, Haynes R, Tam M, Denton E, Ballantyne M, et al. Tackling climate change close to home: mobile breast screening as a model. Journal of Health Services Research & Policy. 2009;14(3):165-7.

42. Chuter R, Stanford-Edwards C, Cummings J, Taylor C, Lowe G, Holden E, et al. Towards estimating the carbon footprint of external beam radiotherapy. Phys Medica. 2023;112:8.

43. Connor A, Lillywhite R, Cooke MW. The carbon footprints of home and in-center maintenance hemodialysis in the United Kingdom. Hemodialysis International. 2011a;15(1):39-51.

44. Connor A, Mortimer F, Higgins R. The follow-up of renal transplant recipients by telephone consultation: Three years experience from a single UK renal unit. Clinical Medicine, Journal of the Royal College of Physicians of London. 2011b;11(3):242-6.

45. Connor MJ, Miah S, Edison M, Brittain J, Kondjin Smith M, Hanna M, et al. Clinical, fiscal and environmental benefits of a specialist led virtual ureteric colic clinic: a report of a prospective study. BJU international. 2019.

46. Coombs NJ, Coombs JM, Vaidya UJ, Singer J, Bulsara M, Tobias JS, et al. Environmental and social benefits of the targeted intraoperative radiotherapy for breast cancer: Data from UK TARGIT-A trial centres and two UK NHS hospitals offering TARGIT IORT. BMJ Open. 2016;6(5):e010703.

47. Cooper D, Bhuskute N, Walsh G. Exploring the impact and acceptance of wearable sensor technology for pre-and postoperative rehabilitation in knee replacement patients: a UK-based pilot study. JBJS Open Access. 2022;7(2):e21.

48. Cooper DM, Bhuskute N, Hepworth C, Walsh G. The Economic Impact of a Pilot Digital Day-Case Pathway for Knee Arthroplasty in a U.K. Setting. JB & JS open access. 2023;8(1).

49. Curtis A, Parwaiz H, Winkworth C, Sweeting L, Pallant L, Davoudi K, et al. Remote Clinics During Coronavirus Disease 2019: Lessons for a Sustainable Future. Cureus. 2021;13(3):e14114.

50. de Preux L, Rizmie D. Beyond financial efficiency to support environmental sustainability in economic evaluations. Future Healthcare Journal. 2018;5(2):103-7.

51. Dorrian C, Ferguson J, Ah-See K, Barr C, Lalla K, van der Pol M, et al. Head and neck cancer assessment by flexible endoscopy and telemedicine. Journal of Telemedicine and Telecare. 2009;15(3):118-21.

52. King J, Poo SX, El-Sayed A, Kabir M, Hiner G, Olabinan O, et al. Towards NHS Zero: greener gastroenterology and the impact of virtual clinics on carbon emissions and patient outcomes. A multisite, observational, cross-sectional study. Frontline Gastroenterology. 2023;14(4):287-94.

53. Miah S, Dunford C, Edison M, Eldred-Evans D, Gan C, Shah TT, et al. A prospective clinical, cost and environmental analysis of a clinician-led virtual urology clinic. Ann R Coll Surg Engl. 2019;101(1):30-4.

54. Moussa G, Andreatta W, Ch'Ng SW, Ziaei H, Jalil A, Patton N, et al. Environmental effect of air versus gas tamponade in the management of rhegmatogenous retinal detachment VR surgery: A multicentre study of 3,239 patients. PLoS ONE. 2022;17(1 January):e0263009.

55. Moussa G, Ch'ng SW, Park DY, Ziaei H, Jalil A, Patton N, et al. Environmental effect of fluorinated gases in vitreoretinal surgery: a multicenter study of 4,877 patients. American journal of ophthalmology. 2021.

56. Natale J, Pascoe J, Horn C, Coode-Bate J, Dickinson A. Teleconsultation versus traditional clinical assessment of patients undergoing circumcision: A retrospective cohort study. Journal of Clinical Urology. 2022.

57. Phull M, Begum H, John JB, van Hove M, McGrath J, O'Flynn K, et al. Potential Carbon Savings with Day-case Compared to Inpatient Transurethral Resection of Bladder Tumour Surgery in England: A Retrospective Observational Study Using Administrative Data. European Urology Open Science. 2023;52:44-50.

58. Richards JD, Stoddart M, Bolland B. Virtual Arthroplasty Follow-Up: Better for the Trust, Patients, and the Planet. Cureus. 2022;14(11):e31978.

59. Rizan C, Bhutta MF. Environmental impact and life cycle financial cost of hybrid (reusable/single-use) instruments versus single-use equivalents in laparoscopic cholecystectomy. Surgical Endoscopy. 2022;36(6):4067-78.

60. Udayaraj UP, Watson O, Ben-Shlomo Y, Langdon M, Anderson K, Power A, et al. Establishing a tele-clinic service for kidney transplant recipients through a patient-codesigned quality improvement project. BMJ open quality. 2019;8(2):e000427.

61. Yong KK, He Y, Cheung HCA, Sriskandarajah R, Jenkins W, Goldin R, et al. Rationalising the use of specimen pots following colorectal polypectomy: a small step towards greener endoscopy. Frontline Gastroenterology. 2022.

62. Zander A, Niggebrugge A, Pencheon D, Lyratzopoulos G. Changes in travel-related carbon emissions associated with modernization of services for patients with acute myocardial infarction: A case study. Journal of Public Health. 2011;33(2):272-9.

63. Beswick DM, Vashi A, Song Y, Pham R, Holsinger FC, Rayl JD, et al. Consultation via telemedicine and access to operative care for patients with head and neck cancer in a Veterans Health Administration population. Head Neck-J Sci Spec Head Neck. 2016;38(6):925-9.

64. Field RR, Calderon M-DC, Ronilo SM, Ma M, Maxwell H, Mensah P, et al. Environmental and Economic Impact of Using a Higher Efficiency Ventilator and Vaporizer During Surgery Under General Anesthesia: A Randomized Controlled Prospective Cohort. Cureus. 2023;15(5):e39534.

65. Frick MA, Baniel CC, Qu V, Hui C, Brown E, Chang DT, et al. Effect of Radiation Schedule on Transportation-Related Carbon Emissions: A Case Study in Rectal Cancer. Advances in Radiation Oncology. 2023;8(5):101253.

66. Jiang CY, Strohbehn GW, Dedinsky RM, Raupp SM, Pannecouk BM, Yentz SE, et al. Teleoncology for Veterans: High Patient Satisfaction Coupled With Positive Financial and Environmental Impacts. JCO Oncology Practice. 2021;17(9):E1362-E74.

67. Kemble JP, Winoker JS, Patel SH, Su ZT, Matlaga BR, Potretzke AM, et al. Environmental impact of single-use and reusable flexible cystoscopes. BJU International. 2023;131(5):617-22.

68. Le NNT, Hernandez LV, Vakil N, Guda N, Patnode C, Jolliet O. Environmental and health outcomes of single-use versus reusable duodenoscopes. Gastrointestinal Endoscopy. 2022;96(6):1002-8.

69. Leapman MS, Thiel CL, Gordon IO, Nolte AC, Perecman A, Loeb S, et al. Environmental Impact of Prostate Magnetic Resonance Imaging and Transrectal Ultrasound Guided Prostate Biopsy. European Urology. 2023;83(5):463-71.

70. Meiklejohn DA, Khan ZH, Nunez KM, Imhof L, Osmani S, Benavidez AC, et al. Environmental Impact of Adult Tonsillectomy: Life Cycle Assessment and Cost Comparison of Techniques. The Laryngoscope. 2023.

71. Mojdehbakhsh RP, Rose S, Peterson M, Rice L, Spencer R. A quality improvement pathway to rapidly increase telemedicine services in a gynecologic oncology clinic during the COVID-19 pandemic with patient satisfaction scores and environmental impact. Gynecologic Oncology Reports. 2021;36:100708.

72. Patel KB, Gonzalez BD, Turner K, Alishahi Tabriz A, Rollison DE, Robinson E, et al. Estimated Carbon Emissions Savings With Shifts From In-Person Visits to Telemedicine for Patients With Cancer. JAMA network open. 2023;6(1):e2253788.

73. Sherman JD, Raibley LAt, Eckelman MJ. Life Cycle Assessment and Costing Methods for Device Procurement: Comparing Reusable and Single-Use Disposable Laryngoscopes. Anesthesia and analgesia. 2018;127(2):434-43.

74. Sillcox R, Blaustein M, Khandelwal S, Bryant MK, Zhu J, Chen JY. Telemedicine Use Decreases the Carbon Footprint of the Bariatric Surgery Preoperative Evaluation. Obesity Surgery. 2023a.

75. Sillcox R, Gitonga B, Meiklejohn DA, Wright AS, Oelschlager BK, Bryant MK, et al. The environmental impact of surgical telemedicine: life cycle assessment of virtual vs. in-person preoperative evaluations for benign foregut disease. Surgical Endoscopy and Other Interventional Techniques. 2023b.

76. Thiel CL, Eckelman M, Guido R, Huddleston M, Landis AE, Sherman J, et al. Environmental impacts of surgical procedures: Life cycle assessment of hysterectomy in the United States. Environmental Science and Technology. 2015;49(3):1779-86.

77. Thiel CL, Mehta N, Sejo CS, Qureshi L, Moyer M, Valentino V, et al. Telemedicine and the environment: life cycle environmental emissions from in-person and virtual clinic visits. Npj Digital Medicine. 2023;6(1).

78. Thiel CL, Woods NC, Bilec MM. Strategies to Reduce Greenhouse Gas Emissions from Laparoscopic Surgery. American journal of public health. 2018;108(S2):S158-S64.

79. Thota R, Gill DM, Brant JL, Yeatman TJ, Haslem DS. Telehealth Is a Sustainable Population Health Strategy to Lower Costs and Increase Quality of Health Care in Rural Utah. JCO oncology practice. 2020;16(7):e557-e62.

80. Vo LV, Mastrorilli V, Muto AJ, Emerson GG. Reuse of shipping materials in the intravitreal bevacizumab supply chain: feasibility, cost, and environmental impact. International Journal of Retina and Vitreous. 2023;9(1):34.

81. Woods DL, McAndrew T, Nevadunsky N, Hou JY, Goldberg G, Yi-Shin Kuo D, et al. Carbon footprint of robotically-assisted laparoscopy, laparoscopy and laparotomy: A comparison. International Journal of Medical Robotics and Computer Assisted Surgery. 2015;11(4):406-12.

82. Woolen SA, Becker AE, Martin AJ, Knoerl R, Lam V, Folsom J, et al. Ecodesign and Operational Strategies to Reduce the Carbon Footprint of MRI for Energy Cost Savings. Radiology. 2023;307(4):e230441.

83. Baboudjian M, Pradere B, Martin N, Gondran-Tellier B, Angerri O, Boucheron T, et al. Life Cycle Assessment of Reusable and Disposable Cystoscopes: A Path to Greener Urological Procedures. European Urology Focus. 2022.

84. Bendine G, Autin F, Fabre B, Bardin O, Rabasco F, Cabanel JM, et al. Haemodialysis therapy and sustainable growth: a corporate experience in France. Nephrology, dialysis, transplantation : official publication of the European Dialysis and Transplant Association - European Renal Association. 2020.

85. Chambrin C, de Souza S, Gariel C, Chassard D, Bouvet L. Association Between Anesthesia Provider Education and Carbon Footprint Related to the Use of Inhaled Halogenated Anesthetics. Anesthesia and Analgesia. 2023;136(1):101-10.

86. Filfilan A, Anract J, Chartier-Kastler E, Parra J, Vaessen C, de La Taille A, et al. Positive environmental impact of remote teleconsultation in urology during the COVID-19 pandemic in a highly populated area. Progres En Urologie. 2021;31(16):1133-8.

87. Rouviere N, Chkair S, Auger F, Alovisetti C, Bernard MJ, Cuvillon P, et al. Ecoresponsible actions in operating rooms: A health ecological and economic evaluation. International Journal of Surgery. 2022;101:106637.

88. Sanchez SA, Eckelman MJ, Sherman JD. Environmental and economic comparison of reusable and disposable blood pressure cuffs in multiple clinical settings. Resources, Conservation and Recycling. 2020;155:104643.

89. Arndt E-M, Jansen TR, Bojko J, Roos JJ, Babasiz M, Randau TM, et al. COVID-19 measures as an opportunity to reduce the environmental footprint in orthopaedic and trauma surgery. Frontiers in surgery. 2023;10:959639.

90. Buttner L, Posch H, Auer T, Jonczyk M, Fehrenbach U, Hamm B, et al. Switching off for future-Cost estimate and a simple approach to improving the ecological footprint of radiological departments. European Journal of Radiology Open. 2021;8:100320.

91. Klein H-M. A New Approach to the Improvement of Energy Efficiency in Radiology Practices. Ein neuer Ansatz zur Verbesserung der Energieeffizienz in radiologischen Versorgungseinheiten. 2023;195(5):416-25.

92. Leiden A, Cerdas F, Noriega D, Beyerlein J, Herrmann C. Life cycle assessment of a disposable and a reusable surgery instrument set for spinal fusion surgeries. Resources, Conservation and Recycling. 2020;156:104704.

93. Muschol J, Heinrich M, Heiss C, Hernandez AM, Knapp G, Repp H, et al. Economic and Environmental Impact of Digital Health App Video Consultations in Follow-up Care for Patients in Orthopedic and Trauma Surgery in Germany: Randomized Controlled Trial. J Med Internet Res. 2022;24(11):11.

94. Schulte A, Maga D, Thonemann N. Combining Life Cycle Assessment and Circularity Assessment to Analyze Environmental Impacts of the Medical Remanufacturing of Electrophysiology Catheters. Sustainability. 2021;13(2).

95. Andrew N, Barraclough KA, Long K, Fazio TN, Holt S, Kanhutu K, et al. Telehealth model of care for routine follow up of renal transplant recipients in a tertiary centre: A case study. Journal of telemedicine and telecare. 2020;26(4):232-8.

96. Davis NF, McGrath S, Quinlan M, Jack G, Lawrentschuk N, Bolton DM. Carbon footprint in flexible ureteroscopy: A comparative study on the environmental impact of reusable and single-use ureteroscopes. Journal of Endourology. 2018;32(3):214-7.

97. McAlister S, McGain F, Petersen M, Story D, Charlesworth K, Ison G, et al. The carbon footprint of hospital diagnostic imaging in Australia. The Lancet Regional Health - Western Pacific. 2022;24:100459.

98. Wombwell A, Holmes A, Grills R. Are single-use flexible cystoscopes environmentally sustainable? A lifecycle analysis. Journal of Clinical Urology. 2023.

99. Cheung R, Ito E, Lopez M, Rubinstein E, Keller H, Cheung F, et al. Evaluating the Short-term Environmental and Clinical Effects of a Radiation Oncology Department's Response to the COVID-19 Pandemic. International Journal of Radiation Oncology Biology Physics. 2023;115(1):39-47.

100. Forner D, Purcell C, Taylor V, Noel CW, Pan L, Rigby MH, et al. Carbon footprint reduction associated with a surgical outreach clinic. Journal of Otolaryngology-Head & Neck Surgery. 2021;50(1).

101. Lambert P, Musto G, Thiessen M, Czaykowski P, Decker K. Impact of Cancer-Related Virtual Visits on Travel Distance, Travel Time, and Carbon Dioxide (CO2) Emissions during the COVID-19 Pandemic in Manitoba, Canada. Curr Oncol. 2023;30(7):5973-83.

102. Tselapedi-Sekeitto B, Rocha T, Sowerby LJ, Rotenberg B, Biadsee A. Telemedicine as an environmental ally-The social, financial, and environmental impact of virtual care in the otolaryngology clinic. American Journal of Otolaryngology. 2023;44(2):103791.

103. Boberg L, Singh J, Montgomery A, Bentzer P. Environmental impact of single-use, reusable, and mixed trocar systems used for laparoscopic cholecystectomies. PLoS ONE. 2022;17(7 July):e0271601.

104. Holmner A, Ebi KL, Lazuardi L, Nilsson M. Carbon Footprint of Telemedicine Solutions - Unexplored Opportunity for Reducing Carbon Emissions in the Health Sector. Plos One. 2014;9(9).

105. Stripple H, Westman R, Holm D. Development and environmental improvements of plastics for hydrophilic catheters in medical care: an environmental evaluation. Journal of Cleaner Production. 2008;16(16):1764-76.

106. Croghan SM, Rohan P, Considine S, Salloum A, Smyth L, Ahmad I, et al. Time, cost and carbon-efficiency: a silver of COVID era virtual urology clinics? Annals of the Royal College of Surgeons of England. 2021;103(8):599-603.

107. Hogan D, Rauf H, Kinnear N, Hennessey DB. The Carbon Footprint of Single-Use Flexible Cystoscopes Compared with Reusable Cystoscopes. Journal of Endourology. 2022;36(11):1460-4.

108. McCarthy CJ, Gerstenmaier JF, O' Neill AC, McEvoy SH, Hegarty C, Heffernan EJ. "EcoRadiology"--pulling the plug on wasted energy in the radiology department. Academic radiology. 2014;21(12):1563-6.

109. Asghari M, Al-e-Hashem S. A green delivery-pickup problem for home hemodialysis machines; sharing economy in distributing scarce resources. Transportation Research Part E-Logistics and Transportation Review. 2020;134.

110. Vaidya JS, Vaidya UJ, Baum M, Bulsara MK, Joseph D, Tobias JS. Global adoption of single-shot targeted intraoperative radiotherapy (TARGIT-IORT) for breast cancer-better for patients, better for healthcare systems. Frontiers in Oncology. 2022;12:786515.

111. Chen M, Zhou R, Du C, Meng F, Wang Y, Wu L, et al. The carbon footprints of home and in-center peritoneal dialysis in China. International Urology and Nephrology. 2017;49(2):337-43.

112. Sørensen BL, Grüttner H. Comparative study on environmental impacts of reusable and single-use bronchoscopes. Am J Environ Prot. 2018;7(4):55-62.

113. Fuschi A, Pastore AL, Al Salhi Y, Martoccia A, De Nunzio C, Tema G, et al. The impact of radical prostatectomy on global climate: a prospective multicentre study comparing laparoscopic versus robotic surgery. Prostate Cancer and Prostatic Diseases. 2023.

114. McLachlan A, Aldridge C, Morgan M, Lund M, Gabriel R, Malez V. An NP-led pilot telehealth programme to facilitate guideline-directed medical therapy for heart failure with reduced ejection fraction during the COVID-19 pandemic. N Z Med J. 2021;134(1538):77-88.

115. Neves JAC, Roseira J, Queiros P, Sousa HT, Pellino G, Cunha MF. Targeted intervention to achieve waste reduction in gastrointestinal endoscopy. Gut. 2022.

116. Lopez-Munoz P, Martin-Cabezuelo R, Lorenzo-Zuniga V, Vilarino-Feltrer G, Tort-Ausina I, Vidaurre A, et al. Life cycle assessment of routinely used endoscopic instruments and simple intervention to reduce our environmental impact. Gut. 2023:E329544.

117. Heye T, Meyer MT, Merkle EM, Vosshenrich J. Turn It Off! A Simple Method to Save Energy and CO2 Emissions in a Hospital Setting with Focus on Radiology by Monitoring Nonproductive Energy-consuming Devices. Radiology. 2023;307(4):e230162.

118. Winklmair N, Kieselbach G, Bopp J, Amon M, Findl O. Potential environmental effect of reducing the variation of disposable materials used for cataract surgery. Journal of Cataract and Refractive Surgery. 2023;49(6):628-34.

119. de Ridder EF, Friedericy HJ, van der Eijk AC, Dankelman J, Jansen FW. A New Method to Improve the Environmental Sustainability of the Operating Room: Healthcare Sustainability Mode and Effect Analysis (HSMEA). Sustainability. 2022;14(21).

120. Rizan C, Bhutta MF. Re: The Carbon Footprint of Single-Use Flexible Cystoscopes Compared with Reusable Cystoscopes: Methodological Flaws Led to the Erroneous Conclusion That Single-Use Is "Better". J Endourol. 2022;36(11):1466-7.

121. Brighton & Sussex Medical School CfSH, and UK Health Alliance on , Change C. Green surgery: Reducing the environmental impact of surgical care (v1.1). London: UKHACC; 2023.

122. Hogan D, Hennessey DB. Response to Rizan et al.: "The Carbon Footprint of Single-Use Flexible Cystoscopes Compared with Reusable Cystoscopes"-Clarification of Methods Due to Apparent Misinterpretation. J Endourol. 2023;37(10):1145-6.

123. Rizan C, Steinbach I, Nicholson R, Lillywhite R, Reed M, Bhutta M. The Carbon Footprint of Surgical Operations: A Systematic Review. Annals of Surgery. 2020;Publish Ahead of Print.

Appendix A: Search strategies

Database: MEDLINE
Host: Ovid
Issue: 1946 to July 11, 2023
Date Searched: 12th July 2023
Searcher: SB
Hits: 3052
Strategy:

1. ((carbon or CO2 or CO2e) adj3 (emission* or footprint or impact* or output or green* or sustainab*)).tw.
2. (greenhouse adj1 (effect or gas*)).tw.
3. (("life cycle" or lifecycle) adj1 (analys?s or assessment*)).tw.
4. ((climate or environment*) adj1 (footprint or impact* or sustainab*)).tw.
5. Carbon Footprint/
6. Greenhouse Gases/
7. Air Pollutants, Occupational/
8. Global Warming/
9. environmental indicators/
10. or/1-9
11. (gastro* or gastric*).tw.
12. (gi adj1 (disease* or disorder*)).tw.
13. ((bowel or gi or intesti* or liver or stomach) adj1 (assessment* or biops* or bleeding or cirrhosis or disease* or disorder* or failure or illness* or cancer* or carcinoma* or tumour* or tumor* or neoplasm*)).tw.
14. ("abdominal adhesion*" or appendicitis or "barrett's esophagus" or "celiac disease" or "colon polyps" or "crohn's disease" or "esophageal varices" or "pancreatic insufficiency" or gallstones or gastritis or h?emorrhoid* or hernia* or colitis or pancreatitis or "peptic ulcer*" or "stomach ulcer*" or proctitis or pylori).tw.
15. Gastroenterology/
16. exp Gastrointestinal Diseases/
17. (appendectomy or colonoscop* or duodenoscop* or endoscop* or gastroscop* or colectomy).tw.
18. exp Endoscopy, Gastrointestinal/
19. manometry.tw.
20. exp Manometry/
21. (barium adj1 (enema or swallow)).tw.
22. (cholangiography or cholangiopancreatography).tw.
23. exp Cholangiography/
24. (esophagogram or electrogastrogram).tw.
25. exp Digestive System Surgical Procedures/
26. exp digestive system neoplasms/
27. or/11-26
28. 10 and 27
29. (orthopedic* or orthopaedic* or musculoskeletal).tw.
30. Orthopedics/
31. exp Musculoskeletal System/

32. ((ankle or bone or cervical or elbow or femoral or finger or hand or hip or joint or knee or neck or shoulder or spine) adj2 (break or broken or fracture*)).tw.
33. (bone adj1 (cancer* or carcinoma* or tumour* or tumor* or neoplasm*)).tw.
34. exp Fractures, Bone/
35. ("carpal tunnel" adj2 (syndrome or release)).tw.
36. Carpal Tunnel Syndrome/
37. osteoporosis.tw.
38. exp osteoporosis/
39. ((ankle or bone or cervical or elbow or femoral or finger or hand or hip or joint or knee or neck or shoulder or spine) adj2 (arthroplast* or arthroscop* or implant* or reconstruction or repair or replacement)).tw.
40. (cementoplasty or diskectomy or "fracture fixation" or "intervertebral disc chemolysis" or laminectomy or laminoplasty or "orthopedic manipulation posterior cruciate ligament reconstruction" or "ulnar collateral ligament reconstruction" or viscosupplementation).tw.
41. exp Orthopedic Procedures/
42. (trauma adj1 (care or "life support" or medic*)).tw.
43. Trauma Centers/
44. exp bone neoplasms/
45. or/29-44
46. 10 and 45
47. (cardiolog* or cardiovascular).tw.
48. exp Cardiology/
49. Cardiology Service, Hospital/
50. ((cardiac or heart) adj3 (arrest or attack* or disease* or disorder* or defect* or dysfunction or failure or sarcoma or transplant*)).tw.
51. "myocardial infarction".tw.
52. ((aortic or artery or arterial) adj1 disease).tw.
53. "intermittent claudication".tw.
54. aneurysm.tw.
55. hypertension.tw.
56. exp Hypertension/
57. exp Heart Diseases/
58. (angioplasty or "arterial switch operation" or "artificial heart valve" or "heart valve replacement" or atherectomy or "cardiac valve annuloplasty" or cardiomyoplasty or "heart bypass" or "heart massage" or "heart valve prosthesis implant*" or "maze procedure" or revascularization or vascularization or "norwood procedures" or "pericardial window techniques" or pericardiectomy or pericardiocentesis).tw.
59. exp Cardiac Surgical Procedures/
60. exp Angioplasty/
61. stent*.tw.
62. exp Stents/
63. exp cardiac imaging techniques/
64. exp heart neoplasms/
65. or/47-64
66. 10 and 65
67. ophthalm*.tw.
68. Ophthalmology/
69. (cataract* or glaucoma).tw.

70. "macular degeneration".tw.
71. "diabetic retinopathy".tw.
72. exp Eye Diseases/
73. ((eye* or retina*) adj3 (care or detachment or disease or disorder* or cancer* or carcinoma* or tumour* or tumor* or neoplasm*)).tw.
74. "intravitreal injection*".tw.
75. Intravitreal Injections/
76. (blepharoplasty or dacryocystorhinostomy or "eye enucleation" or "eye evisceration" or "filtering surgery" or sclerostomy or trabeculectomy or iridectomy or "light coagulation" or "laser coagulation" or "orbit evisceration" or "corneal transplant*" or "radial keratotomy" or "lens implant*" or "posterior capsulotomy" or scleroplasty or "scleral buckling" or vitrectomy).tw.
77. exp Ophthalmologic Surgical Procedures/
78. exp eye neoplasms/
79. or/67-78
80. 10 and 79
81. ((lung or pulmonary or respiratory) adj3 (care or disease* or disorder* or cancer* or carcinoma* or tumour* or tumor* or neoplasm*)).tw.
82. Pulmonary Medicine/
83. ("chronic obstructive pulmonary disease" or COPD).tw.
84. lung diseases, obstructive/
85. exp pulmonary disease, chronic obstructive/
86. ((emergency or hospital or medical or therap*) adj3 oxygen).tw.
87. (bronchoscop* or "endobronchial ultrasound" or bullectomy or "chest drain" or "lung transplant*").tw.
88. exp Respiratory Therapy/
89. bronchoscopy/
90. exp Diagnostic Techniques, Respiratory System/
91. (asthma or inhaler*).tw.
92. Asthma/
93. respiratory tract neoplasms/
94. or/81-93
95. 10 and 94
96. nephrolog*.jn,tw.
97. Nephrology/
98. (renal or kidney*).jn,tw.
99. ((renal or kidney) adj3 (acute or chronic or disease* or "end stage" or failure or injury or injuries or transplant* or cancer* or carcinoma* or tumour* or tumor* or neoplasm*)).tw.
100. nephropathy.tw.
101. exp Kidney Failure, Chronic/
102. exp Kidney Diseases/
103. exp Renal Replacement Therapy/
104. ((kidney or renal) adj3 (therap* or replacement or transplant*)).tw.
105. (dialysis or h?emodialysis or h?emofiltration or h?emoperfusion or lithotripsy).tw.
106. exp Carcinoma, Renal Cell/
107. or/96-106
108. 10 and 107
109. ("critical care" or "intensive care" or intensivist* or icu).jn,tw.

110. (serious adj1 (accident* or injur* or infect*)).tw.
111. exp Critical Care/
112. or/109-111
113. 10 and 112
114. exp Gynecologic Surgical Procedures/
115. (colposcopy or colpotomy or "culdoscopy dilatation and curettage" or "endometrial ablation" or hysterectomy or hysteroscopy or ovariectomy or salpingectomy or salpingostomy or "tubal sterilization" or "uterine artery embolization" or "uterine myomectomy" or vulvectomy).tw.
116. 114 or 115
117. 10 and 116
118. exp Urologic Surgical Procedures/
119. (cystectomy or cystoscopy or cystotomy or "kidney Transplant*" or nephrectomy or nephroureterectomy or nephrolithotomy or nephrotomy or nephrostomy or "transurethral resection" or ureteroscopy or "urinary diversion" or ureterostomy or "male circumcision" or orchiectomy or orchiopexy or "penile Implantation" or prostatectomy or vasectomy or vasovasostomy).tw.
120. 118 or 119
121. 10 and 120
122. exp Otorhinolaryngologic Surgical Procedures/
123. (adenoidectomy or laryngectomy or laryngoplasty or laryngoscopy or rhinoplasty or "neck dissection" or "auditory brain stem implant*" or "cochlear implant*" or "endolymphatic shunt" or "labyrinth fenestration" or mastoidectomy or "middle ear ventilation" or myringoplasty or "ossicular replacement" or "transtympanic micropressure treatment" or tympanoplasty or pharyngectomy or pharyngostomy or tonsillectomy or tracheostomy or tracheotomy).tw.
124. 122 or 123
125. 10 and 124
126. exp chemoprevention/
127. exp chemoradiotherapy/
128. exp chemotherapy, adjuvant/
129. exp consolidation chemotherapy/
130. (chemotherapy or chemoprevention or chemoradiotherapy or radiotherapy).tw.
131. oncolog*.tw.
132. exp Medical Oncology/
133. antineoplastic*.tw.
134. exp Antineoplastic Agents/
135. or/126-134
136. 10 and 135
137. obstetric*.tw.
138. exp obstetrics/
139. ((oxytocin or labo?r) adj3 induc*).tw.
140. ("electro f?etal monitoring" or "continuous EFM").tw.
141. (amniotomy or enema or epidural or episiotomy).tw.
142. ("artificial rupture" adj2 membranes).tw.
143. ("cervical cerclage" or colposcop* or colpotomy or culdoscop* or fetoscop* or hysteroscop* or hysterotomy or "umbilical cord clamp*").tw.
144. abortion*.tw.

