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Title:

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Date:

2024-01-01

Citation:

Carrandi, A., Nguyen, C., Tse, W. C., Taylor, C., McGain, F., Thompson, K., Hensher, M., McAlister, S. & Higgins, A. M. (2024). How environmental impact is considered in economic evaluations of critical care: a scoping review. *Intensive Care Medicine*, 50 (1), pp.36-45. <https://doi.org/10.1007/s00134-023-07274-7>.

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SYSTEMATIC REVIEW



# How environmental impact is considered in economic evaluations of critical care: a scoping review

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## Abstract

**Purpose:** Health care is a major contributor to climate change, and critical care is one of the sector's highest carbon emitters. Health economic evaluations form an important component of critical care and may be useful in identifying economically efficient and environmentally sustainable strategies. The purpose of this scoping review was to synthesise available literature on whether and how environmental impact is considered in health economic evaluations of critical care.

**Methods:** A robust scoping review methodology was used to identify studies reporting on environmental impact in health economic evaluations of critical care. We searched six academic databases to locate health economic evaluations, costing studies and life cycle assessments of critical care from 1993 to present.

**Results:** Four studies met the review's inclusion criteria. Of the 278 health economic evaluations of critical care identified, none incorporated environmental impact into their assessments. Most included studies ( $n = 3/4$ ) were life cycle assessments, and the remaining study was a prospective observational study. Life cycle assessments used a combination of process-based data collection and modelling to incorporate environmental impact into their economic assessments.

**Conclusions:** Health economic evaluations of critical care have not yet incorporated environmental impact into their assessments, and few life cycle assessments exist that are specific to critical care therapies and treatments. Guidelines and standardisation regarding environmental data collection and reporting in health care are needed to support further research in the field. In the meantime, those planning health economic evaluations should include a process-based life cycle assessment to establish key environmental impacts specific to critical care.

**Keywords:** Cost-effectiveness studies, Intensive care, Climate change, Greenhouse gas emissions, EIO (economic input–output) analysis, Life cycle assessment (LCA)

## Introduction

Critical care is one of the highest carbon emitters in health care [1]. This is mostly due to the energy expenditure, single-use plastic consumption, waste disposal and the overall carbon footprint of procedures and advanced equipment used to support life [2–5]. Reducing carbon emissions in critical care is complicated by ethical implications of resource decisions on maintaining the lives of

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critically ill patients, alongside time-limited pressures and extensive investigations and therapies to address multi-organ failure [3]. Yet, intensivists and society more broadly will be facing rising patient numbers related to extreme weather events, heat-related illness and conditions associated with environmental pollution [6]. Physicians and other health sector leaders, therefore, must consider how to measure, monitor and address the environmental footprint of healthcare provision [6, 7].

Health economic evaluations, especially health technology assessments, are often used by policymakers and healthcare providers to maximise health outcomes per dollar spent. They can also be used to minimise resource waste without negatively affecting health outcomes. For example, these methodologies have been used to identify unnecessary testing, overtreatment, inappropriate pricing and care coordination, administrative failures and use of new technologies or medications that do not provide appropriate value. Health economic evaluations are particularly valuable in critical care, given it is a resource-intensive but essential component of healthcare systems globally [8]. Economic evidence can be used to efficiently allocate resources within a given healthcare budget. It is possible that health economic evaluations can be used in critical care to identify strategies that minimise carbon footprint whilst maintaining quality critical care and patient safety. Doing so requires data and costs for key healthcare inputs specific to critical care and robust methods to include and analyse these data in health economic evaluations.

Previous research has suggested the use of life cycle assessments (LCAs) to incorporate environmental impact in health economic evaluations [9]. LCAs, such as process-based LCAs and economic input–output (EIO) methods, have been increasingly used to quantify the environmental impact of different medical supplies, equipment and procedures [4, 7, 10–16]. Process-based LCAs are a bottom-up approach to obtain data regarding the environmental footprint of treatments and therapies, whilst EIO methods use economic cost to produce average environmental footprints across economic sectors. LCAs can also adopt a hybrid approach, incorporating both process-based LCAs and EIO methods, though we recognise, and have published previously, on the caveats of undertaking hybrid LCAs [4]. These assessments have illustrated the environmental and economic burden of a range of healthcare practices and further adds to the impetus for developing sustainable healthcare practices. Still, considerable work is needed to develop robust methods for capturing and incorporating environmental data as part of health economic evaluations [9, 14, 17]. The aim of this scoping review was to synthesise available literature on whether and how environmental impact is

### Take-home message

Health economic evaluations are underutilised in addressing rising carbon emissions in critical care. Critical care researchers, health economists and clinicians should prioritise generating environmental impact data alongside economic evaluations using appropriate life cycle assessments.

incorporated in health economic evaluations of critical care.

