openheart

Environmental impact of cardiovascular healthcare

Alexandra L Barratt ,[1,2] Yan Li,[1] Isabelle Gooroovadoo,[1] Allyson Todd ,[1] Yuanlong Dou,[1] Scott McAlister,[1,2,3] Christopher Semsarian [1,2,4,5]

► Additional supplemental material is published online only. To view, please visit the journal online (http://dx.doi.org/10.1136/openhrt-2023-002279).

To cite: Barratt AL, Li Y, Gooroovadoo I, *et al*. Environmental impact of cardiovascular healthcare. *Open Heart* 2023;**10**:e002279. doi:10.1136/openhrt-2023-002279

Received 9 February 2023
Accepted 24 March 2023

[1]Faculty of Medicine and Health, The University of Sydney, Sydney, New South Wales, Australia
[2]Wiser Healthcare, The University of Sydney, Sydney, New South Wales, Australia
[3]Department of Critical Care, The University of Melbourne, Melbourne, Victoria, Australia
[4]Agnes Ginges Centre for Molecular Cardiology, Centenary Institute, Sydney, New South Wales, Australia
[5]Department of Cardiology, Royal Prince Alfred Hospital, Sydney, New South Wales, Australia

Correspondence to
Professor Christopher Semsarian; c.semsarian@centenary.org.au

ABSTRACT

Importance The healthcare sector is essential to human health and well-being, yet its significant carbon footprint contributes to climate change-related threats to health.
Objective To review systematically published studies on environmental impacts, including carbon dioxide equivalent (CO_2e) emissions, of contemporary cardiovascular healthcare of all types, from prevention through to treatment.
Evidence review We followed the methods of systematic review and synthesis. We conducted searches in Medline, EMBASE and Scopus for primary studies and systematic reviews measuring environmental impacts of any type of cardiovascular healthcare published in 2011 and onwards. Studies were screened, selected and data were extracted by two independent reviewers. Studies were too heterogeneous for pooling in meta-analysis and were narratively synthesised with insights derived from content analysis.
Findings A total of 12 studies estimating environmental impacts, including carbon emissions (8 studies), of cardiac imaging, pacemaker monitoring, pharmaceutical prescribing and in-hospital care including cardiac surgery were found. Of these, three studies used the gold-standard method of Life Cycle Assessment. One of these found the environmental impact of echocardiography was 1%–20% that of cardiac MR (CMR) imaging and Single Photon Emission Tomography (SPECT) scanning. Many opportunities to reduce environmental impacts were identified: carbon emissions can be reduced by choosing echocardiography as the first cardiac test before considering CT or CMR, remote monitoring of pacemaker devices and teleconsultations when clinically appropriate to do so. Several interventions may be effective for reducing waste, including rinsing bypass circuitry after cardiac surgery. Cobenefits included reduced costs, health benefits such as cell salvage blood available for perfusion, and social benefits such as reduced time away from work for patients and carers. Content analysis revealed concern about the environmental impact of cardiovascular healthcare, particularly carbon emissions and a desire for change.
Conclusions and relevance Cardiac imaging, pharmaceutical prescribing and in-hospital care including cardiac surgery have significant environmental impacts, including CO_2e emissions which contribute to climate-related threats to human health. Importantly, many opportunities to effectively reduce environmental impacts exist within cardiac care, and can provide economic, health and social cobenefits.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ What are the environmental impacts of cardiovascular healthcare?

WHAT THIS STUDY ADDS

⇒ Environmental impacts of cardiovascular healthcare include carbon emissions of cardiac imaging, pacemaker monitoring, prescribing and in-hospital care including cardiac surgery. Many opportunities to reduce environmental impacts were identified, and may provide health, financial and social cobenefits.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Cardiovascular healthcare improves health and prolongs life but also has environmental impacts, including carbon dioxide equivalent emissions which contribute to climate-related threats to human health, which warrant further attention.

INTRODUCTION

The healthcare sector is essential to human health and well-being, yet has a significant environmental footprint. If global healthcare was a country, it would be the fifth largest emitter of carbon dioxide equivalent (CO_2e) emissions on the planet.[1] Global healthcare is each year responsible for over two gigatons (2×10^9 tons) or 4%–5% of global greenhouse gas emissions, measured as CO_2e emissions.[2] In turn, these emissions contribute to climate change, and its health-related impacts, with annual emissions resulting in an estimated loss of 3 million disability-adjusted life-years (DALYs).[3] At the UN Climate Conference (Glasgow COP26) in 2021, 50 countries committed to low carbon health systems, with 14 setting net-zero targets,[4] reflecting increasing recognition of the need for healthcare to mitigate its emissions. Of note, environmental impacts may take many forms, beyond greenhouse gases emissions, from plastic and water pollution to small particulates that contribute to air pollution.[5] As such, the environmental impacts of healthcare may undermine the primary mission of practitioners, and minimising them is essential.

Cardiovascular diseases (CVDs), including coronary heart disease and stroke, are the most common non-communicable diseases worldwide. According to the Global Burden of Disease study, CVDs were responsible for >17 million deaths globally in 2017, and for >300 million years of life lost.[6] Furthermore, the burden of CVD is increasing; 21% increase in deaths and 14% increase in years of life lost between 2007 and 2017 worldwide,[6] and its control will continue to require considerable global healthcare resources. In this study, we aimed to review systematically published studies on the environmental impact of contemporary cardiovascular healthcare of all types, from prevention through to treatment.

METHODS

Data sources and search strategy

We searched Medline, Embase and Scopus for studies published from 2011. The search was initially conducted in September 2021, and rerun and updated on 31 March 2022 to identify any newly published articles. We searched broadly with a range of terms covering our key concepts of environmental impact assessment and cardiovascular healthcare. Based on trial searches, we developed our final search strategy: *environmental.mp AND impact.mp AND cardi*.mp limited to publication date 2011 onwards and published in English*. Forward and backward citation searching was undertaken for all included studies. (Further information on our search strategies is available in online supplemental file).

