The green ICU

How to interpret green? A multiple perspective approach

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DOI
10.1186/s13054-025-05316-8

Publication date
2025

Document Version
Final published version

Published in
Critical Care

Citation (APA)
Smale, E., Baid, H., Balan, M., McGain, F., McAlistar, S., de Waele, J. J., Diehl, J.-C., van Raaij, E. M., van Genderen, M., Tibboel, D., & Hunfeld, N. (2025). The green ICU: How to interpret green? A multiple perspective approach. *Critical Care*, *29*, Article 80. https://doi.org/10.1186/s13054-025-05316-8

Critical Care

PERSPECTIVE

Open Access

The green ICU: how to interpret green? A multiple perspective approach

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Abstract

Mitigating environmental impacts is an urgent challenge supported by (scientific) intensive care societies worldwide. However, making green choices without compromising high-quality care for critically ill patients may be challenging. The current paper describes a three-step approach towards green intensive care units. Starting with the measurement of environmental sustainability, intensive care units can identify hotspots, quantify the environmental impacts of products and procedures, and monitor sustainable progress. Subsequently, a multidisciplinary approach is proposed to improve environmental sustainability, including a collaboration of procurement specialists and healthcare professionals, using co-creation and green teams as efficient grassroots change agents. A context-specific approach for enhancing sustainable healthcare practices is key in order to fit local regulatory requirements and create support of professionals. A final step is to share results and create momentum, including publishing initiatives and participating in online (inter)national networks. Based on the core sustainability principles, this three-step approach towards green ICUs provides a valuable tool to professionals worldwide to facilitate change towards environmentally responsible intensive care units.

Keywords Sustainability, Intensive care unit, Multidisciplinary, Sustainability Transitions, Environmental Impact

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Background

Mitigating climate change is an urgent challenge for healthcare providers due to the severe and escalating impacts on human health. Rising temperatures, extreme weather events, malnutrition, mental health issues, displacement, and the spread of infectious diseases are already affecting human morbidity and mortality worldwide [1]. As a result, the healthcare sector currently faces a growing burden from climate-related diseases, while healthcare itself contributes to climate change. Previous research in the Netherlands has shown that the care activities in an Intensive Care Unit (ICU) generate 17 kg of mass per patient per day, and 12 kg CO2 eq. emissions, 300 L of water usage and 4 m2 of agricultural land occupation associated with the production of the products used in the ICU [2]. The carbon footprint of treating patients with septic shock ranged from 88 and 178 kg CO_2 eq. per patient per day in Australia and the USA respectively [3, 4]. On a hospital level, it was shown that critical care, including emergency, perioperative and intensive care, contribute to 9.0% of the carbon footprint of the hospital [5]. Evidently there will be considerable variation between hospitals and nations in the proportion of healthcare's carbon footprint due to ICU care. Accordingly, these results cannot be directly extrapolated to a global scale, yet it can be assumed that the global environmental impact of ICUs is considerable due to the high levels of resource consumption, energy use and medical waste.

To address the environmental impact of ICU care, a global green ICU movement is underway [6], as seen in how intensive care societies worldwide are explicitly committed to sustainability initiatives [6–12]. A recent Green Paper by the European Society of Intensive Care Medicine (ESICM) outlines directions for more environmentally sustainable ICU care [7]. On a national level, there are other examples of greening ICUs, like Choosing Wisely climate-conscious recommendations by the Canadian Critical Care Society [8], green practices gathered by the Netherlands Society of Intensive Care Medicine (NVIC) [9], the three-step pathway originating from a large hospital in The United States [10], and The Sustainability Toolkit for ICU from the Australia and New Zealand Intensive Care Society (ANZICS) and UK's Intensive Care Society (ICS) [11]. Moreover, to guide sustainability leaders, quality improvement approaches have been combined with sustainability goals [12], and ICUs are starting with green teams that support a bottom-up approach [13–16]. Nevertheless, clinicians and hospital leaders may question how to address the perceived oxymoron of a *Sustainable ICU,* i.e., it can undoubtedly be challenging to use fewer resources while maintaining the same high level of care for critically ill patients.