145. (terminat* adj2 pregnancy).tw.
146. exp Pregnancy Complications/
147. exp Obstetric Surgical Procedures/
148. or/137-147
149. 10 and 148
150. (radiolog* or radiotherap*).tw.
151. exp Radiology/
152. (angiography or "CT scan" or echocardiogram or "electrocardiogram" or "magnetic resonance imag* MRI" or "PET scan" or tomography or ultrasound or "x ray").tw.
153. (CT adj2 (micro or "high resolution" or "volumetric quantitative")).tw.
154. ((medical or fluoroscopic*) adj2 imag*).tw.
155. exp Diagnostic Imaging/
156. or/150-155
157. (health or hospital* or medical or medicine or pharmaceutical).tw.
158. exp Hospitals/
159. Hospital Medicine/
160. or/157-159
161. 10 and 156 and 160
162. 28 or 46 or 66 or 80 or 95 or 108 or 113 or 117 or 121 or 125 or 136 or 149 or 161
163. limit 162 to (english language and yr="2008 -Current")

Database: Environment Complete
Host: EBSCO
Issue: n/a
Date Searched: 12th July 2023
Searcher: SB
Hits: 2753
Strategy:

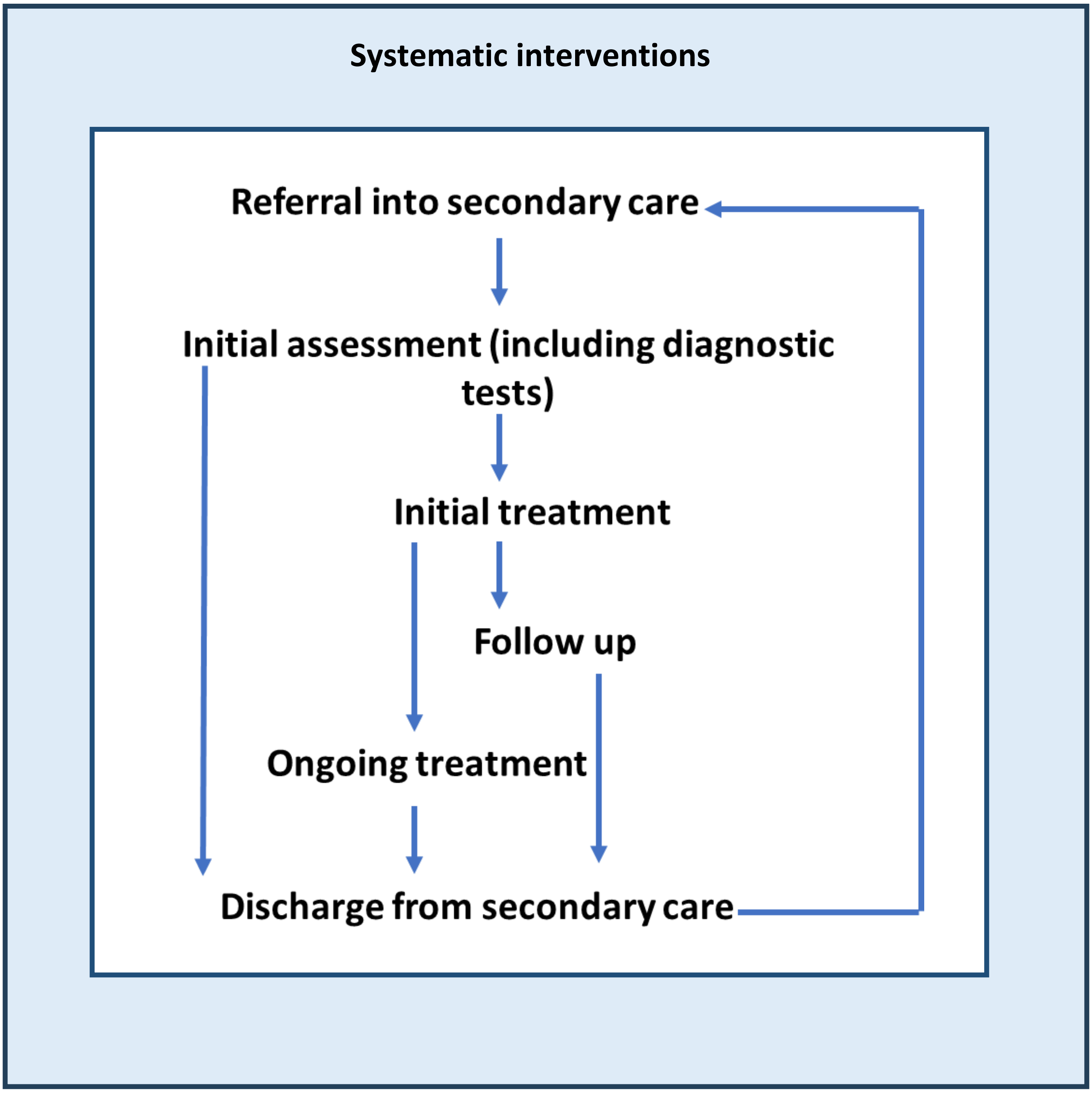
1. TI (healthcare or "health care" or "health service*" or "health system" or hospital* or medical or medicine or pharmaceutical) OR AB (healthcare or "health care" or "health service*" or "health system" or hospital* or medical or medicine or pharmaceutical)
2. DE "MEDICINE"
3. S1 OR S2
4. TI (climate or environment* N2 (footprint or impact* or sustainab*)) OR AB (climate or environment* N2 (footprint or impact* or sustainab*))
5. TI (("life cycle" or lifecycle) N0 (analys?s or assessment*)) OR AB (("life cycle" or lifecycle) N0 (analys?s or assessment*)
6. TI (greenhouse N0 (effect or gas*)) OR AB (greenhouse N0 (effect or gas*))
7. TI ((carbon or CO2) N2 (emission* or footprint or impact* or output or sustainab*)) OR AB ((carbon or CO2) N2 (emission* or footprint or impact* or output or sustainab*))
8. DE "HOSPITAL waste disposal"
9. DE "CARBON emissions"
10. S4 OR S5 OR S6 OR S7 OR S8 OR S9
11. S3 AND S10

Appendix B: Data extraction items for included studies

Study details	Sample characteristics	Intervention/Control Characteristics	Carbon emission calculation methods	PROGRESS-PLUS (detail relevant to below categories extracted)	Other outcomes measured	Carbon emission findings
First author, date of study	Setting	Intervention/first comparator category and name	LCA informed – Y/N	Place of residence	Method of data collection	Summary of main findings (cut and paste)
Title of article	Specialty	Description	If LCA – LCA/Inventory analysis?	Race/ethnicity/culture /language	Outcome measure name	
Publication type	Clinician characteristics	Aim	Standards/reference data used to inform CE calculations	Occupation	Outcome measure category	
Country	Total No. patients (intervention/control)	Details of treatment pathway	Type of CE (Scope 1, 2, 3) (non-LCA studies)	Gender/Sex	Rater	
Income	Dropouts	How accessed	Method of calculating carbon emission data	Religion	Blinded (Y/N)	
Aim of study	Patient characteristics (Procedure, mean age,	Materials required to deliver	Functional unit (as stated)	SES	Analysis method	
Summary of findings (from abstract)	Recruitment method	Procedures	System boundaries	Social capital	Narrative summary of findings	
Study design	Allocation procedure	Who delivered, mode of delivery, frequency/duration, tailored to patient needs, modifications	Stages of system	Personal characteristics associated with discrimination		
Funding statement	Inclusion criteria	Recipients	Statement of representativeness of data	Features of relationships		
Conflict of interest		Adherence/fidelity assessed – if Y, findings extracted		Time-dependent relationships		

Blue shaded cell=data collected from non-LCA studies. CE=Carbon Emissions, LCA=Life Cycle Assessment, N=No, No=Number, SES=Socioeconomic status, Y=Yes

Appendix C: Patient care pathway



Appendix D: List of excluded studies

Bibliographic database searches

Reference	Reason for exclusion
(2013). Mainstreaming Carbon Management in Healthcare Systems: A Bottom-Up Modelling Approach. **47:** 678-686.	Specialty
Adams, L., et al. (2009). "Development of nurse-led, cancer follow-up clinics in community hospitals." European Journal of Cancer, Supplement **7**(2-3): 237.	Abstract
Agarwal, B. B. and K. C. Mahajan (2010). "Carbon footprint of laparoscopic cholecystectomy performed with or without energized dissection-a case controlled study." Surgical Endoscopy and Other Interventional Techniques **24**(1 SUPPL. 1): S590.	Abstract
Al Fannah, J., et al. (2023). "Towards a green hospital approach in Oman: A case study of quantifying an environmental impact." International Journal of Health Planning and Management.	Specialty
Alshqaqeeq, F., et al. (2020). "Choosing radiology imaging modalities to meet patient needs with lower environmental impact." Resources, Conservation and Recycling **155**: 104657.	CE data NR
Andrade, R. S., et al. (2014). "Endobronchial ultrasonography versus mediastinoscopy: a single-institution cost analysis and waste comparison." The Annals of thoracic surgery **98**(3): 1003-1007.	Specialty
Ang, K. S., et al. (2023). "Developing a quality improvement project to tackle the desflurane problem." Bmj Open Quality **12**(1).	Specialty
Babu, M. A., et al. (2019). "Greening the Operating Room: Results of a Scalable Initiative to Reduce Waste and Recover Supply Costs." Neurosurgery **85**(3): 432-437.	CE data NR
Bacon, M. (2014). "Occupancy analytics: a new basis for low-energy–low-carbon hospital design and operation in the UK." Architectural Engineering & Design Management **10**(1/2): 146-163.	Specialty
Baddeley, R., et al. (2022). "Green Endoscopy: Counting the Carbon Cost of Our Practice." Gastroenterology **162**(6): 1556-1560.	Study design
Balys, M., et al. (2021). "LCA and economic study on the local oxygen supply in Central Europe during the COVID-19 pandemic." Science of the Total Environment **786**: 147401.	Specialty
Baxter, N. B., et al. (2021). "Variability in the Use of Disposable Surgical Supplies: A Surgeon Survey and Life Cycle Analysis." Journal of Hand Surgery **46**(12): 1071-1078.	Study design
Bell, J., et al. (2022). "Carbon footprint of maintenance and reliever therapy (MART) versus maintenance plus SABA (Mx+SABA) regimens for asthma: Results from the healthCARe-Based environmental cost of treatment (CARBON) programme." European Respiratory Journal **60**(Supplement 66).	Abstract
Black, S. and K. Torlei (2013). "Designing a New Type of Hospital Gown: A User-centred Design Approach Case Study." Fashion Practice-the Journal of Design Creative Process & the Fashion Industry **5**(1): 153-160.	Study design
Blankush, J. M., et al. (2020). "Unforeseen Consequences: Comparative Environmental Impacts of Robotic and Open Ventral Hernia Repair." Journal of the American College of Surgeons **231**(4 Supplement 2): e149.	Abstract
Bolger, M. P., et al. (2016). "The environmental impact of interventional radiology." Cardiovascular and Interventional Radiology **39**(3 Supplement 1): S213.	Abstract
Boucheron, T., et al. (2022). "Cost and Environmental Impact of Disposable Flexible Cystoscopes Compared to Reusable Devices." Journal of Endourology **36**(10): 1317-1321.	CE data NR
Bunani, A. and T. Villaneuva (2014). "Green mileage - Sustainable program towards eco-friendly dialysis in Saudi Arabia: Results of phase one." Pediatric Nephrology **29**(9): 1780.	Abstract
Burguburu, A., et al. (2022). "Comparative life cycle assessment of reusable and disposable scrub suits used in hospital operating rooms." Cleaner Environmental Systems **4**.	Specialty
Cameron, T. W., 3rd, et al. (2021). "Medical Waste Due to Intravitreal Injection Procedures in a Retina Clinic." Journal of vitreoretinal diseases **5**(3): 193-198.	Study design
Campion, N., et al. (2015). "Sustainable healthcare and environmental life-cycle impacts of disposable supplies: a focus on disposable custom packs." Journal of Cleaner Production **94**: 46-55.	CE data NR

Carpenter, M., et al. (2023). "Robotic-assisted radical prostatectomy as a day-case procedure." Anaesthesia **78**(Supplement 1): 10.	Abstract
Chau, C., et al. (2022). "The environmental impacts of different mask options for healthcare settings in the UK." Sustainable Production and Consumption **33**: 271-282.	Study design
Chenven, L. and D. Copeland (2013). "FRONT-LINE WORKER ENGAGEMENT: GREENING HEALTH CARE, IMPROVING WORKER AND PATIENT HEALTH, AND BUILDING BETTER JOBS." New Solutions: A Journal of Environmental & Occupational Health Policy **23**(2): 327-345.	CE data NR
Chinchilla, G., et al. (2022). "Project Green Endoscopy: GE online successfully reduces carbon footprint associated with patient travel in a metropolitan endoscopy unit." Journal of Gastroenterology and Hepatology **37**(Supplement 1): 249.	Abstract
Coca, K., et al. (2022). "Impact of Telemedicine on Financial Burden to Patients and Carbon Footprint at an Endocrine Oncology Clinic." Otolaryngology - Head and Neck Surgery **167**(1 Supplement): P23.	Abstract
Connor, M. J., et al. (2019). "Clinical, fiscal and environmental benefits of a specialist-led virtual ureteric colic clinic: a prospective study." BJU International **124**(6): 1034-1039.	Duplicate
Cowboy, E. N., et al. (2009). "Reducing the Carbon Footprint by tele-ICU model." Chest **136**(4).	Abstract
Cummings, J., et al. (2022). "Estimating the carbon footprint of the radiotherapy pathway and changes in response to COVID-19." Radiotherapy and Oncology **170**(Supplement 1): S893-S894.	Abstract
Cunha Neves, J. A., et al. (2022). "IMPROVING ENDOSCOPY UNIT THROUGHPUT USING AN AUTOMATED CYBER-PHYSICAL MONITORING SYSTEM : A PILOT STUDY GREEN ENDOSCOPY TO REDUCE COGENERATED BY ENDOSCOPIC WASTE - GECO." Gastrointestinal Endoscopy **95**(6 Supplement): AB128.	Abstract
Cunha Neves, J. A., et al. (2023). "Targeted intervention to achieve waste reduction in gastrointestinal endoscopy." Gut **72**(2): 306-313.	Duplicate
Curtis, A., et al. (2021). "Remote orthopaedic clinics during covid-19: Lessons for a sustainable future." British Journal of Surgery **108**(SUPPL 6): vi129.	Abstract
Davies, J. F., et al. (2023). "Operation clean up: A model for eco-leadership and sustainability implementation." Anaesthesia and Intensive Care **51**(2): 88-95.	Specialty
De Jong, D., et al. (2022). "TOWARDS A GREENER ENDOSCOPY ROOM: RECYCLING PLASTIC WASTE." United European Gastroenterology Journal **10**(Supplement 8): 1082-1083.	Abstract
De Rydt, F., et al. (2020). "Sevoflurane consumption with the How-i ventilator in two versions of automatic gas control algorithms and two settings of manually controlled anesthesia : an economic and ecological assessment." Acta Anaesthesiologica Belgica **71**: 15-20.	Specialty
Dengiz, A. O., et al. (2021). "A goal programming approach for multi objective, multi-trips and time window routing problem in home health care service." Journal of the Faculty of Engineering and Architecture of Gazi University **36**(4): 2167-2181.	Language
Do Thi, H. T., et al. (2021). "Applicability of Membranes in Protective Face Masks and Comparison of Reusable and Disposable Face Masks with Life Cycle Assessment." Sustainability **13**(22).	Specialty
Donahue, L. M., et al. (2020). "A Comparative Carbon Footprint Analysis of Disposable and Reusable Vaginal Specula." Obstetrical and Gynecological Survey **75**(6): 352-354.	Study design
Duane, B., et al. (2014). "Carbon mitigation, patient choice and cost reduction - triple bottom line optimisation for health care planning." Public Health **128**(10): 920-924.	Specialty
Dullet, N. W., et al. (2017). "Impact of a University-Based Outpatient Telemedicine Program on Time Savings, Travel Costs, and Environmental Pollutants." Value in Health **20**(4): 542-546.	Specialty
Dunbar-Reid, K. and E. Buikstra (2017). "Waste reduction in haemodialysis: a multicentre quality activity." Renal Society of Australasia Journal **13**(2): 45-52.	CE data NR
Eckelman, M., et al. (2012). "Comparative Life Cycle Assessment of Disposable and Reusable Laryngeal Mask Airways." Anesthesia and Analgesia **114**(5): 1067-1072.	Specialty
Edison, M., et al. (2019). "Prospective clinical, cost analysis and environmental impact of a clinician-led virtual ureteric colic treatment decision pathway." Journal of Clinical Urology **12**(1 Supplement): 79-80.	Abstract
Enos, M., et al. (2014). "Carbon footprints of an in-centre haemodialysis device, the nxstage system one and the vivia haemodialysis system." Nephrology Dialysis Transplantation **29**(SUPPL. 3): iii219.	Abstract

Essa, H., et al. (2021). "One year outcomes of heart failure multispecialty multidisciplinary team virtual meetings." European Heart Journal **42**(SUPPL 1): 971.	Abstract
Farrell, E. and D. Smyth (2021). "The environmental impact of personal protective equipment in a pre and post COVID era in the ENT clinic." European Archives of Oto-Rhino-Laryngology **278**(12): 5051-5058.	CE data NR
Fatima, R., et al. (2022). "PREVENTING UNNECESSARY CT CORONARY ANGIOGRAPHY BY UTILISING PREVIOUS CT THORACIC IMAGING: A RETROSPECTIVE ANALYSIS." Heart **108**(Supplement 2): A12.	Abstract
Ford, B., et al. (2022). "Reducing Single-Use Surgical Instruments During Laparoscopic Appendicectomy: Using Sustainable Quality Improvement as a Catalyst to Encourage Wider Behavioural Change in a Surgical Department." British Journal of Surgery **109**(Supplement 6): vi5-vi6.	Abstract
Fort, E. J., et al. (2021). "Social and environmental benefits of virtual fracture clinics in trauma and orthopaedic surgery: Reduced patient Travel Time." British Journal of Surgery **108**(SUPPL 6): vi124.	Abstract
Freihoefer, K., et al. (2018). "Setting the Stage: A Comparative Analysis of an Onstage/Offstage and a Linear Clinic Modules." Herd-Health Environments Research & Design Journal **11**(2): 89-103.	CE data NR
Freund, J., et al. (2022). "Environmental considerations in the selection of medical staplers: A comparative life cycle assessment." Journal of Cleaner Production **371**.	CE data NR
Frick, M., et al. (2022). "The Environmental Impact of Telemedicine in a Radiation Oncology Clinic." American Journal of Clinical Oncology: Cancer Clinical Trials **45**(9): S60-S61.	Abstract
Friedericy, H. J., et al. (2022). "Reducing the Environmental Impact of Sterilization Packaging for Surgical Instruments in the Operating Room: A Comparative Life Cycle Assessment of Disposable versus Reusable Systems." Sustainability **14**(1).	Specialty
Furlan, L., et al. (2023). "The environmental cost of unwarranted variation in the use of magnetic resonance imaging and computed tomography scans." European Journal of Internal Medicine **111**: 47-53.	Intervention
Furlan, L., et al. (2023). "The environmental cost of unwarranted variation in the use of magnetic resonance imaging and computed tomography scans." European Journal of Internal Medicine **111**: 47-53.	Study design
Gerris, J., et al. (2014). "Self-operated endo-vaginal tele-monitoring versus traditional monitoring of ovarian stimulation in ART: Prospective randomized trial." Human Reproduction **29**(SUPPL. 1): i112.	Abstract
Gil-Candel, M., et al. (2023). "Developing a telepharmacy programme with home medication dispensing and informed delivery in a tertiary hospital: description of the model and analysis of the results." European Journal of Hospital Pharmacy **30**(2): 107-112.	Specialty
Goel, H., et al. (2021). "Improving productivity, costs and environmental impact in International Eye Health Services: using the 'Eyefficiency' cataract surgical services auditing tool to assess the value of cataract surgical services." BMJ open ophthalmology **6**(1): e000642.	Study design
Gough, V., et al. (2022). "Laparoscopic Cholecystectomy-Can we make it both Greener and cheaper?" British Journal of Surgery **109**(Supplement 9): ix19-ix20.	Abstract
Griffing, E. and M. Overcash (2023). "Reusable and Disposable Incontinence Underpads: Environmental Footprints as a Route for Decision Making to Decarbonize Health Care." Journal of Nursing Care Quality **38**(3): 278-285.	Specialty
Grimmond, T. and S. Reiner (2012). "Impact on carbon footprint: A life cycle assessment of disposable versus reusable sharps containers in a large US hospital." Waste Management and Research **30**(6): 639-642.	Specialty
Grimmond, T. R., et al. (2021). "Before/after intervention study to determine impact on life-cycle carbon footprint of converting from single-use to reusable sharps containers in 40 UK NHS trusts." Bmj Open **11**(9).	Specialty
Hainc, N., et al. (2020). ""Green Fingerprint" Project: Evaluation of the Power Consumption of Reporting Stations in a Radiology Department." Academic Radiology **27**(11): 1594-1600.	CE data NR
Hernandez-de-Anda, M. T., et al. (2023). "Environmental impacts of a Mexican haemodialysis unit through LCA." Journal of Cleaner Production **384**.	Study design

Hicks, A. L., et al. (2016). "Environmental impacts of reusable nanoscale silver-coated hospital gowns compared to single-use, disposable gowns." Environmental Science-Nano **3**(5): 1124-1132.	Specialty
Hogan, D., et al. (2022). "The carbon footprint of single-use flexible cystoscopes compared to reusable cystoscopes." European Urology Open Science **39**(Supplement 1): S89.	Abstract
Hong, Z., et al. (2022). "One step forward to sustainability: The carbon footprint of cataract surgery in Australia." Clinical & experimental ophthalmology.	Study design
Hong, Z., et al. (2023). "One step forward to sustainability: The carbon footprint of cataract surgery in Australia." Clinical and Experimental Ophthalmology **51**(2): 180-182.	Study design
Hu, X., et al. (2021). "The carbon footprint of general anaesthetics: A case study in the UK." Resources, Conservation & Recycling **167**: N.PAG-N.PAG.	Specialty
Hubert, J., et al. (2022). "Carbon emissions during elective coronary artery bypass surgery, a single center experience." Journal of Clinical Anesthesia **80**: 110850.	Study design
Hunt, F. J. N. and A. Wilkinson (2021). "Carbon footprint analysis of the salford lung Study (asthma): A susqi analysis." Thorax **76**(SUPPL 1): A190.	Abstract
Ito, Y., et al. (2021). "Environmental impact of anaesthetic gases at a tertiary hospital: a comparison of subspecialties and analysis of anaesthetic choices." Anaesthesia **76**: 103-103.	Abstract
Jain, M. and V. Agrawal (2023). "Making endoscopy practice environmentally sustainable-Early experience from Central India." Indian Journal of Gastroenterology.	Study design
Jamal, H., et al. (2021). "Non-sterile examination gloves and sterile surgical gloves: which are more sustainable?" Journal of Hospital Infection **118**: 87-95.	Specialty
Janson, C., et al. (2022). "The carbon footprint of respiratory treatments in Europe and Canada: an observational study from the CARBON programme." European Respiratory Journal **60**(2): 2102760.	Intervention
Jemai, J. and B. Sarkar (2019). "Optimum Design of a Transportation Scheme for Healthcare Supply Chain Management: The Effect of Energy Consumption." Energies **12**(14).	Specialty
Jemai, J., et al. (2020). "Environmental effect for a complex green supply-chain management to control waste: A sustainable approach." Journal of Cleaner Production **277**.	CE data NR
Khan, B. A., et al. (2019). "Greenhouse gas emission from small clinics solid waste management scenarios in an urban area of an under developing country: A life cycle perspective." Journal of the Air & Waste Management Association (Taylor & Francis Ltd) **69**(7): 823-833.	Specialty
Khatkar, H., et al. (2022). "The environmental impact of orthopaedic surgery: assessing strategies for change." British journal of hospital medicine (London, England : 2005) **83**(11): 1-4.	Study design
Kim, S. and F. Roodt (2023). "Almost 30% reduction in carbon footprint using volatile anaesthesia - a quality improvement project introducing low-flow anaesthesia in a regional hospital." Southern African Journal of Anaesthesia and Analgesia **29**(1): S4-S5.	Abstract
King, J., et al. (2022). "Towards NHS Zero: greener gastroenterology and the impact of virtual clinics on carbon emissions and patient outcomes. A multisite, observational, cross-sectional study." Frontline Gastroenterology.	Duplicate
Kokare, S., et al. (2022). "A comparative life cycle assessment of stretchable and rigid electronics: a case study of cardiac monitoring devices." International Journal of Environmental Science & Technology (IJEST) **19**(4): 3087-3102.	Specialty
Koo, K., et al. (2021). "The cost of convenience: Estimating the environmental impact of single-use and reusable flexible cystoscopes." Journal of Urology **206**(SUPPL 3): e683-e684.	Abstract
Kuvadia, M., et al. (2020). "'Green-gional' anesthesia: The non-polluting benefits of regional anesthesia to decrease greenhouse gases and attenuate climate change." Regional Anesthesia and Pain Medicine **45**(9): 744-745.	Study design
Kwakman, J. A., et al. (2022). "Single-use duodenoscopes compared with reusable duodenoscopes in patients carrying multidrug-resistant microorganisms: A break-even cost analysis." Endoscopy International Open **11**(6): E571-E580.	CE data NR
Lalman, C., et al. (2023). "To Dispose or to Reuse? Analyzing the Life Cycle Impacts and Costs of Disposal, Sterilization, and Reuse of Electrophysiological Catheters." Sustainability **15**(6).	Specialty

Lee, S. M. and D. Lee (2022). "Developing Green Healthcare Activities in the Total Quality Management Framework." International Journal of Environmental Research and Public Health **19**(11).	CE data NR
Lehtimaki, L., et al. (2020). "Minimising the environmental impact of inhaled therapies." European Respiratory Journal **318**(6): 2000721.	Study design
Lichter, K. E., et al. (2022). "Transitioning to Environmentally Sustainable, Climate-Smart Radiation Oncology Care." International Journal of Radiation Oncology Biology Physics **113**(5): 915-924.	Study design
Lippert, J. F., et al. (2014). "A Pilot Study to Determine Medical Laser Generated Air Contaminant Emission Rates for a Simulated Surgical Procedure." Journal of Occupational and Environmental Hygiene **11**(6): D69-D76.	Specialty
Lodi, C. A., et al. (2020). "The environmental impact of disposables in a new configuration of hemodialysis (HD) system." Nephrology Dialysis Transplantation **35**(SUPPL 3): iii1419.	CE data NR
Luo, H. Y., et al. (2021). "An ACO-based heuristic approach for a route and speed optimization problem in home health care with synchronized visits and carbon emissions." Soft Computing **25**(23): 14673-14696.	Specialty
MacNeill, A. J., et al. (2017). "The impact of surgery on global climate: a carbon footprinting study of operating theatres in three health systems." Lancet Planetary Health **1**(9): E381-E388.	Specialty
Mak, K., et al. (2023). "Reducing the use of ethyl chloride spray in obstetrics with a cool new idea: a quality improvement project." International Journal of Obstetric Anesthesia **54**(Supplement 1): 103729.	Abstract
Maria, M. S., et al. (2022). "Health care in rural areas: proposal of a new telemedicine program assisted from the reference health centers, for a sustainable digitization and its contribution to the carbon footprint reduction." Heliyon **8**(7).	Specialty
Marwick, T. H. and J. Buonocore (2011). "Environmental impact of cardiac imaging tests for the diagnosis of coronary artery disease." Heart **97**(14): 1128-1131.	CE data NR
Materazzo, M., et al. (2022). "MAINTAINING GOOD PRACTICE IN BREAST CANCER MANAGEMENT AND REDUCING THE CARBON FOOTPRINT OF CARE: STUDY PROTOCOL AND PRELIMINARY RESULTS." World Cancer Research Journal **9**.	CE data NR
McAlister, S., et al. (2023). "Carbon emissions and hospital pathology stewardship: a retrospective cohort analysis." Internal Medicine Journal **53**(4): 584-589.	Specialty
McCarthy, C. J., et al. (2014). ""EcoRadiology"-Pulling the plug on wasted energy in the radiology department." Academic Radiology **21**(12): 1563-1566.	Duplicate
McGain, F., et al. (2012). "A Life Cycle Assessment of Reusable and Single-Use Central Venous Catheter Insertion Kits." Anesthesia and Analgesia **114**(5): 1073-1080.	Specialty
McGain, F., et al. (2016). "Hospital steam sterilizer usage: could we switch off to save electricity and water?" Journal of Health Services Research & Policy **21**(3): 166-171.	Specialty
McGain, F., et al. (2017). "Financial and environmental costs of reusable and single-use anaesthetic equipment." British Journal of Anaesthesia **118**(6): 862-869.	Specialty
McPherson, B., et al. (2019). "The impact on life cycle carbon footprint of converting from disposable to reusable sharps containers in a large US hospital geographically distant from manufacturing and processing facilities." Peerj **7**.	Specialty
Meierling, S. (2023). "A race we must win: reuse of disposable products in the operating theater The example of a nearly failed recycling concept." Chirurgie **94**(3): 216-219.	Language
Michard, F., et al. (2023). "Pulse contour techniques for perioperative hemodynamic monitoring: A nationwide carbon footprint and cost estimation." Anaesthesia Critical Care and Pain Medicine **42**(5): 101239.	Specialty
Moses, R., et al. (2016). "Reducing the carbon footprint in a regional long term ventilation service with the use of remote monitoring." Thorax **71**(Supplement 3): A187.	Abstract
Moses, R., et al. (2019). "Reducing the carbon footprint in a regional long term ventilation service with the use of remote monitoring." Physiotherapy (United Kingdom) **105**(Supplement 1): e209-e210.	Abstract
Moussa, G., et al. (2022). "Environmental Effect of Fluorinated Gases in Vitreoretinal Surgery: A Multicenter Study of 4,877 Patients." American Journal of Ophthalmology **235**: 271-279.	Duplicate

Moussa, G., et al. (2023). "The use of fluorinated gases and quantification of carbon emission for common vitreoretinal procedures." Eye (Basingstoke) **37**(7): 1405-1409.	Duplicate
Mushtaq, M. H., et al. (2022). "Environmental Performance of Alternative Hospital Waste Management Strategies Using Life Cycle Assessment (LCA) Approach." Sustainability **14**(22).	Specialty
Nagai, K. and N. Itsubo (2022). "Environmental Impact of Care for End-stage Kidney Disease on the Earth and Humans." JMA journal **5**(1): 109-113.	Intervention
Nagasaki, K., et al. (2023). "The environmental impact of inhaler replacement: A carbon footprint and economic calculation of the National Database of Health Insurance Claims in Japan." Journal of General and Family Medicine.	Intervention
Nair, S. and J. Gautier (2019). "Home hemodialysis (HHD) with low dialysate volume (LDV)-the green benefits." Nephrology Dialysis Transplantation **34**(Supplement 1): a587.	Abstract
Nair, S. and J. gautier (2019). "MON-112 Home Haemodialysis (HHD) with low dialysate volume (LDV) - The green benefit." Kidney International Reports **4**(7 Supplement): S350.	Abstract
Namburar, S., et al. (2022). "Estimating the environmental impact of disposable endoscopic equipment and endoscopes." Gut **71**(7): 1326-1331.	CE data NR
Neves, J. A. C., et al. (2022). "Green Endoscopy to reduce CO2e generated by endoscopic waste-The GECO2e interventional study." British Journal of Surgery **109**(Supplement 5): v3.	Abstract
Nuijts, R. M. M. A., et al. (2022). "The carbon footprint of cataract surgery in a Dutch University hospital." Acta Ophthalmologica **100**(Supplement 268): 38.	Abstract
Olmos, M., et al. (2023). "Evaluating the potential impact of spinal anesthesia use in lumbar surgery on global healthcare cost and climate change." Brain and Spine **3**: 101754.	Intervention
Park, E. A. and K. C. LaMattina (2020). "Economic and Environmental Impact of Single-use Plastics at a Large Ophthalmology Outpatient Service." Journal of glaucoma.	Intervention
Perez Diaz, P., et al. (2021). "Carbon footprint as a marker of environmental impact in patients included in a remote monitoring pacemaker programme." European Heart Journal **42**(SUPPL 1): 409.	Abstract
Pernigotti, D., et al. (2021). "Reducing carbon footprint of inhalers: Analysis of climate and clinical implications of different scenarios in five European countries." BMJ Open Respiratory Research **8**(1): e001071.	Specialty
Plusa, T. and A. M. Badowska-Kozakiewicz (2020). "Carbon footprint of inhalers in COPD therapy in 2018 and 2019 in Poland in response to the Kigali amendment." Polski merkuriusz lekarski : organ Polskiego Towarzystwa Lekarskiego **48**(288): 391-393.	Specialty
Pollard, A. S., et al. (2014). "The carbon footprint of acute care: How energy intensive is critical care?" Public Health **128**(9): 771-776.	Intervention
Power, B., et al. (2021). "Analyzing the Carbon Footprint of an Intravitreal Injection." Journal of ophthalmic & vision research **16**(3): 367-376.	Study design
Raila, E. M. and D. O. Anderson (2017). "Black carbon emission reduction strategies in healthcare industry for effective global climate change management." Waste Management & Research: The Journal for a Sustainable Circular Economy **35**(4): 416-425.	Specialty
Ramani, S. (2022). "A Comparison Study Quantifying Environmental Impact of All Surgical Modalities of Hysterectomies." Journal of Minimally Invasive Gynecology **29**(11 Supplement): S12.	Abstract
Renton, D., et al. (2018). "Reprocessed single-use devices in laparoscopy: assessment of cost, environmental impact, and patient safety." Surgical Endoscopy **32**(10): 4310-4313.	Study design
Reynolds, R., et al. (2019). "The carbon footprint of fluorescein angiography compared to OCT angiography." Investigative Ophthalmology and Visual Science **60**(9).	Abstract
Ribes-Iborra, J., et al. (2022). "Improving perioperative management of surgical sets for trauma surgeries: the 4S approach." BMC health services research **22**(1): 1298.	CE data NR
Rizan, C., et al. (2021). "The carbon footprint of waste streams in a UK hospital." Journal of Cleaner Production **286**.	Specialty
Rizan, C., et al. (2022). "Life cycle assessment and life cycle cost of repairing surgical scissors." International Journal of Life Cycle Assessment **27**(6): 780-795.	Specialty
Rizan, C., et al. (2022). "Minimising carbon and financial costs of steam sterilisation and packaging of reusable surgical instruments." British Journal of Surgery **109**(2): 200-210.	Specialty

Robert, B., et al. (2019). "Plastic waste reduction in different peritoneal dialysis strategies: The impact of disposable choice on carbon footprint." Nephrology Dialysis Transplantation **34**(Supplement 1): a237.	Abstract
Rochon, M., et al. (2023). "Image-based digital post-discharge surveillance in England: measuring patient enrolment, engagement, clinician response times, surgical site infection, and carbon footprint." Journal of Hospital Infection **133**: 15-22.	CE data NR
Roy, W., et al. (2023). "Tele-visits for GERD: "Ecofriendly, efficient and effective"." Journal of Gastroenterology and Hepatology (Australia) **38**(6): 905-909.	CE data NR
Saitch, H., et al. (2022). "A comparison of the sustainable value of single-use direct laryngoscopes versus re-usable videolaryngoscopes." British Journal of Anaesthesia **128**(5): e331.	Abstract
Schleser, A., et al. (2016). "The impact of disposables towards more eco-friendly and less costly haemodialysis." Nephrology Dialysis Transplantation **31**(SUPPL. 1): i494.	Abstract
Sellars, H., et al. (2020). "Video consultation for new colorectal patients." Colorectal disease : the official journal of the Association of Coloproctology of Great Britain and Ireland **22**(9): 1015-1021.	Specialty
Serra, C. M., et al. (2022). "Impact on the reduction of CO2 emissions due to the use of telemedicine." Scientific Reports **12**(1).	Specialty
Sharma, S., et al. (2022). "Environmental Impact of Ambulatory Telehealth Use by a Statewide University Health System During COVID-19." Telemedicine and E-Health.	Specialty
Simpson, I. and V. Bhandari (2022). "CONSIDERING THE SUSTAINABILITY IMPACT OF CONNECTED INHALERS IN THE TREATMENT OF ASTHMA." ONdrugDelivery **2022**(139): 42-48.	Study design
Smith, A. J. B., et al. (2013). "The carbon footprint of behavioural support services for smoking cessation." Tobacco Control **22**(5): 302-307.	Intervention
Snigdha, et al. (2023). "Environmental footprints of disposable and reusable personal protective equipment-a product life cycle approach for body coveralls." Journal of Cleaner Production **394**.	Specialty
Somner, J. E. A., et al. (2008). "Surgical scrubbing: can we clean up our carbon footprints by washing our hands?" Journal of Hospital Infection **70**(3): 212-215.	Specialty
Southorn, T., et al. (2013). "Reducing the carbon footprint of the operating theatre: a multicentre quality improvement report." Journal of perioperative practice **23**(6): 144-146.	CE data NR
Sullivan, G. A., et al. (2023). "Operating Room Recycling: Opportunities to Reduce Carbon Emissions Without Increases in Cost." Journal of Pediatric Surgery.	Specialty
Tan, E. and T. Jennings (2015). "Impact of virtual clinics and tele-health medicine in rural nephrology, New Zealand: A Waikato perspective." Nephrology **20**(SUPPL. 3): 62.	Abstract
Thiel, C. L., et al. (2016). "Environmental life cycle assessment and costs of phacoemulsification at aravind eye hospital in pondicherry, India." Investigative Ophthalmology and Visual Science **57**(12): 5575.	Abstract
Thiel, C. L., et al. (2017). "Cataract surgery and environmental sustainability: Waste and lifecycle assessment of phacoemulsification at a private healthcare facility." Journal of Cataract and Refractive Surgery **43**(11): 1391-1398.	Study design
Thiel, C. L., et al. (2020). "Resource use and carbon footprint of inpatient stays in a us hospital." Journal of General Internal Medicine **35**(SUPPL 1): S258.	Abstract
Tsang, D., et al. (2022). "Evaluating and reducing carbon footprint in urological surgery." Journal of Clinical Urology **15**(1 Supplement): 51-52.	Abstract
Unger, S. and A. Landis (2016). "Assessing the environmental, human health, and economic impacts of reprocessed medical devices in a Phoenix hospital's supply chain." Journal of Cleaner Production **112**: 1995-2003.	Specialty
Unger, S. R., et al. (2017). "Do single-use medical devices containing biopolymers reduce the environmental impacts of surgical procedures compared with their plastic equivalents?" Journal of Health Services Research and Policy **22**(4): 218-225.	CE data NR
Usmani, O. S. and M. L. Levy (2023). "Effective respiratory management of asthma and COPD and the environmental impacts of inhalers." npj Primary Care Respiratory Medicine **33**(1): 24.	Study design