Inclusion criteria

We included systematic reviews and primary studies that measured and reported any type of environmental impact occurring as a result of testing, diagnosing, monitoring or treating CVDs in humans. Care could be delivered as primary care or in-hospital care, and we interpreted care to include any activity that cardiologists, cardiac surgeons or primary care physicians managing cardiovascular conditions might undertake. We excluded opinion pieces, review articles, protocols, conference proceedings (not published in a peer-reviewed journal), animal studies, studies of the impact of environmental change on human health, studies on the environmental impact of general medical practice, which were not specific to cardiovascular healthcare, dietary intervention studies and studies not published in English.

Citation screening and study selection

Titles and abstracts were screened for inclusion/exclusion independently by two reviewers, with disagreements resolved through discussion and consensus. All potentially relevant articles were retrieved for full-text review. Two reviewers independently considered full-text reports for inclusion and again disagreements were resolved by discussion and consensus. Citation management and study selection was undertaken using Covidence.

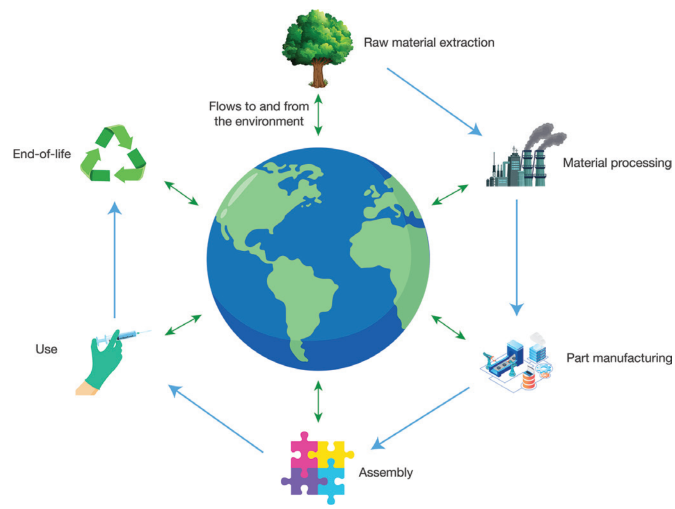


Figure 1 Complete life cycle of a product from raw material acquisition to disposal.[22]

Data extraction and presentation of findings

Two reviewers extracted data independently from included studies with disagreements resolved by discussion and consensus, and data were verified by a third reviewer. For each study, details of publication, study characteristics, methods and findings were summarised in tables. Because of the diversity of the study types, research questions, methods used and outcomes reported, no quantitative synthesis was undertaken. In addition, two reviewers independently conducted content analysis to provide greater insight, again with any disagreements resolved by discussion and consensus. Content analysis identified key themes, how results were contextualised and cobenefits.

Assessment of study quality

Measuring the environmental impact of healthcare products is an emerging research field, drawing on the methods of environmental science and engineering, and the sustainability literature including waste and consumption audits. Environmental impacts of products are best quantified by life cycle assessment (LCA), an internationally standardised method (ISO 14040-44).[7] LCA measures a diverse range of environmental emissions and their impacts, including water, land and air pollution and carbon emissions over the full life cycle of a defined product, from raw material acquisition through manufacturing, packaging, distribution, use and disposal (see figure 1). Downstream consequences of these impacts on human health can be estimated and reported as DALYs.

RESULTS

Study characteristics and methods

Of 1568 studies screened, 12 studies (10 papers and 2 abstracts) were included.[8–19] A Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram showing results of citation searching, screening and study selection process is provided (online supplemental figure 1). Forward and backward citation searching identified no additional studies.

Table 1 reports characteristics of included studies. A wide range of types of cardiovascular healthcare were examined, including cardiac imaging, monitoring devices, drug treatments, diabetes management and in-hospital care for cardiac surgery. Teleconsultation and a cardiology conference were also studied. Diverse methodologies were used: LCA (n=3), eco-audit, consumption and/or waste studies (n=4), patient surveys (n=2), water contamination studies (n=2) and an economic modelling study (n=1).

In most studies (8/12), the main outcome was carbon emissions (reported in kg or tons/tonnes of CO_2e emissions) (8/12 studies). Three of these studies used LCA to quantify CO_2e emissions and reported additional environmental impacts including pollution, resource usage and estimates of long-term impacts on human health in DALYs. The five studies which did not use LCA estimated carbon emissions from consumption of electricity, healthcare services and products, financial costs, or reported distances travelled. The remaining four studies reported environmental outcomes as product usage or waste (two studies) or drug concentrations in waterways (two studies).

Ten studies were descriptive only, that is, they measured or estimated the environmental impact of one or more cardiovascular healthcare products or services. While the authors may have used the results to make recommendations about practice changes to reduce environmental impacts, they did not test an intervention, such as a behavioural or educational intervention, to bring about practice change. In contrast, two studies tested such an intervention—these were a quality improvement intervention to reduce unnecessary test ordering, and a Lean Care intervention to reduce unnecessary use of personal protective equipment (PPE).

Study findings

The main findings of the 12 studies are shown in table 2 and summarised in figure 2. Echocardiography was found to have environmental impacts on human health, ecosystems and resource usage which were 1%–20% of those of cardiac MR (CMR) imaging or Single Photon Emission Tomography (SPECT), based on LCA.[8] Stretchable cardiac monitoring devices were lower in carbon emissions (58% of those of rigid devices), and in other environmental impacts (22%–68% of those of rigid devices), again based on LCA results.[9]

Remote monitoring of pacemakers[10] and telephone consultations[11] reduced estimated carbon emissions and costs, based on patient-reported travel data, compared with in-clinic appointments. The economic modelling study[12] demonstrated that carbon emissions savings, both in absolute terms, and per Life Year gained, are predicted from effective diabetes management compared with cohorts with untreated or poorly controlled diabetes.