To put this challenge of achieving quality care standards with sustainable use of resources into perspective, the current paper pinpoints a three-step approach towards a green ICU by (I) measuring environmental sustainability, (II) outlining strategies to improve sustainability and (III) elaborating on how to communicate results to create a synergy of sustainability initiatives within ICUs (Fig. 1).

How to measure sustainability in ICUs?

Given the high environmental impact of ICU care, assessment tools are needed to identify hotspots, quantify environmental impacts, and monitor sustainable improvements in this resource-intensive healthcare setting. Various methods, such as Life Cycle Assessment (LCA), Material Flow Analysis (MFA) and waste audits can be used for these purposes. Measuring environmental impacts can be done on different levels, encompassing products, processes, care pathways and/or complete ICUs, and taking account of different scopes. Namely scope 1 includes direct emissions from sources owned by the organization such as anesthetic gases, whereas scope 2 covers emissions from energy purchased by the organization, namely for heating and cooling, and scope 3 includes emissions from items/activities not directly owned or controlled by the organization, such as from the supply chain of products purchased by the organization. All methods offer distinct advantages and challenges in assessing sustainability within ICU (*Supplementary Table 1).*

Life cycle assessment

LCA encompasses a comprehensive evaluation of environmental impacts through the lifecycle of a product or process or all products and processes within a care pathway or ICU. This method quantifies environmental impacts from raw material extraction, manufacturing, use, and disposal across multiple environmental indicators, such as climate change, particulate matter, and human- and eco- toxicity [17], and expresses these per functional units, for example, over one year. Although LCAs are well-suited to quantify environmental impacts and identify hotspots, they require comprehensive data across all process stages, making LCAs labor-intensive and requiring specific software. It is important to note that LCA data must be interpreted cautiously as context-specific small changes, like factory location or type of electricity used, can affect outcomes. Moreover, LCAs are best suited for well-defined products and processes, but for larger systems, such as hospitals or healthcare systems, extended economic input–output (EEIO) can estimate impacts. EEIO is a spend-based measurement