Vali, M., et al. (2022). "Care process optimization in a cardiovascular hospital: an integration of simulation-optimization and data mining." Annals of Operations Research **318**(1): 685-712.	CE data NR
Van Leeuwen, R., et al. (2020). "Reducing waste and carbon footprint of intravitreal injections." Acta Ophthalmologica **98**(SUPPL 264): 41-42.	Abstract
Vidal-Alaball, J., et al. (2019). "Impact of a Telemedicine Program on the Reduction in the Emission of Atmospheric Pollutants and Journeys by Road." International Journal of Environmental Research and Public Health **16**(22).	Specialty
Vozzola, E., et al. (2018). "Environmental considerations in the selection of isolation gowns: A life cycle assessment of reusable and disposable alternatives." American Journal of Infection Control **46**(8): 881-886.	Specialty
Vozzola, E., et al. (2020). "An Environmental Analysis of Reusable and Disposable Surgical Gowns." Aorn Journal **111**(3): 315-325.	Specialty
Wang, A. Y., et al. (2022). "Assessing the Environmental Carbon Footprint of Spinal versus General Anesthesia in Single-Level Transforaminal Lumbar Interbody Fusions." World Neurosurgery **163**: e199-e206.	Specialty
Wang, E. Y., et al. (2021). "Environmental emissions reduction of a preoperative evaluation center utilizing telehealth screening and standardized preoperative testing guidelines." Resources, Conservation and Recycling **171**: 105652.	Specialty
Wanigasooriya, K., et al. (2022). "Index telephone two-week wait lower gastrointestinal clinics as a substitute to face to face outpatient appointments during the COVID-19 pandemic." Colorectal Disease **24**(SUPPL 1): 167.	Abstract
Wilkinson, A. J. K., et al. (2019). "Costs of switching to low global warming potential inhalers. An economic and carbon footprint analysis of NHS prescription data in England." Bmj Open **9**(10): e028763.	Specialty
Williams, L. M., et al. (2023). "Circular External Fixator Removal in the Outpatient Clinic Using Regional Anaesthesia: A Pilot Study of a Novel Approach." Strategies in Trauma and Limb Reconstruction **18**(1): 7-11.	CE data NR
Wood, K. F., et al. (2020). "Patient accessibility, cost savings and environmental impact of providing specialist diabetes support by telemedicine clinic in a remote and rural setting." Diabetic Medicine **37**(SUPPL 1): 168-169.	Abstract
Woodcock, A., et al. (2022). "Effects of switching from a metered dose inhaler to a dry powder inhaler on climate emissions and asthma control: Post-hoc analysis." Thorax: thoraxjnl-2021-218088.	Study design
Woods, D., et al. (2013). "Comparison of the environmental impact of commonly used surgical approaches to hysterectomy." Gynecologic Oncology **130**(1): e143.	Abstract
Wormer, B. A., et al. (2013). "The Green Operating Room: Simple Changes to Reduce Cost and Our Carbon Footprint." American Surgeon **79**(7): 666-671.	Specialty
Wyssusek, K., et al. (2022). "Greenhouse gas reduction in anaesthesia practice: a departmental environmental strategy." Bmj Open Quality **11**(3).	Specialty
Yong, K. K., et al. (2023). "Rationalising the use of specimen pots following colorectal polypectomy: A small step towards greener endoscopy." Frontline Gastroenterology **14**(4): 295-299.	Duplicate
Zhang, X., et al. (2022). "Carbon footprinting for hospital care pathways based on routine diagnosis-related group (DRG) accounting data in Germany: An application to acute decompensated heart failure." Journal of Industrial Ecology **26**(4): 1528-1542.	Intervention
Zhao, X., et al. (2022). "How sustainable are the biodegradable medical gowns via environmental and social life cycle assessment?" Journal of Cleaner Production **380**.	Specialty
Ziya-Gorabi, F., et al. (2022). "A new fuzzy tri-objective model for a home health care problem with green ambulance routing and congestion under uncertainty." Expert Systems with Applications **201**.	Specialty

CE=Carbon Emission, NR=Not Reported

Forwards citation chasing searches

Reference	**Reason for exclusion**
Bargallo-Rocha, J. E., et al. (2017). "The impact of the use of intraoperative radiotherapy on costs, travel time and distance for women with breast cancer in the Mexico City Metropolitan Area." Journal of Surgical Oncology **116**(6): 683-689.	CE data NR
Beige, J., et al. (2023). "Green dialysis Effects of sustainable techniques on the real carbon footprint." Nephrologie.	Language
Bhanvadia, R. R., et al. (2022). "Safety and Feasibility of Telehealth Only Preoperative Evaluation Before Minimally Invasive Robotic Urologic Surgery." Journal of Endourology **36**(8): 1070-1076.	CE data NR
Bickhardt, J., et al. (2022). "Reduction of greenhouse gas emissions by inhaler choice in the therapy of asthma and COPD patients." Pneumologie **76**(05): 321-329.	Language
Bonsall, A. (2021). "Unleashing carbon emissions savings with regular teledermatology clinics." Clinical and Experimental Dermatology **46**(3): 574-575.	Abstract
Bringier, R., et al. (2023). "An integrated environmental, economic, and clinician satisfaction comparison between single-use and reusable flexible bronchoscopes for tracheal intubation." British Journal of Anaesthesia **131**(1): E4-E7.	SD
Burns, C. L., et al. (2017). "Cost analysis of a speech pathology synchronous telepractice service for patients with head and neck cancer." Head and Neck-Journal for the Sciences and Specialties of the Head and Neck **39**(12): 2470-2480.	CE data NR
Checcucci, E., et al. (2021). "Implementing telemedicine for the management of benign urologic conditions: a single centre experience in Italy." World Journal of Urology **39**(8): 3109-3115.	CE data NR
Dohmen, J., et al. (2023). "Recycling of Disposable Surgical Instruments - Is It Worth It?" Zentralblatt Fur Chirurgie **148**(04): 329-336.	Language
Farooq, F., et al. (2022). "Telehealth Service Utilization for Gynae & Obstetrics During COVID-19 Pandemic in Lahore, Pakistan." Annals of King Edward Medical University Lahore Pakistan **28**(3): 335-342	CE data NR
George, K., et al. (2022). "Utility and patient acceptance of telemedicine in nephrology." Journal of Nephrology **35**(9): 2325-2331.	CE data NR
Haripriya, A., et al. (2023). "Changing operating room practices: the effect on postoperative endophthalmitis rates following cataract surgery." British Journal of Ophthalmology **107**(6): 780-785.	CE data NR
Hlavin, C., et al. (2023). "Clinical Outcomes and Hospital Utilization Among Patients Undergoing Bariatric Surgery With Telemedicine Preoperative Care." Jama Network Open **6**(2): 11.	CE data NR
Hogan, D. and D. B. Hennessey (2023). "Re: The Carbon Footprint of Single-Use Flexible Cystoscopes Compared with Reusable Cystoscopes-Letter by Rizan et al (2022): Clarification of Methods Due to Apparent Misinterpretation." Journal of Endourology: 2.	SD
Lambooy, S., et al. (2021). "Telemedicine for Outpatient Care of Kidney Transplant and CKD Patients." Kidney International Reports **6**(5): 1265-1272.	CE data NR
Lee, A. W. L., et al. (2021). "Life cycle assessment of single-use surgical and embedded filtration layer (EFL) reusable face mask." Resources Conservation and Recycling **170**: 12.	Speciality
Liang, S. Y., et al. (2022). "The effect of COVID-19 on telehealth: Next steps in a post-pandemic life." International Journal of Gynecology & Obstetrics **159**(3): 996-997.	CE data NR
Margolin, E. J., et al. (2021). "Telemedicine in management of genitourinary malignancies: Patient and physician perspectives." Urologic Oncology-Seminars and Original Investigations **39**(8): 480-486.	CE data NR

Maria, M. S., et al. (2022). "Health care in rural areas: proposal of a new telemedicine program assisted from the reference health centers, for a sustainable digitization and its contribution to the carbon footprint reduction." Heliyon **8**(7): 6.	Speciality
Masino, C., et al. (2010). "The Impact of Telemedicine on Greenhouse Gas Emissions at an Academic Health Science Center in Canada." Telemedicine Journal and E-Health **16**(9): 273-276.	Speciality
McAlarnen, L. A., et al. (2021). "Virtual visits among gynecologic oncology patients during the COVID-19 pandemic are accessible across the social vulnerability spectrum." Gynecologic Oncology **162**(1): 4-11.	CE data NR
Meiklejohn, D. A. and V. M. Chavarri (2021). "Cold Technique in Adult Tonsillectomy Reduces Waste and Cost." Ent-Ear Nose & Throat Journal **100**(5_SUPPL): 427S-430S.	CE data NR
Meissner, M., et al. (2023). "Evaluating the Environmental Impact of Single-Use and Multi-Use Surgical Staplers with Staple Line Buttressing in Laparoscopic Bariatric Surgery." Risk Management and Healthcare Policy **16**: 1423-1433.	CE data NR
Mojdehbakhsh, R. P., et al. (2022). "The long game: Telemedicine patient satisfaction metrics and methods of recurrence detection for gynecologic cancer patients throughout the initial year of the COVID-19 pandemic." Gynecologic Oncology Reports **42**: 5.	CE data NR
Morris, M. I. R. and A. Hicks (2022). "Life cycle assessment of stainless-steel reusable speculums versus disposable acrylic speculums in a university clinic setting: a case study." Environmental Research Communications **4**(2): 13.	Speciality
Nardelli, L., et al. (2023). "Incremental peritoneal dialysis allows to reduce the time spent for dialysis, glucose exposure, economic cost, plastic waste and water consumption." Journal of Nephrology **36**(2): 263-273.	CE data NR
Ong, C. S. H., et al. (2021). "Implementation of a Ureteric Colic Telemedicine Service: A Mixed Methods Quality Improvement Study." Urology **147**: 14-20.	CE data NR
O'Reilly, D., et al. (2021). "Virtual oncology clinics during the COVID-19 pandemic." Irish Journal of Medical Science **190**(4): 1295-1301.	CE data NR
Patel, S., et al. (2021). "Climate Change Impact of Virtual Urology Meetings." European Urology **80**(1): 121-122.	Abstract
Pollard, A. S., et al. (2013). "Mainstreaming Carbon Management in Healthcare Systems: A Bottom-Up Modeling Approach." Environmental Science & Technology **47**(2): 678-686.	Speciality
Pradhan, R., et al. (2021). "Virtual phone clinics in orthopaedics: evaluation of clinical application and sustainability." Bmj Open Quality **10**(4): 7.	CE data NR
Quam, N., et al. (2022). "Perception of Telehealth During the COVID-19 Pandemic Among Survivors of Gynecologic Cancer." Oncologist **27**(6): 512-515.	CE data NR
Rajeev, A., et al. (2023). "Patient Outcomes of Virtual Foot and Ankle Telephone Clinics During COVID-19 Pandemic: 1 Year Experience." Journal of Foot & Ankle Surgery **62**(3): 571-575.	CE data NR
Ramdas, Y., et al. (2020). "First Intraoperative Radiation Therapy Center in Africa: First 2 Years in Operation, Including COVID-19 Experiences." Jco Global Oncology **6**: 1696-1703.	CE data NR
Richter, H., et al. (2020). "The carbon footprint of anaesthesia How the choice of volatile anaesthetic affects the CO2 emissions of a department of anaesthesiology." Anasthesiologie & Intensivmedizin **61**: 154-161.	Speciality
Shiff, B., et al. (2021). "Patient Satisfaction With Telemedicine Appointments in an Academic Andrology-focused Urology Practice During the COVID-19 Pandemic." Urology **153**: 35-41.	CE data NR

van der Pol, M. and L. McKenzie (2010). "Costs and benefits of tele-endoscopy clinics in a remote location." Journal of Telemedicine and Telecare **16**(2): 89-94.	CE data NR
Yadav, N. and A. Tanksale (2023). "A multi-objective approach for reducing Patient's inconvenience in a generalized home healthcare delivery setup." Expert Systems with Applications **219**.	CE data NR
Zhou, J., et al. (2021). "A novel two-phase approach for the bi-objective simultaneous delivery and pickup problem with fuzzy pickup demands." International Journal of Production Economics **234**.	Speciality

Appendix E: Description of interventions evaluated by LCA studies

Specialty	Study: Setting	Intervention/ Comparator	Intervention aim	Intervention/Comparator description
Product level: Reuseable equipment				
Urology	Baboudijian 2023: NR(83)	C1 Disposable cystoscope, C2 aS4C reusable cystoscope	NR	***C1*** Disposable cystoscope: Ambu (Ballerup, Denmark), ***C2*** aS4C reusable cystoscope (aScope)
	Davis 2018: Austin Hospital, Melbourne(96)	C1 Single use flexible ureteroscope, C2 Reusable flexible ureteroscope	NR	***C1*** Single use flexible ureteroscope (LithoVue, Boston Scientific), ***C2*** Reusable flexible ureteroscope (Olympus Flexible Video scope or URV-F)
	Hogan 2022: NR(107)	C1 Single use FLEXIBLE cystoscope, C2 Reuseable flexible Cystoscope	For cystoscopy	***C1*** Ambu aScope 3 Cysto. Packaged into punch, inner box, and outer box and sterilized in bulk using ethylene oxide according to EN ISO 11135 and EN 551-1. ***C2*** Olympus SD Flexible Cysto-Nephro videoscope (CYF-VA2). Sterilized between each use, starting with preclean immediately after cystoscopy, then sterilisation in an EndoThermo Disenfectors endoscopic reprocessing machine. They are then repacked in a vacuum sealed plastic container to allow storage for 72hrs. Average lifespan: 7 years
	Kemble 2023: Urology(67)	C1 Single-use flexible cystoscope, C2 Reuseable cystoscopes	Lower initial acquisition costs, no reprocessing, and greater portability	A SU flexible cystoscope was recently introduced with the proposed advantages of lower initial acquisition costs, no reprocessing, and greater portability to enable use in diverse and resource-limited clinical settings. While SU cystoscopes may have reduced initial costs compared to the purchase of a fleet of reusable devices, there are conflicting reports as to whether exclusive use of SU cystoscopes is cost-saving in the long term. Purported economic benefits aside, other non-economic aspects of SU cystoscopes relevant to urology practices are not well characterized
	Wombwell 2023: Urology department(98)	C1 Single use flexible cystoscope: Ambu® aScope™ 4 Cysto System	Reduce environmental impact	Flexible cystoscopy is a commonly used procedure in urological practice to endoscopically assess the urethra and bladder for a multitude of conditions. Single-use cystoscopes also overcome issues of the infrastructure required for re-processing and sterilising scopes as they are sterile and portable
Gastroenterology	Boberg 2022: Skåne University Hospital, Lund(103)	C1 Mix of reusable and single use-trocars, C2 single use trocars]	NR	Trocars for laparoscopic cholecystectomies ***C1***-one system was a mix of reusable and single-use trocars (Helsingborg Hospital. The mixed system used a single-use trocar 5–12 mm, a reusable trocar 10 mm, and a reusable trocar 5 mm. ***C2*** - one system consisted only of single-use trocars
	Le 2022:NR(68)	Duodenoscope C1 Single use, C2 Reusable with disposable endcaps, C3 conventional reusable	Compare the environmental and human health burden of SDs and RDs	Duodenoscopes ***C1 -*** Boston Scientific Exalt Model D, ***C2*** - An RD with disposable endcaps (TJF-Q190V; Olympus). ***C3 -*** A conventional RD (Olympus TJF-Q180V).
	Rizan 2022: Operating room(59)	Laparoscopic cholecystectomy [C1 hybrid instruments, C2 disposable instruments]	Reduce environmental impact	We included in our analysis three types of instrument routinely used in laparoscopic cholecystectomy: laparoscopic clip appliers, laparoscopic scissors, and ports (small diameter 5 mm ports, and large diameter 10–11 mm ports). These instruments have both disposable and hybrid versions available on the market

Specialty	Study: Setting	Intervention/ Comparator	Intervention aim	Intervention/Comparator description
	Sherman 2019: Yale New Haven Hospital(73)	Laryngoscopy [C1 reuseable equipment, C2 disposable equipment]	Reduce environmental impact and costs	NR
Orthopaedics and Trauma	Leiden 2020; Germany(92)	C1 Disposable surgery instrument set, C2 Reuseable instrument set	Compares environmental impact of a reusable and a disposable spinal fusion instruments set	***C1***, the Neo Pedicle Screw System from Neo Medical SA is used. It consists of one package with few instruments, one package with two rods and two packages with each two screws, nuts, screw extenders, and screw drivers. All parts of this single-use set are applied for a one level lumbar fusion surgery. The total weight is 2.0 kg per set. After manufacturing and packaging, the set is 60Co gamma-sterilized, transported to the central distribution point Frankfurt and delivered to the hospitals. Here the whole set is used once for a one level lumbar fusion surgery. Screws and rods are implanted, packaging and instruments are discarded and incinerated as solid waste. The disposable system is a new development and served in modular packages, which clearly focusses on reducing the number of required instruments for the surgery and therefore allows using less instruments. ***C2***, the Viper 2 surgical instruments and implants set from DePuy Synthes: VIPER®, 2019 used. It encompasses six boxes including eleven trays with several instruments, screws and rods (left side of Fig. 2). Depending on the requirements of the lumbar surgery, only a part of the set is applied. The total weight is 45.5 kg per set. It is used for five years and discarded through a solid waste incineration process at the end of life. It is assumed that the conventional set is used for 60 lumbar fusion surgeries per year. Hence, 300 surgeries can be realized throughout the lifetime of one reusable set
Intensive Care Unit	Sanchez 2020: NR(88)	C1 Reuseable blood pressure cuff; C2 Disposable blood pressure cuff	Reduce environmental and economic impact	Designed to be used by multiple patients, ***C1*** can either be stationary and remain with the monitoring equipment itself (e.g., in the operating room) and is shared among multiple patients each day; or in can be dedicated and remain with a patient (e.g., the critically ill) during their entire health care visit. The reusable BP cuff must be cleaned between patient encounters, and thus whether it is shared or dedicated to a single patient throughout their visit has implications for the number of cleanings it must undergo each day. ***C2*** The disposable cuff is designed to be used by one patient only. It is distributed to them upon admission and remains with them over the duration of stay, even as they move among clinical departments. The disposable cuff is discarded at the end of the entire patient encounter
Cardiology	Schulte 2021: NR(94)	C1 Remanufactured electrophysiology catheter C2 Virgin electrophysiology catheter	Reduce environmental impact	Cardiac reuseable equipment: catheter. The electrophysiological diagnostic catheter is mainly used in cardiac ablations procedures, a procedure to alleviate or eliminate specific cardiac arrhythmia forms
Respiratory	Sorensen 2018: NR(112)	C1 Reuseable bronchoscope, C2	Reduce environmental impact	After cleaning, ***C1*** must be brought from a washer to a dryer/storage cabinet [16] in a clean environment with the operator wearing one set of protective equipment such as an apron, protective shoes, gloves, etc. (see table 1). After using the RBs many times (number of times unknown) they are discarded ***C2*** Single-use bronchoscopes are assumed to be used similarly to the RBs, then discarded afterwards
Product level: Equipment type				

Specialty	Study: Setting	Intervention/ Comparator	Intervention aim	Intervention/Comparator description
Urology	Stripple 2008: NR(105)	C1 TPU catheter, C2 polyolefin-based elastomer catheter, C3 PVC catheter	Reduce environmental impact	***C1*** -TPU is chemically less homogenous and can be considered more as a group of plastics, ***C2 -*** A new polymer material was developed, analysed and implemented in the urinary catheter production process. This new plastic material is principally based on different bulk polyolefins and styrene block copolymer ***C3*** - A urinary catheter is used as a standardized treatment method for intermittent emptying of the bladder, e.g. for patients suffering from urine retention. The product in this study is a single-use hydrophilic catheter used in hospital medical care and for home treatment of patients. The main function of the product, besides the medical treatment, is to offer patients a comfortable therapy, efficient treatment and a safe product. The urinary catheter consists of a catheter tube and a connector that can be connected to a urine collection bag. The tube and the connector are welded together. The physical geometry of the product and the surface structure are of great importance for the product's functionality. The catheters are produced with different diameters (charrie`re 06-24) and different lengths (15, 20, 30 and 40 cm) to fit varying patient requirements. The charrie`re number is three times the outer diameter of the catheter tube, measured in millimetres. The two most common catheter tips are Nelaton and Tiemann....The PVC plastic used is of a plasticized type and the PVC polymer is produced with suspension polymerization. Different plasticizers can be used, but DEHP is the most common and best evaluated plasticizer for PVC and thus assumed in this study
Accessing care				
Hand and plastic surgery	Holmner 2014: Patient's home/ primary health centre(104)	C1 Telehealth, C2 Physical visit	Reduce carbon emissions	***C1 -*** Appointments included follow-ups, interventions, consultations, and assessments of various conditions, such as amputations of one or more fingers, osteoarthritis, flexor tendon injuries, radius fractures, finger fractures, and ligament injuries. Hand/Plastic surgery: 81 appointments conducted in the patient's home using a PC or tablet computer, 157 at the closest primary health centre using standard videoconferencing equipment. Speech unit: patient home or closest primary health centre. ***C2*** - Telemedicine appointments were compared with care-as usual scenarios that require the patient travel to the hospital for a face-to-face visit
Gastroenterology	Sillcox 2023b: NR(75)	C1 Telehealth, C2 F2F	NR	NR
Multiple	Thiel 2023: NR(77)	C1 Telehealth, C2 F2F	Reduce carbon emissions/ increase accessibility	***C1*** - For the virtual visit, the patient connects with a single clinician either by video conferencing or by telephone without video. ***C2*** - For in-person visits, patients must travel to the clinic, where they wait in a waiting area and are then escorted to a private exam room. Prior to their doctor's visit, a nurse will often have the patient complete a digital questionnaire and (additionally, in office), will collect some data on the patient's health, including blood pressure readings, height, and weight, depending on the specialty
Care delivery				
Renal	Connor 2011a: Patient's home/Clinic(43)	Treatment modality - Dialysis regimen	To deliver maintenance hemodialysis (HD),	Modality/Machine type/frequency of treatments/duration of treatments (h): ***C1*** - ICHD Standard 3 d a wk 4, ***C2*** - HHD Standard 4 d a wk 4.5 ***C3*** - HHD Standard 6 d a wk 2, ***C3*** - HHD Standard 5 d a wk 4, ***C4*** - HHD Standard 6 nights a wk 7, ***C5*** - HHD Standard 3 nights a wk 7, ***C6*** - HHD NxStage 5.5 d a wk 3, ***C7*** - HHD NxStage 6 nights a wk 7

Specialty	Study: Setting	Intervention/ Comparator	Intervention aim	Intervention/Comparator description
Urology	Fuschi 2023: Urology clinic(113)	Surgical procedure [C1 Standard v C2 robotic assisted laparoscopy]	To estimate the CO2 consumption/production and evaluate all the instruments used during a standard laparoscopic or robot-assisted radical prostatectomy with or without lymphadenectomy for prostate tumors	A standardized surgical technique was used for both the robot-assisted and laparoscopic approaches, and the procedures were performed by the same team of expert surgeons. The patient was placed in a supine position with abdominoperineal disinfection and sterile placement of an 18-ch Foley catheter Rectal probe was inserted for the hydropneumatic rectal test at the end of procedure. We then proceeded with a supraumbilical incision and the introduction of a Verres needle for the induction of pneumoperitoneum to 12 mmHg with a standard CO2 insufflator with no AirSeal. The patient was then placed in the Trendelemburg position (25°). Two single use trocars (12 mm) and two trocars (5 mm) were used in the laparoscopic approach; four multi-use robotic trocars of 8 mm, one of 12 mm, and one of 5 mm were used in the robotic approach. A disposable single-use aspirator and multiuse forceps were used by the surgeon at the operating table during the robotic procedure. During laparoscopic procedures, a LigaSure vessel sealing system by Medtronic and a second multiuse forceps were also used. A hemostatic section of the lateral prostatic peduncles was made using medium or large hem-o-locks. Closure of the dorsal venous plexus of Santorini was made using a barbed V-Loc 3.0 suture. An endobag was used to remove the surgical specimens. Vesical-urethral anastomosis with the modified Van Velthoven technique was performed with Strata fix 3.0, and a second definitive 18-ch Foley catheter was placed in the bladder at the end of the anastomosis
	Leapman 2023: tertiary care center located in the Northeastern USA(69)	Treatment modality - Diagnosis pathway [C1 bpMRI with targeted and systemic biopsies, C2 mpMRI with targeted biopsy cores only, C3 Systematic biopsy without MRI, C4 mpMRI with systematic biopsy, C5 mpMRI with targeted & systematic biopsies (baseline)]	Reduce low-value clinical care. Reduce environmental pollution	We estimated the environmental impacts associated with reducing the overall number and varying the approach of a prostate biopsy by using MRI as a triage strategy or by omitting MRI. ***C5*** - The prostate biopsy pathway was divided into three process steps, as shown in Figure 1: (1) prebiopsy prostate MRI, (2) a TRUS biopsy in an outpatient clinical setting, and (3) pathologic processing of biopsy specimens in a clinical laboratory. For ***C1*** , we assumed shorter durations of active and standby time as well as the omission of MRI contrast and associated materials. For ***C2***, we explored biopsy sampling strategies including combined systematic and MRI-ultrasound fusion biopsies: targeted biopsy cores only. For ***C3***, we explored biopsy sampling strategies including combined systematic and MRI-ultrasound fusion biopsies, MRI-ultrasound fusion alone, and systematic biopsy alone, systematic biopsy without MRI. For ***C4***, we explored biopsy sampling strategies including combined systematic and MRI-ultrasound fusion biopsies: systematic biopsy with MRI
Ear, Nose and Throat	Meiklejohn 2023: Operating room - University of New Mexico Hospital(70)	Surgical procedure - tonsillectomy, without adenoidectomy or other procedures,	To quantify cost & environmental impact of techniques for Otolaryngology surgery, and identify areas to maximally reduce this impact	***C1*** monopolar electrocautery, ***C2*** coblation, ***C3*** cold excision without cautery
Gynaecology	Thiel 2015: Magee Women's Hospital (Magee) of the University of Pittsburgh Medical Center (UPMC)(76)	Surgical procedure [C1 Abdominal, C2 Vaginal, C3 Laparoscopic, C4 Robotic	Complete hysterectomy	Method to perform hysterectomy

Specialty	Study: Setting	Intervention/ Comparator	Intervention aim	Intervention/Comparator description
Multiple				
Radiology/ Radiotherapy	Chuter 2023: Christie Centre; Mount Vernon Cancer Centre, Guys and St Thomas, South West Wales Cancer Center(42)	Setting, Care delivery radiotherapy [C1- SABR (Stereotactic ablative radiotherapy) protocol, C2 - Before intervention]	Limit footfall and reduce infection risk	***C2*** - For all centres, the prostate dataset consisted of 10 patients treated with 60 Gy in 20 fractions ***C1*** - two patients treated with SABR technique (36.25 Gy in 5 fractions): this reflected the implementation of a SABR protocol used to treat approximately 5% of these patients to limit foot-fall and therefore infection risk during COVID. The COVID breast dataset consisted of 10 breast patients receiving ultra-hypofractionated RT (26 Gy in 5 fractions)
Multiple[a]	Rouviere 2022: 24 OR (among which 4 ambulatory rooms), 3 preoperative rooms, 3 post anaesthesia care units, and SPD(87)	Waste management, anesthesia, surgical equipment, purchasing	Reduce environmental and economic impact	The sustainable actions concerning SMD were implemented in the 24 OR. Waste reduction actions (Specialty: Neurosurgery, digestive, gynecological): custom brain surgery pack, custom coelioscopy pack. Change of anaesthesia face masks to version without plastic hook (Specialty: Anesthesia), Redon drain without premounted needle for robotic urological surgery (Speciality: Urology), change from single use to reusable laryngoscope blades (Speciality: Anesthesia), implementation of a moveable irrigation fluid recovery system for wastewater (Specialty: urological/orthopedic surgery), single pack surgical kits (Specialty: Urology, some general surgeries). Waste sorting actions: recycling aluminum blisters of surgical sutures (All surgical specialties), optimising selective waste sorting in OR, metal waste recycling at SPD, rationalisation of use of triclosan coated surgical sutures (Specialty: all surgical), recycling of ES wires. Eco-responsible purchasing action: creating sustainable development questionnaire for medical device suppliers (Surgical medical devices referenced in hospital database). Training or information on the action was given during its implementation. Thirteen actions were evaluated: seven concerned waste reduction, five concerned waste sorting, and one concerned eco-responsible purchases. Seven actions concerned all the hospital OR, one concerned both OR and SPD, one concerned neurosurgery, one concerned coelioscopic surgery, one concerned urological robotic surgery, and one concerned the urological and orthopedic surgery departments
Gynaecology	Thiel 2018: Operating room - Magee-Womens Hospital University of New Mexico Hospital(78)	Product level - Anasthesia[C1 Desflurane alone, C2 desflurane with N2O, C3 sevoflurane with N2O, C4 sevoflurane alone, C5 propofol only	Reduce carbon emissions	Desflurane is 2500 times more potent than is CO2. N2O, at 310 times the heat-trapping potential of CO2, is used as a carrier gas in conjunction with the use of either sevoflurane or desflurane although it can be safely excluded from surgery.28Sevoflurane, with 130 times the heat-trapping potential of carbon dioxide (CO2) on a 100-year time scale, is environmentally preferable to desflurane Propofol is an injectable anesthetic with limited GHG emissions, with impacts mainly from its production and delivery, and is sometimes used as the primary anesthetic for hysterectomy

Specialty	Study: Setting	Intervention/ Comparator	Intervention aim	Intervention/Comparator description
		Setting - Recycling [C1 Maximize recycling, C2 Maximize regulated medical waste, C3 Reusing cotton OR towels, C4 Switch to reusable linens, C5 Reprocess SUDs where possible, C6 Minimal instruments hysterectomy, C7 minimal materials and maximum reuse]		We identified recycling potential (***C1)*** in the initial study; these include spunbondmeltblown-spunbond plastics (drapes and gowns), hard plastic basins, metals and glass from pharmaceutical vials, and paperboard or paper used in packaging. ***C2*** At the time of the original study, UPMC was sorting most of their surgical waste away from red bag or hazardous waste. At UPMC, non-hazardous, or white bag, waste is sent to a sanitary landfill, and regulated medical waste is autoclaved before landfilling, adding extra treatment and emissions to the end-of-life scenario. We created the maximizing regulated medical waste intervention to determine the effect of this regulated medical waste diversion policy relative to disposing of surgical waste completely via the red bag treatment path. ***C3*** We assumed cotton towels to have a 10-use life span, and we assumed third-party linen laundering to be the sterilization pathway. Although life spans may be shorter or longer, this was the life span hospital staff estimated. Our estimates of energy and detergent use were from the original study. ***C4*** Reusable gowns and laparotomy drapes have an estimated life span of 75 uses and are sterilized between cases with laundering, drying, and autoclaving cycles, per manufacturer recommendations. In our estimates of emissions, we assumed that the sterilization process is conducted in-house (therefore, there are no off-site transportation emissions). ***C5,*** We identified reprocessable SUDs as the surgical instruments UPMC's current third-party reprocessor can accept. These include endoshears (Medtronic, North Haven, CT), Carter-Thomason CloseSure System (Medline, Mundelein, IL), Versa-Port plus v2, 5 to 12 millimeter (Medtronic), LigaSure blunt tip laparoscopic sealer–divider 5 millimeter blunt tip laparoscopic sealer (Medtronic), LigaSure (Medtronic), and LigaSure Vessel Sealing 5 millimeter (Medtronic). We estimated emissions from reprocessing using values from previous literature.2 ***C6*** A panel of 3 practicing gynecologists at UPMC determined a list of the bare essentials of surgery; these include a uterine manipulator, a monopolar shears, a vessel sealer, a grasper, laparoscopic suturing equipment, suture, ports, and an insufflator. We calculated the environmental impacts from these single-use instruments using their purchase prices and the Economic Input Output LCA database.1 We assumed these supplies were single-use disposables (although reusable supplies do exist for some of these items) and that the original disposable custom pack (with single-use surgical supplies for laparoscopic hysterectomy) was still in use. Our gynecologist panel reported using this minimal supply set in at least one third of their laparoscopic cases. **C7** Combination of the following interventions: Bare minimum materials, Reusable linens and towels, Maximized recycling, Reprocessing was not available for items on the bare minimum list
		Setting - Energy consumption [C1 Occupancy sensors installed for off-hours C2 Switch to maximum renewable energy C3 Combo: occupancy sensors and low-carbon energy grid mix]		***C1*** installing occupancy sensors to minimize electricity and energy use during nonoperative or low-use times, Weather conditions, occupancy, equipment and OR size remain unchanged Does not include 20-min room turnover between cases HVAC settings in "energy saving" mode include a 40% reduction in air changes per hour (from 20 to 12) and a 15% reduction in temperature set point (from 20°C to 17°C). These are the lowest-energy operating conditions for the ORs at Magee, and may not be optimal for all HVAC designs25. ***C2*** switching to a low-carbon electricity source. Proposed energy mix (available through PG&E Corp Energy Company) is 2.2% oil, 35.7% nuclear, and 62.1% hydro, with GHGs averaging 0.05 lbs CO2 per kWh26 Total consumed kWh/h remained the same in each hysterectomy. ***C3*** Combination of C1+C2
		Waste management, product level, energy conservation		Optimized: ideal green hysterectomy: Combination: Sevoflurane only+Minimum materials+Maximum reusable materials+Maximum recycling+Occupancy sensors for low-energy ORs in off-hours+ Low-carbon electricity grid mix

Specialty	Study: Setting	Intervention/ Comparator	Intervention aim	Intervention/Comparator description
Setting				
Multiple	de Ridder 2022: Leiden University Medical centre(119)	C1 Multiple C2 Usual care	Reduce carbon footprint of caesarean section procedures	***C2*** - As illustrated in case study: Preparation room: four categories of products enter 1) Instrument tray (contains reusable surgical instruments that are used during the procedure. Originates from the Central Sterile Supply Department within the hospital and is packed in polypropylene blue wrap), 2) Prepack (Custom pack used for every C-section. This is a pre-packed tray with sterile disposable items assembled especially for a specific kind of surgery), 3) Individually wrapped reusable products 4) Individually wrapped disposable products. Individually wrapped disposable and reusable products can be collected separately when requested by the surgeon. Packaging and other waste disposed of in preparation room in 3 waste streams 1) Residual waste (8): incinerated, 2) Paper waste (11): Incinerated - collected separately but treated aws MSW by waste handling company, 3) Plastic foils (3): recycled. Reuseable and disposable products used during surgery enter operating room. The disposables are disposed in 2 waste streams after use: 1) Residual waste (19): incinerated, 2) Regulated medical wase (1) incinerated at different waste incineration plant. ***C1*** - 1) A multidisciplinary team is assembled ensuring diverse expertise and unbiased outcomes. The team leader oversees meetings and guides the process, aiming for 6-10 members for balanced input and effective discussion over 4-6 sessions. 2) The process flowchart is developed to provide a comprehensive understanding of waste generation, identifying sub-steps and waste streams through graphical representation. 3) Hazard analysis quantifies environmental risks associated with waste disposal, utilizing DEFRA greenhouse gas conversion factors and a decision tree to streamline the analysis process. 4) Action and outcome measures focus on sustainable solutions for waste reduction, applying the principles of 'reduce,' 'reuse,' 'recycle,' 'rethink,' 'refuse,' and 'refrain' to mitigate environmental impact and ensure stakeholder safety. 5) Calculations for carbon footprint and sustainability interventions are conducted using a spreadsheet, facilitating data entry and comparison between baseline and revised scenarios
Gastroenterology	López-Muñoz 2023: Hospital (116)	C1 Multiple: Reuseable equipment, recycling C2 No recycling	Evaluate composition & environmental impact of commonly used endoscopy instruments (biopsy forceps, polypectomy snares and haemostatic clips) from four different manufacturers, quantifying the parts that could be recycled	Biopsy forceps, polypectomy snares and haemostatic clips from four different manufacturers (A, B, C and D) were selected: biopsy forceps (A, B and C), polypectomy snares (A, B and D) and haemostatic clips (A and B). All instruments were analysed after the endoscopic procedure, adding a mark on the instruments to identify parts not in contact with the endoscope, outside the working channel, which could be recyclable. Our hypothesis to develop a sustainability intervention is based on one simple proposal: some parts of the instrument may not be considered as BMW. Parts of the instrument body and the handle are not in contact with patient fluids or secretions. Our proposal consists in taking apart the instrument after the procedure (upper from the mark), sending the handle and part of the body to recycle and the rest (in contact with the working channel of the endoscope) to BMW management. An experiment was conducted in our daily practice to mark the proximal part of the instrument body not in contact with the working channel. Marking of the sheath was made during 30 consecutive diagnostic endoscopic procedures to determine this contact mark for gastroscopy and colonoscopy. Mean, median, range and SD of distance from the instrument tip to the marked point of the instrument body were calculated. Although the device has not been inside the endoscope, it would still be in contact with the hands of the endoscopist and the assistant, with multiple passes. To reduce the potential risk contamination, 5cm away from the contact mark with the working channel was considered safe and marked as our recyclable mark or green mark (figure 1). After the procedure, in the same endoscopy room, instruments were cut into pieces with a wire cutter by the endoscopist
Radiology/ Radiotherapy	McAlister 2022: Hospital, Australia(97)	Energy conservation	Support the more appropriate use of imaging	Different imaging modalities: ***C1*** Chest X-Ray, ***C2*** Ultrasound, ***C3*** Mobile chest x-ray scanner was located in the intensive care unit, St George's Hospital, Sydney, ***C4*** Computerised tomography, ***C5*** Magnetic resonance imaging (MRI) at Footscray Hospital in Melbourne, Australia