Two studies examined concentrations of cardiovascular and lipid regulating drugs in effluent water released from municipal wastewater treatment plants, and in surface waters globally. Many cardiovascular drugs (58 of 82 drugs assessed in a systematic review of 322 studies,[13] and 19 of 26 drugs assessed in a recent primary study in Shanghai, China)[14] were detected in both types of waterways, in concentrations of up to several µg/L in wastewater and up to hundreds of ng/L in surface waters. ß-blockers, lipid regulating agents, ACE inhibitors, angiotension II receptor antagonists and diuretics were commonly studied and found in waterways, even after wastewater treatment. Physiological and reproductive effects on aquatic organisms (including shellfish and fish) were found, mostly for ß-blockers and lipid regulating drugs, including at concentrations found in some surface waters. Research is lacking currently on any possible impacts on human health from consumption.

One study conducted an eco-audit of consumption of disposable medical products, pharmaceuticals (including anaesthetic gases) and electricity during cardiac surgery, and estimated that each adult cardiac surgery resulted in 124 kgCO_2e emissions.[18] Another study in the context of cardiac surgery examined whether the negative environmental impact of medically regulated waste treatment and disposal could be reduced by rinsing the by-pass circuits after use, thereby converting this waste from regulated medical waste to solid municipal waste.[17] The rinsing procedure took no additional theatre time, cost less than US$2 per procedure for additional prime fluid, and diverted 15 lb of circuits from regulated medical waste per procedure. A cobenefit was 240 mL of cell salvage blood available for transfusion.

Two studies evaluated interventions to reduce unnecessary or low value clinical care in before-and-after studies. In one study,[15] the intervention was a quality improvement project consisting of staff engagement, educational posters and feedback on test ordering frequency, aimed at reducing unnecessary ordering of biochemical tests. The intervention in the other study[16] used staff engagement and value stream mapping to increase the value of ward admission procedures, with the aim of reducing unnecessary use of PPE and minimising risk of staff exposure to COVID-19-positive patients. Both studies reported reductions in test ordering/PPE use, respectively, with associated reductions in costs, waste and estimated carbon emissions.

The final LCA study[19] looked at the environmental impact of holding a cardiology conference virtually by webinar (necessitated by the COVID-19 pandemic), compared with a hypothetical traditional conference of 2.5 days duration for 1374 attendees. The environmental impact of the virtual conference was 4 tons of CO_2e emissions, compared with 1920 (note publication by Duane *et al*[19] contains a typographical error reporting 192 tons) tons of CO_2e emissions (1.4 tons of CO_2e emissions per person) for the in-person conference, an estimated reduction of >99%.

Table 1 Characteristics of included studies

Author, publication year	Country	Study setting	Research question	Study type	Type of cardiovascular healthcare	Comparator(s) (if any)	Primary outcome(s)	Other outcome(s) measured	Method(s) used to measure environmental impact
Imaging and monitoring									
Marwick and Buonocore[8] 2011	USA	Heart and Vascular Institute	What are the environmental impacts of cardiac imaging tests for diagnosis of coronary artery disease?	Comparative life cycle assessment (LCA)	Cardiac MRI	Cardiac Echo, SPEC (CT)	Human health damage (reported as DALYxe^{-06})	▶ Ecosystem quality (PDF×m^2 year) ▶ Energy and resource use (MJ)	Process-based LCA
Kokare *et al*[9] 2021	Sweden	Technology Research Institute	What is the relative environmental impact of stretchable vs rigid cardiac monitoring devices?	Comparative LCA†	Stretchable cardiac monitoring device	Rigid cardiac monitoring device	18 environmental impacts* including CO_2e emissions (no primary defined)		Process-based LCA
Perez Diaz *et al* (Abstract only)[10] 2020	Spain	Hospital Arrhythmia Unit	What is the environmental impact of in-clinic versus remote pacemaker monitoring?	Patient survey	Remote monitoring of pacemaker	In-clinic appointment to review pacemaker	▶ Distance travelled ▶ CO_2e emissions	▶ Patient time ▶ Accompanying person and transport needs ▶ Time off work	CO_2e emissions estimated from patient journeys
Out of hospital consultations and medical treatment									
Yao *et al* (Abstract only)[11] 2021	UK	Cardiology outpatients	What are the sustainability benefits of teleconsultations in stable patients?	Patient survey	Telephone consultation	In-clinic appointment	▶ Distance travelled ▶ CO_2e emissions	▶ Patient time ▶ Petrol and parking costs	Unclear
Fordham *et al*[12] 2020	UK	People with type 2 diabetes in the UK	What is the impact on carbon emissions of effective management of type 2 diabetes (compared with inadequate glycemic control) over time horizon of 50 years?	Economic model	Type 2 diabetes management for two cohorts (1) first-line pharmacotherapy and (2) third-line medical treatment under 2 scenarios (1) maintain HbA1C of 7% (53 mmol/mol) and (2) reduce HbA1C by 1% from baseline	Unchanging gylycemic control (untreated)	CO_2e emissions per patient	CO_2e/LY	CO_2e emissions estimated from healthcare resources, services and costs
Zhang *et al*[13] 2020	Global	Waterways and waste water treatment plants	How common are cardiovascular system drugs in fresh surface waters, and what is their impact on aquatic organisms?	Systematic review of primary studies of water contaminants	82 cardiovascular drugs selected to represent major drug classes	NA	Drug concentrations	▶ Ecotoxicity ▶ Changes in function or behaviour of aquatic organisms	Drug residue samples in fresh surface waters and waste water treatment plants, and assessments of their ecotoxicities
Zuo *et al*[14] 2022	Shanghai China	Waterways and waste water treatment plants		Primary study of water contaminants		NA	Drug concentrations		Drug residue samples in fresh surface waters and waste waters
In-hospital care and cardiac surgery									