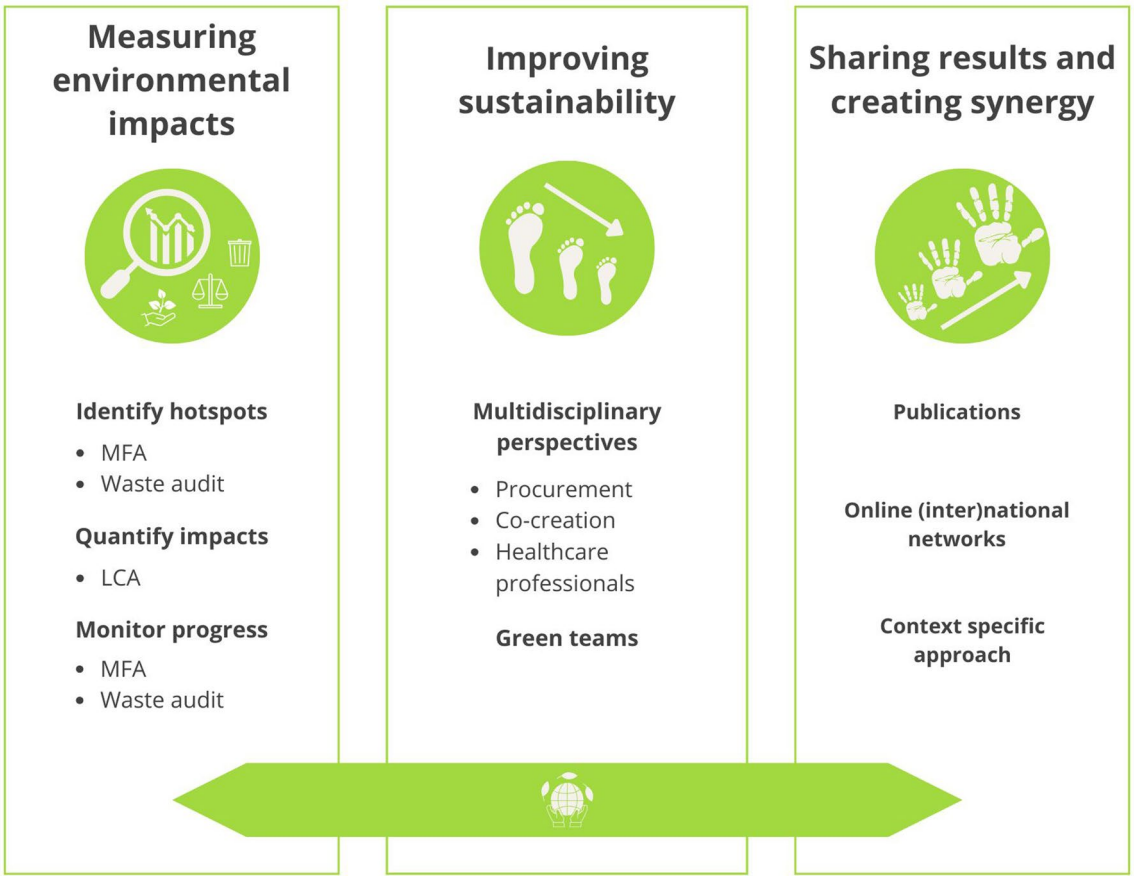

Fig. 1 Three-step approach towards green ICU's

that calculates environmental impacts from economic costs in a specific sector.

Two LCAs have been conducted in the ICU setting, revealing contrasting findings on energy use (i.e., heating, ventilation, and air conditioning). One study found energy demands accounted for about three-quarters of the carbon footprint in American and Australian ICUs [3], while another American-based study reported energy use contributing to just one-third [4]. These differences may be due to variations in methodology, as the second study used EEIO [4], which could have deflated the carbon footprint of relatively cheap items like energy [18]. Additionally, the national energy mix, particularly reliance on coal power, may have influenced the findings in the first study.

An increasing number of LCAs of medical products and pharmaceuticals have created momentum to encourage practitioners to shift away from single-use equipment [19–21]. HealthcareLCA has compiled healthcare-related LCA data in a free online repository, facilitating an easy starting point for ICU teams interested in greening their practices [22]. However, as illustrated by the example above, interpreting LCA findings for specific contexts requires caution [18]. Another challenge lies in translating LCA data into practice because (de)implementation can be complex and may require the expertise of implementation scientists [23].

Material flow analysis

Material and resource flows within a defined system, such as an ICU, are tracked and quantified through the MFA methodology. An MFA generates an overview of products that enter and leave the system and thus is well-suited to identify hotspots in material use and waste generation. However, it only assesses the broader environmental impacts with additional analysis, and absolute outcomes are hard to compare. Its strength lies in improving a system's circularity by identifying resource depletion hotspots and monitoring progress towards reduction goals. MFA is relatively new in healthcare, but an ICU MFA analysis recently showed an environmental impact of 17 kg of mass of medical products (comprising of 11.9 kg of liquids, such as intravenous fluids) per patient per day [2]. The main hotspots were non-sterile

gloves, isolation gowns, bed liners, surgical masks and syringes (including packaging), motivating the development of green practices targeting these materials [2]. These hotspots, with three commonly used personal protective equipment products, can be easily measured, implemented and evaluated as green interventions by other ICU's (see Table 1).

Waste audit

A waste audit is a valuable tool for developing a detailed understanding of waste generation and composition. Waste audits do not require specific knowledge or software and offer rapid insights into feasible opportunities for waste reduction and waste management practices, including appropriate waste segregation (i.e., reducing the amount of specific hospital waste or increasing recycling). Although waste audits are often the easiest and quickest method, they are the least impactful of the three common measurement strategies since they focus on downstream waste rather than root causes of waste generation. Further, even where there is a concerted effort to recycle, particularly amongst ICU nursing professionals, limited recycling rates of total waste are achieved [24, 25]. Moreover, findings are often specific to the context and represent a snapshot rather than a long-term trend. Several waste audits in ICUs have been published, including general ICU waste [26] with others focusing on recyclable and medication waste [27, 28]. A waste audit can be the starting point for an ICU recycling program [29], segregating waste (e.g., plastic, paper, glass) and optimizing waste flows. An interesting target is avoiding disposal of non-contaminated material (like empty medication vials) as biohazardous waste as this waste stream is incinerated on higher temperatures at higher financial and environmental costs. After implementing such a measure, the waste audit should be repeated to evaluate effects and find new targets.