### Methods

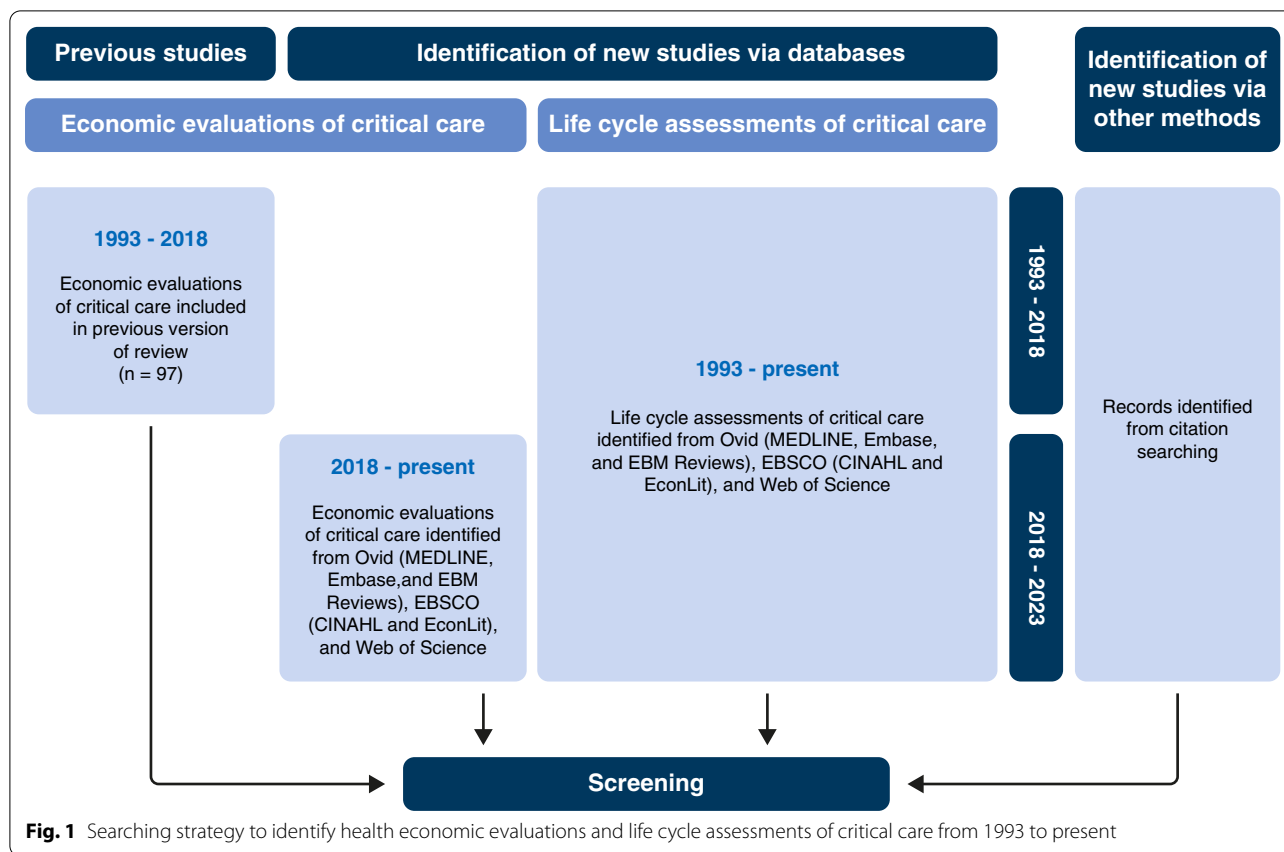
A scoping review methodology was chosen given the broad scope of the review question [18]. The scoping review was conducted in accordance with the JBI methodology for scoping reviews [19] and the protocol was registered prospectively with Open Science Framework Registry [20]. Reporting followed the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) [21] (electronic supplementary material (ESM) 1).