Continued

Table 1 Continued

Author, publication year	Country	Study setting	Research question	Study type	Type of cardiovascular healthcare	Comparator(s) (if any)	Primary outcome(s)	Other outcome(s) measured	Method(s) used to measure environmental impact
Regan *et al*[15] 2018	England	Paediatric cardiology ward	Can a Quality Improvement Project reduce unnecessary biochemistry test ordering by half in 8 weeks?	Resource consumption audit	Test ordering after QI intervention	Test ordering before QI intervention	▶ Costs (£) ▶ CO_2e emissions	Unnecessary tests ordered	CO_2e emissions estimated from cost savings
Sheehan *et al*[16] 2021	Ireland	Paediatric hospital	Can a Lean Care intervention applied to admissions of children for congenital cardiac surgery reduce waste from unnecessary PPE set use?	Resource consumption audit	Use of PPE after Lean Care Value Stream Map intervention	Usual practice before Lean Care intervention (before COVID-19 pandemic and since pandemic began)	Reduction in unnecessary PPE set use	▶ Staff exposure to COVID-19 ▶ Cost (€) ▶ Plastic waste	Measurement of consumables
Debois *et al*[17] 2013	USA	Adult cardiac surgery operating theatre	Can regulated medical waste (RMW) from heart lung bypass circuits be converted to solid municipal waste (SMW) to reduce volume of waste?	Waste audit	Rinsed heart lung machine bypass circuits suitable for disposal as SMW	Usual cardiac surgery procedures for disposing of heart lung machine bypass circuits as RMW	% of procedures in which circuit waste was converted to SMW	▶ Weight (lbs) of circuit waste converted to SMW ▶ Costs ($US)	Measurement of waste
Grinberg *et al*[18] 2021	France	Adult cardiac surgery operating theatre	What is the environmental impact of conventional adult cardiac surgery?	Eco-audit	Cardiac surgical procedures including anaesthesia	NA	CO_2e emissions		CO_2e emissions estimated from consumption of electricity, pharmaceuticals and disposable medical products
Other professional activities									
Duane *et al*[19] 2021	Ireland	Cardiology conference	What is the environmental footprint of a virtual cardiology conference, compared with equivalent in person conference?	Comparative LCA	Virtual conference/webinar	In-person conference (hypothetical)	CO_2e emissions	15 other environmental impacts*	Process-based LCA

*Eg Water use, ionising radiation, ozone formation and depletion, particulate matter formation, human carcinogenic and non-carcinogenic toxicity.
†In this comparative analysis, only those parts of the life cycle which were different were included, for example, lithium batteries are used in both devices and this energy use was excluded from the analysis.
CO_2e, carbon dioxide equivalent emissions; DALY, disability-adjusted life-year; HbA1c, glycated haemoglobin; MJ, megajoule, a measure of energy and resource use; NA, not applicable; PDF, potentially displaced fraction, a measure of biodiversity impact; PPE, personal protective equipment; SPECT, single photon emission tomography.

Table 2 Study findings

Study	Type of cardiovascular healthcare/intervention	CO_2e emissions/saved emissions	Waste/reduction in waste	Cost/change in cost	Human health damages (DALYxe^{-06})	Other, for example, ecosystem quality energy use, travel distances
Imaging and monitoring						
Marwick and Buonocore[8]	MRI ECHO SPECT	See Human health damages			MRI 84.2 ECHO 1.35 SPECT 8.63	Ecosytem quality (PDFm2year): MRI 2.215 ECHO 0.054 SPECT 0.285 Energy and resources use (MJ): MRI 57.85 ECHO 0.569 SPECT 10.27
Kokare *et al*[9]	Stretchable device Rigid device	58% (relative impact) 100%				22%-68% (relative environmental impacts) 100%
Perez Diaz *et al*[10]	Remote monitoring of pacemaker In-clinic appointment	15 kg CO_2e emissions saved per remote monitoring cycle				1.4 km vs 63 km travelled 60 mins vs 150 mins time spent 85.6% vs 0% required accompanying person
Out of hospital consultation and medical treatment						
Yao *et al*[11]	Teleconsultation	0.49 tonnes CO_2e emissions saved		£3000 saving to NHS trust		1368.5 travel miles saved
Fordham *et al*[12]	Cohort 1 (1st line Rx) Maintain Reduce Cohort 2 (3rd line Rx) Maintain Reduce	Emissions saved/patient: 1546 kg CO_2e/pt (18%) 1049 kg CO_2e/pt (12%) 937 kgCO_2e/pt (13%) 655 kgCO_2e/pt (9%)				Emissions saved/Life-Year gained 669 kgCO_2e/LY (20%) 721 kgCO_2e/LY (14%) 666 kgCO_2e/LY (15%) 699 kgCO_2e/LY (11%)
Zhang *et al*[13]	Cardiovascular and lipid regulating drugs					58 of 82 selected drugs detected in wastewater and surface waters globally (detections in all continents). ß blockers and lipid regulating drugs detected in drinking water in Europe, USA, Japan and China.
Zuo *et al*[14]	Cardiovascular and lipid regulating drugs					19 of 26 target drugs detected in waste and surface waters, predominantly angiotension II receptor antagonists and ß-blockers
In-hospital care and surgery						

Continued

Barratt AL, *et al. Open Heart* 2023;**10**:e002279. doi:10.1136/openhrt-2023-002279