How to change and improve environmental sustainability in ICUs?

Behaviour change can be challenging in ICU settings where patients are facing life-threatening illnesses, are treated by a large multi-disciplinary team and where local practices may be deeply ingrained, thereby relegating sustainability initiatives as a lower priority. Planning green practices that are feasible, realistic, and relevant to the local context, while maintaining safety and quality standards may also be challenging. However, green ICU initiatives may start small and practical, thereby generating motivation and support for sustainable change. So-called "less is more" practices that limit low-value or harmful care, such as unnecessary screening, diagnostic and monitoring tests, over-diagnoses and over-treatment, may therefore be a compelling target for reducing carbon emissions of ICUs, while improving quality of care and cutting costs [30–32]. To create a continuous

Table 1 Quick-start practical guide with sustainability initiatives for green teams of ICUs

Topic	Intervention	Examples of metrics for maintaining quality of care	Reference
Pulse oximeters	Replace disposable pulse oximeters with reusable alternatives	Audits to ensure proper cleaning protocols	[19]
No risk, no glove	Redesign of glove dispenser to ensure single dispensing	Hospital-acquired infection rates	[25]
CCRT bags	Reduce plastic waste by recycling CRRT bags and their packaging	Check usability of plastic with waste processor	[25]
Isolation gowns	Replace disposable isolation gowns with reusable alternatives or with aprons (50% reduction of plastic)	Hospital-acquired infection rates	[25, 36–38]
Paracetamol challenge	Reducing intravenous paracetamol administrations in ICUs by at least 25% by replacing it with oral paracetamol	The use of opioids or otheranalgesic meds and pain scores	[39]
Infusion bags	Choose appropriate size of infusions bags	Number of complications like fluid overload or dehydration and incomplete infusions	[40]
Recycling infusion bags	Recycling all i.v. fluid bags that are not contaminated with blood or infectious substances	Check usability of plastic with waste processor	[41]
Absorption mats (bed liners)	Replace by towels (washing process is optimized from environmental perspective)	Regular audits of the laundry processes	ICU Erasmus MC
Catheter replacement	Only change indwelling catheters on clinical suspicion of infection, instead of routine replacement every 5–8 days	Evaluate the CVL infection rates	[9]

CRRT continuous renal replacement therapy, *CVL* Central Venous Line

cycle of implementing and evaluating green practices, multi-disciplinary approach that interlinks healthcare professionals (i.e., nurses, intensivists, clinical pharmacists amongst others in the ICU clinical team) with hospital procurement, suppliers, waste management services and the infection prevention and control team is needed [33].

Green teams

Green teams are effective grassroots change agents for local sustainability projects in ICUs [16]. Several resources to guide green team leaders have been published [13, 15]. An important first step for green teams is to engage with the right stakeholders, representing a broad range of expertise, at least including ICU healthcare providers (e.g., intensivists, nurses and pharmacists), quality managers, procurement and infection prevention control.

A following critical step for newly formed green teams is goal-setting and careful selection of initiatives with a high likelihood of success as this provides the opportunity to further engage professionals and celebrate successes. The green team model effectively enabled sustainability achievements on various projects and in different ICUs [34]. To enable a quick start guide, Table 1 describes a list of initiatives that have been successfully implemented to reduce the environmental impacts of a Dutch ICU.