### Search strategy

An initial limited search of the peer-reviewed literature was undertaken to identify studies reporting on environmental impact in health economic evaluations of critical care. A 2019 systematic review of cost-effectiveness studies in critical care was identified [8], which included all cost-effectiveness studies in critical care from 1993 to June 2018. The 2019 review, however, did not specifically aim to include LCAs. Our search strategy aimed to locate published health economic evaluations of critical care from June 2018 to present, as well as LCAs of critical care from 1993 to present. The following databases were searched: Ovid (MEDLINE Epub Ahead of Print, In-Process & Other Non-Indexed Citations, Embase, and EBM Reviews [Health Technology Assessments and NHS Economic Evaluation Database]), EBSCO (CINAHL and EconLit), and Web of Science. The search was restricted to human studies published in English. The reference list of included sources of evidence and relevant systematic reviews were also screened for additional studies. The searching process is further illustrated in Fig. 1 and the complete search strategy is presented in ESM 2.

### Inclusion and exclusion criteria

This review included full and partial economic evaluation studies and modelling studies, including cost, cost-minimisation, cost-effectiveness, cost-utility, EIO LCAs and return on investment analyses. Opinion, theory, protocol and methodology papers were also considered for inclusion, whilst book reviews, letters, conference abstracts, systematic reviews and meta-analyses were excluded.



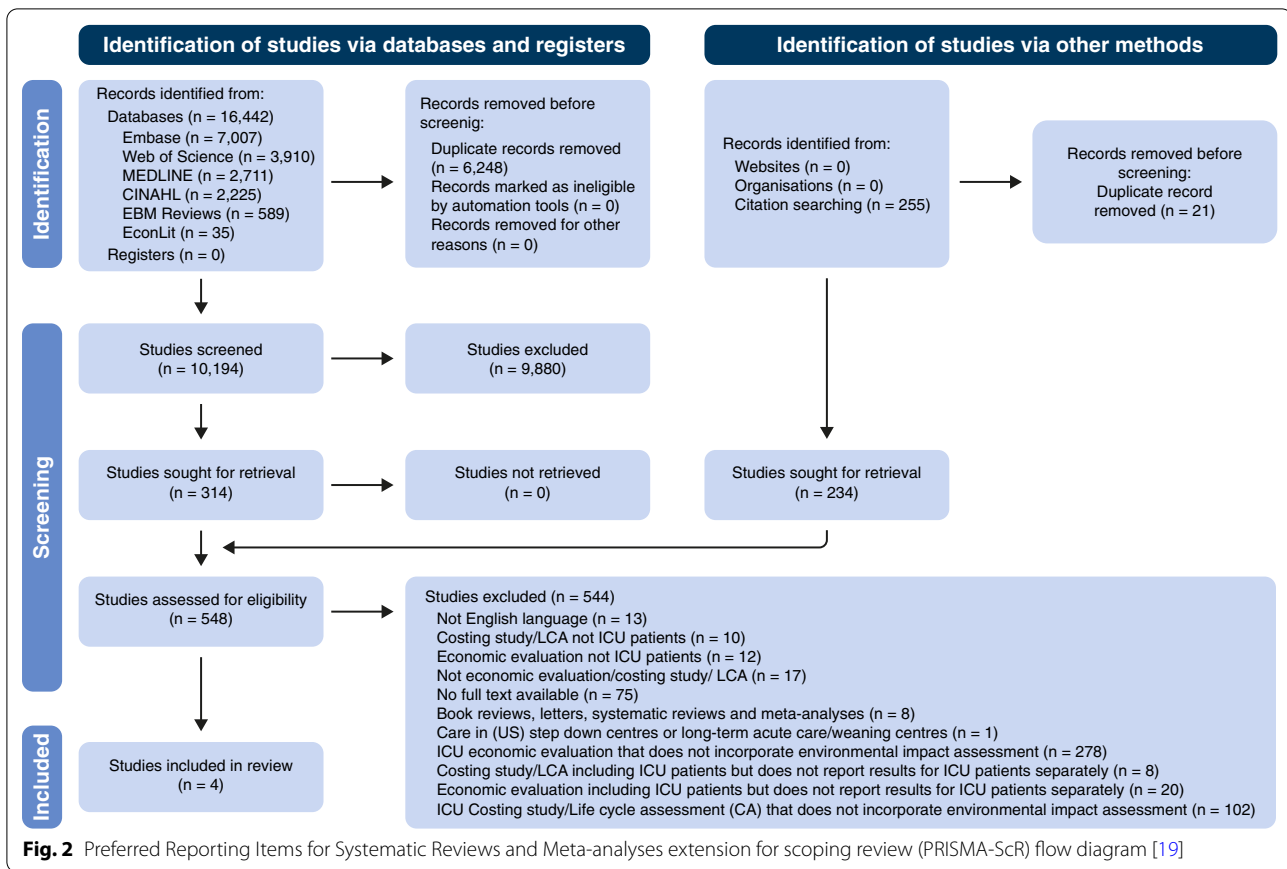
Studies reporting on outcomes related to critical care patients were included. For the purposes of the review, critical care included, but was not limited to, the provision of care within intensive care units (ICUs), neonatal intensive care units (NICUs), paediatric intensive care units (PICUs), special care nursery, respiratory units and hospital units caring for critically ill patients. The scope of this review focussed on treatments and therapies specific to critical care. Thus, we did not include studies relating more broadly to the management of all patients beyond critical care, e.g. pathology and radiology. Studies focussed on specialised weaning centres and long-term hospital stays were excluded, in addition to studies reporting on the provision of non-critical care or care provided outside of the clinical setting.