Table 2 Continued

Study	Type of cardiovascular healthcare/intervention	CO_2e emissions/saved emissions	Waste/reduction in waste	Cost/change in cost	Human health damages (DALYxe^{-06})	Other, for example, ecosystem quality energy use, travel distances
Regan *et al*[15]	Quality Improvement Programme to reduce unnecessary test ordering. Programme used a simple educational intervention.	10 042 kg (10 tonnes) CO_2e emissions saved (1-year follow-up) 17 800 kg (17.8 tonnes) CO_2e emissions saved (32 months follow-up)		£6396 (23%) saved (1 year) £11 338 (13.5%) projected saving (32 months)		Significant reduction in number of unnecessary tests ordered.
Sheehan *et al*[16]	Quality Improvement Programme (Lean Care) to reduce unnecessary PPE set use. Programme based on Value Stream Maps.		PPE sets reduced from 13 to 1 per patient (total saving of 156 sets over 3 weeks of study period) Saving of 132 pieces of single use plastic per patient. Potential saving of 69 696 pieces of single use plastic pa.	Saving of €69.24 per patient. Estimated potential saving of €36, 529 pa		Reduction in COVID-19 close contact staff from 13 to 1 per patient (156 fewer staff close contacts)
Debois *et al*[17]	Rinsing of heart lung bypass circuits		90% reduction in regulated medical waste (90% of procedures waste conversion was successful). 15lb waste (plastic tubing and other plastic parts) converted from regulated medical waste to solid municipal waste per procedure.	<US$2 additional cost per procedure for rinsing		
Grinberg *et al*[18]	Adult cardiac surgery:- disposable medical products pharmaceuticals (incl anaesthetic gases) electricity consumption Total	 107.9 kg CO_2e 12.4 (11.1) kg CO_2e 4.0 kg CO_2e 124.3 kg CO_2e				
Other professional activities						
Duane *et al*[19]	Virtual conference In-person conference	4 tons CO_2e 1920 tons CO_2e				Virtual conference performed better across all environmental impact categories

*CO_2e emissions (leading to climate change) are included within endpoint of human health damage
CO_2e, carbon dioxide equivalent emissions; DALYs, disability-adjusted life-years; NHS, National Health Service; PPE, personal protective equipment; SPECT, single photon emission tomography.

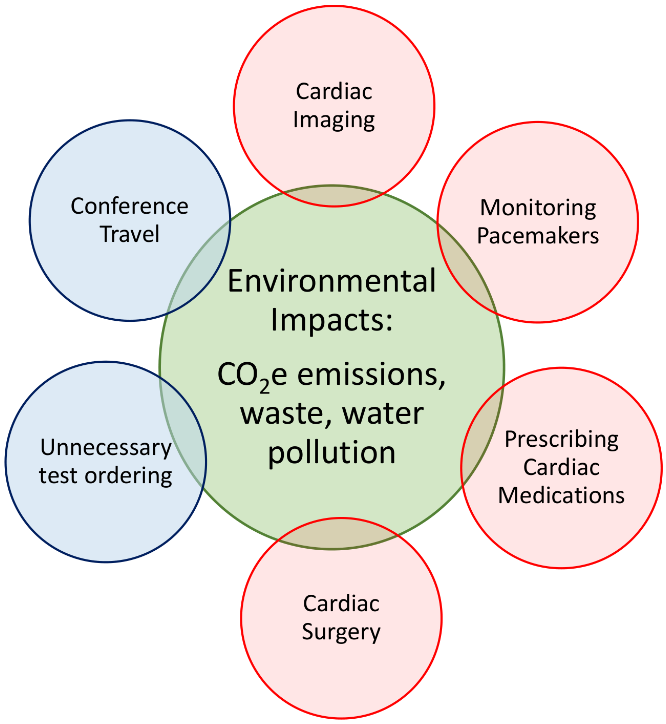


Figure 2 Summary of main findings—environmental impacts of cardiovascular healthcare: red circles cardiac care, blue circles general activities, green circle key environmental impacts. CO_2e, carbon dioxide equivalent emissions.

Findings from the content analysis

We identified three key themes: (1) concern about cardiovascular healthcare's environmental footprint and a desire to reduce it; (2) results being contextualised and (3) cobenefits. These themes and illustrative quotations from several studies are shown in table 3.

All studies' stated research aims reflected awareness of the need to measure the environmental impact of cardiovascular healthcare, within the context of healthcare becoming more sustainable. Across all studies, authors were keen to move beyond measurement to propose or, in two studies to test, specific practice changes to reduce the environmental impact of cardiovascular healthcare. They used various ways to make their study results more meaningful to readers. The most commonly reported cobenefits of reducing environmental impacts were cost savings, health benefits, such as salvage blood for transfusion, and reduced risk of exposure to COVID-19-positive patients, and social benefits such as reduced time away from work and reduced burden on carers' time.

DISCUSSION

This is the first study to review evidence on the environmental footprint of cardiovascular healthcare. Activities undertaken regularly in the course of delivering cardiac care, including imaging, testing, monitoring, prescribing and surgical intervention, all have environmental impacts, including carbon emissions which contribute to climate change. Importantly, many opportunities exist to effectively reduce environmental impacts within cardiac care, and can provide economic, health and social cobenefits.

Motivation appears high among investigators to find ways to reduce impact, and these studies have highlighted a variety of ways this could be done. Some options include using echocardiography as the first-line test, before considering CMR imaging or SPECT, using stretchable rather than rigid devices, using remote pacemaker monitoring when clinically appropriate to do so, and reducing or avoiding low value care. CVD drugs are widespread in waterways and highlight the need to avoid unnecessary prescribing but also the importance of effective management in primary care, for example, of type 2 diabetes which can reduce environmental impact by effective prevention of disease progression.

Implementation of simple, low-cost interventions, such as quality improvement programmes, aimed at cutting unnecessary test ordering and use of PPE, can realise environmental benefits and reduce costs. Changes to theatre practice, to reduce waste and rinse bypass circuits, can have environmental benefits, reduce costs and provide additional cobenefits such as collection of cell salvage blood available for perfusion.

This is the first review of studies on the environmental impact of cardiology practice. Others have noted the potential for 'greener cardiology'.[20 21] For example, in a review of the use of medical imaging in 10 diagnostic imaging categories (and 162 subcategories), it was found that the greatest opportunity to reduce energy consumption lay within cardiac imaging,[21] highlighting, as we found, the scope to reduce the environmental impact of cardiac imaging by using lower energy consumption alternatives, such as echocardiography, as the first-line test, before considering CT or CMR imaging when clinically appropriate.