Upon achieving early successes as a newly formed green team, it is important to maintain an overview of the effect of sustainability on the quality of care. The use of metrics to ensure maintenance of quality of care must ensure that sustainability practices do not negatively impact quality of care. Different measures can be utilized for this purpose, like studying hospital-acquired infection rates after changing hand hygiene and glove use policies, or studying the use of other opioids and other analgesics during the paracetamol challenge (Table 1). Green teams can rely on existing quality of healthcare measures (e.g., complication rates, treatment durations, readmissions, mortality rates) that are collected as part of standard care, like the National Intensive Care Evaluation (NICE) in the Netherlands [35]. Such an approach can be complemented with a multi-directional perspective (e.g., balancing measures) that avoids negative impacts elsewhere (in the hospital).

Co-creation perspective

Environmental hotspots in healthcare are often complex issues stemming from multiple sources. For instance, excessive glove consumption in the ICU is a common challenge. In 2019, an average of 108 gloves were consumed and disposed per patient per day at the Erasmus MC ICU [2], contributing significantly to material consumption and waste. Healthcare worker behavior, infection prevention protocols, and supplier-related packaging inefficiencies drive this excessive use of gloves. Addressing these challenges requires a collaborative approach involving all relevant stakeholders, which was used in the co-creation of an ICU glove dispenser that only dispensed one glove at a time and better meets infection prevention criteria [25]. Although patients and family members are not the key stakeholders in glove use, their views and clear communication about new ways of working is needed, such as an information poster in the family waiting room [42].

Co-creation in healthcare involves the collaborative effort of multiple stakeholders, including patients, families, healthcare providers, policymakers, industry representatives, and researchers, to jointly develop and implement healthcare solutions. Key benefits of co-creation in healthcare include combining knowledge and perspectives, creating shared understanding, building trust, and increased ownership. Accordingly, stakeholders can develop sustainable solutions that meet the needs of all involved and contribute to a more environmentally friendly healthcare system. One of the challenges for co-creation in the healthcare sector is the high workload. Consequently, co-creation sessions must be designed in such a way that require minimal time of healthcare workers to get and stay involved.

Procurement perspective

The environmental impact of ICUs is influenced by which products are selected (e.g., reusables versus single-use disposables) and which suppliers are chosen (e.g., location of manufacturing, mainly related to the electricity grid used). Procurement professionals support ICUs in specifying what products are needed, how much is needed, which purchasing criteria are used to award contracts, the type of contract used, and to what extent suppliers are incentivized to develop and offer sustainable products and services to ICUs. Purchasing decisions are typically made in multidisciplinary teams with budget holders, clinical professionals, medical technology, assortment coordinators and procurement involved [43]. All these professional experts need to be aware of environmental impact, hotspots, and alternatives on the market and be willing to include environmental impact in their decisions. Too often, however, knowledge about sustainability is limited, and procurement decisions are based on product quality and price only or are influenced by greenwashing as products are promoted as environmentally preferable. Procurement can actively seek sustainable technologies, business models, and suppliers, while incorporating sustainability criteria into the

process and collaborating with both internal teams and the supply market to help overcome these challenges.

Intensivist perspective

Every day, everything intensivists do has an environmental footprint. Environmental sustainability from an intensivist perspective starts with being aware of this footprint and being open to optimizations through refusing, reducing, reusing, recycling, rethinking, and research [44]. These actions can be incorporated into individual patient decisions daily, prioritizing patient-centered outcomes whilst encouraging financially and environmentally sustainable outcomes. All ICU physicians can follow the adage *less is more in the ICU* [30–32], encouraging clinicians to achieve the best for the patient using just enough resources and no more. Sustainability initiatives on this level include but are not limited to more prudent ordering of ICU tests [45], undertaking those difficult end-of-life care conversations and advanced Care planning, altering dogmatically held prescribing patterns like potassium supplementation post cardiac surgery [46], and reducing heating, ventilation, and air conditioning (HVAC) energy use through collaboration with hospital engineers [47]. Finally, a daily review of all drugs the patient is receiving, specifically antimicrobials as these impact the environment in multiple ways [48], is a simple yet effective strategy to reduce the environmental impact of intensive care.