Following a pilot test of five studies, titles and abstracts were screened by two independent reviewers against the inclusion criteria for the review. Potentially relevant studies that were full or partial economic evaluations or LCAs of critical care patients were retrieved in full. The studies included in the 2019 systematic review of cost-effectiveness studies in critical care from 1993 to 2018 [8], as well as studies identified through reference list searching, were imported directly to the full-text stage. The full-text studies were assessed by two independent

reviewers against the abovementioned inclusion criteria, as well as the additional criterion related to environmental impact. Environmental impact included, but was not limited to, greenhouse gases, water use, eutrophication (pharmaceutical and chemical contamination), ecotoxicity, particular matter or air pollution, plastic waste, ozone depletion, ionising radiation, urban and natural land transformation, mineral depletion, fossil fuel depletion and photochemical oxidant formation [22, 23]. Reasons for exclusion of studies at the full-text stage were recorded (Fig. 2). Any disagreements that arose between the reviewers at each stage of the selection process were resolved by an additional reviewer.

#### Data extraction and analysis

The primary outcome of interest was how environmental impact was incorporated into health economic evaluations of critical care. Data reporting on environmental impact without costing and outside of the critical care context were not presented. Costs were reported in 2022 United States dollars (USD), where the study reported the currency and year of data collection. National consumer price index statistics from relevant countries [24, 25] were used to inflate costs to 2022 and purchasing power parity statistics from the Organisation for



Economic Co-operation and Development (OECD) [26] were used to translate costs to USD. In addition to the economic methodologies employed in the studies, other outcomes of interest included study setting and the types of interventions being assessed.

Data were extracted from studies included in the scoping review by two independent reviewers. The finalised data extraction form is presented in ESM 3. Any disagreements that arose between the reviewers were resolved through discussion. A quality assessment was not conducted on included studies, as the purpose of this review was to understand how environmental impact is incorporated in economic evaluations of critical care, not to critique the quality of the literature.

## Results

Of the 10,428 studies screened for eligibility, 4 studies met the inclusion criteria and underwent data extraction (Fig. 2). Of the 278 health economic evaluations of critical care identified in our scoping review, none incorporated environmental impact into their assessments. Of the 104 LCAs and costing studies of critical care identified in our scoping review, 4 (4%) incorporated both costs and environmental impacts.

## Summary characteristics

Most included studies ( $n=3/4$ ; [4, 27, 28]) were LCAs in the ICU, and the remaining study was a prospective observational study in the PICU [2] (Table 1). Three studies were conducted in the United States (US) [2, 27, 28], and one study was conducted in the US and Australia (AUS) [4]. All studies were published from 2018. All studies quantified the costs of medical consumables, equipment or services from a hospital perspective. Two LCAs utilised EIO analysis to determine the effect of medical consumables, equipment or services on greenhouse gas emissions [4, 28]. The remaining LCA utilised life cycle costing to model the costs of reusable and disposable medical consumables with varying cleaning frequencies [27]. The results reported in individual studies are presented in ESM 4.