Our study has important strengths and limitations to be considered. The strengths of our study include a broad and comprehensive search with independent double screening of title and abstracts and independent double extraction of data. We used a mixed-methods approach to extract and narratively synthesise the quantitative findings of the studies, together with a content analysis to provide additional insights through qualitative data extraction and analysis. An inherent limitation of this study is the small number of papers in this review which reflects the topical and novel nature of this research. The 12 studies selected are mainly from developed countries. Future studies in low-income and middle-income countries, with larger populations, may provide new insights into the environmental impact of cardiovascular healthcare. We may have missed some reports despite our broad search strategy, and new studies may have been published since our last search and will continue to emerge.

With respect to study quality, reporting standards for environmental impact studies of healthcare have yet to be developed so we did not conduct a risk of bias assessment. LCA is a robust and reliable method that has been

Table 3 Results of content analysis

Theme	Example
Concern about cardiovascular healthcare impacts on the environment	'cardiovascular drugs and lipid regulating agents have received not sufficient attention for their ecotoxicological implications and their environmental risks'[13] 'a novel approach was taken to map the link between healthcare and carbon emission associated with the management of type 2 diabetes mellitus.'[12]
Concern about climate change and its impact on human health	'There is overwhelming evidence to support the increasing concerns regarding the health of our planet…one could argue that the most pressing threat for humanity is climate change'[19] 'increasing greenhouse gas emissions has led to climate change, which directly impacts public health in many ways (such as air quality, malnutrition and vectorborne diseases)'[18]
Contextualisation of results to help readers understand meaning of results	'a standard 5-hour cardiac procedure yields the global warming equivalent of 9.9 days of the daily routine consumption of a French citizen'[18] 'resource use for a face-to-face conference lasting 2.5 days for 1374 attendees is equivalent to 400 times what an average person would use in one year, the climate change and photochemical ozone formation approximately 250 times …'[19] 'at present, the energy use of a 3 Tesla MRI scanner over a day (960 kWh/day) is similar to that of an average US household over a month (920 kWh/month)'[8]
Cobenefits: Cost savings Health and social benefits	'led to a sustained reduction in the ordering of expensive combined biochemical tests, saving an estimated £11 338 (or 13.5%) on biochemistry tests and around 17.8 tonnes of carbon dioxide across a 32-month follow-up period'[15] 'The use of LEAN methodology can reduce waste of PPE and plastic, resulting in cost savings while reducing staff exposure…and prevent cancellation of surgery'[16] 'an additional 240 mL of processed cell salvage blood was available for transfusion'[17] 'The remote monitoring pacemaker programme in the health district of our city has a very positive healthcare, social-occupational and environmental impact, which is manifested both from an objective point of view (greater independence, less time spent per appointment, less distance travelled, fewer healthcare transport needs, less workplace absenteeism by family members and approximately a 10% reduction in CO_2 emissions per monitoring cycle) and a subjective point of view (lower impact of appointments on patients' lives and greater perception of satisfaction from the patients and their companions).'[10]

used in other sectors for many years, but to date has been little used in health research. Of note, only three studies in our review used LCA. The remainder used simpler approaches, ranging from an eco-audit to measuring product consumption, waste generation or distances travelled by patients to clinics. As such, these studies provide a less complete view of the environmental impacts of a product or service, but may still provide actionable information for clinicians. A priority in future work is to strengthen measurement quality in studies of the environmental impact of healthcare, and to couple this with stronger intervention study designs to assess clinical, environmental and economic outcomes.

Our study highlights the scope of the environmental footprint of cardiology practice, and identifies some important implications for cardiologists to 'green' their practice. Further opportunities likely exist as part of a growing professional desire to transition to more sustainable healthcare without compromising health outcomes for patients. As an example, interventional cardiologists may conduct waste audits of their practice, which could support practice changes such as recycling packaging of catheters, balloons, stents and other equipment, or leveraging their purchasing power to encourage suppliers to reduce unnecessary packaging.

The finding that the environmental footprint of international conferences is substantial may have implications for cardiology as a profession that convenes many conferences globally each year. Conference organisers could consider hybrid meetings (or alternate annual in person meetings with online meetings) to reduce their footprint, and provide social benefits—online meetings are more accessible to participants in low-income and middle-income countries, older participants, and those with disabilities. Teleconsultations may reduce emissions through less patient and doctor travel, and appear to provide social and economic cobenefits. However, research is needed to evaluate the impact of telehealth on health outcomes and on subsequent health service utilisation.

CONCLUSIONS

Within the context of cardiovascular healthcare, unnecessary tests and medicines have significant environmental impacts. Reducing unnecessary care is an important strategy for reducing the environmental impact of cardiac care. Cardiac imaging, monitoring, prescribing and in-hospital care including cardiac surgery all have important environmental impacts, however, many effective opportunities to reduce these exist, and provide economic, social and health cobenefits. Our review represents a first step into an emerging field. Further research is needed to investigate the environmental footprint of additional aspects of cardiology practice, to undertake intervention studies to discover ways to reduce the carbon footprint, and to establish the most effective ways to educate and raise awareness among cardiologists, nurses and other health professionals, about the environmental impact of cardiovascular healthcare.

Twitter Allyson Todd @allyson_todd_ and Christopher Semsarian @CSHeartResearch

Contributors All authors were involved in study design, collection and analysis of selected papers, and writing the manuscript. AB is the guarantor.

Funding This work was supported by National Health and Medical Research Council funding to Barratt (#1104136) and Semsarian (#1154992).

Competing interests None declared.

Patient consent for publication Not applicable.

Ethics approval Not applicable.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement No data are available.