Nursing perspective

ICU nurses comprise a large proportion of the ICU workforce; therefore, nurse involvement is crucial to reducing the environmental footprint of ICUs. For every clinical shift caring for an ICU patient, nurses monitor the health status continuously, prepare and administer medications, hydration and nutrition, provide personal care and change linen, all of which involves resources with an environmental impact. Circular economy principles [44, 49] encourage reusable supplies to prevent such high volumes of waste generated from the accumulation of these nursing activities, examples include reusable gowns [36], incontinence pads [50] and cloths [51]. Switching from sterile to non-sterile clean water for mouth care and enteral flushes reduces financial and environmental costs. Reducing routine intravenous line changes to weekly, only changing ventilator tubing if obviously soiled and avoiding the unnecessary use of gloves and personal protective equipment are other practical things nurses can do to decrease excessive waste [47]. Furthermore, it is essential for nurses and others in the ICU team to ensure waste is segregated into the appropriate bin to avoid needless incineration and to support recycling where possible.

Pharmacist perspective

Medications are a large contributor to the environmental impact of healthcare in general [52] and specifically in ICUs [2], indicating an important role for pharmacists in establishing environmentally sustainable ICUs. Pharmacists should make sure that medications are only given if medically needed within the ICU setting, eliminating inappropriate medications during ICU admission, like bisphosphonates and over-the-counter medications, and advising about stop dates for temporarily used medications (i.e., antibiotics, electrolytes, delirium medications and anti-emetics) [9]. Also, the pharmacist has a crucial voice in the sustainable administration of medication, such as choosing the right administration route (enteral > parenteral) [53], infusion rate and appropriate volume of infusion bags or syringes [40]. Switching from intravenous to oral paracetamol administration reduces carbon emissions up to 16 times [54], and in a Dutch study, this approach appeared feasible for 50% of the administrations [39]. Finally, an important task lies in reducing and managing pharmaceutical waste, for instance by monitoring expiry dates, switching the stock to prefilled sterilized ready-to-administer syringes [55] or advising on more extended use of unmanipulated infusion bags [56].

Artificial intelligence perspective

Artificial intelligence (AI), specifically in the form of large language models (LLMs), is increasingly being used in healthcare. LLMs are a powerful example of generative AI applied to language, enabling the automation of tasks that involve the understanding and producing of text, enabling analysis of vast amounts of (medical) data. As such, LLMs hold promise in addressing several pressing healthcare challenges by optimizing workflows, supporting clinical decision-making, and improving patient outcomes. However, these models depend on energy-intensive hardware, requiring vast amounts of energy, water and generating substantial GHG emissions [57, 58]. Estimates indicate that the training of a LLM emits similar GHGs as an MRI operating for 9.5 years, while the emissions of a trained model is expected to be way lower than an MRI (respectively 0.5 g and 14,600 g CO2-equivalent) [57]. It is important that users of LLMs in healthcare are aware of these impacts and make responsible choices to reduce their energy use. Importantly the sustainable use of AI is one of the key principes of the World Health Organization (WHO) and is as such a moral obligation of its users.

Regulatory perspective

To drive meaningful change toward sustainable practices, regulatory support is essential—particularly once the

low-hanging fruit has been picked, and more bold, transformative initiatives are needed to meet sustainability goals. This requires the support of the hospital administration. Whereas many sustainability initiatives may cut costs, others may incur investment cost (i.e., the purchasing of reusable equipment/supplies). A valuable approach that is now being implemented in some hospitals is to reinvest the cost-savings generated by Green Teams into supporting further sustainability initiatives, providing dedicated support to increase their efforts via a so-called 'green fund'.

Also at the governmental level, both locally and nationally, regulatory guidance can aid sustainable change. By setting targets for sustainability, initiating nationwide research programs, providing guidelines and stimulating collaborations, for instance, governmental support have supported change in several countries, including 'the Green Deal for Sustainable Healthcare' in the Netherlands, ' delivering a net zero NHS' in the UK and the ban on desflurane in Scotland [59–61]. A potential next step for local governments could be to benchmark variations in wasteful practices across ICUs to support more effective change management.

How to share sustainability results?