## Methods used to incorporate environmental impact into economic evaluations

The prospective observational study in a US-PICU collected unused medical waste over a 3-week period, and the cost of disposed items was quantified [2]. One LCA of the three collected actual purchasing and labour costs from site records and observations [27]. The average

**Table 1 Summary characteristics of life cycle assessments and health economic evaluations of critical care that have incorporated environmental impact**

First author (publication year)	Country	Study design	Perspective	Year of cost collection	Measurement and valuation of resources and costs
Ghersin (2020) [2]	United States	Prospective observational	Hospital	NR	Cost of unused and disposed medical consumables
Sanchez (2020) [27]	United States	Life cycle assessment with cost modelling	Hospital	NR	Adjusted lifetime of a reusable blood pressure cuff to reach financial parity with a disposable cuff
Prasad (2022) [28]	United States	Life cycle assessment with economic input–output modelling	Hospital	2017	Carbon footprint (kg CO <sub>2</sub> -e) per dollar spent on medical consumables and equipment
McGain (2018) [4]	United States and Australia	Life cycle assessment with economic input–output modelling	Hospital	2017	Carbon footprint (kg CO <sub>2</sub> -e) per dollar spent on pharmaceuticals, intravenous fluids, and pathology tests

labour required was observed, and then costs were allocated to the task based on the salary of the staff member performing the task. Costs for materials and utilities were allocated per item based on purchasing records and observations. Life cycle costing was used to model the adjusted lifetime of a reusable blood pressure cuff with varying cleaning frequencies to reach financial parity with a disposable cuff.

Two LCAs used EIO analysis. One LCA estimated the greenhouse gas emissions from the production of disposable supplies and allocated capital equipment production using an EIO LCA model [28]. The remaining LCA used an EIO LCA model to attribute an environmental impact from the cost of pharmaceuticals, intravenous fluids and pathology [4]. The researchers developed a life cycle inventory (LCI) that quantified materials and energy used, and then translated patient data into environmental impacts by dividing data on environmental impacts per ICU patient per day by an average European person's total daily environmental effects. This provided a comparison of the environmental impacts of an ICU patient with all other people's daily routine activities.

## Discussion

Critical care demands continuous staff activity, resource use and energy demand [29], which comes with high costs and greenhouse gas emissions. Health economic evaluations have the potential to identify strategies to improve economic and environmental efficiency without negatively affecting patient outcomes. We used a robust scoping review methodology comprising a systematic search of six academic databases to identify health economic evaluations, LCAs and costing studies of critical care. In this review, we considered studies that included

environmental impact in their health economic evaluations. Of the 278 health economic evaluations of critical care identified, none incorporated environmental impact into their assessments. Of the 104 LCAs and costing studies of critical care identified, 4 (4%) incorporated both costs and environmental impacts, including three LCAs in the ICU and one prospective observational study in a PICU. LCAs used a combination of process-based data collection and EIO modelling to incorporate environmental impact into their economic assessments.

Reducing health care's environmental footprint is becoming increasingly paramount, particularly in critical care [29]. Global trends towards sustainable healthcare practices have been prompted by health concerns associated with climate change [30], complications with amplified production and resultant disposal of healthcare waste [12] and strains on resource supply [3]. Halting the cycle of adverse health consequences [31] and increasing healthcare expenditure [32] associated with climate change requires investigation into the environmental impact of healthcare services and strategies to improve their efficiency [7]. Yet, very few LCAs specifically relevant to critical care have been undertaken, and whilst health economic evaluations of critical care are frequent, none have incorporated environmental outcomes. Previous research has suggested ways in which health economic evaluations might consider environmental impact, such as shadow pricing, generating the social cost of carbon, including health gains from improved environmental outcomes into estimates of health-related quality-of-life, considering healthcare decision-makers' willingness to pay for environmental gains, process-based LCAs, EIO methods or including environmental factors in multi-criteria decision analyses [9, 17, 33–37].

However, frameworks for systematically measuring environmental impact and incorporating these measurements into health economic evaluations are still in their early stages, so there is no definitive source of guidance yet. Furthermore, variability in environmental impact outcome reporting between health economic evaluations contribute to challenges of providing meaningful comparisons.