Specialty	Study: Setting	Intervention/ Comparator	Intervention aim	Intervention/Comparator description
Opthalmology	Winklmair 2023: 3 Austrian hospitals[b] (118)	Waste management [C1 Recycling C2 100% incineration]	Compare material composition and carbon emission	Variability in cataract package composition across 3 Austrian hospitals considered. Compared environmental effect of recycling all technically recyclable materials

[a]All surgical specialties (neurosurgery, otolaryngology, ophthalmology, orthopaedic, plastic, vascular, gynaecology, urology, and digestive surgery) and anesthesia were included in the study to involve all the professionals working in the OR and SPD. [b]Hanusch Krankenhaus Wien, Barmherzige Briider Wien and Privatklinikk Hochrum. bpMRI=biparametric MRI, C=Comparator, DEHP=di(2-ethylhexyl) phthalate, F2F=Face to face, HD=Home Hemodialysis, ICHD=In-centre hemodialysis, mpMRI=multiparameter MRI, MRI=Magnetic Resonance Imaging, OR=Operating room, SD=Standard deviation, SPD=Sterile Processing Department, PVC=Polyvinylchloride, RD=Reuseable duodenoscope, TPU=Thermoplastic polyurethane

Appendix F: Speciality specific findings

Broad intervention: Accessing care

Telemedicine: Non-LCA studies

Six observational studies were conducted within oncology/radiation oncology services.(35, 63, 66, 72, 79, 101) Studies showed the beneficial effects of telemedicine in reducing carbon emissions, however all studies based their carbon emission calculations solely on patient travel saved. Other outcomes categories considered included patient costs saved (n=4),(63, 66, 79, 101) patient time saved (n=3),(63, 66, 101) clinician travel saved (n=1),(35) time from evaluation/referral to treatment (n=1),(63) patient petrol saved (n=1),(72) costs to services (n=1),(35) and environmental costs (n=1).(101) All outcomes favoured the telehealth intervention, with the exception of time from referral to surgery, which favoured face-to-face care in one study.(63) The majority of comparisons between intervention and control groups were calculated using descriptive statistics and narrative techniques, with the exception being the calculation of patients costs within one study.(101) Poor access to, or difficulty using, technology impacted patient satisfaction,(66) with higher rates of telehealth utilisation associated with longer travel times, male gender and higher age.(101) Descriptive statistics in two studies highlight the cost savings for services associated with the telehealth interventions.(53, 56) Only one study statistically compared attendance/cancellation rates between telehealth and face-to-face control groups, demonstrating no significant difference between groups.(56) This study also demonstrated no significant difference in cancellation rates in patients aged above 50 years of age.(56)

Five observational studies were conducted within urology services.(45, 53, 56, 86, 106) All studies reported carbon-emission reductions in relation to intervention implementation, however only one of these studies went beyond basing these calculations on patient travel data to also include patient and staff energy use.(86) Narrative/descriptive findings indicated the patient benefits associated with the telehealth intervention included travel saved (n=3),(45, 53, 106), time saved (n=2),(86, 106), and reduced costs (n=2). (86, 106)

Four studies were conducted within the orthopaedics and/or trauma speciality, two observational,(49, 58) and two utilising an experimental comparative study design.(89, 93) Two of these studies incorporated measures of power and/or technology use into their carbon emission calculations, alongside impact of patient travel saved.(58, 89) All four studies reported in favour of the intervention reducing carbon emissions. One study reported no statistically significant difference in patient satisfaction, adverse events or accessibility between individuals receiving a telehealth intervention vs those receiving face-to-face care,(49) with another reporting no statistically significant difference in rates of patient attendance/cancellation or work absence.(93) Two studies reported greater patient time saved for individuals receiving telehealth interventions.(49, 89) Greater carbon reductions were found for individuals living further away from service.(89) Access issues highlighted that half of the individuals completing the virtual care intervention were dependent on an escort,(89) and that those with a higher level of disability were more likely to be unsatisfied with telehealth services.(58) However, the influence of patient age on patient satisfaction varied across studies. One study reported older patients being more likely to have difficulties accessing a virtual care intervention,(49) whilst another reported a weak predictive value of greater distance travelled and age with increased overall satisfaction.(58) One study highlighted that the costs of follow-up appointments were greatest for unemployed patients.(93)

Three observational studies were conducted within the renal speciality.(44, 60, 95) All reported in favour of telehealth interventions (vs face-to-face care) in reducing carbon emissions, although these calculations were solely based on patient travel saved. Other outcomes measured relied on descriptive or narrative comparisons between intervention and control groups. The majority reported improved scores in the intervention group in relation to: patient travel distance saved (n=3),(44, 60, 95) patient time saved (n=1),(95) attendance/cancellations (n=1),(60) patient costs saved (n=1),(95) and service costs saved (n=1).(60)

Two observational studies were conducted within gastroenterology,(52, 74), one of which incorporated emissions associated with software and infrastructure use into their carbon emission calculations.(52) Both reported reduction of carbon emissions associated with telehealth vs face-to-face visits, although one study noted no significant difference when adjusting for number of appointments and no significant difference between non-tertiary and tertiary delivery sites.(52) A statistically significant difference was found between intervention and control groups in favour of the telehealth intervention for patient travel distance saved,(74) There was no statistically significant difference between groups regarding time from referral to surgery.(74) Measures of attendance/cancellation demonstrated conflicting findings, either favouring face to face appointments,(47) of the telehealth intervention.(74) Findings relating to adverse events differed between studies, with one reporting no statistically significant difference between groups,(74) and one reporting no statistically significant difference between groups for 90 day admission/mortality rate, but favoured face-to-face care regarding number of blood test requests after appointment.(52)

Two studies were conducted within ENT services, one was observational,(51) and the other was a prospective comparative study.(102) Both based their carbon emission calculations on patient or staff travel saved, reporting reductions in carbon emissions due to a telehealth (vs face-to-face) intervention. One study reported no statistically significant difference in patient satisfaction between the two groups and provided descriptive statistics which indicated greater patient travel saved within the intervention group.(102) The other study provided descriptive statistics to indicate reduced time from referral to initial consultation in the telehealth group, and a statistically significant difference in favour of face-to-face care regarding service costs.(51)

One before and after study conducted within the cardiology speciality,(114) and one observational study conducted within gynaecological services,(71) reported reduced carbon emissions within the telemedicine group. Neither study reported comparative data for any other outcome measure, aside from patient travel saved – which favoured the telehealth condition.(71)

Product Level

Reuseable equipment: LCA studies

Five studies were conducted within urology,(67, 83, 96, 98, 107) with the majority (n=4) comparing carbon emissions associated with the use of reuseable versus disposable cystoscopes.(67, 83, 98, 107) One of these was an LCA appraised as 'High' quality,(83) two studies were 'Medium' quality inventory analyses,(67, 98) and one was a 'Low' quality study based on simplified LCA methodology.(107) Three of the studies indicated that single-use devices were associated with reduced carbon emissions when compared to reuseable devices,(83, 98, 107) however the results of the "Low" quality study based on simplified-LCA methodology(107) have been queried by Rizan and Bhutta (2022),(120) who raised concerns that the carbon emissions attributed to the reprocessing of reuseable cystoscope and manufacturing of a single use cystoscope were incorrect, due to an over-estimation in carbon emissions associated with the reprocessing of reuseable devices and incorrect use of the characterisation factor from a referenced study.(96) Rizan et al (2022) provided amended figures that reuseable cystoscopes are associated with reduced carbon emissions when compared to single use.(120) Hogan et al (2023) stand by their initial calculations, citing variation in reprocessing times and fuel mix across different contexts and attributing the difference in the characterisation factor they utilised, compared to those cited in Davis et al, to the different composition of cystoscopes vs ureteroscopes.(96, 122)

One 'Medium' quality inventory analysis also indicated that reuseable cystoscopes were associated with lower carbon emissions than single-use.(67) Four impact categories were evaluated by the "High" quality study using LCA methods. Single use devices were associated with reduced environmental impact within Mineral resource depletion and Acidification impact categories, whilst no difference in environmental impact was observed within the categories Ecotoxicity and Eutrophication.(83) One study indicated reduced environmental impact for solid waste for disposable devices.(107) One inventory analysis appraised as "Low" quality compared reuseable with disposable flexible ureteroscopes, indicated no significant difference in carbon emissions associated with disposable versus reuseable ureteroscopes.(96)

Four studies were conducted within gastroenterology,(68, 73, 103, 123) with equipment including trocar systems (n=1),(103) duodenoscopes (n=1),(68) laparoscopic surgery equipment (n=1),(59) and laryngoscopes (n=1).(73) All studies were appraised as being as “High” (n=3),(73, 103, 123) or “Medium” (n=1) quality,(68) and indicated reduced carbon emissions associated with reuseable or hybrid instruments when compared with single use. All the impact categories included in the study evaluating single use vs reuseable laryngoscopes favoured reuseable equipment.(73) Findings for the other impact categories for other equipment types were more varied, although the majority of environmental impacts associated with reuseable and hybrid equipment were either reduced, or not significantly different, when compared with single-use equipment.(68, 103, 123) Two studies evaluated the impact of reuseable vs disposable equipment on cost, both concluding that reuseable or hybrid equipment cost less than disposable.(73, 103)

One LCA appraised as “High” quality calculated the carbon emissions associated with newly-manufactured catheters vs remanufactured catheters within a Cardiology setting,(94) and another study conducted across multiple settings including ICU, evaluated carbon emissions associated with reuseable vs disposable blood pressure cuffs.(88) Both of these studies reported reduced carbon emissions associated with reuseable equipment. In contrast, one LCA appraised as “Medium” quality evaluating single-use vs reuseable bronchoscopes reported that carbon emissions were reduced for single-use equipment or did not differ significantly between groups, depending on quantity of PPE and cleaning procedures used for reuseable bronchoscopes.(112) However, these findings have been queried by another study which highlights that whilst Sorensen and Grüttner (2008) acknowledge reuseable bronchoscopes are associated with reduced carbon emissions when compared with disposable bronchoscopes, and when two or more bronchoscopes are reprocessed together, they omitted this from main analysis.(120) The majority of the other impact categories evaluated for the first two studies favoured reuseable equipment,(88, 94) whilst the two impact categories associated with the study evaluating reuseable vs single-use bronchoscopes favoured single-use.(112)

Setting

Waste management non-LCA studies

Two of the four studies conducted within gastroenterology were before and after studies,(27, 115) one was a modelling study,(40) and one was a retrospective observational study.(61) All interventions focused on methods of reducing waste associated with conducted endoscopies, including water bottle recycling,(27) improving waste segregation and recycling within endoscopy rooms,(115) reducing paper waste associated with patient information leaflets, questionnaires and reports and contrast,(40) and reducing number of plastic pots used for polyp removal.(61) Carbon reduction calculations focused mainly on carbon emissions associated with reducing quantity of waste created and/or disposed, without consideration of carbon emissions associated with recycling processes.(27, 40, 61, 115) and hence indicated that waste management interventions were associated with carbon emission reductions. The only outcomes consistently measured across these studies were quantity of waste reduction (n=3),(27, 61, 115) and service costs (n=3),(27, 40, 115) all of which indicated beneficial effects of the intervention. Other outcomes assessed included patient clinical outcomes,(27, 115) patient satisfaction,(40) clinician satisfaction,(115) social sustainability,(27) and fidelity to clinical process.(61) However, no comparative data was available for the majority of these outcomes, and thus did not support evaluation of the impact of the intervention.

Aims of other studies within this category included one modelling study estimating the impact of changing the composition of patient blood-testing kit for renal transplant/dialysis patient,(28) one retrospective cohort study evaluated an educational intervention focusing on reducing use of inhaled halogenated anaesthetic gases in individuals undergoing organ transplants, one before and after study evaluated an intervention aimed at reducing waste and materials associated with carpel tunnel surgery and an observational cohort study investigated the impact of reusing shipping materials used to package materials for intravitreal injections.(80) All were associated with reduced carbon emissions when compared with standard practice. System components/stages included within carbon emission calculations were often focused on one or two states e.g. use/reuse or waste disposal,(32, 33, 85) but two studies expanded on this to include all three stages and/or transport.(28, 80) Other outcome measures included patient satisfaction (n=1), patient clinical outcomes (n=1),(28) clinician satisfaction (n=1),(28) cost saved,(28, 32, 33, 80, 85) waste reduced,(32, 33, 80) all of which favoured the waste reduction intervention.

Care Delivery

Treatment pathway-non-LCA studies

One controlled-trial within the orthopaedic and/or trauma speciality,(47, 48) demonstrated "incremental" reductions in carbon emissions resulting from establishing a day-case treatment pathway for patients undergoing knee arthroplasty, which included changes to in-hospital care and a remote monitoring package. Carbon reductions were mainly associated with reductions in face-to-face contact. including number of face-to-face visits, hospital length of stay (LOS), service costs and number of physio appointments favoured the intervention group.

Appendix G: Accessing care

Overview of non-LCA studies - Telehealth

Specialty	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Feature	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient travel	Patient costs	Patient time	Time to referral	Attendance/Can	Adverse	Cost to	Other outcomes	Outcomes with no comparative
Cardiology	McLachlan 2021: New Zealand [HF service at Counties Manukau District Health Board](114)	Using latest decision pathway for optimisation of HF treatment aims: facilitate titration, limiting F2F visits by using patient self-monitoring with package including funded home BP monitors, electronic scales & NP-led phone support	Experimental: Before and After: C1 Telehealth vs C2 F2F [52]	HF N(%) Of 50 patients: New diagnosis of HFrEF: (76%), History of CVD: 21 Hypertension: 34 Atrial fibrillation/flutter: 12 Obstructive sleep apnea: 6, T2DM (44%), non-concordance: 8, smoking: 10, Harmful alcohol use: 8, HbA1c (mmol/l): Mean 64 (43–100), BMI (kg/m2):Mean 32 (range 18–59), CKD (eGFR <50ml/min/1.73m2): 11 IICD in situ: 4	Patients taught to identify fluid congestion/monitor vital signs with NP-led telephone support. Team introduced process. Self-help material included visual scale+book "Living Well with Heart Failure," for monitoring symptoms/vital signs. BP monitors+ electronic scales provided following practical demonstration. Booked fortnightly TC from NP/CNS agreed. Clinical support/guidance available from consultant cardiologist. F2F option if required. Each patient met HF member supporting them at beginning of trial. Some patients preferred email contact/text, TC most common. Up-titration facilitated by ePrescription+eLabform process	Accessibility benefits to patient from VC: distance travelled from patient's home address to outpatient department (Google Maps). Petrol costs: Standard car petrol use. Travel time: off peak traffic volumes for conservative estimate time saved. Data collected included no.contacts	Patient travel [$/ patient. Total CO2: 3]	During trial period, 216 contacts made: 129 (60%) telephone and 87 (40%) face to face. By eliminating travel need estimated saved on average 2.12hrs and 73.6km/patient travel costs: $2,908 during pilot ($58.17/patient). Total CO2 emissions reduced by 607kg, which would require 27.9 medium-sized trees to absorb within 1yr	***Gender*** Male: 38 (76%), ***Mean age*** all: 58.9yrs, ***Nationality*** Maori: 12 (24%), Pacific Islanders: 17 (34%), Others: 21 (42%).	NCD						NCD			PU, Cl.E./ PH, AE/ PSa, AC

Specialty	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Feature	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient travel	Patient costs	Patient time	Time to referral	Attendance/Can	Adverse	Cost to	Other outcomes	Outcomes with no comparative data
Renal	Andrew 2020: Australia [Royal Melbourne Hospital, renal transplant unit](95)	Describe telehealth care model used to provide routine follow up to patients' post-kidney transplant	Observ.: Retrospective review of database (CE data only): C1-Telehealth vs C2-F2F [45][a]	Kidney transplant: NR	Clinicians access Health Direct Videocall via web-link or desk-top icon on outpatient clinic room computers, patients access from any device with microphone & webcam. Sometimes, reviews conducted along with patient's local dialysis facility, GP or nurse; other patients connect directly from chosen place. F2F reviews interspersed with telehealth, frequency depending on duration post-transplant+patient factors. Referrals predominantly internal+informal, offered to patients at physician's discretion. Referral triage-assessment of: patient's ability to self-monitor BP, HRa+weight, involvement of local dialysis facility, GP or nurse, technology access and internet reliability, distance from hospital or individual circumstances warranting telehealth	Telehealth patient and appointment data collated/ analysed using Microsoft Excel 2010. Distance between hospital and longitude/latitude of each postcode calculated using the Geo-Coded National Address File.[1] Estimates CO_2 emissions calculated based on United States Environmental Protection Agency calculation of 404g of CO_2 emitted/mile (251g/km) for average passenger vehicle.[2] Patient location data plotted on map, with size of marker proportional to frequency of appointments/ postcode represented	Patient travel [Tonnes CO_2 equivalents: 3]	Estimated reduction GHG emissions: 51 tonnes CO_2 eq	***Place of residence:*** Approx. half all RMH kidney transplant recipients live in regional areas	NCD	C1>C2 (N)	C1>C2 (N)	C1>C2 (N)						PU

Specialty	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Feature	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient travel	Patient costs	Patient time	Time to referral	Attendance/Can	Adverse	Cost to	Other outcomes	Outcomes with no comparative data
Renal	Connor 2011b: UK [The University Hospital of Coventry and Warwick-shire renal service: telephone clinic](44)	Follow-up to renal transplant recipients over a 3yr period, outlines benefits of service to patients, providers, and environment, discuss provision of virtual care to patients with kidney disease and possibilities of more widespread adoption	Observ.: Cross-sectional: C1-Service delivery/ Telehealth vs C2 -F2F [30]	Kidney failure: Renal transplant patients attending 2xfollow-up TC	Service offered to patients at physician's discretion. Most patients well known to department, all stable graft function. Patients receive quarterly clinic appointments-one remains F2F. Patient ringS through to clinician at time in appointment letter, which requests provide weight/BP readings. As with F2F consultations, blood tests undertaken beforehand; patients may attend family practice, city centre phlebotomy service, or local hospitals. 15min allocated/consultation. Clinic letters copied to patient, along with necessary prescriptions, blood test form, and next appointment details. Annual F2F consultation allows for physical examination (including urinalysis)	Data collected prospectively from 30 patients attending 2 consecutive telephone clinics. Each patient's return journey length calculated from postcode using Google Maps. Calculated using DEFRA conversion factors specific to transport modality used to attend local clinic.17 Mean value of 8.05 kg CO2 equivalents (kgCO2eq) identified. Reduced physician travel across 2 sites to outlying clinics based on 20 clinics across two sites, assuming physician return journeys from site by car	Patient travel, clinician travel [kg CO2eq: 3]	Annual 350 TCs: estimated reduction in GHG emissions of 2,818 kgCO2eq. Reduced physician travel to outlying clinics: estimated annual total annual reduction GHG emissions of ([10x0.20487x2x 20.4]+[10x 0.20487x2x 36.2]) 231.8 kgCO2eq (where 20.4 and 36.2 are return distances to outlying clinics, in km, and 0.20487 is conversion factor for average-sized car. Further potential, carbon savings result from reductions in building energy use (e.g. Lighting/heating hospital waiting room) and staff commuting (e.g. outpatient nurses and reception staff). Annual carbon saving estimated: >three tonnes CO2 eq (Sufficient to fill 3xlarge detached houses)	NR		C1>C2 (N)								

Specialty	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Feature	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient travel	Patient costs	Patient time	Time to referral	Attendance/Can	Adverse	Cost to	Other outcomes	Outcomes with no comparative
Renal	Udayaraj 2019: UK [North Bristol NHS Trust Renal Unit](60)	Test introduction of tele-clinic service to reduce no. patients not attending F2F clinics	Observ.: before and after, Iterative PDSA cycles: C1 – Telehealth vs C2 - F2F [185][b]	Kidney transplant: NR	PDSA cycles to test introduction of tele-clinic service. Codesigned the service with patients and developed prototype delivery model and tested over 2xPDSA improvement ramps containing multiple PDSA cycles to embed the model into routine service delivery	Miles calculated based on patient survey (Miles travelled to face-to face appointments combined with transport used, 57.7% response rate)	Patient travel [kg CO2: 3]	Among survey respondents: average distance travelled by patients to F2F appointments=36.4 miles. Tele-clinic saved 3527m of motorized travel in total=Saving of 1035 kgCO2. Actual reduction in travel distance and CO2 emissions will be higher as response rate to patient survey only 57.7%	NR	NCD	C1>C2 (N)				C1>C2 (N))	NCD	C1>C2 (N)[c]		AC, BTC, AD, PSn, UA, ISU

Specialty	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Feature	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient travel	Patient costs	Patient time	Time to referral	Attendance/Can	Adverse	Cost to	Other outcomes	Outcomes with no comparative data
Orthopaedics (and Trauma)	Arndt 2023: Germany [Outpatient clinic of O+T surgery, German University Hospital](89)	Compare estimated CO2 emissions in 6-months conducting VC with period of exclusive F2F outpatient clinic	Experimental: Before and After: C1 Telehealth vs C2 F2F [52][d]	Spinal surgery, joint surgery, paediatric orthopaedics, and accident surgery: Spinal surgery, joint surgery, paediatric orthopaedics, and accident surgery. Median age 51 [2-7-87.9yrs]	VC in the outpatient clinic	GHG emissions were assessed with CO2 calculations based on data from the German FEA. Avg emissions for car journeys were estimated at 143 g CO2e/ person-km. Reduction of GHG emissions also considered emissions during VC and power consumption of data centres. Fiber optic technology was found to be the most environmentally friendly= 2 g CO2e/hr of video streaming compared to 90 g CO2e/hr for 3G networks. IF widespread VDSL connections in German homes, a 1-hour VC session= 4 g CO2e	Use/reuse (power consumption), patient travel [g CO2e: 3]	Significant difference between groups favouring intervention for CO2 reduction ($p < 0.001$). (Referring to Federal Environment Agency, implementation VC: reduction in GHG missions over 0.5 tons CO2e for respondents VS patients traveling by car. Time patient and doctor involved during VC included: approx. 160 g of CO2e for all VC	***Place of residence:*** Among 51 respondents, 31% reported travelling <20km to the clinic and 35% reported travelling>50km. ***Personal characteri-stics associated with discrimen-ation:*** Half respondents (n=22) who completed VC dependent on escort	NCD			C1>C2 (N)						PSn

Specialty	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Feature	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient travel	Patient costs	Patient time	Time to referral	Attendance/Can	Adverse	Cost to	Other outcomes	Outcomes with no comparative data
Orthopaedics (and Trauma)	Curtis 2021: UK [Orthopaedic emergency clinic in large district general hospital](49)	Establish whether NF2F clinics sustainable according to "triple bottom line" framework by considering impact on patients, planet, and financial cost	Observ.: Retrospective cohort: C1 Telehealth vs C2 F2F [180, 76 F2F, 104 TH]	NR: mean age was 48 (range: 3 months to 92 years), with 56% female and 44% male participants. Patient demographics did not vary significantly ($p > 0.05$) between groups	NR	Patients contacted by telephone and asked questions about mode of transport. Estimates of CO_2e made for each mode of transport	Patient travel [$kgCO_2e$: 1, 2 and 3]	Mean return journey distance (home to hospital): 18.6m. Reduced CO_2e: 65% car, 84% taxi, 57% bus due to NF2F clinics. Overall, total carbon emissions reduced: 563.9 $kgCO_2e$ (66%) or 3.1 $kgCO_2e$/ person=2,106m driven in medium-sized petrol car. Outpatient carbon cost associated with each visit (heating, lighting, waste generated): 56 $kgCO_2e$ /patient8=10,080 $kgCO_2e$ for all 180 patients. Utilizing NF2F consultations for 104 patients, led to 58% reduction 5,846 $kgCO_2e$	***Personal characteristics associated with discrimination:*** Those unable to use VC significantly older by 17 years ($p < 0.001$)	><(S)		C1>C2 (N)				><(S)		Accessibility ><(S)	

Specialty	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Feature	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient travel	Patient costs	Patient time	Time to referral	Attendance/Can	Adverse	Cost to	Other outcomes	Outcomes with no comparative data
PaOrthopaedics (and Trauma)	Muschol 2022: Germany [Single University hospital, Depart. Trauma, Hand and Reconst-ructive Surgery](93)	Provide first health economic analysis comparing telemedicine in follow-up of patients in O+T surgery with knee and shoulder disorders with conventional F2F examinations in clinic in Germany	RCT: C1 Telehealth vs C2 F2F [60, 30 TH, 30 Control]	Knee and shoulder disorders: N (%). Medical indication C1 v C2: Knee - 10 (38) v 9 (35), Shoulder - Intervention 16 (62) v 17 (65); Age: 18-40 7(27). V 5 (19), 41-60, 17(65), v 15 (58), >60 2 (8) v 6(23); Female: 11 (42) v 10 (38); Employed: 20 (77) v 19 (76)	Intervention: replaced standard outpatient follow-up appointments with real-time online VC with treating physician. VC platform was browser-based for physicians and accessible via digital health apps or browser-based software for patients. The VC procedures were simplified to ensure practicality, involving direct communication between physicians and patients without involvement of other medical providers. Patients received written instructions for VC and incurred no additional costs, as the digital health app or software was free to use. Patients needed a device with microphone and camera capabilities and an internet connection, with examination costs covered by health insurance	1) Environmental impact assessed by multiplying average emissions/ passenger-km by km travelled by car to/from clinic. Public transport emissions not calculated due to minimal usage in study. 2) Average environmental costs per passenger-km calculated using a cost rate from Federal Environment Agency. 3) Model estimates potential savings in emissions and environmental costs if 8 patients/week opt for VC instead of clinic consultations	Patient travel [Average emissions/ passenger -kilometre (pkm): 3]	Total emissions saved (26 patients in TH group): 292.448 kg. Use of TH saved approx. 3.73 in environmental costs per patient= 97.07 for all patients study. Potential savings for 1 year (8 patients/wk VC instead of clinic consultation): For 384 patients who would not have to travel to clinic each year: 4009.88 kg GHG, 24.80 kg of CO, 3.96 kg volatile hydrocarbons, 10.02 kg NOx, 0.16 kg particulates could be avoided. In addition, at 195/ ton CO2e, 1330.91 could be saved. Environment costs could further be reduced by €2661.82, at €95/ton CO2e, or by €6798.33, at €680 per ton of CO2 equivalent	***Occupation*** ***:*** In the TH group, follow-up appointme nts cost €16.11 for employed patients and €5.85 for unemploye d patients, contrasting Societal costs of lost production were €241.74 for full-time employees and €114.97 for part-time employees in the TH group			C1>C2 (N)	C1>C2 (S)[e]		>< (S)			Work absence >< (S)	

Specialty	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Feature	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient travel	Patient costs	Patient time	Time to referral	Attendance/Can	Adverse	Cost to	Other outcomes	Outcomes with no comparative data
Orthopaedics (and Trauma)	Richards 2022: UK [Hospital (Musgrove Park, Taunton)](58)	Aimed to examine outcomes of Virtual Arthroplasty Follow-Up service and benefits for trust, patients, and planet	Observ.: retrospective cohort: c1 Telehealth vs c2 F2F [132 of 240 eligible][f]	Hip arthroplasty: Hip arthroplasty. Patient survey group (n=52). Mean age: 75.5. Mean oxford hip score: 836.9/48, Mean UCLA activity score 4.19	First follow: VC 6wks post op. 2nd virtual follow up: 1yr post op. 7-yr follow up only for patients who received initial op under 50yrs of age. 10yr follow up: all patients. If patients>80yrs at 10yr follow up can be discharged to GP. All others to continue follow up at 13yrs. At 13yrs: all patients over 80 discharged. Further follow up in 3yr intervals for<80yrs. Key changes from F2F: key changes were a virtual follow-up (via telephone) at 1yr and removal of 5yr follow-up for all patients to a seven-year follow-up for patients who had their index operation performed at age <50yrs	52 patients surveyed travelled average 24.6 miles total (to/from the hospital) for clinic appointments=1,279 miles not driven. If all drive equivalent of average petrol car=358kg CO2e saved.[3] Additionally, use of F2F clinic space has associated environmental cost (lighting, heating, waste generated), previously calculated between 56 and 76kg CO2e/clinic slot.[4,5]	Use/reuse (clinic space), disposal, patient travel [kg CO2 e: 1, 2, 3]	If all patients drive equivalent of average petrol car: 358kg CO2e saved. Additionally, using F2F clinic space has associated environmental cost (lighting, heating, waste generated), previously calculated between 56 and 76kg CO2e/clinic slot[4,5] between 2,912 and 3,952 kg CO2e for this group=total carbon saving for 52 patients to a lower estimate of 3,270kg CO2e or 62.9kg CO2e/patient per appointment. Upscaling these averages to all 132 VARF patients equates to over 8 tonnes CO2e saved	***Place of residence/ ge:*** Age and distance= weak correlations with satisfaction levels. Patients with lower scores on the OHS= 9x more likely to be neutral or unsatisfied with the service. There was a moderate correlation between UCLA activity score and overall satisfaction	NCD		C1>C2 (N)							ACS, PF, QOL, PS, ACY

Specialty	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Feature	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient travel	Patient costs	Patient time	Time to referral	Attendance/Can	Adverse	Cost to	Other outcomes	Outcomes with no comparative data
Ear, Nose and Throat	Dorrian 2009: UK [Remote tele endoscopy in Gilbert Bain Hospital Shetland](51)	Feasibility study to establish whether ENT tele-endoscopy suitable for service delivery for patients living in Shetland Island	Observ.: Prospective cohort: C1 Telehealth vs C2 F2F [42]	Head and neck cancer: Symptoms of possible head/neck cancer. Otherwise, NR	Patients referred from primary care selected for pilot study by consultant otolaryngologist in Aberdeen and two local doctors on Shetland. Laryngoscope (ENF GP Rhino-laryngoscope, Olympus) connected to videoconferencing unit via S-video cable. Video conferencing with Aberdeen conducted at 384 kbit/s via ISDN network. First 20 patients followed up after 2 and 6 months to confirm patient safety. Initially tele-endoscopy images recorded in Aberdeen and captured on DVD recorder on theatre stack used for endoscopic examination. This allowed ENT consultant to compare images for diagnostic accuracy. After first two clinics, ENT consultant decided live videoconferencing images supported accurate diagnosis	CO_2 savings from avoided travel were calculated based on the DEFRA guidelines. journey from the hospital Shetland Islands to the specialist centre in Aberdeen's Road distance calculated using a standard route planner, the distance between airports determined using Vincenty's formula. TH enabled an ENT consultant to see 42 patients remotely. Emissions from a car with an average-sized diesel engine calculated at 0.199 kg CO_2/km. Considering air travel, the emission from the short domestic flight was estimated at 0.158 kg CO_2/km	Staff travel [kg CO_2: 3]	Avoided road travel saved 9.15kg CO_2 emissions and 0.158 kg CO_2/km from a short (domestic) flight. Avoided air travel saved emission of 52.2kg CO_2. Total saved emissions for journey: 61.3kg CO_2/person (one-way) or 123kg CO_2/person (return)	NR	NCD				Initial consultation C1>C2 (N)		NCD	C2>C1 (S)[g]		PS, DD, ACS, AE

Specialty	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Feature	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient travel	Patient costs	Patient time	Time to referral	Attendance/Can	Adverse	Cost to	Other outcomes	Outcomes with no comparative
Ear, Nose and Throat	Tselapedi-Sekeitto 2023: Canada [otolaryngology clinic, Hospital, London Ontario](102)	Investigate patients' satisfaction, travel cost, productivity loss, and CO_2 emissions involved with synchronous virtual care and in-person assessments in rhinology and sleep apnoea clinics	Prospective comparative study: C1 Telehealth vs C2 F2F [94, 34 TH, 60 F2F][h]	Rhinology pathologies e.g. chronic rhinosinusitis, nasal septal deviation, sleep apnoea, allergic rhinitis, or post-operative rhinosinusitis: In the virtual care group; mean age was 48 ± 16 years, 14 (42.4 %) males and 19 (57.6 %) females, while in the in-person group, mean age was 51.4 ± 19, 35 (58.3 %) males and 25 (41.7 %) females	NR	Carbon footprint and environmental impact assessed based on CO_2 emission, calculated as 252.5g CO_2/km (travel distance - round trip), expressed in Kg/consultation	Patient travel [kg CO_2: 3]	Carbon footprint analysis showed an environmental impact generated by in-person group visits of 32 ± 39 kg of CO_2 emitted/consultation	***Personal characteristics associated with discrimination*** Among 7 domains evaluated by PSQ-18, satisfaction with "Time spent with the doctor" correlated directly with age in the in-person group ($r = 0.27$; $p = 0.037$). In a subgroup analysis based on diagnosis, patients with allergic rhinitis had significantly lower general satisfaction scores in VC visits vs in-person visits (3.28 vs. 4.25, $p = 0.04$)	>< (S)			C1>C2 (N)						PPL

Specialty	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Feature	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient travel	Patient costs	Patient time	Time to referral	Attendance/Can	Adverse	Cost to	Other outcomes	Outcomes with no comparative
Urology	Connor 2019: UK [Tertiary centre: Virtual uteric colic clinic](45)	Evaluate clinical, fiscal and environmental impact of specialist-led acute ureteric colic virtual clinic pathway	Observ.: Prospective cohort: C1 Telehealth vs C2 F2F [1008]	Ureteric colic: 763 male, 245 female. Mean age: male 40.5 (13.1), female 32 (5.7). Majority of patients referred were of working age: 702 men (92.0%) and 220 women (89.8%)	VC TC: by specialist nurse/consultant urologist via patient's personal mobile or landline. VC pro-forma used; approx. 15 min. Attempt to contact patient min. 3 times. Following this, patients deemed 'did not attend'. VC, letter sent to patient/GP+ documented on patient records. Documentation shared with referrer. VC patient outcomes: discharge investigations and further VC, FTF clinic or direct referral for stone intervention (PCNL, URS or ESWL). VC supervised by 3xurologists. In case of clinical uncertainty, patient referred to FTF clinic. Adverse events (repeat presentation with sepsis, obstruction) +complaints logged. Min. follow-up 3 months. Working age defined 18– 65 yrs	Carbon footprint generated on patient mode of transport: train or car. Department of Transport vehicles analysis used example of 1800 cc petrol engine car to calculate presumed journeys.[6] Total trip from patient's home to hospital calculated using patient's residential address. Distance calculated using Google Maps. Carbon footprint using calculator supplied by Carbon Footprint.[7] No. trees required to offset calculated carbon footprint derived using FTF clinic as alternative and inputting data into the published agricultural algorithm provided by 'Trees for the Future'[8]	Patient travel [Metric tons CO2E: 3]	Mean (IQR) patient distance travelled: 4.3 (2.5–6) miles. Carbon footprint attributable to travel avoidance: 0.70–2.93 metric tonnes of CO2e production (depending on transport mode). To offset this carbon footprint would require planting 14.7 trees	NR		C1>C2 (N)			NCD		NCD	C1>C2		TR, TS, AE, SC, PH