ORCID iDs
Alexandra L Barratt http://orcid.org/0000-0002-2561-3319
Allyson Todd http://orcid.org/0000-0001-6948-9754
Christopher Semsarian http://orcid.org/0000-0001-6441-274X

REFERENCES

1. Health Care Without Harm. *Health care's climate footprint: how the health sector contributes to the global climate crisis and opportunities for action. Climate smart health care series green paper number one*. Produced in collaboration with Arup, 2019.
2. Lenzen M, Malik A, Li M, *et al*. The environmental footprint of health care: a global assessment. *Lancet Planet Health* 2020;4:e271–9.
3. Tang L, Furushima Y, Honda Y, *et al*. Estimating human health damage factors related to CO2 emissions by considering updated climate-related relative risks. *Int J Life Cycle Assess* 2019;24:1118–28.
4. Wise J. COP26: fifty countries commit to climate resilient and low carbon health systems. *BMJ* 2021;375:2734.
5. Eckelman MJ, Huang K, Lagasse R, *et al*. Health care pollution and public health damage in the United States: an update. *Health Aff (Millwood)* 2020;39:2071–9.
6. GBD 2017 Causes of Death Collaborators. Global, regional, and national age-sex-specific mortality for 282 causes of death in 195 countries and territories, 1980-2017: a systematic analysis for the global burden of disease study 2017. *Lancet* 2018;392:1736–88.
7. ISO 14040:2006. *Environmental management. Life cycle assessment: principles and framework*. 2nd edition. Geneva, Switzerland, 2006.
8. Marwick TH, Buonocore J. Environmental impact of cardiac imaging tests for the diagnosis of coronary artery disease. *Heart* 2011;97:1128–31.
9. Kokare S, Asif FMA, Mårtensson G, *et al*. A comparative life cycle assessment of stretchable and rigid electronics: a case study of cardiac monitoring devices. *Int J Environ Sci Technol (Tehran)* 2022;19:3087–102.
10. Perez Diaz P, Jimenez Diaz J, Higuera Sobrino F, *et al*. Carbon footprint as a marker of environmental impact in patients included in a remote monitoring pacemaker programme. *Eur Heart J* 2021;42.
11. yao zhihong, Farag A, Mullineux P, *et al*. 82 out of sight but not out of mind. A district hospital cardiology teleclinic setup… patients', sustainability and environmental benefits. *Heart* 2021;107 (Suppl 1):A66–a67.
12. Fordham R, Dhatariya K, Stancliffe R, *et al*. Effective diabetes complication management is a step toward a carbon-efficient planet: an economic modeling study. *BMJ Open Diabetes Res Care* 2020;8:e001017.
13. Zhang K, Zhao Y, Fent K. Cardiovascular drugs and lipid regulating agents in surface waters at global scale: occurrence, ecotoxicity and risk assessment. *Sci Total Environ* 2020;729:138770.
14. Zuo S, Meng H, Liang J, *et al*. Residues of cardiovascular and lipid-lowering drugs pose a risk to the aquatic ecosystem despite a high wastewater treatment ratio in the megacity Shanghai, China. *Environ Sci Technol* 2022;56:2312–22.
15. Regan W, Hothi D, Jones K. Sustainable approach to reducing unnecessary combined biochemistry tests on a paediatric cardiology ward. *BMJ Open Qual* 2018;7:e000372.
16. Sheehan JR, Lyons B, Holt F. The use of lean methodology to reduce personal protective equipment wastage in children undergoing congenital cardiac surgery, during the COVID-19 pandemic. *Paediatr Anaesth* 2021;31:213–20.
17. Debois W, Prata J, Elmer B, *et al*. Improved environmental impact with diversion of perfusion bypass circuit to municipal solid waste. *J Extra Corpor Technol* 2013;45:143–5.
18. Grinberg D, Buzzi R, Pozzi M, *et al*. Eco-audit of conventional heart surgery procedures. *Eur J Cardiothorac Surg* 2021;60:1325–31.
19. Duane B, Lyne A, Faulkner T, *et al*. Webinars reduce the environmental footprint of pediatric cardiology conferences. *Cardiol Young* 2021;31:1625–32.
20. Braga L, Vinci B, Leo CG, *et al*. The true cost of cardiovascular imaging: focusing on downstream, indirect, and environmental costs. *Cardiovasc Ultrasound* 2013;11:10.
21. Alshqaqeeq F, McGuire C, Overcash M, *et al*. Choosing radiology imaging modalities to meet patient needs with lower environmental impact. *Resources, Conservation and Recycling* 2020;155:104657.
22. McAlister S, Morton RL, Barratt A. Incorporating carbon into health care: adding carbon emissions to health technology assessments. *Lancet Planet Health* 2022:e993–99.

Literature search strategy

We searched broadly with a range of terms covering our key concepts of environmental impact assessment and cardiovascular (or cardiac or cardiological) healthcare, guided by keywords in the titles and abstracts of papers which we had obtained through our broader work in the area on the environmental impact of healthcare, including one paper specific to cardiac care (our target publication). Our initial search strategies resulted in either too few citations (in the range of 0 to 100 without finding our target publication) or too many (e.g. 10,000-60,000 citations with large volumes of apparently irrelevant articles). Tables S1 and S2 illustrate the broad range of terms we tried in our initial searches. Based on these trial searches, we developed our final search strategy: *environmental.mp AND impact.mp AND cardi*.mp limited to publication date 2011 onwards and published in English.* Initial searches were done in August-September 2021. The final search strategy was rerun on 31 March 2022 to identify additional citations. Citations were imported to Covidence for title and abstract screening as per PRISMA flow diagram (Supplementary Figure 1).

Table S1: Search terms tested in Medline (and Embase)