Health care systems at large have been called upon to develop and adopt measures of health care quality that incorporate sustainability to allow for international comparison, validation and standardisation of sustainability indicators [38, 39]. Discussions regarding standardisation of sustainability indicators and environmental reporting in healthcare must also consider cost data and valuation of resources, in light of the potential for health economic evaluations to improve decision-making about reducing carbon emissions whilst maintaining or improving patient outcomes. The standard inclusion of environmental impact into health economic evaluations is reasonable because both health benefits and environmental impact can be valued from a societal perspective and the outcome remains maximising patient outcomes [36]. However, the incorporation of environmental impacts in health economic evaluations of critical care is uncommon, and the methods used vary from quantifying the cost of disposed items [2], life cycle costing [27], and EIO modelling [4, 28]. Achieving agreement on how best to incorporate environmental impacts into health economic evaluation and health technology assessments should ideally be done by agreement between key international health technology agencies [17, 40], such as the Canadian Agency for Drugs and Technologies in Health (CADTH) who have begun developing criteria for conducting environmental assessments in health technology assessments [36]. Incorporating environmental impact in health technology assessments may represent an opportunity to measure the impact of products or services on the triple bottom line of sustainability—economic, environmental, and social impacts. Adopting standardised measures can improve transparency and repeatability, facilitate comparisons of climate change mitigation strategies across various settings and identify the local drivers of success. These comparisons can inform specific recommendations regarding mitigation strategies where data are less available and difficult to obtain, such as in low- and middle-income countries [7]. Environmental impacts should be incorporated into available evidence to ensure that decisions about which interventions to invest in (or de-invest in) are made with all relevant information.

In the absence of standardised methods for incorporating environmental impacts into health economic evaluations, clinicians and researchers planning clinical

trials with a health economic evaluation of critical care should expand to include a process-based LCA to provide relevant information on key environmental impacts. Even if these cannot yet be directly incorporated into the health economic evaluation by a standard method, gaining more data on environmental impacts is very useful in its own right. Considerations must also be made for the resource, education and practical requirements when planning to conduct an LCA. This review identified three LCA studies, of which two utilised EIO methods. Since currently available healthcare data for the environmental footprint of products and services are often opaque, researchers tend to use EIO average economic sector modelling to assess environmental impact. Environmental impact, therefore, is estimated from the total dollar spent purchasing from and the total emissions of the pharmaceutical sector, resulting in a linear relationship between purchasing cost and emissions. For example, a product that costs ten times as much as another product has tenfold the environmental impact [4]. This method would, therefore, be inaccurate when assessing the environmental impact of locally produced medicines that may cost more due to higher labour and energy costs but have a lower carbon footprint due to the shorter distance between the pharmaceutical facility and the hospital. This method would also be inaccurate for single-use critical care equipment which is often cheaper but has a higher carbon footprint and for expensive, patented drug that costs tenfold a non-patented drug with similar or the same carbon footprint [4]. Such uncertainty in the relationship between cost and environmental impact makes it difficult to use EIO to accurately determine the environmental impact of critical care and, ultimately, determine strategies that minimise resource waste without negatively affecting health outcomes. One of the included LCAs highlighted that the use of EIO methods significantly altered the costs of various products so reported the process-based LCA results separately [4]. Process-based LCAs provide detailed assessments of environmental impact and can supply health economic evaluations with robust environmental and cost inputs. Generating data that captures the full value of the carbon footprint of a product or service may help to overcome some of the methodological challenges and bridge the practical-knowledge gap in this field [39]. For example, critical care services with high air exchange rates and continuous activity consume a disproportionate amount of electricity [41], so carbon footprint assessments must consider the energy source of the hospital (e.g. renewable versus coal or gas). We recommend that future health economic evaluations include process-based LCA studies to establish environmental and cost inputs specific to critical care, particularly in the areas of single-use

plastic consumption, waste disposal and overall carbon footprint of procedures and advanced equipment used to support life [5].