Specialty	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Feature	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient travel	Patient costs	Patient time	Time to referral	Attendance/Can	Adverse	Cost to	Other outcomes	Outcomes with no comparative data
Urology	Croghan 2021: Ireland [Urban tertiary referral unit-virtual clinic](106)	Evaluate impact of virtual outpatient clinics on travel time, monetary cost to patients and carbon emissions	Observ.l: Cross-sectional: C1 Telehealth vs C2 F2F [1016, 736 TH]	General urology and subspecialist (including uro-oncology, urolithiasis and female, functional and reconstructive: NR. Of virtual care patients, 40% (295 of 736) considered 'rural-dwelling'. Mean age: 62.9 yrs (range 18–95), significant portion of patients were of 'working age'; 54.7% (403 of 736) 66 years old or younger, the state retirement age, 68.75% (506 of 736) aged 70 years or below	Outpatients triaged to determine clinical urgency/appropriateness of virtual review. F2F consultations scheduled when required. Any necessary imaging or blood tests arranged in advance of VC. VCs performed by telephone, although video-conferencing platforms available. Symptoms discussed, investigation or treatment plan agreed upon with patient, and documentation of interaction recorded in chart. A letter to patient's GP is generated, and a prescription, where required, posted to patient	Patients' usual mode of transport to hospital visits was determined during clinical consultations. Travel time, petrol, toll, and parking costs, along with carbon emissions for hospital attendance, were calculated for each patient based on this information. AA Route Planner and Google Maps were used to calculate travel distances and times. Carbon emissions were estimated using an online calculator from Carbon Footprint Ltd, and the number of trees required to absorb emissions was calculated using information from the Tree Council of Ireland. Public transport carbon emissions were not calculated	Patient travel [tonnes CO2: 3]	Establishing VC: estimated reduction 6.07 tonnes CO2 emissions, based on predicted carbon footprint of 'car traveller' patients. Estimated volume CO2 emissions would take 434 established (10-year-old) evergreen trees to absorb in 1yr	***Age:*** Significant portion of patients were 'working age' ***Place of residence:*** distance saved: Overall 31,038 miles (49,951km) /rural-dwelling patient 93.8 miles (151km).		C1>C2 (N)	C1>C2 (N)	C1>C2 (N)		NCD				CI.E, AT

Specialty	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Feature	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient travel	Patient costs	Patient time	Time to referral	Attendance/Can	Adverse	Cost to	Other outcomes	Outcomes with no comparative data
Urology	Filfilan 2021: France [Teleconsultations for 2 academic urology departments in Paris](86)	Assess environmental cost of urology teleconsultation vs F2F consultations	Observ.: Cross-sectional: C1 Telehealth vs C2 F2F [80]	Oncological (n = 49; 61%), functional urology (n = 14; 18%) and benign prostatic hyperplasia (n = 13; 16%): Reason for consultation: oncological (n = 49; 61%), functional urology (n = 14; 18%) and benign prostatic hyperplasia (n = 13; 16%). Median age [IQR] was 66 years [56—71], 10 patients were female (13%). 20 (25%) new patients	Teleconsultations led by 5xsenior urologists and had been introduced in these departments for first time 1 month previously as a response to COVID-19 lockdown. Teleconsultation performed using website doctolib. Patients who lived in another country excluded from to have better far distance homogeneity	TC: Energy consumption was calculated for a 20-minute live video connection, assuming 15 minutes for consultation and 5 minutes for administrative tasks. Energy usage was converted to CO2e using French National Environmental calculator conversion factors. Estimated energy consumption for F2F included travel mode and distance. For car journeys, Car emissions were estimated using average diesel car emissions. Carbon and equivalent costs of public transport were evaluated using national French railway company emissions. Patients walking was considered emission-free	Use/ reuse, patient travel [CO2e: 2 and 3]	Estimated CO2e emissions avoided due to lack of travel: 1.1 tonnes during 1-month study period. Teleconsultations (two computers connected) responsible for 1.1 kg CO2e emissions vs in-person consultations (1 computer used by consultant): 0.5kg of CO2e. Total reduction GHGs: 1141 kg CO2e, a 99% decrease in emissions	NR	NCD		C1>C2 (N)	C1>C2 (N)						PS, CS

Specialty	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Feature	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient travel	Patient costs	Patient time	Time to referral	Attendance/Can	Adverse	Cost to	Other outcomes	Outcomes with no comparative data
Urology	Miah 2019: UK [Urology clinic](53)	Quantify clinical, financial and environmental benefits of virtual urology clinic	Observ.: Prospective cohort: C1 Telehealth vs C2 F2F [409]	Purpose: Venous biochemistry review; Venous haematology review; Radiological investigation review; Symptom review; Pathology review: 281 male (mean age 60 yrs), 128 female patients (mean age 61.5 yrs. Majority patients, male and female (n = 162, 57.7%, and n = 71, 55.5%, respectively) working age	TH using either patient's landline or mobile number. All patients selected for VC follow-up made aware of this method of follow-up consultation in their prior F2F clinical encounter and agreed to use it. They were given number of administrative team to raise any concerns regarding VC. Patients made aware of protocol if they were not contactable on multiple attempts. Patients scheduled for results review that unable to contact were provided with a letter explaining result and plan of action; sent to both patient and GP. Alternatively, patient offered F2F clinic. VC undertaken by middle-grade urologist under supervision of named consultant available for clinical concerns/ queries. Adverse events complaints log performed following min. 4mnth period after each VC	Calculated range for carbon footprint generated. For journeys by car, selected 1800 cc petrol engine car Total travel distance for each patient calculated on round-trip from patient's residential address to institution using Google Maps and selecting car as mode of travel. Estimated carbon footprint calculated using calculator supplied by Carbon Footprint. No. trees required to offset carbon footprint generated by alternative F2F clinic calculated using need to plant five trees for one to mature into an adult (Trees for the Future)	Patient travel [CO2 tonnes: 3]	Estimated avoided carbon footprint due to travel: 0.35–1.45 metric tonnes CO2e. Predicted 12-month avoided carbon footprint: 1.05–4.35 metric tonnes of CO2e. No. trees needed to be planted to offset carbon production: 1.75–7.25 trees. No. to be planted to offset higher estimate of predicted 12-month carbon production: 21.75	NR	NCD	C1>C2 (N)						C1>C2 (N)		PS

Specialty	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Feature	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient travel	Patient costs	Patient time	Time to referral	Attendance/Can	Adverse	Cost to	Other outcomes	Outcomes with no comparative data
Urology	Natale 2022: UK [Urology unit SW England](56)	To determine whether standalone tele-consultation is effective alternative to F2F assessment of patients requiring circumcision. Determine environ-mental and efficiency benefits result from service alteration	Observ.: Retrospective cohort: C1 Telehealth vs C2 F2F [101, 42 TH, 59 F2F]	Circumcision: Circumcision. Mean age: TC 36, F2F 50. Charlson comorbidity index <1 TC 72%, F2F 38%. Smoker TC 13% F2F 10%, Obesity TC 11% F2F 31e%, Diabetes mellitus TC 11%, F2F 24%	Arranged TC with day-of-operation consent and examination	Crude estimation of CO2 emission conducted using Environmental and Social Sustainability in NHS Innovation toolkit[9]	NR [kg of CO2: CT]	For studied cohort, estimated 3647 kg CO2 generated. A further 6897m3 of water used and 43 kg of waste produced. Per patient this equates to 45kg of CO2, equivalent to driving from London to Sheffield. Had all patients been seen in a telephone clinic estimated reduction of 637kg of CO2 could have been achieved	***Personal characteristics associated with discrimination:*** to control for older, more comorbid population in F2F group, subgroup analysis performed for patients aged over 50yrs (N=43, 12 TC vs 31 F2F). No sig. difference in odds of cancellation (p=0.28)						>< (S)		C1>C2 (N)		

Specialty	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Feature	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient travel	Patient costs	Patient time	Time to referral	Attendance/Can	Adverse	Cost to	Other outcomes	Outcomes with no comparative data
Oncology	Beswick 2016: USA [Tertiary otolaryngology facilities- 2 Remote VHA sites: ENT/ Oncology](63)	To evaluate telemedicine model utilizing AV teleconference as a preop. visit	Feasibility study/ Retrospective cohort: C1 Telehealth vs C2 F2F [21, 15 patients full protocol (pre to post op]	Head and neck cancer: Total 47. Remote patients (21): Pathology, no. Carcinoma 5, Warthin's tumour 3 ,Low-grade salivary neoplasm 3, Osteoradionecrosis 1, Substernal goitre 1, Cystic lesion 1, Low-grade laryngeal chondrosarcoma 1; F2F patients (26). 24 with high-grade neoplasms (carcinoma 5; melanoma 5; & metastatic thyroid cancer 5 1) and 2 with low-grade pathology (atypical fibroxanthoma 1, and osteoradionecrosis 1)	Eligible patients were offered telemedicine consultations upon referral, alongside standard in-person consultations. The telemedicine protocol involved tissue diagnosis and imaging acquisition at a remote site, followed by a review of clinical data and discussion at a multidisciplinary tumour board. Preoperative counselling was conducted via TH, involving the patient, nurse, and speech pathologist, facilitating nasopharyngoscopy. Surgical patients received preoperative clearance during telemedicine visits, with referrals made electronically for necessary evaluations. Operative intervention and immediate postoperative care were provided at the local tertiary site, with routine follow-up and additional telemedicine visits as needed. Non-operative patients received treatment in their home area or were referred to appropriate specialists	Parameters related to patient's treatment timeline calculated, including time from referral request to time of telemedicine consultation and time from telemedicine consultation to intervention. Travel time based on average driving or flying time from remote locations to hospital. Cost of travel and procedures based on federal government's reimbursement rate for travel[10] and calculations by VHA finance department when determining cost of the fee based on specific procedures. CO_2 emissions calculated from the Environmental Protection Agency's formula and based on road travel in a car or light truck/ patient	Patient Travel [CO_2 tonnes: 3]	Intervention prevented 14.5 metric tons CO_2 emissions based on Environmental Protection Agency formulas[11]	Remote patient ***Mean age*** 64yrs (28–95 yrs) ***Gender:*** all men In person patients. Mean age NR (range NR), gender NR,			C1>C2 (N)	C1>C2 (N)	Time to referral C1>C2 (N), evaluation to OR/surgery C2>C1 (N)					

Specialty	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Feature	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient travel	Patient costs	Patient time	Time to referral	Attendance/Can…	Adverse	Cost to	Other outcomes	Outcomes with no comparative …
Oncology	Jiang 2021: USA [Ann Arbor Veterans Affairs Medical Center](66)	To better understand tele oncology's potential to facilitate VHA-based care, Assess Veteran views & satisfaction with technology. Generate estimates of private and social, financial, and environmental impacts to inform future policy trade-offs	Observ.: Retrospective cohort: C1 Telehealth vs C2 F2F [100 out of 366 eligible initial survey, 42 follow up survey]	Cancer, N.S.: For 366 eligible vs 100 surveyed. Primary site of disease[i]: Bladder 8 v 2, Breast 10 v 4, CNS 1 v 0, Endocrine 1 v 9, GI/ Hepatobiliary 110 v 23 Testicular 3 v 0, Head/neck 23 v 4, Lung 82 v 18, Neuroendocrine 9 v 4 Prostate 93 v 29, Renal 6 v 3, Skin/Soft tissue 20 v 9	Oncology encounters completed via tele oncology (video visits, telephone, secure messages, electronic consults) from March to June 2020. Types of tele oncology visits: audio-only, audiovisual only, or both audio-only and audiovisual visits	Travel distance and time estimates between patient ZIP code and VAMC Ann Arbor generated using Google Maps, selected for shortest time if multiple routes available, and multiplied by two to estimate round-trip distance. Automobile CO_2 emissions served as proxy of carbon footprint. CO_2 emissions estimated as product of round-trip distance and mean automobile CO_2 emission of 411 g CO_2/mile, converted to metric tonnage.[12] Refer to Data Supplement for additional information on calculations for financial and environmental impacts	Patient travel [Metric tons CO_2 emissions: 3]	560 total tele oncology encounters conducted between March 2020 and June 2020 saved geographically diverse patient population cumulative 86,470m travel (mean 154.4 m/patient encounter). Transitioning to tele oncology responsible for estimated carbon footprint reduction:35.5 metric tons CO_2, approx. 106 metric tons of CO_2 on an annualized basis in savings	For 366 eligible v 100 surveyed ***Race/Ethnicity:*** Included population - White/Caucasian 288 v 76 Black/African American 38 v 11, Hawaiian or Pacific Islander 6 v 3 Did not declare 34 v 10 ***Personal characteristics associated with discrimination:*** Poor access to or difficulty using technology impacted patient satisfaction ***Mean age:*** 68.7(SD9.3) v 68.6(SD 8.8). 16(4.4) female v female	NCD	C1>C2 (N)	C1>C2 (N)	C1>C2 (N)						PSn

Specialty	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Feature	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient travel	Patient costs	Patient time	Time to referral	Attendance/Can	Adverse	Cost to	Other outcomes	Outcomes with no comparative data
Oncology	Lambert 2023: Canada [CancerCare Manitoba, provincial agency](101)	Describe patterns of visit types (in-person versus virtual) during pandemic at CancerCare Manitoba, and impact of virtual visits on hypothetical travel distance, travel time, and CO2 emissions generated by travel	Observ.: retrospective database review: C1 Telehealth vs C2 F2F [Total visits: 306, 234, In person: 160,668, Virtual: 145, 566]	All visits for invasive and in situ cancers: Age group (N): Under 18: 5198, 18–39: 13,805, 40–64:108,457, 65–79: 137,951, 80+: 40,823. Gender (n, %) Women 147,178, Men 159,043, Other 13. Cancer site-Breast: 41,178 (13.4), Digestive: 45,957 (15.0) Gynaecologic: 21,514 (7.0), Haematology: 45,879 (15.0), In situ and benign: 23,774 (7.8) Men's genitourinary: 42,571 (13.9), Respiratory: 30,093 (9.8), Other: 55,268 (18.0)	Telehealth provides videoconferencing through many facilities across Manitoba for health care services, continuing education, meetings, and family visits. For some appointments, instead of an in-person visit, individuals could remain in their homes and interact with health care providers through telephone and videoconferencing. This was in addition to the telemedicine already used in Manitoba (Manitoba Telehealth) prior to pandemic where individuals could travel to a health care facility and have a videoconference with a health care provider at another facility. Manitoba Telehealth visits combined with in-person visits because of requirement of travel to health care facility	Estimated travel distance converted into estimated metric tons of CO2 emissions: 206g CO2/km=average based on newly registered vehicles in 2017 in Canada[13]	Patient travel [CO2 tonnes: 3]	Estimated CO2 emissions prevented during study period varied from 87 to 155 metric tons/month ***PROGRESS PLUS*** ***Place of residence:*** Northern Manitoba residents longest travel distances and times for cancer care, with Northern region often having lowest rates of VC, though this trend changed in part during 2021. Interlake–Eastern RHA, had among lowest monthly rates of VC	***Gender:*** Men had higher rates of VC, with small differences observed during COVID-19 lockdowns. ***Age:*** % of VC visits increased with age, particularly between ages <18 vs 18- 39		C1>C2 (N)	C1>C2 (S)	C1>C2 (N)					Environmental cost C1>C2 (N))	

Specialty	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Feature	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient travel	Patient costs	Patient time	Time to referral	Attendance/Can	Adverse	Cost to	Other outcomes	Outcomes with no comparative data
Oncology	Lewis 2009: [Bronglais General Hospital, Aberystwyth] (35)	Evaluation of environmental impact of using VC vs meeting in person	Observ.: Cross-sectional:C1 VC vs C2 F2F [60 clinicians, 21 meetings]	Cancer: NR	Telemedicine service launched in Sept 2005 to assist meetings between MDT to improve cancer services. Implemented throughout the network	In Oct 06 and Oct 07, users of VC equipment at hospital completed questionnaires to quantify if time/travel costs reduced by attending meetings via VC vs F2F. Questionnaires recorded distance travelled, journey time, vehicle engine size, petrol/diesel, no passengers, and staff group. Journeys converted into CO2 savings using UK government calculator.[14] Journey cost calculated from financial information provided by Trust finance department	Patient travel [kg of CO2 emissions: 3]	During October 2006 total of 18000km car travel avoided, equivalent to 1696kg CO2 emission. During October 2007, total of 20800km car travel avoided, equivalent to 2590kg CO2 emission. Estimate 48 trees would take 1yr to absorb that quantity CO2	NR								C1>C2 (N)	Clinician travel saved C1>C2 (N)	

Specialty	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Feature	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient travel	Patient costs	Patient time	Time to referral	Attendance/Can	Adverse	Cost to	Other outcomes	Outcomes with no comparative data
Oncology	Patel 2023: USA [single-institution National Cancer Institute-designated comprehensive cancer centre](72)	To assess carbon savings achieved from telemedicine visits	Observational: Cross-sectional: C1 vs C2 F2F [49329 TH visits, 23,228 patients]	NR: NR: For patients with visits within 60min vs >60min of driving time, median (IQR) age was 62.0 years (52.0-71.0 years) v 67.0 years (57.0-74.0 years), 12 334 v 13 468 of the visits were female, and 9934 v 10 217 of the visits were by patients privately insured; 1685 v 1056 were Black, 1500 v 1364 were Hispanic, and 16 010 v 22 457 were non-Hispanic White	Telemedicine: real-time care delivered through a synchronous videoconferencing. Starting in April 2020, instituted a synchronous video platform (Zoom Meetings) for telemedicine visits	All patients within Florida assumed to travel round-trip by car from their home addresses to MCC. Addresses were geocoded to calculate driving distance using the Buxton Company's analytics platform. CO2 emissions savings for vehicle travel were estimated using the EPA emissions calculator, with emissions per mile ranging from 386 g to 435 g.	Patient travel [kg CO2: 3]	Patients within a 60-minute driving distance from MCC saved over 1 million round-trip miles through telemedicine, resulting in 424,471 kg of CO2 emissions savings. Each visit saved an average of 48.1 miles and 19.8 kg of CO2 emissions. For those living more than 60 minutes away, approximately 6.7 million miles were saved, corresponding to 2,744,248 kg of CO2 emissions savings. Each visit for these patients saved an average of 239.8 miles and 98.6 kg of CO2 emissions. Patients living over 60 minutes away had about six times more CO2 emissions savings. Using different emissions per mile estimates, savings ranged from 398,651 to 449,257 kg for patients within 60 minutes and 2,577,323 to 2,904,496 kg for patients living over 60 minutes away	***Place of residence:*** Subgroups divided based on driving time of 60 minutes or less vs greater than 60 minutes for further analysis to determine CO2 emissions saved between the 2 groups [See CE column]. ***Race/ ethnicity:*** 1685 (7.8%) were for Black patients, 1500 (7.0%) for Hispanic patients, and 16 010 (74.5%) for non-Hispanic White patients		C1>C2 (N)							Patient petrol saved C1>C2 (N)	Patient electricity and energy use, equivalent carbon sequestration (tree seedlings grown/10 years and acres US forests/1 yr

Specialty	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Feature	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient travel	Patient costs	Patient time	Time to referral	Attendance/Can	Adverse	Cost to	Other outcomes	Outcomes with no comparative
Oncology	Thota 2020: USA [Telehealth oncology clinic: Sevier Valley Hospital linked to tertiary medical centre](79)	Can telehealth between a tertiary cancer centre and rural health systems improve access to cancer care, decrease financial burdens, save time for patients with cancer living in rural Utah, and support local health delivery systems?	Observ.: retrospective cohort: C1 Telehealth vs C2 F2F [119 patients, 1025 encounters]	Cancer: Diagnosis - Malignant Haematology: 18%, Solid tumours, local: 23%, Solid tumours, Metastatic: 35%, classical haematology: 24%	Patients seen by medical oncologists, certified oncology nurses, and other subspecialists and ancillary staff via TH. Sustaining TH: Identify local providers to manage cancer care with support from a consulting oncologist, arrange TH enabled clinic rooms for synchronous video-based calls between tertiary and rural-based facilities, collaborate with patient navigators, social workers, palliative care, and cancer network services, ensure nearby and adequate emergency medical support, Support ongoing evaluation and treatment with local laboratory, radiology, and infusion services, provide ongoing administrative support to ensure compliance and implement regulatory changes, safely administer chemotherapy and immunotherapy under supervision of certified oncology nurses and oncologists	Travel hours and mileage saved calculated using Google Maps to estimate driving distance from Sevier County to IHC oncology facility emissions calculated using data from US Environmental Protection Agency, which calculates driving 1 mile=404 g carbon emissions[15] (based on average 8,887g CO2 generated/gallon gasoline and 22.0m travelled/ gallon consumed for typical passenger vehicle[15]	Patient travel [kg CO2: 3]	Intervention reduced carbon emissions by approximately 150,000 kg for 119 patients over 4-year period	NR		C1>C2 (N)	C1>C2 (N)					NCD		SP

Specialty	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Feature	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient travel	Patient costs	Patient time	Time to referral	Attendance/Can	Adverse	Cost to	Other outcomes	Outcomes with no comparative
Gynaecology	Mojdehbakhsh 2021: N [GynOnc Carbone Cancer Center clinic at University of Wisconsin School of Medicine and Public Health](71)	Within 1wk of initial intervention, convert min 50% of all F2F outpatient encounters to TH, 100% documentation of TH consent in providers' notes 3) Elicit patient feedback regarding TH and determine potential impact on patient care. 4) Calculate amount of CO_2 emissions prevented	Observ.: Cross-sectional: C1 Telehealth vs C2 F2F [192, Of which 113 responded (217 encounters)]	NR: Based on 192. Mean age 63,42 (SD 13.26). Primary Cancer site: Uterus 80 (41.7%), ovary 62 (32.3%), Fallopian tube 13(6.8%), cervical 11(5.7%), vulva/vagina 5(2.6%), peritoneum 4(2.1%), GTN 2(1.0%). Stage: one 72(37.5%), two 17(8.9%), three 47(24.5%), five 27(14.1%).	Using PDSA cycles, initial intervention agreed upon at meeting of GynOnc physicians. Meeting topics included: institutional TH platform, location of instructions and available support; visit coding in EHR, time & consent documentation; workflow to transition encounters to TH using visit schedulers. **Initial intervention**: all GynOnc providers convert appropriate surveillance visits to TH format through clinic scheduler. 1wk after, data analysed and fell short of primary and secondary aims, therefore second PDSA cycle implemented with more intervention over a two-day period, including: 1) APPs and nursing staff leading conversion to TH visits with physician approval; 2) implementation of standardized TH note template; 3) additional review of coding in EHR, time and consent documentation	Distance from patient's home address to the Carbone Cancer Clinic calculated and multiplied by two to represent round trip estimate of number of miles saved by conducting telemedicine visit. This number= 15,511.8 miles for sample of 192 patients. Using EPA's estimate of 4.03 x10-4 metric tons of CO_2 emissions/mile driven in an average passenger vehicle	Patient travel [metric tons of CO_2e emissions: 3]	6.25 metric tons of CO_2 emissions prevented by patients during 4wk study period	NR	NCD	TH (N)					NCD			PSn, Cl.E, PS

Specialty	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Feature	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient travel	Patient costs	Patient time	Time to referral	Attendance/Can	Adverse	Cost to	Other outcomes	Outcomes with no comparative
Gastroenterology	King 2023: UK [GE outpatient appointments 11 NHS Trusts across the South East UK analysed (5 tertiary centres and 6 non-tertiary centres)](52)	Calculate true reduction in CE resulting from transition to virtual consultations during global pandemic and assess safety compared with F2F consultations	Observational: Retrospective cross-sectional: C1 Telehealth vs C2 F2F [2140, F2F 1081 (only 756 analysed for CE outcome), Virtual: 1059 (only 1055 analysed CE data)]	NR: Total 2140: F2F Median age 53 (IQR 39-67,) 59.8% f. Centre: Tertiary 486(45%), non-tertiary 595 (55%). Virtual Median age 52 (IQR 37-67), 57% f. Centre: Tertiary 474 (44.76%), non-Tertiary 585 (55.24%)	NR	Distance travelled: estimated using shortest route from patient's home to hospital, assuming return trip. Carbon emissions from cars and taxis based on national average (146.5g/km), while motorbikes assumed to emit 116.7g/km. Public transport emissions not included as not impacted by patient attendance. For VC, emissions from infrastructure and VC services considered, with telephone-only clinics assuming higher emissions from mobile phone calls. Consultation durations adjusted to 20mins to minimize underestimation of emissions for group 2 appointments	Patient travel, software [kg CO2e: 2 and 3]	Overall reduction of 1159.92kg CO2e (99.37%; p=0.0001). No sig. difference in kg CO2e between non-tertiary and tertiary sites overall (group 1: p=0.62, group 2: p=0.95) or when adjusting for no. appointments (group 1: p=0.45, group 2: p=0.89)	NR						C1<C2(S)	C1<>C2(S)j			

Specialty	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Feature	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient travel	Patient costs	Patient time	Time to referral	Attendance/Can	Adverse	Cost to	Other outcomes	Outcomes with no comparative data
Gastroenterology	Sillcox 2023a: USA [Bariatric surgery clinic](74)	Hypothesized telemedicine would decrease carbon emissions, improve patient compliance with appointments, and decrease overall preoperative evaluation time to surgery	Observ.: before and after C1 Telehealth vs C2 F2F [106, 51 F2F, 55 TH]	Bariatric surgery: F2F: Average age 44.5(range 25.8-66 years). 18 underwent RYGB, 42 (82.3%) F. Telemedicine: Average age 46(range 28-68 years), 32 (58.2%) underwent FYGB, 49(89%)F	Preop. visits with dietician, mental health provider, or bariatric surgery provider were classified as in-person or telemedicine. Telemedicine visits: clinic appointments completed remotely using AV conferencing. Each of our patients seen in-clinic at least once by surgeon preop.	Estimated CO2 emissions for each visit determined using EPA) formula [15] of 404g CO2/mile. Assumed patients drove to clinic from primary address. GHG emissions from TH use assumed to be small compared to emissions from vehicle travel and main focus was on estimated GHG emissions reduction due to personal vehicular travel differences	Patient travel [kg CO2: 3]	In-person visits:145 patient travel distances recorded-median [IQR] 29.5 [13.7, 85.1] miles resulting in 38.22–39.61 kgCO2-eq emitted. For telemedicine visits, mean (SD) visit time: 40.6 (17.1) min. Telemedicine GHG emissions ranged from 2.26 to 2.99 kgCO2-eq depending on device used. In-person visit=25X more GHG emissions vs telemedicine visit (p<0.001)	NR		C1>C2 (S)			evaluation to OR/surgery >< (S)	C1<>C2(S)	>< (N)			

>< = no difference/ no detrimental effect, C1 > C2 = Analysis favoured Comparator 1 over C2, C1<> C2 = both comparator favoured in some scenario. a=263 scans. b=of 389 eligible, c=Service provided an immediate saving to commissioners of £6060, but this excludes the blood sampling costs in primary care. Generating a definitive estimate of cost saving for the tele-clinic project has proved challenging due to the way that activity and costs are recorded in secondary care. Isolating the total specific costs for a face-to-face clinic versus a teleclinic not possible d=of 51 consultations, e=Based on treatment/appointment duration, f=52 provided patient experience feedback, g=Threshold at which tele-ENT became cheaper than travel was workload of 35 patients/yr. Actual workload during pilot study=29 patient/yr, h=Of 329 approached, i=Numbers for primary site of disease don't add up for 100 surveyed, j=For 90 day admission/mortality rate. Favours F2F for no.blood test requests after appointment. AC=Acceptability, ACY=Acceptability, ACS=N.new patients accessing/Accessibility, AD=Appointment Duration, AE=Adverse Events/patient safety, APP=Advanced Practice Providers, AT=Attendance, AV=Audiovisual, BMI=Blood Mass Index BP=Blood Pressure, BTC=Blood Tests ordered Correctly/Available, C1=Comparator 1, C2=Comparator 2, CE=Carbon Emissions, CKD=Chronic Kidney Disease, Cl.E.=Clinical Effectiveness, CNS=Central Nervous System, CO2=Carbon Dioxide, CS=Clinician Satisfaction, CT=Can't Tell, DD=Discharge Destination, DSL=Digital Subscriber Line, EHR=Electronic Health Record, ENT=Ear, Nose and Throat, EPA=Environmental Protection Agency, ESWL=Extracorporeal Shockwave Lithotripsy, F2F=Face-to-Face, GHG=Greenhouse Gas, GI=Gastrointestinal, GP=General Practitioner, HF=Heart Failure, HR=Hazard Ratio, HR=Heart Rate, IQR=Interquartile Range, ISU=Inappropriate Service Use, K=Potassium, LVEF=Left Ventricular Ejection Fraction, MDT=Multi-disciplinary Team, N=Number, N=Narrative synthesis, NA=Not Applicable, NCD=No Comparative Data, NP=Nurse Practitioner, NR=Not Reported, NS=Not specified, O+T=Orthopaedics and Trauma, PH=Patient Health, PSa=Patient Safety, PF=Physical Functioning, PPL=Patient Productivity Loss, PU=Patient Understanding, PCN=Percutaneous Nephrolithotomy, PDSA=Plan Do Study Act, PS=Patient Safety, PSn=Patient Satisfaction, SBP=Systolic BP, S=Statistical analysis, SC=Service/staff costs, SP=Service Profit, TC=Telephone Call, T2DM=Type 2 Diabetes Mellitus, TH=Telehealth, TR=Time to Referral, TS=Time to Surgery, UA=Urgent Admissions, URS=Ureteroscopy, USD=US Dollars, VC=Video/Virtual Consultations, VDSL=Very High Speed Digital Subscriber Line, VHA=Veteran's Health Administration. 1=Department of Industry, Innovation and Science. PSMA Geocoded National Address File (G-NAF), https://data.gov.au/dataset/19432f89-dc3a-4ef3-b943-5326ef1dbecc 2=United States Environmental Protection Agency. Greenhouse Gas Emissions from a Typical Passenger Vehicle, https://www.epa.gov/greenvehicles/greenhousegas-emissions-typical-passenger-vehicle (2018, accessed June 2018). 3= UK Government. Greenhouse gas reporting: conversion factors 2020: condensed set (for most users). (2020). Accessed: November 2, 2022: https://www.gov.uk/government/publications/greenhouse-gas-reportingconversion-factors-2020 4=Curtis A, Parwaiz H, Winkworth C, et al.: Remote clinics during coronavirus disease 2019: lessons for a sustainable future. Cureus. 2021, 13:e14114. 10.7759/cureus.14114, 5=Manchester University NHS Foundation Trust. Code green: delivering net zero carbon at MFT . (2022). Accessed: Novemeber 2, 2022: https://mft.nhs.uk/app/uploads/2022/02/MFT-Green-Plan_V1.0.pdf .6=Driver and Vehicle Licensing Authority. Vehicle Licensing Statistics: 2013. London: Department for Transport, 2014 7= Kmietowicz Z. NHS hits target on reducing carbon emissions. BMJ 2016; 352: i587 8=Trees for the Future. Carbon tree plantation calculator, 2018. Available at: www.trees.org. Accessed March 2019. 9= Waddingham P. Environmental and Social Sustainability in NHS Innovation toolkit, 2021, Yorkshire and Humber Health Sciences Network. 10=Privately owned vehicle mileage reimbursement rates. Available at: http:// www.gsa.gov/portal/content/100715. Accessed March 9, 2015. 11=Passenger vehicles per year. Available at: http://www.epa.gov/cleanenergy/ energy-resources/refs.html. Accessed May 13, 2015. 12=Greenhouse Gas Emissions From a Typical Passenger Vehicle. 2018. https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle. 13=

Specialty	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Feature	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient travel	Patient costs	Patient time	Time to referral	Attendance/Can	Adverse	Cost to	Other outcomes	Outcomes with no comparative
International Energy Agency. Fuel Economy in Major Car Markets: Technology and Policy Drivers 2005–2017; International Energy Agency: Paris, France, 2019 14=Department for Environment, Food and Rural Affairs. Act on CO2 Calculator: Public Trial Version. London: DEFRA, 2007. 15=US Environmental Protection Agency: Greenhouse gas emissions from a typical passenger vehicle. Office of Transportation and Air Quality 2018; https:// nepis.epa.gov/Exe/ZyPDF.cgi?Dockey5P100U8YT.pdf.																			