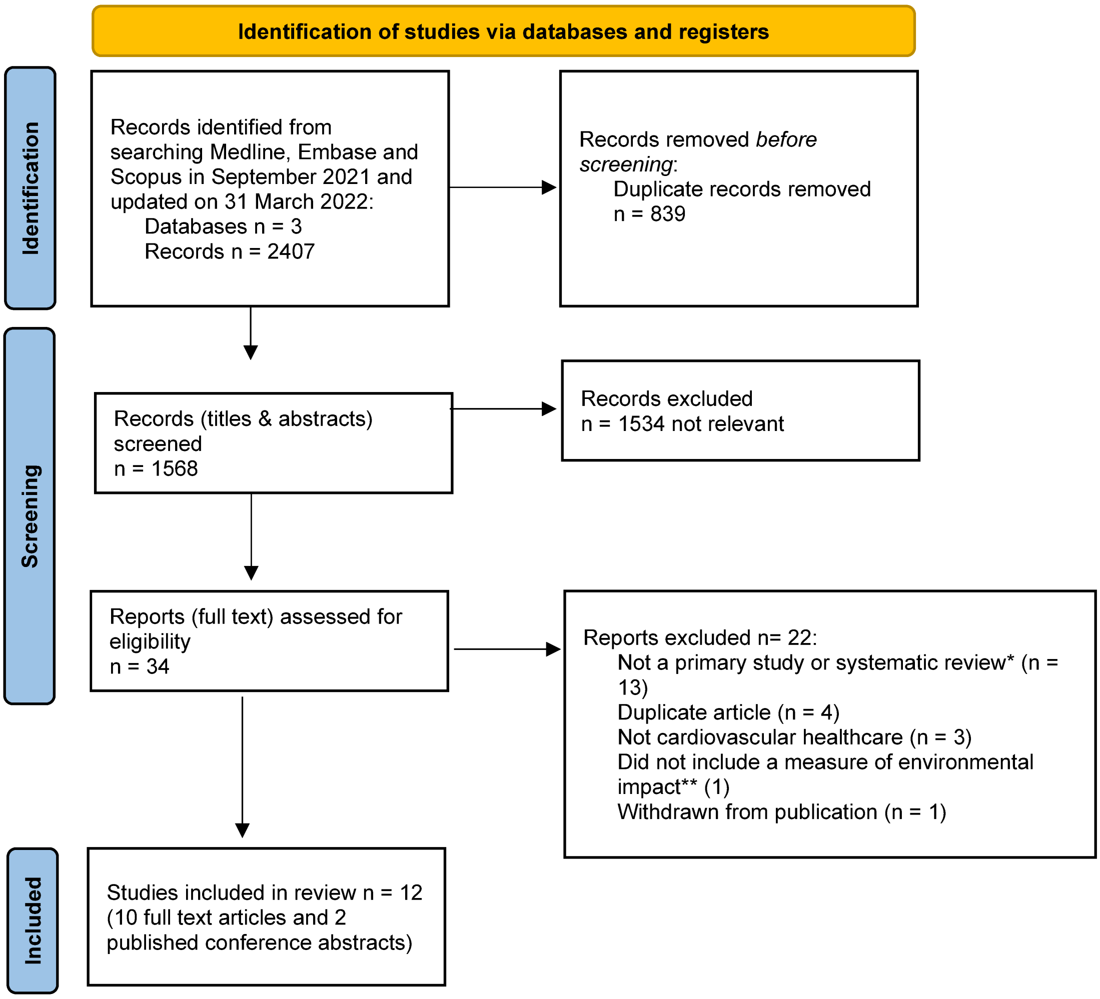
Concept 1: Environmental impact		Concept 2: Healthcare including screening, testing, diagnosis, monitoring, treatment and surgical treatment		Concept 3: Cardiovascular disease prevention or treatment
Carbon footprint*.mp		Healthcare*.mp		Cardiovascular*.mp
OR	AND	OR	AND	OR
Emission*.mp		Prevention*.mp		Coronary*.mp
OR		OR		OR
Greenhouse gas*.mp		Diagnosis*.mp		Cardiac*.mp
OR		OR		OR
Gas pollute*.mp		Screening*.mp		Heart*.mp
OR		OR		OR
Carbon Dioxide*.mp		Treatment*.mp		Circulatory*.mp
OR		OR		OR
Carbon dioxide emission*.mp		Testing techniques*.mp		Heart function*.mp
OR		OR		OR
Contaminant*.mp		Medicine*.mp		Circulatory system*.mp
OR		OR		OR
Contamination*.mp		Procedures*.mp		Myocardial*.mp
OR		OR		OR
Smog*.mp		Mediation*.mp		Heart failure*.mp
OR		OR		
Fluorocarbon*.mp		Medical examination*.mp		
OR		OR		
Poisonous gases*.mp		Test*.mp		
OR		OR		
Pollutants*.mp		Operation*.mp		
OR		OR		

Climate change*.mp		Health management*.mp		
OR				
Global warming*.mp				
Including: abstract in English, only humans, time period within 10 years				
Excluding: review articles, opinion pieces, protocol papers, conference proceedings, animal studies, papers with discussion of environmental impact on individuals				

Table S2: Search terms tested in Scopus

Concept 1		Concept 2		Concept 3
“Carbon footprint” *		“Healthcare” *		“Cardiovascular” *
OR		OR		OR
“Emission” *		“Prevention” *		“Coronary” *
OR		OR		OR
“Greenhouse gas”*		“Diagnosis” *		“Cardiac” *
OR		OR		OR
“Gas pollute” *		“Screening” *		“Heart” *
OR	AND	OR	AND	OR
“Carbon Dioxide” *		“Treatment” *		“Circulatory” *
OR		OR		OR
“Carbon dioxide emission” *		“Testing techniques “*		“Heart function” *
OR		OR		OR
“Contaminant” *		”Medicine“*		“Circulatory system” *
OR		OR		OR
“Contamination” *		“Procedures” *		“Myocardial” *
OR		OR		OR
“Smog” *		“Mediation” *.		“Heart failure” *
OR		OR		
“Fluorocarbon” *		“Medical examination” *		
OR		OR		
“Poisonous gases” *		“Test” *		
OR		OR		
“Pollutants” *		“Operation” *		
OR		OR		
“Climate change” *		“Health management” *		
OR				
“Global warming” *				
Including: abstract in English, only humans, time period within 10 years				
Excluding: review articles, opinion pieces, protocol papers, conference proceedings, animal studies, papers with discussion of environmental impact on individuals				

Supplementary Figure 1 PRISMA flow diagram showing results of searches, title and abstract screening, full-text review of retrieved reports and final included studies



* For example, perspective pieces, commentaries or opinions, narrative reviews. Four of these were published prior to 2011 and therefore ineligible for at least two reasons.

**For example, measured only health outcomes, or other outcomes such as awareness of radiation risks from diagnostic procedures among physicians.

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/