Health economists working in the critical care field should familiarise themselves with the literature on incorporating environmental impacts and keep abreast of developments, so that they can include appropriate measures as standardised approaches emerge. Methods used to incorporate environmental impact into health economic evaluations have changed in the past five years. When McGain et al. conducted their LCA in the US-ICU and AUS-ICU [4], they used EIO data to estimate the carbon footprint of pharmaceuticals, intravenous fluids and pathology testing. Now, with new data, researchers [42] are able to use process-based LCA data to give a more nuanced view of the real carbon footprint of pathology testing in the hospital. Similar opportunities exist for many other treatments in critical care and beyond. The HealthcareLCA database is an open access, living LCA repository of healthcare products and processes and can be used by researchers wishing to incorporate environmental impacts into their assessments [43], though we note that there is no apparent formal quality control of the LCAs included. Furthermore, whilst there is increasing interest in developing methodology to incorporate environmental impact into health economic evaluations, another area where health economists can make a strong contribution involves the intersection of low-value care and environmental harms [40]. Value-based health care has emerged to diminish the use of clinical interventions and services that are resource-intensive and non-beneficial or cost-ineffective [44]. Recent estimates indicate 40% of healthcare is of low-value or harmful [45], which equates to over 8000 kilotons of carbon dioxide equivalent emissions per year in Australia [46]. As critical care and healthcare services more broadly grapple with the two significant challenges to health system sustainability—low-value care and climate risk [46]—health economists are well placed to assist with identifying efficient strategies that can reduce carbon emissions. Promising sustainability strategies for critical care include efforts to *reduce* unnecessary tests and low-value care interventions, *reuse* equipment, *rethink* treatment pathways and opportunities for innovation, and *research* strategies to generate environmental impact data in clinical research [1] (Fig. 3). Successful examples of sustainability strategies for critical care involve better waste segregation [47, 48], establishing a “green team” to promote collective action amongst staff [49], and avoiding inappropriate interventions [44].

### Strengths and limitations

The results of this scoping review provide a comprehensive overview of the current evidence on environmental impact considerations in health economic evaluations of critical care. It delivers key information to decision-makers and policymakers on ways of including environmental impact into the prioritisation of critical care when aiming for a more equitable distribution of health resources. We also offer practical advice for clinicians and researchers planning health economic evaluations regarding future methodological development and research. This review excluded general LCAs that may be relevant to critical care (e.g. pathology and radiology) but were not conducted specifically in the critical care setting. Critically ill patients have unique needs that differ from ward-based patients, and the critical care setting is characterised by higher resource and energy demands and extensive investigations and therapies. The impacts of these demands on costs and environmental footprint would not be captured in LCAs of hospitals more generally. Another limitation of this review was that the literature in this area came from the high-income countries of the US and Australia. Differences in healthcare challenges between high-income and low- and middle-income countries (e.g. infrastructure and technologies), and how these challenges relate to environmental impact, mean that measuring and valuing costs and environmental impact may differ between these settings [7]. It is recommended that process-based LCAs are prioritised in resource-constrained settings to ensure that cost and environmental impact data captured in health economic evaluations are contextually relevant.

### Conclusion

Reducing health care’s environmental footprint is becoming increasingly paramount, particularly in critical care. Health economic evaluations have the potential to identify strategies that improve the economic and environmental efficiency of care, whilst maintaining or improving the quality of care. This review aimed to synthesise available literature on whether and how environmental impact is incorporated into health economic evaluations of critical care. Health economic evaluations of critical care, however, have not incorporated environmental footprint into their assessments. Furthermore, few LCAs exist that are specific to critical care therapies and treatments. Frameworks for incorporating environmental impacts into health economic evaluations and standardisation of environmental data collection and reporting in health care are still in their early stages, so there is no definitive source of guidance yet. In the absence of guidance for incorporating environmental impacts into health economic evaluations, we recommend that clinicians and



researchers planning health economic evaluations of critical care should include a process-based LCA to provide relevant information on key environmental impacts. Generating data on environmental impacts strengthens future analyses, even if these cannot yet be directly incorporated into the health economic evaluation by a standard method. Health economists in the critical care field are well placed to identify strategies that may address rising carbon emissions in critical care and should familiarise themselves with the current literature on incorporating environmental impact in health economic evaluations as standardised approaches emerge.

#### Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1007/s00134-023-07274-7>.

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#### Author contributions

AC, CT, FM, KT, MH, SM, and AMH contributed to the study conception and design. Screening and data extraction were performed by AC, CN, WCT, and AMH. The first draft of the manuscript was written by AC, and all the authors commented on previous versions of the manuscript. All the authors read and approved the final manuscript.

#### Funding

Open Access funding enabled and organized by CAUL and its Member Institutions. AH is supported by an NHMRC (National Health and Medical Research Council) Emerging Leader Fellowship (GNT2008447).

#### Data and/or code availability

Not applicable; no new data were produced.

## Declarations

### Conflicts of interest

The authors declare no conflicts of interest.

### Ethical approval

Ethics approval was not necessary as no new data were produced.

### Informed consent

Not applicable.

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Received: 17 August 2023 Accepted: 11 November 2023

Published: 8 January 2024

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