Speciality	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Patient features	Intervention description	CE calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient travel/ Distance to point of care
Renal	Asghari 2020: Iran/ France [Renal home health service](109)	To improve classic pickup and delivery models, make them more useful for decision-makers to enhance performance of sharing operations while serving customers with timely home health services and provides the individuals a compact source of income	Modelling: C1 - care equipment delivery vs C2 - NA [13]	Renal failure: Patient's receiving HHM	System objective: determine optimal configuration of routes, vehicle types, and delivery sequence/pickups to satisfy patients' needs while minimizing total costs of item sharing system and reducing carbon emissions from vehicles. System supplies Home Health Monitoring (HHM) devices either from central depot or from individual owners. In sharing economy model, individuals who own HHM devices can participate in home health care system by sharing their devices through company's fleet, earning income. After delivering portable HHM devices to patients, they are collected, disinfected, and reallocated other customers. The Systematic Depot Pickup Problem is comprehensive model where company aims to serve kidney patients with limited set of portable haemodialysis machines using fleet of vehicles. Patients' requests, time windows, and individual HHM pickup time windows and max. rental time received in advance. Key differences between depot and individuals include depot being compulsory starting point for fleet tour, while individuals are not necessarily starting point. Picking up HHMs from individuals incurs renting costs based on rental period, unlike depot. Patients typically need HHMs for a few hours (≤2 h) and used HHMs picked up by vehicles can be prepared for the next use after necessary disinfection and safety checks. Distribution involves mixed sequence of pickup-delivery activities, where vehicles can visit nodes multiple times	Optimization model aims to minimize company's total loss by reducing transportation costs, including fuel consumption and penalty costs, while minimizing total carbon emissions from vehicles. Model utilizes linear mathematical formulation solved by fuzzy aggregated method and meta-heuristic approach called self-learning NSGA-II for medium- and large-sized problems. The self-learning aspect adjusts probabilities based on changes in fitness function value. Sensitivity analysis compares different approaches. For detailed assumptions/sets, see paper	Patient travel [CO2 per litre of fuel or km travelled, 3]	Sharing policy: 25% saving in total cost, and 21% drop in total carbon emissions. Effectiveness and applicability of proposed model demonstrated by computational results on real case. Tests confirm economic and environmental benefit of scarce delivery-pickup platform significantly profits from economies of sharing in both solution techniques	NA	

Radiology	Bond 2009: UK [Norfolk and Norwich University Hospital NHS Trust, 2xhospitals& mobile units](41)	Compare distances travelled by patients attending mobile breast screening clinics compared to distance travel if screening services were centralized	Observ. Retro-spective data-base review: C1 Mobile clinic vs C2 Central-ized care (hospital) [60675: 21415 hospital; 39260 mobile clinic, (valid postcodes obtained for 99.5%=60372))]	Breast cancer screening: NR	Breast screening service provided by the Norfolk and Norwich University Hospital NHS Trust. Breast screening in central Norfolk provided at 2Xxhospital sites in Norwich and 20 dispersed locations by mobile units	Estimated carbon reduction benefits in terms of patients' journeys to existing services vs travel if no mobile services were provided. Anonymised records of attendances for breast screening over 2004–2006 examined (contained person's postcode, clinic attended, appointment date). Postcodes of 2xhospitals and locations of each mobile clinic obtained. Home address/ clinic postcodes converted into Ordnance Survey grid references and straight-line distance between home address and clinic attended and straight-line distance between each home address and closest of 2 hospitals calculated. Straight line distances increased by 20% account for approx. ratio of driving distances along road network vs straight line distances.[1,2] 2 distance estimates compared to identify savings in travel provided by mobile clinics. Carbon implications: assumed patients drove to appointment in cars with average emission of 167.2 g/km CO2.[3] (equivalent to emissions 2008 1.8 litre Ford Focus.[4] This figure must be offset by CO2 emitted through transport and servicing of mobile breast screening units. Range of distances driven use 1695–1977 ltrs diesel, converted to kg CO2 using factor developed by the US EPA of 2664.2g/itre of diesel.[5]	Patient travel, travel+ servicing of mobile breast screening unit [kg CO2, tonnes: 1,3]	Return journey distance: savings of 1,429,908km through use of mobile screening clinics=239 tonnes of CO2 over 3yrs.CO2 emitted through transport/servicing of mobile breast screening units: Range of distances driven use 1695–1977ltrs diesel: 4516–5267kg CO2. Thus, in 1 year, use of mobile screening units saves approx. 75 tonnes CO2	NR	C1>C22 (N)
Oncology	Forner 2021: Canada [Head and neck oncology clinic,	Estimate the carbon footprint savings associated with head and neck surgery outreach clinic	Cross-section-al survey: C1 Outreach clinic vs C2 Regional cancer centre) [118]	Head and neck cancer: Mean age 64.8yrs (SD: 13.2). Gender (N, %): Male: 76 (67.3), Female: 37	Regionalized advanced head and neck surgical oncology service, Outreach clinic: approx. 325 km from regional centre. Surgical outreach clinic held by attending surgeon from regional centre for new consultations and ongoing oncology surveillance, allowing patients living in province of PEI to access aspects of care intra-provincially. Pathology treated	NRC 1995-2020 Fuel consumption rate datasets for motorized vehicles accessed.12 Datasets contain make, model & year of vehicles with their associated fuel consumption rates (L/100	Patient travel, surgeon travel [CO2 emissions (grams) generated by their vehicles as a product of	Median distance participants homes to surgery outreach clinic: 29.0 km (IQR 6.0–51.9;). Median distance to regional centre: 327.0 km (IQR 309.0–337.0)=difference of 317.5 km (IQR 250.2–325.6). CE efficiency vehicles: mean 199.6 g·km− 1 (SD: 43.4) to	NR	

	Cancer Treatment Centre](100)			(32.7), Income Quintile (N, %): 1: (Lowest): 25 (23.4), 2: 38 (35.1), 3: 25 (25.2), 4: 13 (12.5), 5 (Highest): 3 (2.8), Missing: 2 (1.9) (Income Quintile n=107 = number of people used for carbon footprint analysis. Missing value due to inability to perform geocoding)	includes upper aerodigestive tract, thyroid, salivary gland, and cutaneous malignancies of head/neck. Only surgeon travels from regional centre to outreach clinic as all other necessary staff (e.g. nursing/ administrative) local	km). Rates generated using combination of data from vehicle manufacturers that incorporate standard laboratory testing and procedures to estimate fuel consumption rates of models. 13 The product of combined fuel consumption rate (L·100 km− 1) of each vehicle and amount of CO2 generated per ltre fuel (2300 g·L− 1) yields CO2 generated/km (g·km− 1) of travel; these values used to calculate carbon footprint as function of distance travelled. Two additional variables used to calculate specific CE yields but were unavailable in this study (engine size and number of cylinders). To accommodate this uncertainty, both lowest and highest available CE for each make, model, and year calculated and ranges provided. Postal code of each participant and surgical outreach clinic entered into Google Maps to calculate distance travelled Return trip distances travelled by each patient used to calculate/compare total vehicle CO2 emissions (g) as product of distance (km) and CE efficiency (g·km− 1). Average total annual CE savings: multiplying average CE difference/ person by expected no. patients/3-month period (approx. 100 patients) and multiplying by four	distance (kilometres) and CE efficiency (g·km-1): 3]	243.6 g·km− 1 (SD: 61.6). Median observed low estimate of CE: 10,411.2 g (IQR: 2267.2–21,254.4) vs expected estimate: 130,082.0 g (IQR: 107,724.0–149,960.0)=mean CE difference of 117,495.4 g (SD: 29,040.0). High estimate saved CE: 143,570.9 g (SD: 40,236.0). Extrapolating three-month period to an annual basis: CE savings of approx. 46,998,160 g. Total distance travelled by attending surgeon: 330.0km. CE efficiency: 211 g·km− 1, yielding carbon footprint of 69,630g/clinic. Across time of study, 3 clinics held= 208,890 g carbon emitted		

1=Williams AP, Schwartz WB, Newhouse JP, Bennett BW. How many miles to the doctor? New Engl J Med 1983;331: 958–63 2=Transport Direct .CO2 information. 2008. See http://www. transportdirect.info/Web2/staticnoprint.aspx?id=_web2_ help_helpcarbon (last checked 30 April 2008) 3=What Green Car. 2008. See http://www.whatgreencar.com/ news-item.php?Record-low-for-new-car-CO2-emissions (last checked 29 April 2008) 4=Vehicle Certification Agency. VED Calculator. 2008. See http://www.vcacarfueldata.org.uk/search/vehicleDetails. asp?id=17908 checked 29 April 2008) 14 5=US Environmental Protection Agency. Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel. Report No. EPA420-F-05-001. Washington, DC: EPA, 2005. A&E=Accident and Emergency, CF=Conversion Factor, CE=Carbon Emissions, CO2=Carbon Dioxide, EPA=Environmental Protection Agency, DEFRA=Department of Food and Rural Affairs, GH=GH, Interquartile Range, LSOA=Lower Super Output Area, MI=MI, NHS=National Health Service, N=Number, NCD=No Comparative Data, NR=Not Reported, NRC=Natural Resources Canada, Ppci=Primary percutaneous coronary intervention, SD=Standard Deviation, STEMI= ST elevation MI, UK=United Kingdom

Appendix H: Setting

Summary overview non-LCA studies - Setting

Speciality	Author date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition /procedure: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon emission findings	PROGRESS-PLUS	Patient Satisfaction	Patient Clinical outcome	Clinician Satisfaction	Service products saved	Savings in service product purchased	Service burden	Durability	Service costs saved	Service energy savings	Service waste saved	Social sustainability
Gastroenterology	Betts 2022: UK [Endoscopy Unit: Royal Cornwall Hospital](27)	1. Organize the unit and empower staff to recycle all sterile water bottles that are used on the unit daily 2. To change the CLO test reporting system to reduce waste and low value use of admin staff time	Experimental: Before and After; C1 - Waste management a: Sterile water bottle recycling b: Electronic CLO testing C2: Usual care [NA;NA'NA]	Endoscopy: Patients undergoing endoscopy	Waste management: We set up a recycling bin, ensuring there was one clear collection point for bottles each day. We discussed the change at morning safety huddles for one week, and laminated signs for all procedure rooms to remind staff and labelled the recycling bin point. We converted the electronic results already on our systems to a word document that could be emailed to GP practices	Tracked daily bottle recycling rates over 2wk period and projected annual savings. Carbon emissions from waste disposal were calculated using data from Rizan et al. CLO test usage over 3 months was analysed alongside consumable costs, including paper and postage. Paper emissions were determined using a weight-based approach, while postage emissions were estimated from financial data. Email substitution emissions were derived from overall paper savings	Water bottles: Waste disposal, CLO test results: use+ reuse [kg CO2e / year: 1]	Combined, the projects will save 921.44kg CO2e and £1,558.72, equivalent to driving 2,653.9 miles in an average sized car. Water bottle recycling saving: 362.548kg CO2e / year, Electronic CLO testing; 558.89 kg CO2e / year	NR		C1>C2 [N]						C1>C2		C1>C2	C1>C2 [N]

Speciality	Author date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition /procedure: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon emission findings	PROGRESS-PLUS	Patient Satisfaction	Patient Clinical outcome	Clinician Satisfaction	Service products saved	Savings in service product purchased	Service burden	Durability	Service costs saved	Service energy savings	Service waste saved	Social sustainability
Gastroenterology	Cunha Neves 2023: Portugal [Portimão endoscopy unit of Algarve University Hospital Centre](115)	To assess and compare the waste carbon footprint and waste processing expenses induced by endoscopic procedures (upper endoscopy and diagnostic colonoscopy	Experimental: Before and After; C1 - Waste management C2: Before intervention; [535:NR:NR]	Patients undergoing endoscopy. Before - 185 (85 upper endoscopies and 100 colonoscopies), 178 in 1 month after intervention (84 upper endoscopies and 94 colonoscopies) 4 months after: 172 (75 upper endoscopies and 97 colonoscopies)	1-week intervention was held. Entire endoscopy unit team (medical, nursing, and auxiliary staff) involved. Presentation of retrieved data from study's first stage and two seminars regarding waste handling, segregation, and disposal in endoscopy units. Additionally, recycling bins acquired at cost of approximately €60, labelled and placed within endoscopy rooms, and landfill and RMW bins were relocated to avoid landfill and RMW systematic misclassification	CO_2e used as measurement unit to calculate waste carbon footprint. Equivalence of 1kg of landfill waste to 1kgCO_2e and 1kg of RMW to 3 kgCO_2e applied	Waste disposal [kgCO_2e: 1]	Preintervention versus 1 month after intervention - An overall reduction of the waste carbon footprint of 31.6% (138.8 kg CO_2e) was obtained (109.7 kg CO_2e vs 74.9 kg CO_2e, $p=0.018$), corresponding to a waste carbon footprint's yearly reduction of 1665.6 kg CO_2e (figure 4). One month after intervention versus 4 months after intervention. Mean waste carbon footprint (74.9 kg CO_2e vs 71.7 kg CO_2e, $p=0.841$)	NR			C1>C2 [N]					C1>C2 [S]		C1>C2	

Gastroenterology	Owens 2023: UK [Endoscopy unit Swansea Bay University Health Board](40)	1. To reduce printing and paper use in the Endoscopy department by transitioning to electronic ways of working; 2. To redirect Contrast waste from sharps (incineration) disposal to be recycled	Modelling; C1 - Multiple: Setting; C2 - Usual care [NA]	Endoscopy: Patients undergoing endoscopy	1a Paper reduction: - Proposed giving patients links to online leaflets instead of printing information. Considered transitioning to electronic endoscopy reports, Patient follow-up and care pathways were ensured. - Patients notes: Electronic reporting system uploads to the WCP. Endoscopy images made available on WCP. Histology and referring consultant: Encouraged registration for WCP alerts instead of printing reports. Patient and GP: Encouraged registration for digital access to reports and results, trialling digital alerts for practices unable to access WCP. - utilizing confidential waste disposal for printed reports with errors., Introduced electronic submission of post-procedure questionnaires. 1b Established a process for recycling contrast by sending it back to the supplier in recycling pots instead of disposing of it in sharps bins	An emissions factor for one A4 piece of recycled paper (0.003 kg CO_2e) was provided by our paper supplier, Steinbeis. To calculate savings from ink, we used an emissions factor based on pounds spent from the Small World Consulting Database of 0.392 per pound spend, provided by CSH (this database is not publicly available). The CO_2e for one piece of paper printed with double-sided ink is 0.0284 kgCO_2e. For patient questionnaires, we assumed that it takes patients 5 minutes for a patient to fill out questionnaire on an iPad to calculate the energy consumption of this, using the emissions factor for energy from the Government Database	Waste prevention + disposal [kg CO_2e: 1]	i) Patient information leaflet - Saving: 142.5 double sided pages per week = 4.047 kg CO_2e ii) Endoscopy reports - Saving: 450 double sided pages printed per day = 12.78 kg CO_2e - Saving per week: 63.9 kg CO_2e iii) Patient questionnaires 360 double sided pages printed = 10.224 kg CO_2 - 360 questionnaires completed on iPad = 0.25 kg CO_2e - Saving per day = 9.974 kg CO_2- Saving per week = 49.87 kg CO_2e Total reduction per week: 117.8 kg CO_2e. Projected across a year across the three units, we could save 6,126.48 kg CO_2e per year (2,042.16 kg CO_2e per unit). 1b) Recycling of contrast. We estimate a reduction of 19.5kg / year (0.0195 tonnes / year). This equates to a saving of 21 kg CO_2e / year. Our project combined will save 6,147.48 kg CO_2e per year, equivalent to driving 17,705.9 miles in an average car	NR	C1>C2 [N]							C1>C2			

Speciality	Author date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition /procedure: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon emission findings	PROGRESS-PLUS	Patient Satisfaction	Patient Clinical outcome	Clinician Satisfaction	Service products saved	Savings in service product purchased	Service burden	Durability	Service costs saved	Service energy savings	Service waste saved	Social sustainability
Gastroenterology	Yong 2022:UK [Three hospital sites of the Imperial College Healthcare NHS trust, London (St Mary's, Charing Cross and Hammersmith Hospitals)](61)	Determine whether combining multiple small colorectal polyps within a single specimen pot can reduce carbon footprint, without an associated deleterious clinical impact	Observ.: retrospective C1: Single pot vs C2: multiple pots [2502 procedures performed where 5125 polyps removed]	Patients receiving lower gastrointestinal endoscopy-polyps removal. 610 procedures (1281 polyps) performed as part of the Bowel Cancer Screening Programme (652 (1456 polyps) as a part of surveillance, while 1240 (2388 polyps) were for the investigation of GI symptoms	Multiple pots - Sending colorectal polyps resected during endoscopy as separate samples. Single pots - We determined that a number of pot usage if all polyps less than 10mm were placed within a single colonic segment (rectum, sigmoid, descending, splenic flexure, transverse, ascending and caecum), hemicolon (right hemicolon: caecum to ascending colon; left hemicolon: hepatic flexure to sigmoid and rectal) or throughout the colon	Estimates of the carbon footprint were based on previous work in this area, which described the processing of a single pot with an emission of 0.28 kgCO2e.5 Our local pathway from tissue processing to production of histology report was in accordance with the Royal College of Pathology Tissue Pathway. Statistical analysis was performed by using IBM SPSS Statistics for Windows, V.28.0 (IBM). A p<0.05 was considered statistically significant. Descriptive statistics were used to report the data. The statistical significance in reduction in carbon footprint by putting all small polyps in whole colon was analysed with Z test	Waste prevention [kgCO2e:1]	Reduction in pot usage would have resulted in a reduction in carbon footprint to 572 kgCO2e, 490 kgCO2e and 289 kgCO2e, respectively. The reduction in carbon footprint by putting all small polyps in a pot for the whole colon, in comparison with one pot per hemicolon was statistically significant (p<0.00001), as was the comparison between placing in segmental distribution versus hemicolon distribution **PROGRESS-PLUS:** ***Age:*** Mean age of patients with detected polyp: 63.9yrs (range 24-96yrs) Other outcome: Fidelity to clinical process: C1 <> C2											C1>C2	

Speciality	Author date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition /procedure: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon emission findings	PROGRESS-PLUS	Patient Satisfaction	Patient Clinical outcome	Clinician Satisfaction	Service products saved	Savings in service product purchased	Service burden	Durability	Service costs saved	Service energy savings	Service waste saved	Social sustainability
Renal	Bird 2022:UK [Renal transplant department](28)	Measure environmental, social & financial benefits of new postal system compared with old postal system	Modelling C1: Waste management - Changing composition of patient blood test kit C2: Usual care [30:30:NR]	Renal transplant or dialysis: Patients awaiting renal transplant or simultaneous kidney and pancreas transplant	Use of lightweight, recyclable plastic pouch with pre-paid postage labels, eliminating the trip to the post office (in favour of closest post box) to convenience of patients	A process-based carbon foot printing analysis was used to estimate the carbon footprint of both kits (blood tests were the same in both kits and therefore excluded from analysis). Data on type of material taken from product specification sheets, and each material weighed. Assumed both kits disposed of in domestic waste. Carbon emission factors for waste disposal taken from recent study from Rizan (2021) looking at carbon footprint of waste streams in a UK hospital. Financial data was used to estimate the carbon emissions associated with postage. Looked only at the emissions associated with sending kits from hospital to patient only	Use+ reuse+ transport to patient +waste disposal [kg CO2e: 1]	The total emissions per test (kit + postage) were reduced by 5.495 kgCO2e. Extrapolated across a year with average of 30 low clearance/pre-dialysis clinic patients requiring 3 monthly blood tests, annual total of 222 blood tests, this is a saving of 1219.9 kgCO2e	NR	C1>C2 [N]	><	C1>C2 [N]					C1>C2			

Speciality	Author date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition /procedure: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon emission findings	PROGRESS-PLUS	Patient Satisfaction	Patient Clinical outcome	Clinician Satisfaction	Service products saved	Savings in service product purchased	Service burden	Durability	Service costs saved	Service energy savings	Service waste saved	Social sustainability
Renal	Milne 2010:UK [Maidstone dialysis unit](38)	Investigated the potential costs and benefits of retrofitting heat exchangers to their existing Braun Dialog+ haemodialysis machines	Modelling C1: Heat exchangers; C2: Conventional care [NA]	Patients receiving haemodialysis treatment	Heat is recaptured from the dialysis effluent ('used' dialysate) and transferred to the incoming dialysate, warming it up before it enters the heater and thereby saving energy and reducing the environmental impact of a haemodialysis treatment. The renal technicians at the Maidstone dialysis unit decided to investigate the possibility of retrofitting heat exchangers to their existing machines. Retro-fit heat exchanger kits for Braun Dialog+ machines can be fitted by most renal technicians in less than half an hour	Assuming each machine is used twice daily, six days a week for 52 weeks of the year, an annual power saving of 536.64 kWh per machine (2 * 6 * 52 * 0.86) is predicted	Use+ reuse [tonnes CO2e: 2]	Applying a conversion factor of 0.50748 kg CO2 equivalents per kWh, this in turn equates to an annual saving of 272.33 kg (0.272 Tonnes) of CO2 equivalents per machine per year. For the 83 machines across the Kent and Canterbury renal service, this equates to an annual power saving of 44,541 kWh and an annual carbon saving of 22.6 Tonnes of CO2 equivalents	NR								C1>C2	C1>C2		

Speciality	Author date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition /procedure: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon emission findings	PROGRESS-PLUS	Patient Satisfaction	Patient Clinical outcome	Clinician Satisfaction	Service products saved	Savings in service product purchased	Service burden	Durability	Service costs saved	Service energy savings	Service waste saved	Social sustainability
Renal	Milne 2023:UK [East Kent Renal Service](37)	Investigate the possibility of retro-fitting heat exchangers to their existing machines	Modelling C1: Heat exchangers; C2: Conventional care [NA]	Patients receiving haemodialysis treatment	Retrofit of heat exchangers to 52 machines across East Kent renal service	Assuming each machine is used twice daily, six days a week for 52 weeks of the year, an annual power saving of 536.64 kWh per machine (2 * 6 * 52 * 0.86) is predicted	Use+ reuse [tonnes CO2e: 2]	Applying a conversion factor of 0.50748 kg CO2 equivalents per kWh, this in turn equates to an annual saving of 316.5 kg (0.3165 Tonnes) of CO2 equivalents per machine per year. For the 52 machines retrofitted across the Kent and Canterbury renal service, this equates to an annual power saving of 27,905 kWh and an annual carbon saving of 16.46 tonnes of CO2 equivalents. Although the manufacture of heat exchangers incurs a carbon cost in itself, this is estimated to amount to less than one percent of the carbon savings derived from the improved energy efficiency in the first year of use alone	NR								C1>C2	C1>C2		

Speciality	Author date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition /procedure: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon emission findings	PROGRESS-PLUS	Patient Satisfaction	Patient Clinical outcome	Clinician Satisfaction	Service products saved	Savings in service product purchased	Service burden	Durability	Service costs saved	Service energy savings	Service waste saved	Social sustainability
Radiology	Buttner 2021: Germany; [University department (three major university campuses and several smaller hospitals)](90)	Investigate if switching off workstations after core working hours can lower energy consumption considering both ecological and economical aspects	Cross-sectional/ modelling C1: Energy savings - a: Switching off workstations outside core working hours; b: Reduced working workstations outside normal working hrs C2: Usual care [NA;NA'NA]	NR:NA	The energy consumption of reading workstations was measured, comprising a desktop computer, two medical-grade diagnostic monitors, and a third monitor for the radiology information system. Various theoretical work scenarios were extrapolated based on measurements and shift planning. C1a: Workstations being turned on during the 9 -h core working time 5 days a week between 7.30 a.m. and 4:30 p.m. and then turned off..., users were briefed to switch off the workstations after core working hours. In addition, reminders were attached to the workstations to shut them down at the end of the working day. C1b: All radiology workstations are switched on during 9h core working hours (7:30 a.m. to 4:30 p.m.). After core working time, most of the workstations are turned off, only 15 workstations remain on for late shift (4:30 p.m. to 10 p.m.), 6 workstations for night shift (10 p.m. to 7:30 a.m.), and an additional 6 workstations for 24 -h shifts at weekends and on national holidays	The reading workstations, comprising a desktop computer, two medical-grade diagnostic monitors and a third monitor for the radiology information system (RIS), had their power consumption measured in watts. Extrapolations for various work scenarios were made based on these measurements and shift planning. Ammeters were installed at three workstations for continuous power consumption measurement over 6 months, with users subsequently briefed to switch off workstations after core hours and reminders attached. The measured energy consumption was extrapolated to calculate total annual consumption for all 227 workstations. The cost difference and CO2 emissions were also estimated based on current electricity prices and the country's energy mix. Startup and standby mode times were measured, and personnel costs resulting from manual restart waiting time were calculated based on hospital salary tables	Use+ Reuse [Tonnes of CO2: 2]	For C2, annual emission was 123.0 tons of CO2 emissions. C1a would reduce kWh consumption to 31.8 tons of CO2. C1b would reduce emissions to 35.3 tons of CO2), a reduction of 71.3% compared to scenario 1. This scenario is considered to be ideal and feasible for radiology departments. After briefing users to switch off the workstations after work, extrapolated consumption would be 102,871.7 kWh/year (see Fig. 2), resulting in a saving of 2,100.7 USD and 3.2 tons of CO2. Potential saving in the ideal but realistic situation (C1b) would be an additional 35,970.69 kWh (see Fig. 2), meaning a further reduction of 35.0% or 19.0 tons of CO2. Compared to our initial situation, in total, the power consumption of our workstations could be reduced by 38.6%, accordingly 22.2 tons of CO2 emissions could be avoided	NR								C1>C2	C1>C2		

Speciality	Author date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition /procedure: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon emission findings	PROGRESS-PLUS	Patient Satisfaction	Patient Clinical outcome	Clinician Satisfaction	Service products saved	Savings in service product purchased	Service burden	Durability	Service costs saved	Service energy savings	Service waste saved	Social sustainability
Radiology	Heye 2023: Switzerland [Tertiary care radiology department](117)	Identify idle energy consuming imaging modalities and electronic devices in a hospital setting to reduce energy consumption and CO2 emissions	Prospective cohort C1: Energy saving C2: Before intervention; [NA;NA'NA]	NA	From Oct - Dec2022, monitored 60 medical imaging systems, including CT, MRI, PET/CT, radiography, angiography, and ultrasound units, along with 80 PACS workstations, 165 personal computers, six smart monitors, and 53 printers. Using a self-developed Python script, the network status of each device was automatically tracked in 15-minute intervals by pinging their respective IP addresses or DNS host names. Data on client names, network statuses, and timestamps were recorded in a database and visualized using live dashboards or business intelligence software. Live dashboards were provided to department staff, showing devices left on during off-hours and potential energy, cost, and CO2 emission savings. A workflow was established to power down devices not in use during off-hours, including nights and weekends	A self-developed Python script designed to track activity of devices by querying network status (online vs offline) at 15-minute intervals using their IP addresses or DNS host names. This script records client names, network statuses, and timestamps in a database and visualizes the data using live dashboards or business intelligence software. Energy consumption of devices measured using in-house power meters, and savings calculations based on national-specific carbon intensity of 0.128 kg CO2 equivalent per kilowatt-hour	Use+ reuse [Metric tons CO2 emissions: 3]	The realized per-year energy savings was 72 337 kWh, representing $19 531 in energy costs in 2022 ($60 937 in 2023) and 9.26 metric tons in CO2 emissions	NR								C1>C2	C1>C2		

Radiology	Klein 2023: Germany [1) Energy optimized medical centre with different clinical disciplines and radiology practice, 2) Open MRI practice](91)	We examined ways to improve energy efficiency in radiology by using regenerative and energy-friendly technology in the construction & operation of two radiological facilities	NR: C1: Energy optimised medical centre C2: Open MRI practice/Practice for low-field MRI C3: Medical centre without regenerative technology [NA;NA'NA]	NA	C1: In 2009-2010, an energy-efficient medical center was constructed, featuring a 29.92 kWp photovoltaic system and a heat exchanger for thermal energy recovery. It housed various clinical disciplines, including a radiology practice with a 1.5 T MRI machine and a CT scanner.in 2012, a four-floor building was built to accommodate various medical services, meeting German Energy Saving Ordinance regulations. The radiology practice in this building utilized a CT scanner, ultrasound equipment, and a 1.5 T MRI machine, with heat recovery for building heating. C2: In 2019, an energy-efficient open MRI practice was established nearby. It featured a 0.35 T open MRI machine powered by a permanent magnet, along with a photovoltaic system and a 10 kWh lithium-ion battery for sustainable energy production. Additionally, a photovoltaic array was installed on the building's roof	Energy consumption and production processes were documented for all types of centers, with a focus on carbon emissions associated with these processes. Energy consumers included heating/air conditioning, radiology equipment (1.5 T MRI, 0.35 T MRI, and CT), and data processing systems, while energy producers included heat exchangers and photovoltaic systems. Electricity and gas consumption data were collected for the medical center, while energy monitoring for the open low-field MRI practice was conducted using electronic measuring equipment. Consumption values were measured for various operating states of the components, with the generation of carbon dioxide (CO2) used as a parameter for energy efficiency. Normalization to CO2 generation was applied to electricity, gas consumption, and thermal energy variables for comparative analysis	Use [kg CO2e: 2]	Energy optimization of the medical center resulted in an annual CO2 reduction of about 54% from 153,146 to 70,631 kg/year. See full text for more info	**NR**								**C1>C2>C3**	**C1>C2>C3**		

Speciality	Author date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition /procedure: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon emission findings	PROGRESS-PLUS	Patient Satisfaction	Patient Clinical outcome	Clinician Satisfaction	Service products saved	Savings in service product purchased	Service burden	Durability	Service costs saved	Service energy savings	Service waste saved	Social sustainability
Radiology	McCarthy 2014: Ireland [University teaching hospital, Dublin](108)	We sought to perform an energy audit of our department to identify where savings could be made. We re-audited the energy use 18 months after an educational session within the department	Before and After; C1: Energy conservation C2: Before intervention [NA;NA'NA]	NA	Results of 1 week energy audit presented at a departmental teaching session	The energy consumption throughout the department was measured using a power monitor. Electrical energy usage during overnight hours on weekdays (5pm to 8am) and throughout weekends (from Saturday 8am to Monday 8am) was calculated, totalling 6396 hours annually. In cases where connecting the monitor to a device was not feasible, technical manuals were consulted instead. Monitoring of computers and monitors left on at 6.30pm during a one-week period allowed for estimation of annual power consumption when not in active use. Air conditioner status was also observed during this time. Central air conditioning in other areas could not be measured or turned off. Additionally, air conditioning units in conference rooms were frequently left running. Technical manuals for these units were obtained, and the average power consumption was documented	Use+ reuse [metric tons of CO2 equivalent : 2]	From desktop computers left on overnight/weekends /both: estimated greenhouse emissions of 17.7 metric tons of CO2 EQ, similar to emissions from 3.7 passenger cars. From PACS reporting stations left on overnight/at weekends/both: 33.5 metric tons, CO2, equivalent to annual emissions of 7 passenger cars. Overnight operation of two air con units: 26.2 metric tons of CO2e, similar to emissions of 5.5 passenger cars/year. Follow up audit indicated a slight increase to number of PACS workstations left on overnight	NR								NC	NC		

Speciality	Author date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition /procedure: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon emission findings	PROGRESS-PLUS	Patient Satisfaction	Patient Clinical outcome	Clinician Satisfaction	Service products saved	Savings in service product purchased	Service burden	Durability	Service costs saved	Service energy savings	Service waste saved	Social sustainability
Radiology	Woolen 2023; USA [Department of radiology and biomedical imaging, university of California, San-Francisco outpatient](82)	To determine the energy, cost, and carbon savings that could be achieved through different scanner power management strategies	Retrospective cohort C1: Energy saving C2: Normal hours [NA;NA'NA]	NA	C1a: COCIR self-regulatory initiative for the eco-design of medical imaging equipment was followed to identify the highest-impact energy modes to target for innovation (6). COCIR identified the nonproductive scanning periods as targets for MRI. The off mode was targeted for innovation. MRI unit 1 included a power-save mode. In MRI units 2–4 (i.e., the three scanners not equipped with power-save mode), the cold head compressor for individual MRI units was switched off for 30 minutes to measure the power consumption. The cold head compressor data were used to simulate the technique used with MRI unit 1 to evaluate the impact of implementing this capability on other systems. MRI Operations When Not in Use Scanner hours of operation were set in accordance with the COCIR report (6), which defined a typical outpatient day as having 12 overnight hours of non-use	To assess energy, cost, and carbon emission savings from low-power scanner modes during off hours, two standardized operational MRI models were examined. The first model involved 12 hours of non-use overnight daily, while the second model extended this to 48 hours during weekends. Power meters were installed in equipment rooms to monitor energy consumption continuously. Data collected from September 29 to November 1, 2022, and January 13–17, 2023, were analysed. Different power modes of the MRI scanners were assessed, including off, idle, prepared-to-scan, scan, and an Eco-Power mode. Nonproductive energy consumption also evaluated, with carbon emission savings calculated based on the U.S. national average carbon dioxide marginal emission rate using the AVERT tool	Use+ reuse [CO_2 tonnes equivalent : 2]	Scenario 1, where MRI units 1–4 were set to the lowest power mode for 12 hrs overnight- potential annual savings of 8.7–14.9 MTCO_2 eq. For switching from idle to off mode, with an additional 6.2–8.1 MTCO_2 eq for switching from off to power-save mode. Scenario 2, where units were set to the lowest power mode for 12 hrs overnight on weekdays and 48 hrs on weekends, potential annual savings were 11.2–19.2 MTCO_2 eq for switching from idle to off mode, with an additional 8.0–10.4 MTCO_2 eq for switching from off to power-save mode. Extrapolating these results, a department with 30 MRI machines turned off for 12 hrs overnight could save annually 260.9–447.2 MTCO_2 eq	NR						C1>C2		C1>C2	C1>C2		

Speciality	Author date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition /procedure: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon emission findings	PROGRESS-PLUS	Patient Satisfaction	Patient Clinical outcome	Clinician Satisfaction	Service products saved	Savings in service product purchased	Service burden	Durability	Service costs saved	Service energy savings	Service waste saved	Social sustainability
Multiple: orthopaedic & traumatology, ear/nose/throat surgery, ophthalmology, visceral, urology, gynaecology, neurosurgery, obstetrics, cardiology, liver, kidney, pancreatic, cardiac, radiology,	Chambrin 2023: France [4 University hospitals Lyon with surgical activity](85)	To assess whether implementing information campaigns was associated with a decrease in carbon footprint related to inhaled halogenated anesthetics	Retrospective cohort C1: Anaesthesia Education C2: NR [121 anesthesia providers (53 nurses, 38 anesthesiologists, 30 residents) Questionnaire: 180 anesthesia providers completed (80 nurses, 62 anesthesiologists, 38 residents)]	Extracorporeal lithotripsy, liver, kidney and heart transplants; NA	An initiative on sustainable anesthesia practices was launched in January 2018, involving regular meetings every six months at each hospital to disseminate information. Topics covered included the environmental impact of anesthetic drugs, waste reduction, recycling, and energy-saving measures. Additionally, an awareness campaign in June 2019 specifically addressed the environmental impact of hypnotic drugs, with meetings held at each hospital and information distributed via email. An online questionnaire was provided to gauge anesthesia providers' interest and intention to change practices regarding the use of halogenated anesthetics, with reminders sent between June and July 2019, and the questionnaire accessible until October 2019	From Jan 2015-Feb 2020, data on sevoflurane, desflurane, and propofol purchases were collected from monthly product order databases at each hospital. Monthly carbon footprint estimates from desflurane& sevoflurane perioperative emissions were expressed as CDE100. An estimate of annual N2O consumption distributed to each hospital from external gas cylinders was made. The total no of procedures performed monthly under local, regional, and general anesthesia was recorded. Data were retrieved from EMR systems, primary endpoint was CDE100 in tons related to inhaled halogenated anesthetics. Interrupted time-series data were analyzed by segmented regression for carbon footprint, hypnotic purchases, and costs related to the 3 gases. seasonality-adjusted analyses performed and the number of general anesthesia uses included in the regression formula. The analysis was conducted using R 4.0.3	Use/reuse [CO2 equivalency over 100 years CDE100 : 1]	After the establishment of sustainable anesthesia practices, the carbon footprint of sevoflurane and desflurane showed a significant decrease, with a slope changing from -0.27 to -14.16 tons/month for desflurane and a decrease in slope to -7.58 tons/month after a targeted information campaign. The median carbon footprint from perioperative desflurane decreased from 271.1 tons to 22.4 tons, and from 12.3 tons to 22.2 tons for sevoflurane. When weighted by surgical activity, the median emissions from perioperative inhaled halogenated anesthetics decreased from 66.2 kg CDE100/general anesthesia to 6.5 kg CDE100/general anesthesia	NR				C1<C2 for all three gases	>< for all three gases			C1>C2			

Speciality	Author date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition /procedure: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon emission findings	PROGRESS-PLUS	Patient Satisfaction	Patient Clinical outcome	Clinician Satisfaction	Service products saved	Savings in service product purchased	Service burden	Durability	Service costs saved	Service energy savings	Service waste saved	Social sustainability

Speciality	Author date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition /procedure: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon emission findings	PROGRESS-PLUS	Patient Satisfaction	Patient Clinical outcome	Clinician Satisfaction	Service products saved	Savings in service product purchased	Service burden	Durability	Service costs saved	Service energy savings	Service waste saved	Social sustainability
Orthopaedics	Kodumuri 2022;2023: UK [2 district general hospitals](32, 33)	Model 1 - To determine the carbon footprint of CTR, Model 2 - To construct and implement the lean and green model for the operation. The financial costs associated with the two models were also determined, we also commented on the environmental, financial and social impacts of the study	Experimental: Before and After C1 - Setting; C2 - Standard model [110: 103 intervention, 7 control]	Patients undergoing carpel tunnel surgery	The study utilized the four-step approach suggested by the Centre for Sustainable Healthcare (CSH), involving goal setting, studying the existing system, studying the lean and green model system, and measuring impact. Phase 1 evaluated the standard clinical practice of carpal tunnel release using a generic hand set of surgical instruments and formal extremity drape system over 2 months. Phase 2 introduced a lean and green model via two pilot lists, which included reducing the generic handset to a carpal tunnel release-specific set, changing to smaller drapes, and minimizing the use of single-use non-recyclable items. Phase 3 involved implementing the carpal tunnel release in the lean and green model as standard practice following review of the pilot lists from Phase 2	A digital suspension weighing machine to measure waste generated after each CTR, documenting the mass of waste in clinical waste bags post-surgery. The carbon footprint for CTR was defined by calculating carbon emissions for each inventory item using an online calculator based on LCA from the CSH. Disposable item emissions were determined based on material type and weight. In the standard model, surgical trays and instruments were weighed, and the carbon emission factor for stainless steel adjusted for re-sterilization. This, combined with disposable item emissions, yielded the carbon footprint of a CTR. For the lean and green model, essential disposable item emissions were added to the carbon emissions of re-sterilizing a specific tray with essential instruments. The difference between the two models estimated probable CO_2 emissions savings for each CTR	Disposal [kg CO_2e: 1]	Prospective evaluation of carbon footprint calculation of the lean and green model showed a reduction in carbon emissions to 6.6 kg (range 6.2–7.3) (Figure 5). This represented an 80% reduction with the carbon footprint of the sterile field reduced by 98% just by changing to smaller drapes (9.3 kg versus 0.2 kg). Smaller trays with essential instruments reduced the emissions for the instrumentation component by 66% (14.1 kg versus 4.7 kg)	NR						C1>C2 [N]		C1>C2		C1>C2	

Speciality	Author date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition /procedure: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon emission findings	PROGRESS-PLUS	Patient Satisfaction	Patient Clinical outcome	Clinician Satisfaction	Service products saved	Savings in service product purchased	Service burden	Durability	Service costs saved	Service energy savings	Service waste saved	Social sustainability
Ophthalmology	Vo 2023: USA [Retina clinics](80)	Analyses the feasibility, environmental impact, and cost of reusing shipping materials for intravitreal injection medications, as compared to wasting coolers and cold packs after single-use	Observational: cohort; C1: Reuse Packaging C2: Standard practice [NA;NA'NA]	NA	Shipping materials related to weekly shipments of repackaged bevacizumab for intravitreal injection were collected upon receipt in a clinic after overnight shipping from an outsourcing facility in New York via UPS. The packaging materials included 3 polystyrene coolers, 11 cold packs, and 3 card boxes, which were typically discarded. These materials were inspected and returned to the outsourcing facility via UPS ground shipping, with damaged items replaced. Temperature compliance was ensured by reviewing the cold packs upon arrival to confirm they were frozen, while the syringes of Avastin were not frozen. The study spanned 10 weeks, consisting of 10 roundtrips for the packing materials	The materials were weighed using a multifunction scale and recorded in a spreadsheet. Photographs were taken with an iPhone 11. The cost analysis utilized material and shipping costs from the outsourcing facility, considering applicable bulk discounts. Carbon dioxide equivalent (CO2e) was estimated based on Environmental Protection Agency (EPA) data, as described previously	Transport (from raw materials stage to clinic and return of used materials to outsourcing facility), waste disposal) [kg CO2e: 2]	Total CO2e emissions were reduced 43% by reusing shipping materials, as compared to the standard practice of disposing containers after single use, as shown in Table 1	NR							C1>C2 [N]*	C1>C2		C1>C2	

*Cold packs shipping materials were less durable than polystyrene foam coolers, Green cell - statistically significant, [N]=supported by narrative write up (no formal statistics), C1<> C2 -both comparator favoured in some scenario, >< - no detrimental effect/ no difference, BEIS=Business, Energy & Industrial Strategy, C=Comparator, CDE100=CO2 equivalency over 100 years, CLO=Campylobacter-like organism, CO2=Carbon Dioxide, COCIR=The European Co-ordination Committee of the Radiological, Electromedical, and Healthcare Information Technology Industry, CSSU=Central sterile services unit, CT=Computed tomography, CTR=Carpal tunnel release, GHG=Greenhouse gases, DNS=Domain name system; EMR=Electronic Medical Record, GP=General practitioner, ICE=The Inventory of Carbon & Energy database, IQR=Interquartile range, MRI=Magnetic resonance imaging, N20=Nitrous oxide, NA=Not Applicable, NCD=No comparative data, NR=Not reported, OR=Operating Room, PACS=Picture archiving and communication system, PET=Positron emission tomography, RMW=Regulated medical waste, SDU=Sustainable Development Unit, UPS=United Parcel Service

Appendix I: Product level

Summary other impact categories - LCAs evaluating 'Product-level' interventions (Reuseable instruments) within urology

Study, Speciality: Study Design	Name of Interventions (C1 vs C2 etc…)	Other Impact Categories					
		Mineral resource depletion	Ecotoxicity	Acidification	Eutrophication	Solid Waste produced	Cost
Baboudjian 2022, Urology; LCA(83)	C1: RU flexible cystoscopes vs C2: SU cystoscopes	Favours SU	No difference	Favours SU	No difference		
Hogan 2022, Urology; Prospective single-centre cohort study: controlled trial[a,b] (107)	C1: RU vs C2: Disposable flexible cystoscopes					Favours D	
Kemble 2023, Urology; Inventory Analysis(67)	C1: SU vs C2: RU cystoscopes						
Wombwell 2023, Urology; Inventory analysis(98)	C1: SU Ambu® aScope™ 4 Cysto System (Ambu®) vs C2: RU Olympus CYF-VH flexible video-cystoscope						
Davis 2018, Urology; Inventory analysis[c](96)	C1: RU flexible ureteroscopes vs C2 2: Disposable flexible ureteroscopes						

Green cell=Study appraised as 'High' quality, Blue cell=Study appraised as 'Medium' quality, Orange cell=study appraised as 'Low' quality. [a]Incorporates simplistic LCA methods, [b]Results queried by Rizan – see Appendix F, [c]Stated as LCA but incomplete impact assessment. C=Comparator, D=Disposable, RU=Reuseable, SU=Single Use

Summary other impact categories - LCAs evaluating 'Product-level' interventions (Reuseable instruments) within gastroenterology

Study, Name of Interventions (C1 vs C2…)	Findings from Other Environmental Impact Categories																								
	Stratospheric ozone	Ozone depletion	Smog	Ionising radiation	Ozone formation:	Ozone formation: Terrestrial	Fine	Mineral resource	Ecotoxicity	Terrestrial ecotoxicity	Freshwater ecotoxicity	Marine water	Acidification	Freshwater Eutrophicati	Marine eutrophicati	Land use	Fossil resource	Water consumptio	Human carcinogenic	Human non-carcinogenic	Endpoint: Resources	Endpoint: Non-renewable resource use	Endpoint: Ecosystem quality	Endpoint: Human Health	Cost
Boberg 2022, C1: Single-use trocar system vs C2: Reusable trocar system vs C3: Mixed trocar systems for laparoscopic chole-cystectomies(103)																					SU vs RU: Favours RU. SU vs Mixed: No SD		SU vs RU: Favours RU. SU vs Mixed: No SD	SU vs RU: Favours RU. SU vs Mixed: Favours Mixed	RU and mixed trocar systems approx. half as expensive as SU
Le 2022, C1: Reuseable duodenoscope vs C2: Reuseable duodenoscopes with disposable endcaps vs C3: Single-use duodenoscopes(68)																						C3 vs C1+C2: Favours C1+C2. C1 vs C2: No SD	C3 vs C1+C2: Favours C1+C2. C1 vs C2: No SD	C3 vs C1+C2: Favours C1+C2.[a] C1 vs C2: Favours C2[b]	

Study, Name of Interventions (C1 vs C2…)	Findings from Other Environmental Impact Categories																								
	Stratospheric ozone	Ozone depletion	Smog	Ionising radiation	Ozone formation:	Ozone formation: Terrestrial	Fine	Mineral resource	Ecotoxicity	Terrestrial ecotoxicity	Freshwater ecotoxicity	Marine water	Acidification	Freshwater Eutrophicati	Marine eutrophicati	Land use	Fossil resource	Water consumptio	Human carcinogenic	Human non-carcinogenic	Endpoint: Resources	Endpoint: Non-renewable resource use	Endpoint: Ecosystem quality	Endpoint: Human Health	Cost
Rizan 2022, C1: Single-use vs C2: Hybrid surgical instruments used for Laparoscopic cholecystectomy (laparoscopic clip appliers, laparoscopic scissors, and ports)(59)	H			SU	H	H	H	H		See SM	SU[c]	SU[c]	H	H	SU	H	H	H	H	H	H		H	For endpoint categories: combination of hybrid laparoscopic clip appliers, scissors, and ports for single laparoscopic cholecystectomy saved estimated 1.13 e−5 DALYs	H
Sherman 2018, C1: Reusable vs Single-use/ disposable laryngoscopes(73)		RU	RU				RU[d]		RU			RU[e]	RU		RU				RU	RU					RU

Green cell=Study appraised as ‘High’ quality, Blue cell=Study appraised as ‘Medium’ quality, Orange cell=study appraised as ‘Low’ quality [a]SD 13-26 times worse than 2 types of RDs in terms of environmentally mediated human health impacts (not counting direct impact from infections). If infections included, human health burden of SD close to total human health impact of RD. If assumption disposable endcap reduce infection risk of RDs by 50% realized, human health burden of RDs with disposable endcaps would then be lower than that of SDs (a factor of .75 of the SD lower bound). If infection rate of RDs decreases to 23/500,000 or .0046%, overall negative human health impact of RD will fall below lower bound health impact of an SD, [b]RDs with disposable endcaps perform similarly to traditional RDs in all categories, with advantage of potentially reducing infections, [c]RE: Laparoscopic scissors only, [d]Labelled as 'Respiratory effects', [e]HLD of reusable handle produced the fewest emissions in all impact categories except fossil fuel depletion, HLD fewest emission for Blades across all impact categories. C=Comparator, H=Hybrid, RU=Reuseable, SD=Significant Difference, SU=Single Use

Summary other impact categories - LCAs evaluating 'Product-level' interventions (Reuseable instruments) within cardiac, ICU and respiratory

Study, speciality: intervention comparison	**Findings from Other Environmental Impact Categories**																					
	Ozone depletion	**Smog**	**Ionising radiation**	**Ozone formation: human health**	**Fine particulate matter**	**Ecotoxicity**	**Freshwater ecotoxicity**	**Marine water ecotoxicity**	**Acidification**	**Eutrophication**	**Freshwater Eutrophication**	**Marine eutrophication**	**Eutrophication terrestrial**	**Land use**	**Fossil resource scarcity**	**Water consumption**	**Human carcinogenic toxicity**	**Human non-carcinogenic toxicity**	**Loss of scarce resources**	**Resource use: energy carriers**	**Resource use: metals and minerals**	**Respiratory inorganics (Disease incidents)**	**Cost**
Schulte 2021, Cardiac; C1: newly-manufactured catheter vs C2: remanufactured catheter (94)	RM		RM	RM[a]			RM		RM		Virginj	RM	RM	Virgin[b]		No difference	RM	RM		RM	RM	RM	
Sanchez 2020, Multiple, including ICU; C1: RU vs C2: Disposable BP cuffs(88)	RU	RU			RU[c]	RU			RU	RU					RU		RU	RU					RU[d]
Sorensen 2018 , Respiratory; C1: SU flexible device for bronchoscopy vs C2: RU bronchoscope(112)																			SU[e]	SU[e]			

Green cell=Study appraised as 'High' quality, Blue cell=Study appraised as 'Medium' quality, Orange cell=study appraised as 'Low' quality. [a]'Photochemical ozone formation', [b]Primary data for virgin production missing. Due to this lower level of detail calculated environmental impacts of virgin production route tend to be underestimated vs medical remanufacturing route, [c]Labelled as 'Respiratory effects', [d]Disposable cuffs not cleaned over 5-day stay show slight cost advantage vs reusables. When reusable cuffs shared+cleaned after each patient encounter in the Regular Ward, additional labour and wipe costs incurred mean disposable cuffs preferable, even when dedicated disposables disinfected daily. However, if Regular Ward patients to use dedicated reusable cuffs, e.g. in ICU setting, reusables would be more favourable, [e]Using one set of protective wear/operation and materials for cleaning and disinfection determine reusable scopes have higher values of resource consumption. Cleaning two or more reusable scopes per set of PPE makes the impacts fairly comparable. C=Comparator, RM=Remanufactured, RU=Reuseable, SU=Single Use

Summary other impact categories - LCAs evaluating 'Product-level' interventions (Equipment composition) within urology

Study, Speciality: Name of intervention comparison	Findings from Other Environmental Impact Categories
Stripple 2008, Urology; C1: TPU catheter vs C2: PVC catheter vs C3: Polyolefin-based elastomer catheter(105)	***NOx and SO2 emissions:*** follow the same emissions pattern as for CO2. ***Eco-indicator 99 model - summary findings:*** Compared to TPU, new polyolefin-based elastomer shows lower environmental impact in all categories except ecotoxic emissions and extraction of minerals. Compared to PVC, polyolefin-based elastomer shows a lower impact in six of nine categories (Impact categories: Climate change, Ozone layer depletion, Carcinogenic substances, Respiratory substances (org) Respiratory substances (inorg), Ecotoxic emissions, Extraction of minerals, Extraction of fossil fuels Acidification and Eutrophication) . ***CM2 model - summary findings:*** New material shows an overall low environmental impact. Compared to TPU, polyolefin-based elastomer has a lower or equivalent environmental impact in all impact categories. Compared to PVC, its impact is lower in five out of 10 impact categories (Impact categories: Abiotic depletion ADP, Global warming GWP100, Ozone layer depletion, Eutrophication EP, Acidification AP, Photochemical oxidation POCP, Human toxicity, Terrestrial ecotoxicity, Marine aquatic ecotoxicity, Freshwater aquatic ecotoxicity). ***EPS 2000 model- summary findings:*** Results show highest environmental impact for TPU catheter, while the polyolefin-based elastomer and the PVC catheters show almost equivalent environmental impact, with a small favour towards the PVC catheter (Final scores based on weighted values) ***EPD model - summary findings:*** New material has low general environmental impact compared vs older materials+lower impact than TPU in all impact categories and lower impact than PVC in all categories except global warming, eutrophication and photochemical ozone. Increased acidifying potential for PVC attributable to HCl emissions to water caused by landfilling of PVC and higher ODP level caused by use of CFC/HCFC in PVC polymer production. TPU's high eutrophication potential is caused by the polyurethane material's nitrogen content. Potential environmental gain from waste energy relatively low (impact categories included: Energy resources: non-renewable (%) Energy resources (%): renewable Global warming potential (%) Eutrophication potential (%) Acidifying potential (%) Photochemical ozone POCP (%) Ozone depletion potential ODP 20 (%))
Blue shaded=study appraised as 'Medium' quality. C=Comparator, GWP=Global Warming Potential, NOx=Nitrous Oxide, PVC=Polyvinyl Chloride, SOx=Sulphur Oxides	

Summary carbon emission findings- non-LCA studies (Equipment type)

Speciality	Author date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon emission findings	PROGRESS-PLUS	Patient Clinical outcome	Clinician Satisfaction	Fidelity to clinical process	Saving in service products	Service costs saved	Service energy savings	Service waste savings	Social sustainability
Trauma and Orthopaedics	Chan 2023:UK [Orthopaedic surgery Gloucester-shire Hospitals NHS Foundation Trust](30)	1) Evaluate and compare the carbon footprint of the Ecopulse compared to the Pulsvac Plus 2) Evaluate and compare the cost of Ecopulse compared to Pulsvac Plus 3) Clinical evaluation of Ecopulse by surgeons	Before and After study; Pule lavage Equipment C1: Ecopulse vs C2: Pulsvac Plus [NR]	Patients receiving total joint arthro-plasty	Ecopulse - the only commercially available carbon neutral pulsatile lavage system on the market. The main difference between these systems is that the Ecopulse is powered via the power tool handpiece already in use on joint replacement sets. This removes the battery waste and reduces the size and weight of the product, resulting in less raw materials required	Obtained product weights and packaging information from manufacturers and confirmed through individual weighing. Carbon footprints calculated using UK Government GHG conversion factors for both materials and transportation. Total carbon footprint for each product projected annually. The Ecopulse model had formal carbon footprint analysis by Carbon Footprint Ltd., providing detailed report. Authors couldn't replicate this level of detail for other models, simplified method aimed to verify results and enable a more accurate comparison	Use+ reuse+ transport [kgCO2e: 1,3]	Overall footprint of the Ecopulse significantly smaller than Pulsvac, reflecting a 2.6x carbon emissions saving compared to battery-powered Pulsvac. Assuming, 95% of cases are eligible to switch to the Ecopulse project a saving of 4,501.1 kgCO2e=equivalent to driving 12,9634 miles in average car. Switching from battery to AC powered option for remaining 5% of cases will save further 128.5 kgCO2e giving total saving estimate of 4,629.6 kgCO2e (13,334 miles driven).	NR		C1 > C2 [N]			C1 > C2			C1 > C2 [N]

Multiple: General, Gynaecology, Ophthalmology, Orthopaedics, Plastics, Urology	Field 2023:USA [Operating room/ anasthesia](64)	Assess whether or not low-volume anesthesia machines, deliver volatile anesthetics more efficiently than traditional anesthesia machines and, secondarily, whether this was in a meaningful economic or environmentally conscious way	RCT C1: Low-volume anesthesia machine (Maquet Flow-i C20 anesthesia workstation (MQ)) vs C2 traditional anesthesia machines (GE Aisys CS) [103 of 100 analyzed; MQ: 52; GE:51]	Patients scheduled for surgery. Height (cm, MQ vs GE): 167 ± 11 vs 169 ± 10 Weight (kg, MQ vs GE): 71 ± 12 vs 70 ± 13;BMI (kg/m2, MQ vs GE): 25 ± 3.0 vs 24 ± 3.1; Total case length (min, MQ vs GE): 210 ± 122 vs 236 ± 125; Surgery type (n, MQ vs GE): General 12 vs18; Gynecology 18 vs 5 Ophthalmology 2 vs 2 Orthopedics 6 vs 12 Otolaryngology 0 vs 1 Plastics 6 vs 7 Urology 8 vs 6	The study team pre-filled and weighed two MQ cassettes/vaporizers to minimize workflow disruption. The study protocol was reviewed with anesthesia providers before patient transport to ensure uniform practice. During induction, fresh gas flow was set at 15 L/minute, and tidal volumes were standardized at 6-8 mL/kg ideal body weight with a PEEP of 6 cmH2O. Upon reaching steady state, fresh gas flow was reduced to 2 L/minute, and the second cassette/vaporizer was used. Data logging continued during the emergence phase	NR	Use reuse [Metric tonnes CO2: 1]	This 20% decrease in CO2 equivalent emissions corresponds to 201 metric tons less greenhouse gas emissions over a decade compared to the GE, which is equivalent to 491,760 miles driven by an average passenger vehicle or 219,881 pounds of coal burned. To put sevoflurane usage reduction found in this study in the larger context, over the course of one year in a 2023 surgical facility with 20 operating rooms performing 5.5 cases per day, the total difference in greenhouse gas production between the two anesthesia machines would be approximately 402.26 metric tons of CO2 [10,11]. This is equivalent to the greenhouse gas production from an average passenger vehicle driven 983,521 miles, the CO2 emissions from 48.2 homes' energy use for one year, or the greenhouse gas emissions avoided by 140 tons of waste recycled instead of landfilled	***Gender*** (n, MQ VS GE): Female 35 vs 29, Male 17 vs 22; Age in years (n, MQ vs GE): 42 ± 14 vs 44 ± 13	**C1>C2**		**C1 <> C2**	**C1>C2**	**C1>C2**			

Speciality	Author date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon emission findings	PROGRESS-PLUS	Patient Clinical outcome	Clinician Satisfaction	Fidelity to clinical process	Saving in service products	Service costs saved	Service energy savings	Service waste savings	Social sustainability
Ophthalmology	Mousa 2021:UK [Three tertiary hospital units : Manchester Royal Eye Hospital (MREH), Birmingham and Midland Eye Centre (BMEC), and University Hospitals Coventry and Warwickshire (UHCW)](55)	Report the potential reduction of carbon emissions by utilising AT instead of fluorinated gases in the management of RRDs at two large tertiary referral vitreoretinal (VR) centres	Retrospective, continuous, comparative multicentre study; C1: Air versus C2: gas tamponade [3239;NR;NR]	Patients with rhegmatogenous retinal detachment (RRD)	Fluorinated gases - sulphur hexafluoride (SF_6), hexafluoroethane (C_2F_6) and octafluoropropane (C_3F_8) Air tamponade - NR	Data from three different hospitals (MREH, BMEC, UHCW) were collected through various methods including Microsoft Access databases, electronic patient records, and surgeons' logbooks. Gas masses were converted to GWP100 using IPCC reference values. Efficiency was determined through staff surveys and pharmacy order history. Statistical analysis was conducted using IBM SPSS Statistics (Version 27.0), with significance set at $p<0.05$ and adjustments made for multiple analyses using Bonferroni correction	Use [mean equivalent mass of CO_2 (kg) per patient: 1]	UHCW reduced CO_2 emissions by 47.0% and 41.1% compared to MREH and BMEC, respectively, through the use of AT. BMEC also showed a 10.0% reduction in emissions per patient compared to MREH due to different gas tamponade proportions ($p<0.001$). The gas cylinders at MREH result in 63 times higher CO_2 emissions per RRD repair compared to UHCW. Assuming 30% of RRDs are suitable for AT, this could lead to 2,921 fewer RRDs repaired with fluorinated gas annually in the UK, reducing CO_2 emissions by 44.3% to 56.6%. This could save up to 716.5 tons of CO_2 annually, equivalent to electricity for 121 homes	NR					C2>C1			

Speciality	Author date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon emission findings	PROGRESS-PLUS	Patient Clinical outcome	Clinician Satisfaction	Fidelity to clinical process	Saving in service products	Service costs saved	Service energy savings	Service waste savings	Social sustainability
Ophthalmology	Moussa 2022:UK [Three tertiary hospital units: Manchester Royal Eye Hospital (MREH), Birmingham and Midland Eye Centre (BMEC), and University Hospitals Coventry and Warwickshire (UHCW)](54)	Investigate the direct contribution to carbon emissions of fluorinated gases used in all vitreoretinal (VR) procedures utilizing gas tamponade and assess the respective carbon footprint of the three different gas delivery system	Retrospective, continuous, comparative multicenter study; Three different gas delivery systems and fluorinated gas use [4877; NR;NR]	Patients undergoing vitreoretinal procedures utilizing gas tamponade	UHCW: 30 mL single-use gas canisters (Arcadophta, Toulouse, France); BMEC: 75 mL multi-use gas canisters (ALCHIMIA Srl, Padova, Italy); MREH: traditional gas cylinders of 2 kg SF6, 1 kg C2F6, and 1 kg C3F8 (British Oxygen Company [BOC] Healthcare, UK	Data Acquisition: VR procedures data extracted from databases at MREH, BMEC, and UHCW. Environmental Impact Calculations: Gas masses converted to Global Warming Potential (GWP) over 100 years (GWP100) using the modified Ideal Gas Law formula. Significance defined as $P < .05$; Statistical analysis: IBM SPSS Statistics used; Metrics for Meaningful Comparisons: Total and mean CO2 equivalent calculated for each fluorinated gas; Bonferroni correction applied for multiple analyses	Use [mean equivalent mass of CO2 (kg) per patient: 1]	The CO2 emission ranged from a mean equivalent of 3.17 kg per patient using 30 mL canisters to 124.8 kg using cylinders metric tons) for BMEC and MREH for each intraocular gas. Over 4 years, the GWP100 of equivalent CO2 at BMEC and MREH amounted to 16.7 and 276.8 tons, corresponding to an annual equivalent CO2 mass of 4.2 tons and 69.2 tons, respectively. Figure 2B shows the potential equivalent CO2 mass production at BMEC and MREH over the 4-year period if each unit were to use the three gas delivery systems (30 mL canister, 75 mL canister, and the cylinder). This resulted in a wide range of CO2 equivalent mass production, with the gas cylinders reaching 40 times higher emissions compared with the 30 mL canisters	NR								

Green cell=Statistically significant outcome, >< = no difference/ no detrimental effect. ASA=American Society of Anesthesiologists status, AT=Air tamponade, C1 > C2=Analysis favoured Comparator 1 over C2; C1<> C2 -=both comparator favoured in some scenario, CE=Carbon emissions, CO2=Carbon Dioxide, DEFRA=Department of Food and Rural Affairs, EPA=Environmental Protection Agency, GE=GE Aisys CS, Gi=Gastrointestinal, GHG=Greenhouse gases, GWP100=Global Warming Potential (GWP) over 100 years, IQR= Interquartile Range, MQ=Maquet Flow-i C20 anaesthesia workstation, [N]=Narrative or descriptive synthesis, NA= Not Applicable, NR=Not reported

Appendix J: Care delivery

Summary carbon emission findings- non-LCA studies – treatment regimen and surgical procedure

Speciality	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participant N]	Specific health condition /procedure: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient outcome	Patient travel saved	Patient time saved	Patient travel cost saved	Accessibility	Patient complications	Service cost saved
Renal	Chen 2017: China [Medical centre](111)	Determine carbon footprints of differing modalities/ treatment regimes to deliver PD	Experimental-Controlled Trial: Different treatment regimen: Modality/Treatment site/Dialysate volume l/day [68 total: DAPD/Home/6 (13), DAPD/Home/8 (10), CAPD/Home/6 (16), CAPD/Home/8 (21), DAPD/Hospital/6 (1), DAPD/Hospital/8 (4), CAPD/Hospital/6 (1), CAPD/Hospital/8 (2)]	Kidney failure: Patients receiving continuous ambulatory peritoneal dialysis or daytime ambulatory peritoneal dialysis	RRT: life-sustaining treatment for patients with ESRD. Includes HD and PD (alternative form of RRT). Daytime exchange consisted of 1.5 or 2.5% glucose with total volume of 6–8l/day in all patients. Automated PD not included. PD regimen: DAPD Home 6 13, PD regimen: DAPD Home 8 10, PD regimen: CAPD Home 6 16, PD regimen: CAPD Home 8 21, PD regimen: DAPD Hospital 6 1, PD regimen: DAPD Hospital 8 4, PD regimen: CAPD Hospital 6 1, PD regimen: CAPD Hospital 8 2	Based on PAS protocol 2050 developed by BSI and DEFRA,[1] activity data collected for various aspects of PD treatment, including energy/water use, patient/staff travel, paper, electricity, waste disposal, procurement. Emissions reported in kg of CO2eq/yr. PD treatment emissions included fixed, variable, and random components, normalized to a 2-liter PD dialysate dose and presented as median values. Emission factors for PD dialysate solution and packaging materials calculated using ICE database,[2] including distances and modalities, collected for outpatient appointments, inpatient admissions, dialysis treatments, and laboratory investigations. PD-related energy consumption included dialysate heating and disinfection methods. Assumed optimal waste management strategies within practical limits. Primary activity data for waste production collected through direct measurement, emission factors applied accordingly	Procurement + Use (Building energy use, travel, transport), waste [kg CO2eq/year; 1, 2, 3]	Fixed emissions higher in patients receiving PD therapy in centre than at home, mostly due to consumption of electricity. PD treatment performed in centre emission than at home, resulting from reduced constituent percentage of waste disposal and transport. In total, PD treatment in centre produced less carbon footprints than HHD, showing advantage reducing GHG by medical disposal. Actual impact of PD on GHG emissions could be underestimated since waste disposal generated in manufacturing process not considered, including reuse, recycling, and sale. A no. raw materials supposed to exceed final quantity of PD products in manufacturing process	NR								

Speciality	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participant N]	Specific health condition /procedure: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient outcome	Patient travel saved	Patient time saved	Patient travel cost saved	Accessibility	Patient complications	Service cost saved
Oncology	Coombs 2016: UK [Radiotherapy centre](46)	To quantify the journeys and CO2 emissions if women with breast cancer are treated with risk-adapted single-dose targeted intraoperative radiotherapy (TARGIT) rather than several weeks' course of external beam whole breast radiotherapy (EBRT) treatment	Experimental: Randomised controlled trials: C1-TARGIT IORT vs C2 -EBRT [485 Breast cancer: 249: TARGIT, 236 EBRT]	Breast cancer screening: NR	The TARGIT-A trial was an international randomised controlled trial initiated in the UK that showed that a single dose of IORT using the Intrabeam device (Carl Zeiss) was not inferior to traditional EBRT in local control after breast-conserving surgery.17 This delivers a single fraction of radiotherapy (20 gy) into the tumour cavity and adds about 20–40 min to operative procedure. Patients who received TARGIT were recommended additional breast EBRT (without a tumour bed boost) if their final tumour histology had prespecified adverse prognostic factor	For each patient, the study calculated the shortest driving distance and travel time to the radiotherapy center using Google Maps, factoring in additional journeys for consent and radiotherapy planning for those receiving external beam radiotherapy (EBRT). Patients living more than 60 miles from a TARGIT trial center were excluded. Comparison was made between treatment arms and trial centers. Carbon dioxide emissions from private transport were estimated based on fuel economy assumptions, with diesel and petrol cars producing different amounts of CO2 per mile driven (CO2 produced by a 40 mpg diesel car is 299 g/mile (186 g/km) and that produced by a 40 mpg petrol car is 272 g/mile (169 g/km))	Use of fuel to attend treatment [Total CO2 emissions for all patients (tonnes), mean per patient (kg), 3]	TARGIT patients travelled significantly fewer miles: TARGIT 21 681, mean 87.1 (SE 19.1) versus EBRT 92 591, mean 392.3 (SE 30.2); had lower CO2 emissions 24.7 kg (SE 5.4) vs 111 kg (SE 8.6) and spent less time travelling: 3 h (SE 0.53) vs 14 h (SE 0.76), all p<0.0001. Patients treated with TARGIT in 2 hospitals in semirural locations were spared much longer journeys (753 miles, 30 h, 215 kg CO2 per patient)"	***Place of residence*****:** Two-thirds (63%) of the UK population live outside of towns that have a radiotherapy centre			C1>C2	C1>C2				

Speciality	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participant N]	Specific health condition /procedure: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient outcome	Patient travel saved	Patient time saved	Patient travel cost saved	Accessibility	Patient complications	Service cost saved
Oncology	Frick 2023: USA [Radiation oncology department] (65)	Characterize the outcomes of a hypo fractionated radiation schedule for transportation associated GHG emissions using rectal cancer as a case study	Experimental: Controlled Trial: C1 - SCRT vs C2 LCRT [334. SCRT:73, LCRT: 261]	Rectal cancer: Patient receiving short or long form radiation therapy for rectal cancer	The median dose delivered for SCRT was 25 Gy in 5 fractions	Estimated travel distance and time to radiation appointments using Google Maps based on patients' home addresses, selecting the shortest travel time route. GHG emissions were calculated according to vehicle type and statewide registration statistics, considering emissions from fuel production and use. GHG emissions were converted to carbon dioxide equivalents (CO_2e) for comparison. Travel costs determined using 2022 IRS mileage reimbursement rate. Comparative analyses were conducted using t-tests in Stata version 14.2	Patient travel: Well-to-wheel model (accounts for all emissions related to fuel) : kg CO_2e, Total CO_2e, 3]	Over the total treatment course, LCRT was associated with nearly 4.5 times greater GHG emissions than SCRT. Total CO_2e emissions for LCRT and SCRT were 665.3 kg CO_2e and 149.9 kg CO_2e per patient treatment course, respectively ($P < .001$), with a net difference of 515.4 kg CO_2e	NR			C1>C2	C1>c2	C1>C2			

Speciality	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participant N]	Specific health condition /procedure: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient outcome	Patient travel saved	Patient time saved	Patient travel cost saved	Accessibility	Patient complications	Service cost saved
Oncology	Langstaff 2023; UK [Christie NHS Foundation Trust, Manchester UK](34)	To evaluate the clinical, social, financial, and environmental impacts of PBM as a supplemental treatment for the prevention and/or reduction of oral mucositis for base of tongue and tonsil oncology patients undergoing radical radiotherapy +/- chemotherapy.	Before and After: C1 - PBM VS C2 - Conventional care [22: Intervention (PBM): 11 vs Control: 11]	Oral mucositis: Base of tongue and tonsil oncology patients undergoing radical radiotherapy +/-chemo-therapy	The prevention of oral mucositis involves applying light to tissues to promote healing, reduce inflammation, and increase cell metabolism. PBM stimulates the natural healing process by displacing mitochondrial nitric oxide, reducing oxidative stress, and increasing cellular ATP production. A trial was conducted over four months at The Christie involving 11 head and neck patients who received PBM treatment alongside their radiotherapy for 30 consecutive days. PBM treatment was administered before each radiotherapy session using a hand-held probe to deliver light to the oral mucosa for one minute per area, totalling approximately 15 minutes per session. Subsequent treatments were self-administered by the patients, contributing to reduced treatment duration and patient burden	The carbon savings from Pharmacological Pain Management treatment estimated based on various factors. This included estimating CO2e for unplanned admissions using emissions factors for ward bed days and patient travel distances. Reductions in CO2e due to decreased medication usage calculated using emissions factors for pharmaceuticals. However, carbon savings from nasogastric tube insertion and feeds not included due to data limitations. CO2e from PBM device and treatment estimated by calculating electricity use/patient, although device itself was not carbon footprinted due to its frequent use resulting in negligible emissions/use	Use+ reuse+ patient transport [kgCO2e:1, 2,3]	For a 30-day period, each patient contributes 0.04 kgCO2e, resulting in a total carbon saving of 2,613.99 kg CO2e per year for 11 patients. When considering eligibility for full treatment among 180 tonsil and base of tongue cancer patients annually, the savings increase to 42,774 kgCO2e per year. Additional benefits, e.g. reduced nasogastric tube usage & medication courses post treatment, may result in further savings. CO2e savings include reductions in bed days, travel, antibiotic prescriptions, morphine usage, and medication prescriptions during radiotherapy, favouring the treatment group in each instance	NR	NCD*	C1>C2**					C1>c2	C1>C2

Speciality	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participant N]	Specific health condition /procedure: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient outcome	Patient travel saved	Patient time saved	Patient travel cost saved	Accessibility	Patient complications	Service cost saved
Oncology	Vaidya 2022: Multi-country [Centres using TARGIT-IORT: 242 centres across 35 countries](110)	TARGIT-IORT delivers radiotherapy targeted to the fresh tumour bed exposed immediately after lumpectomy for breast cancer. TARGIT-A trial found TARGIT-IORT to be as effective as whole-breast radiotherapy, with significantly fewer deaths from non–breast cancer causes. This paper documents its worldwide impact and provides interactive tools for clinicians and patients	Observational: retrospective cohort: C1 - TARGIT-IORT vs C2 - EBRT [44752]	Breast cancer: Patients receiving treatment for breast cancer	Targeted intraoperative radiotherapy (TARGIT-IORT) delivers radiotherapy targeted to the fresh tumour bed exposed immediately after lumpectomy for breast cancer. This treatment delivers effective radiotherapy targeted to the fresh tumour bed exposed immediately after lumpectomy (4, 5) while sparing nearby tissues and nearby vital organs such as the heart and lung. TARGIT-A RCT (Coombs) used risk adapted single-dose TARGIT-IORT during lumpectomy	international network was established among centers using TARGIT-IORT for breast cancer treatment. Data on the first patient treated and total cases were collected via Google forms and electronic communication from numerous centers, including those not involved in TARGIT trials. The collected information was visualized using Google My Maps, showcasing each hospital's first case date and total cases treated. Patients undergoing. A previous study found that patients in the TARGIT-A trial saved an average of 305 to 753 miles of travel, depending on their location. These savings were converted into CO2 emissions saved, considering standard emissions for a medium-sized car. The study assumed a higher proportion of urban dwellers and developed an interactive web application for individual travel estimates, incorporating patient feedback for improvements	Patient travel [KgCO2, 3]	Scaling up the journeys saved by avoiding EBRT, because of the use of TARGIT-IORT, to the 44,752 patients, we estimate that over 20 million (20,134,909) miles of travel have already been saved, representing a carbon footprint reduction of 5.6 million kg of CO2 emissions	NR		C1>C2 (Non cancer mortality) ><breast cancer outcomes/mortality	C1>C2					

Speciality	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participant N]	Specific health condition /procedure: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient outcome	Patient travel saved	Patient time saved	Patient travel cost saved	Accessibility	Patient complications	Service cost saved
Oncology	Woods 2015: USA [Surgery/ Operating room](81)	Quantify/ compare total greenhouse gas emissions, or 'carbon footprint', attributable to three surgical modalities	Observational: retrospective database review: C1: Robotically-assisted laparoscopy (RA-LSC) vs C2: Laparoscopy (LSC) vs C3: Laparotomy (LAP) [50]	Endometrial cancer: Patients undergoing staging procedure for endometrial cancer	NR	Data from 150 staging surgeries conducted between 2008 and 2011 collected to calculate carbon footprint by summing associated solid waste production and energy consumption. Waste production categorized, and energy consumption determined for various components (environmental, equipment, instrument, and robotic systems), with statistical analyses comparing variables and controlling for confounding factors. Student's t-test, Kruskal–Wallis test, or ANOVA, with Bonferroni's method used for multiple comparisons. Categorical variables compared using Pearson's $\chi 2$ test, with an α-level of 0.05	Transport from clinic to outsourcing facility) + waste disposal: Cold pack landfill Emissions solely based on transportation to landfill (20 miles), Across all stages: materials: foam, cardboard and cold pack plastic [KgCO2e ,1]	Total carbon footprint for all 150 procedures: 4498 kg CO2e, average 30 kg CO2e/patient. RA-LSC=highest carbon footprint (40.3 kg CO2e/patient), followed by LSC (29.2 kg CO2e/patient) and LAP (22.7 kg CO2e/patient). Energy consumption varied, with RA-LSC consuming most energy (26 kg CO2e/patient), followed by LSC (18 kg CO2e/)patient and LAP (14.4 kg CO2e/patient). Environmental energy usage comparable across modalities, with LAP producing least solid waste (8.3 kg CO2e/patient), followed by LSC (11.24 kg CO2e/) patient and RA-LSC (14.3 kg CO2e/patient)	NR								

Speciality	Author, date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participant N]	Specific health condition /procedure: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon Emission findings	PROGRESS-PLUS	Patient satisfaction	Patient outcome	Patient travel saved	Patient time saved	Patient travel cost saved	Accessibility	Patient complications	Service cost saved

* The requirement to attend a different area of the hospital for PBM posed challenge for some patients with reduced mobility, ** Patient outcome: pain, hospital admission. Intervention participants generally prescribed pain medication longer. Green cell - statistically significant outcome, [N] = supported by narrative write up (no formal statistics), ATP - Adenosine triphosphate, BSI=British Standards Institution, CAPD=Continuous Ambulatory Peritoneal Dialysis, C1> C2 -C1 favored over C2, CO_2=Carbon Dixoxide, DAPD=Daytime Ambulatory Peritoneal Dialysis, DEFRA- Department for Environment, Food, and Rural Affairs, EBRT - External beam radiotherapy, ESRD - End Stage Renal Disease, GHG - Greenhouse gases, HD - Haemodialysis, HHD - Home Haemodialysis, HHM - Home Health Monitoring, ICHD=In center Haemodialysis, LAP - Laparotomy, LCRT - Long course radiation therapy, LSC - Laparoscopy, NA - Not Applicable; NR - Not reported, PBM - Photobiomodulation, PD=Peritoneal Dialysis, RA-LSC - Robotically-assisted laparoscopy, RRT=Renal Replacement Therapy, SCRT - Short court radiation therapy, SDPP - Systematic Depot Pickup Problem , TARGIT-IORT - Targeted intraoperative radiotherapy

Care pathway

Specialty	Author, date: Country [Setting]	Aim	Study design: Comparison (Intervention vs Control/ Comparator) [Participants N]	Specific health condition: Patient characteristics	Intervention description	CE Calculation methods	Boundaries of system evaluated [Unit: CE Scope]	Summary of CE findings	PROGRESS-PLUS	No. F2F visits	Patient travel distance	LOS	Service costs	N. Physio appointments	Readmissions	Other outcomes measured with no comparative data
Orthopaedics	Cooper 2023: UK [Separate sites within Calderdale and Huddersfield NHS Foundation Trust](48)	To understand if use of digital system could improve patient experience and efficiency of post operative physiotherapy care provided. (1) Explore if wearable sensor reduced no. F2F physiotherapy visits, (2) Measured reception and utilization of messaging system by patients and clinicians	Experimental: Pilot controlled trial - CE data based on modelling: C1: Digital day case care pathway vs C2: standard care pathway [21, 14 day case, 7 control (5 short stay, 2 long stay)]	Knee arthroplasty: 16 TKA, 5 UKA. Mean age: 57.6 yrs (SD 8.9 yrs), 9f & 12m patients	See paper for detail	Model created using pilot study data for all 435 knee arthroplasties/ yr where 79% knee replacement patients have ASA grade of I or II10. Assuming 65% patients would have access to a smart device for use with BPM pathway, total of 218 patients (51.4%) enrolled in digital day-case program. Decision tree created showing not all patients would be suitable for accelerated digital day-case pathway, as patients with ASA grade of ‡III unsuitable for discharge within 24hrs and patients without smartphone unable to utilize remote-monitoring system. Only 51.4% of all possible knee arthroscopy patients in budget-impact model shown to be suitable for accelerated digital day-case program, and remaining 48.6% budgeted according to the standard pathway. To test robustness of reported model, several parameters subjected to	BMP pathway box & USB-C charger, strap& device, patient bed day, outpatient appointment, patient travel [kg CO2: NA]	NA	NR			C1 > C2 (N)	C1 > C2 (N)	C1 > C2 (N)		C, PF, PS, ST

Specialty	Author, date: Country [Setting]	Aim	Study design: Comparison (Intervention vs Control/ Comparator) [Participants N]	Specific health condition: Patient characteristics	Intervention description	CE Calculation methods	Boundaries of system evaluated [Unit: CE Scope]	Summary of CE findings	PROGRESS -PLUS	No. F2F visits	Patient travel distance	LOS	Service costs	N. Physio appointments	Readmissions	Other outcomes measured with no comparative data
						univariate deterministic sensitivity analysis to determine impact of variation in parameters. Parameters systematically varied between upper and lower bounds. Costs varied by ±20% of the base case values, and LOS and percentage of patients with ASA grade of ‡III varied by ±20%, according to guidance from Hospital Episode Statistics database and National Joint Registry.[a] Data regarding hospital LOS in digital day-case cohort presented as mean and 95% confidence interval, time spent on messaging is estimated. See paper for detail re: sustainability assumptions and parameters										

Specialty	Author, date: Country [Setting]	Aim	Study design: Comparison (Intervention vs Control/ Comparator) [Participants N]	Specific health condition: Patient characteristics	Intervention description	CE Calculation methods	Boundaries of system evaluated [Unit: CE Scope]	Summary of CE findings	PROGRESS-PLUS	No. F2F visits	Patient travel distance	LOS	Service costs	N. Physio appointments	Readmissions	Other outcomes measured with no comparative data
Orthopaedics	Cooper 2022: UK [2 separate sites within the Calderdale and Huddersfield NHS Foundation Trust](47)	Assess implementation of digital day-case pathway for knee replacement surgery	Experimental: Pilot controlled trial - CE data based on modelling: C1: Digital day case care pathway vs C2: Standard care pathway [21, 14-day case, 7 control (5 short stay, 2 long stay]	Knee arthroplasty: 16 TKA, 5 UKA. Mean age: 57.6 yrs (SD 8.9 yrs), 9f & 12m patients		NR	BMP pathway box & USB-C charger, strap& device, patient bed day, outpatient appointment, patient travel [: Scope 1, 2, 3]	Because of reduced No. F2F visits, model predicted incremental reduction of 119,381 kg CO2 emissions associated with knee replacement procedures	NR	C1 > C2 (N)						PC, PF, PS
Cardiology	Nielsen 2022: UK [Cardiac ICU Southampton Hospital](39)	NR	Before and After: C1: Early mobilisation vs C2: Before intervention [238 recruited to mobilisation programme][b]	Patients receiving open heart surgery	CICU team recruited therapy technician to work alongside qualified physiotherapist, to help set up project and deliver therapy sessions. Technician helped: educating CICU staff, including use of Motomed equipment required for exercising sedated patients. Therapy assistant systematically initiated mobilising patients who fitted protocol criteria. These patients received 30mins rehab 2xday, continuing until discharge from CICU. Staff selected highest level of activity in which patient could	Data gathered before and after introduction of EMP on no.days patients received artificial ventilation, LOS intensive care, in CHC beds, on ward and total hospital LOS. CE calculation methods NR	NR. Assumed: Use/Reuse [tonnes CO2e: CT]	Carbon footprint of no. days saved: 48.5 tonnes CO2e, equivalent to annual carbon footprint of almost 5 UK citizens and 18 return trips London-Sydney in economy class over 2-year programme	NR			C1 > C2 (N)[c]	C1 > C2 (N)			

Specialty	Author, date: Country [Setting]	Aim	Study design: Comparison (Intervention vs Control/ Comparator) [Participants N]	Specific health condition: Patient characteristics	Intervention description	CE Calculation methods	Boundaries of system evaluated [Unit: CE Scope]	Summary of CE findings	PROGRESS-PLUS	No. F2F visits	Patient travel distance	LOS	Service costs	N. Physio appointments	Readmissions	Other outcomes measured with no comparative data
					participate eg if patient intubated and ventilated, Motomed device used for passive exercise; if patient awake then options included sitting on edge of bed, standing, marching on spot, transferring from bed to chair and mobilising											

Cardiology	Zander 2011: UK [NHS hospital, east of England](62)	Little attention has been paid on the carbon footprint of different healthcare service models. We examined this question for service models for patients with acute STEMI	Modelling: C1 Ambulance transport based on pPCI model in tertiary centres vs C2 Thrombolysis model based in hospitals [41449 patients. pPCI care model: 3 hospitals, thrombolysis model: 18 hospitals]	MI during 5-year period: NR	pPCI care model based in tertiary centres. pPCI benefits are critically dependent on its timeliness (more so than for thrombolysis). Clinical guidelines recommend pPCI ideally conducted within 600 from time administration of thrombolysis would have been possible, and within 900 from 'first medical contact'. Unlike thrombolysis that can be effectively and safely administered in the community (pre-hospital thrombolysis) or at GH, pPCI requires '24/7' availability of on-call interventional cardiology team and cardiac catheterization facilities. Clinical quality best assured in high volume centres. These factors restrict pPCI provision to a much smaller number of care points (i.e. tertiary cardiac units) compared with district GHs. Change in pPCI care model for STEMI patients means ambulances have to travel to 3xcardiac centres (as opposed to 18 district GHs in historical	Two matrices of destination 'care points' constructed. 1 for thrombolysis care model (corresponding to 18 regional district GH with A&E departments) and one for pPCI care model (corresponding to 3 regional pPCI centres). ArcEditor GIS software with Network Analyst extension used to compute 'real world' distances from LSOA centroids to district GH A&E destinations, using OS Meridian2 East of England road network info. Distance from each LSOA centroid to closest care point under two models selected from all other possible care point destinations (either one of 18 district GHs under thrombolysis model or 1 of 3 pPCI centres under new model) using Excel 'MIN' formulas. For either service model, total (minimum) transport distances required for all STEMI patients from their LSOA centroid to closest care point during 5-year study period averaged=mean ambulance journey mileage required for management of a STEMI patient under either service model. Mileage converted to CO_2 emissions using standard coefficients, published by DEFRA.12 In absence of CF specifically for ambulances, used CO_2 CF for 'large vans' as appropriate proxy, (1 km	Patient transport via ambulance [CO_2 tonnes: 1]	Average distance to transport STEMI patient to closest care point: 13.0km (thrombolysis model) vs 42.2km (pPCI model)=CO_2 emissions of 3.46 and 11.2kg, respectively. Introducing pPCI management>triples ambulance journey mileage and associated CE required for STEMI patient transport (factor of 3.24). Using HES online data 2002 – 03 to 2006 –07 for all MI admissions (STEMIs and non-STEMIs) and multiplying by 0.4 to derive estimate of only STEMI events,13,14 = 3316 STEMI hospital admissions expected to occur/yr in East of England. If all events occurred out-of-hospital and required transport to either thrombolysis or pPCI care point=total patient (ambulance) journey mileage of 43 100km/yr (or 11.5tonnes CO_2 emissions) for thrombolysis model and 139 000km/year (or 37.2tonnes CO_2) for pPCI model. Thus, introducing pPCI care model: additional 96 700km/yr ambulance travel and additional 25.7 tonnes/yr CO_2 emissions. If CF (CO_2 emissions/km traveled) changed from baseline 0.2661 to 0.2042 (for cars), then emissions/STEMI patient proportionally	NR		C2>C1(N)					

					thrombolysis model)	travelled to 0.2661 kg of CO2).12 This CF estimated using average values for UK van fleet in 2005, calculated based on average speed and distance of UK trips and adds 15% on emissions to model 'real world' driving effects		reduced to 2.7 and 8.6kg CO2 under thrombolysis and pPCI care models, respectively. If CF increased to 0.4200 (half of CF value for average bus) emissions/STEMI patient increase proportionally to 5.5 and 17.7kg CO2, respectively. If no. STEMI events requiring ambulance transfer to NHS hospital approx. halved to 1650/yr,13 total distance travelled will be proportionally reduced to 21 500 and 69 600 km/yr for thrombolysis and pPCI care models, respectively, whereas CO2 emissions proportionally reduced to 18.9 and 61.4 tonnes/year under the pPCI care model								

Specialty	Author, date: Country [Setting]	Aim	Study design: Comparison (Intervention vs Control/ Comparator) [Participants N]	Specific health condition: Patient characteristics	Intervention description	CE Calculation methods	Boundaries of system evaluated [Unit: CE Scope]	Summary of CE findings	PROGRESS-PLUS	No. F2F visits	Patient travel distance	LOS	Service costs	N. Physio appointments	Readmissions	Other outcomes measured with no comparative data
Urology	Phull 2023: UK [NA: 116 UK hospital trusts](57)	Investigate estimated difference in carbon footprint between day-case and inpatient TURBT surgery in England	Observational: Retrospective Review of Data: C1: Day pathway vs C2: Inpatient stay [209269. 41 583 (20%) day cases, 167680 (86 %) inpatients]	TURBT: Day vs inpatient n (%) : Age group <50 yr: 2633 (6.3) vs 5057 (3), 50–59 yr: 5032 (12) vs 12 427 (7), 60–69 yr: 10487 (25) vs 33 895 (20), 70–79 yr: 15522 (37) vs 61 721 (37), Over 80 yr: 7909 (19) vs 54 586 (33). Gender: Female: 10 804 (26) vs 36, 817 (22). HFRS category: None: 25 194 (61) vs 79 093 (47), Mild: 12 056 (29) vs 57 039 (34), Moderate: 3987 (9.6) vs 27 616 (17), Severe: 346 (0.82) vs 3938 (2.3). IMD quintile: 1 (most deprived): 6298 (15) vs 28 965 (17), 2: 7626 (19) vs 31 014 (19), 3: 8966 (22) vs	Day case admission for transurethral resection of bladder tumour surgery	Carbon footprint of day-case and inpatient TURBT procedures calculated using Sustainable Healthcare Coalition (SHC) carbon footprint data.[d] SHC data estimate carbon footprint of ‘‘average’’ surgical procedure as 35.1 kg CO2e.[e] This figure is a generic estimate, including items covering consumables, equipment, medical gases, staff travel, energy, water use, and waste; used in this study as a proxy for carbon footprint for TURBT. All data analysed on a secure server controlled by NHS England using standard statistical software. Data summarised using standard descriptive statistics, depending on data level. Carbon factors calculated at patient level and aggregated for day case and overnight-stay patients and per financial year, as appropriate. Total carbon saved calculated using 2013–2014 as baseline. To provide context, CO2e emissions converted to	Use/reuse, waste, staff transport [kg CO2: 1, 2, 3]	From 2013–2014 to 2021–2022, increase in day-case surgery reduced carbon footprint of TURBT by 24kg CO2e/patient. Estimated cumulative saving from baseline of 2013–2014 was approx. 2.9 million kg CO2e (2.9 kilotons), equivalent to powering 2716 UK homes with electricity for 1yr. For financial year 2021–2022, average carbon footprint=41.5kg CO2e for pathway involving day case surgery and 115.0kg CO2e for pathway with inpatient surgery. Adjusted upper-quartile value=39% day-case surgery. If all 87 trusts below upper-quartile for day-case surgery rate had met this target, total carbon saving would be 217,599kg CO2e (equivalent to powering 198 homes for 1yr). Adjusted upper-decile value=51% day-case surgery. If all 104 trusts below upper-decile for day-case surgery rate had met this target, total carbon saving=372,127kg	***Personal characteristics associated with discrimination:*** no evidence of nonlinearity in the relationship between log odds of day-case surgery and age. Day-case patients were younger and less frail than inpatients			C2 > C2 (S)			C2 > C2 (N)	

Specialty	Author, date: Country [Setting]	Aim	Study design: Comparison (Intervention vs Control/ Comparator) [Participants N]	Specific health condition: Patient characteristics	Intervention description	CE Calculation methods	Boundaries of system evaluated [Unit: CE Scope]	Summary of CE findings	PROGRESS -PLUS	No. F2F visits	Patient travel distance	LOS	Service costs	N. Physio appointments	Readmissions	Other outcomes measured with no comparative data
				34 845 (21), 4: 9134 (22) vs 36 560 (22), 5 (least deprived): 9206 (22)vs 34 716 (21)		CO2e to power an average UK home with electricity for 1 yr using conversion factor of 1098.9 kg CO2e/home/ yr		CO2e (equivalent to powering 339 UK homes with electricity for 1yr)								

Specialty	Author, date: Country [Setting]	Aim	Study design: Comparison (Intervention vs Control/ Comparator) [Participants N]	Specific health condition: Patient characteristics	Intervention description	CE Calculation methods	Boundaries of system evaluated [Unit: CE Scope]	Summary of CE findings	PROGRESS-PLUS	No. F2F visits	Patient travel distance	LOS	Service costs	N. Physio appointments	Readmissions	Other outcomes measured with no comparative data
Ear, Nose and Throat	Burton 2022: UK-Wales [NR](29)	To support care pathway to be retained post-Covid and spread to other hospitals in Wales and UK, by: Analysing social, financial and environmental impact of new fractured nose manipulation LA pathway, compare new LA pathway to fractured nose manipulation GA pathway, embed change within department by educating clinicians on benefits of new pathway, capture data on patient satisfaction for fractured nose manipulation under LA	Modelling: C1: LA vs C2: GA [NA]	Patients requiring urgent but not life/ limb saving treatment for fractured nose	Treatment for fractured nose under LA. ENT team involved in implementing change, including consultants, specialist registrars, senior house officers, foundation doctors, ANPs, ENT clinic nurses, HCAs and receptionist. LA procedure protocol created, with procedures initially performed by specialist registrars. Training/competency document subsequently created to formalise the teaching and assessment process for ANPS and junior doctors, expanding no. competent staff available to safely perform LA procedure. Staff reassured strong evidence for use of LA for fractured nose manipulation in most patients. While bleeding risk from LA procedure is small, plans and stock put in place in case of any significant epistaxis	Theatre data from 3 years post pandemic obtained to estimate average no. adult procedures performed/ yr with average of 122 adult cases/yr. However, as not all cases are suitable for LA, took 90% of cases for more realistic estimate of potential environmental and financial savings. Hybrid approach to carbon footprinting (bottom up and top-down methods used) taken. Applied emissions factors to activities and consumables involved in GA and LA pathways to compare CO2e of procedure under each approach. Applied saving from performing LA procedure to 90% of total procedures for fractured nose manipulation completed annually to provide CO2e saving. Emissions factors taken from The Sustainable Development Units 2015 Care Pathways Guidance on Appraising Sustainability.[f] Attendance at outpatient clinic (Emission factor for a GP consultation used as	Use, reuse, patient transport [kg CO2e: 1, 2, 3]	Based on 90% of 122 annual cases switching to LA instead of GA, anticipate savings of 4,137.26 kgCO2e/yr, equivalent to driving 11,916m (19,177km), or 15 return trips from Cardiff to Glasgow in average car. If 100% of cases performed under LA, savings would increase to 4,596.96 kgCO2e, equivalent to 13,239 m (21,306 km) travelled in average car, or 16.7 return journeys from Cardiff to Glasgow by car	NR				C1 > C2 (N)			PS

Specialty	Author, date: Country [Setting]	Aim	Study design: Comparison (Intervention vs Control/ Comparator) [Participants N]	Specific health condition: Patient characteristics	Intervention description	CE Calculation methods	Boundaries of system evaluated [Unit: CE Scope]	Summary of CE findings	PROGRESS-PLUS	No. F2F visits	Patient travel distance	LOS	Service costs	N. Physio appointments	Readmissions	Other outcomes measured with no comparative data
						more closely mimics 10-min. ENT casualty clinic appointment for assessment of fractured nose) and elective theatre (1.14 kgCO2e/per visit), patient travel to and from appointments (2.9 kgCO2e/one way), A&E visit (13.8 kgCO2e, Inpatient bed day - low intensity ward (37.9 kgCO2e/ bed day), surgical procedure (35.1 kgCO2e/66 minutes)										

[a]NJR. National Joint Registry. https://www.njrcentre.org.uk/njrcentre/default.aspx2021, [b]Conflicting numbers presented. Previous audit without input: N=41, Current trial 17-18: N=121, Current trial 2018-19: n=117 = Total of 279. [c]Including ventilation, cardiac ICU, cardiac high care, ward and total LOS, [d]Coalition for Sustainable Pharmaceuticals and Medical Devices. Care pathways: guidance on appraising sustainability, main document. Newton Abbot, UK: Sustainable Healthcare Coalition; 2015. [e]Coalition for Sustainable Pharmaceuticals and Medical Devices. Care pathways: guidance on appraising sustainability, surgical procedure module. Newton Abbot, UK: Sustainable Healthcare Coalition; 2015. [f]Moore A, Burton H. Genetic ophthalmology in focus. A needs assessment and review of specialist services for genetic eye disorders, PHG Foundation, 2008. ACP=Advanced Care Practitioner, ANP=Advanced Nurse Practitioners, ASA=American Society of Anesthesiologists, C=Complications, C1/C2=Comparator 1 or 2, CE=Carbon Emission, CHC=Cardiac High Care, CICU=Cardiac Intensive Care Unit, CO2=Carbon Dioxide, CT=Can't Tell, DEFRA=Department for Environment, Food, and Rural Affairs, EMP=Early Mobilisation Programme, ENT=Ear, Nose and Throat, F=Female, F2F=Face to Face, GA=General Anaesthetic, GH=General Hospital, HCA=Health Care Assistants, ICU=Intensive Care Unit, IV=Intravenous, LA=Local Anaesthetic, LOS=Length of Stay, M=Male, [N]=supported by narrative write up (no formal statistics), NA=Not Applicable, MR=Modified Release, NHS=National Health Service, NR=Not Reported, OT=Occupational Therapist, PC=Patient Compliance PF=Physical Functioning, pPCI=Primary percutaneous coronary intervention, PS=Patient Satisfaction, ROM=Range of Motion, SD=Standard Deviation, ST=Staff time, STEMI=ST segment elevation myocardial infarction, TKA=Total Knee Arthroplasty, TURBT=Transurethral Resection of Bladder Tumour, UKA=Unicondylar Knee Arthroplasty

Appendix K: Multiple components

Specialty	Author date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition /procedure: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon emission findings	PROGRESS-PLUS	Patient Satisfaction	Patient Clinical	Patient travel distance	Clinician Satisfaction	Service costs saved	Water consumption	Service energy savings	Service waste saved
Renal	Bendine 2020; France [Nephro-Care centres](84)	Describe data collection begun in the Nephro-Care centres in France and the changes observed during a 13-year period regarding environmental parameters	Observational: retrospective cohort, C1: Multiple-Setting; C2: Standard practice [2642 in 2018]	Renal failure: Patients receiving haemodialysis treatment	FMC's environmental commitment started in 2005 with eco-reporting on electricity, water consumption, and waste production. Dialysis-related consumption tracked individually, with data sent quarterly to headquarters for benchmarking. Environmental plans, implemented in phases, focus on awareness, eco-efficient technologies, and ISO 14001 certification, with precise targets set in subsequent plans. See paper for full detail	Number of dialysis sessions automatically recorded by clinic management system, linked with dialysis machines (4008, transitioning to 5008). Carbon equivalents of power, water, and waste sparing are calculated using a tool from the Association Bilan Carbone, accessible to trained personnel	Use+ reuse [CO2 tonnes equivalent : 2]	Due to electricity savings, CO2 equivalent reduced for analysed period from 92,400 tons, 10,000 tons for care-related wastes, and 17.5 tons for water. In total, 102,440 tons of CO2 equivalent were saved, an amount that represents CO2 production of plane flying around the globe 11,500 times	NR						C1>C2	C1>C2	C1>C2

Specialty	Author date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition /procedure: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon emission findings	PROGRESS-PLUS	Patient Satisfaction	Patient Clinical	Patient travel distance	Clinician Satisfaction	Service costs saved	Water consumption	Service energy savings	Service waste saved
Renal	Hardy 2022; UK [Satellite dialysis unit, Leeds teaching Hospitals NHS Trust](31)	To reduce carbon & waste	Modelling; C1 - Multiple: Setting; C2 - Conventional care [NA]	Haemodialysis: Patients receiving haemodialysis treatment	Aims: 1. Reducing disinfections of dialysis machines to once every 24 hours in a staggered manner and replacing others with rinsing processes. 2. Placing dialysis machines on standby mode after the initial priming process until patients are connected. 3. Decreasing pharmacy deliveries from weekly to biweekly for the satellite dialysis unit. Staff engagement was sought and encouraged for aims 1-3, with daily handovers used to discuss proposed plans and gather input. The entire unit's visibility aided in reminding staff of the changes during the initial stages. Aim 3 also involved exploring storage space availability, rearranging cupboards, and relabelling them to accommodate the new delivery schedule	Aim 1: Electricity and water usage during disinfection and rinse cycles for one dialysis machine were measured over 24-hour periods, with projections made for one year. Aim 2: Data on waiting times between priming dialysis machines and patient connection were collected over a week to calculate average daily waiting times per dialysis station. Consumption of electricity, water, and central acid during this waiting period was measured per minute and projected over a year, with potential additional savings from reduced central acid deliveries. Aim 3: Reducing pharmacy deliveries from weekly to biweekly could save an average of 104 miles in transportation per year. Collaboration with other satellite units within the Trust is underway to explore similar changes for increased mileage savings	Use+ reuse, + transport [kgCO2e: 1,3	Conversion factors for travel, water, and energy sourced from UK government BEIS 2021 database, pharmaceutical carbon factors obtained from Greener NHS Team 2020-21. The implemented changes from aims 1, 2, and 3 projected to save 1,914.4 kgCO2e and £2,837.05. Other ongoing projects were excluded from analysis. Implementing the proposed changes could result in a reduction of 0.1845 kgCO2e per patient per dialysis session. If similar changes were applied nationwide to the 24,365 individuals receiving dialysis in the UK, and assuming consistent energy consumption across the 70 renal centers, the national CO2 emission reduction could be approximately 4,495 kg per treatment session, translating to around 700 tonnes per year if each patient underwent thrice-weekly dialysis	NA					C1>C2	C1>C2	C1>C2	

Specialty	Author date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition /procedure: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon emission findings	PROGRESS-PLUS	Patient Satisfaction	Patient Clinical	Patient travel distance	Clinician Satisfaction	Service costs saved	Water consumption	Service energy savings	Service waste saved
Radiation oncology	Cheung 2023; Canada [Single institution] (99)	To assess the environmental effect of our single radiation oncology department's collective strategic changes implemented during the pandemic to reduce foot traffic to the hospital	Experimental: Retrospective before and after. Quality improvement C1 - Multiple: waste reduction, care delivery, travel, telemedicine; C2 - before intervention [10 175. Intervention: 4877, Control: 5298]	Cancer, N.S: Control v intervention - Treatment course (N/%): Conventional curative 2175 (41.0%) vs 1452 (29.8%) Hypofractionation curative 969 (18.3%) vs 1,236 (25.4%) Conventional palliative 106 (2.0%) vs 123 (2.5%) Hypofractionation palliative 1552 (29.3%) vs 1488 (30.5%) SBRT 496 (9.4%) vs 578 (11.9%)	Specifically, the main changes that were implemented at our department were an increased use of (1) hypo fractionated regimens, (2) virtual patient care, and (3) personal protection equipment during the COVID-19 pandemic	Patient travel distances were calculated from postal codes using Google Maps. Assumptions included passenger vehicles, normal driving conditions, and exclusion of out-of-province patients. CO2 emissions were calculated based on vehicle types. LINAC power usage was measured per fraction delivered to patients, with CO2e calculated based on electricity generation data. PPE orders (bouffant cap, disinfectant wipes, face shields, gloves, disposal gowns, surgical masks and N95 respirators, safety glasses, and shoe covers) were compared between two fiscal years, with CO2e calculated based on LCA	Use+ reuse+ patient travel [kg CO2e: 2, 3]	The changes in hypofractionation radiation regimens, with the consequent reduction in radiation therapy visits, combined with the rapid switch from in-person to virtual care, even accounting for the slight increase in LINAC power usage, and PPE, translated into a net saving of 743,641 kg CO2e (Fig. 3). The CO2e emission from the accounted sources was 1,956,175 kg CO2e in 2019 to 2020 FY and 1,212,534 kg CO2e in 2020 to 2021 FY, representing a 39% reduction in the CO2e emission. The CO2e saving was equivalent to the CO2e sequestered by approximately 12,000 seedling trees planted and grown for 10 years25 or the CO2e from the annual energy consumption of 182 Canadian households.26	Control vs Intervention group. ***Mean age***: 63.6 [range 1.6-101.9] vs 64.5 [range 1.8-99.3]. ***Gender*** Male/ Female (%): 52:48 vs 50:50		C1>C2	C1>C2					

Specialty	Author date: Country [Setting]	Aim	Study design: Intervention vs Comparator [Participants N]	Specific health condition /procedure: Patient features	Intervention description	Carbon emission calculation methods	Boundary of system evaluated [Unit: CE Scope]	Carbon emission findings	PROGRESS-PLUS	Patient Satisfaction	Patient Clinical	Patient travel distance	Clinician Satisfaction	Service costs saved	Water consumption	Service energy savings	Service waste saved
Gastroenterology	Materacki 2023; UK [4 Endoscopy units, Gloucestershire](36)	To establish a multiprofessional green endoscopy working group in Gloucestershire; To make at least one change to improve sustainability in endoscopy in Cheltenham General Hospital and measure its environmental (CO2e), financial and social impact	Before and After; C1: Multiple - setting, product-level C2: Conventional care [17;NA:NA]	Endoscopy: Patients receiving endoscopy	The endoscopy department implemented several sustainability initiatives: 1. Offering patients electronic copies of pre-procedure booklets via email. 2. Designating a 'green champion' within the bookings/ administrative team to enhance engagement. 3. Negotiating with the leaflet printing company to use recycled paper for future leaflet orders. 4. Providing washable patient gowns instead of single-use shorts during lower GI endoscopies. 5. Reducing prophylactic inkopad usage by implementing responsive practice based on endoscopist request or high-risk situations. 6. Encouraging patients to bring their own water bottles or reusable coffee cups to reduce single-use cup usage post-procedure	1. Pre-endoscopy leaflets: The environmental impact was estimated by calculating the carbon emissions factor per leaflet. We have calculated the paper and envelope emissions using weights, postage and travel. 2a. Single use shorts. The environmental impact was determined by considering materials, transport, and waste disposal. Reusable gowns: Carbon emissions were approximated based on assumptions about gown weight, material, washing process, and disposal. 2b. Inkopads: Carbon emissions per inkopad were calculated based on material weight, with assumptions about distribution from Sweden	Use+ reuse+ transport (from manufacturer to Gloucester Royal Hospital or supplier to hospital) [kgCO2e: 1,3]	1. 49% of patients opted for electronic leaflets which would reduce the annual no of paper leaflets from 16,971 to 8,655, resulting in savings of 1,701 kgCO2e. 2a. About 95% of patients undergoing colonoscopy & flexible sigmoidoscopy were estimated to switch to reusable gowns. The carbon emissions saved annually from reduced shorts manufacture and waste incineration and considering the procurement and laundry costs for reusable gowns, were estimated at 1,886 kgCO2e. 2b Estimating a reduction in inkopad use by 10% for OGD or flexible sigmoidoscopy and 50% for colonoscopy, approx. 12,735 fewer inkopads would be used annually, resulting in savings of 3,032 kgCO2e from reduced manufacture and incineration. Implementing these interventions across all endoscopy units would yield annual savings of £9,568 and 6,619 kgCO2e	NR		>< [N]		C1<>C2 [N]	C1>C2			

Green cell - statistically significant outcome, >< - no difference/ no detrimental effect , [N] = supported by narrative write up (no formal statistics), C1 > C2 - Analysis favoured Comparator 1 over C2, C1<> C2 - both comparator favoured in some scenario, CE=Carbon emissions, CO2=Carbon Dioxide, CSSU=Central Sterile Services Unit, CTR=Carpal Tunnel Release; EMEA=Europe, Middle East and Africa , FMC =Fresenius Medical Care, GHG=Greenhouse Gases; GP=General Practitioner; ICE= The Inventory of Carbon & Energy database; KPI=Key Performance Indicators, [N]=Narrative/descriptive analysis – no formal statistics, NA =Not Applicable, NR=Not Reported, NHS=National Health Trust, OGD=Oesophago-Gastro-Duodenoscopy , PPE=Personal Protective Equipment, SBRT=Stereotactic Body Radiation Therapy, WCP=Welsh Clinical Portal