Disseminating the results of environmental impact studies in ICU is important to increase the magnitude and level of evidence to inform sustainability initiatives for those in clinical, research, education, management, and policy roles. As with other research, it is of utmost importance that non-successful results are also shared to prevent duplication of work. Healthcare journals are now encouraging publications related to environmental topics, including the *Intensive Care Medicine's* My Green ICU collection [6] and the Canadian Anesthesia Journal's green edition [62]. Moreover, platforms like the HealthcareLCA database make LCA data freely accessible [22]. Other opportunities to share results can come through conference presentations, webinars, and online networks.

While broad dissemination remains important to share ideas with a broader audience, regional sustainability networks are equally vital. Uniform approaches may be applicable to some general challenges, like reducing energy use via building efficiency and smart HVAC systems, but other initiatives require a context-specific approach. For instance, low value care practices highly differ between healthcare systems and the suitable (de) implementation tools may vary per context. Regional sustainability networks, like Choosing Wisely Canada [8] and the Green ICU in the Netherlands [9], are essential to tailor initiatives and implementation strategies to local needs. By linking sustainability to quality improvement efforts through the Sustainability in Quality Improvement (SusQI) Framework [63], regional networks can build upon national guidelines while addressing the unique challenges of each ICU. This multi-level approach will drive more effective and contextually relevant sustainability actions across the healthcare system.

Discussion

Climate change already significantly impacts human health, indicating the urgent need for mitigating measures of all human activities, specifically the ones in healthcare. All ICU activities have an environmental footprint; therefore, we have the collaborative responsibility to achieve the best quality care for patients, while benefiting the triple bottom line (environmental, social, and economic benefits).

Measuring local resource use is a good starting point to identify environmental hotspots and guide the multidisciplinary ICU green team, as the three-step approach implies. However, measuring environmental impacts can pose challenges that may require specialized expertise. While methods such as LCAs, MFAs, and waste audits are needed to provide insight to environmental targets, it should not distract from the main goal: implementing sustainability reforms. Clinicians could start by focusing on low-hanging fruits, such as reducing low-value/high-resource practices, yielding immediate improvements. In this process, implementation research could help to ensure practical, scalable strategies. Once these are addressed, a collaboration with procurement specialists, industry partners, and policymakers can help further develop evidence-based initiatives for achieving sustainable ICUs. Accordingly, sustainability measures, like mass, carbon footprint and waste generation, should be incorporated as core outcome parameters for teams caring for critically ill patients, while maintaining or improving medical and nursing standards. This ensures that sustainability is prioritized alongside high-quality care.

Disseminating environmental impact data and sustainability successes within the hospital, regionally and globally, is critical for an efficient and collaborative approach to the planetary health emergency. Although this paper discussed a perspective from ICUs of high-income settings, we must consider the viewpoints and learnings from low and middle-income countries that provide critical care medicine in resource-limited settings, such as a solar-power based baby-warmer to prevent hypothermia among newborns in India [64] and at a healthcare institution in India the carbon footprint per phacoemulsification was approximately 5% of the same procedure in the United Kingdom with comparable outcomes [65]. Vice versa, many green ICU initiatives start with simple, low-cost actions that have an immediate environmental and financial impact, thus LMICs can adopt these basic

steps to begin their journey towards greener practices. For instance, reducing energy consumption by optimizing temperature and ventilation, replacing fossil fuel with renewable energy generation, or reducing low-value care like the overuse of medications [66]. Further, minimizing waste through better management practices, or reducing unnecessary resource use (such as single-use plastics) can often be implemented with minimal investment. By incorporating the viewpoint of LMICs, we can create more effective and equitable solutions to sustainable challenges, which is of outmost importance as particularly these countries will disproportionately experience the health effects of climate change [1].

Conclusions

In conclusion, this paper provides a three-step approach towards green ICU's: (I) measuring environmental sustainability; (II) addressing ways to improve sustainability; and (III) elaborating on how to share results to create a synergy of sustainability initiatives within ICUs. By embracing this approach, we can pave the way for more sustainable ICU practices that not only enhance patient care but also contribute to the health of future generations and the planet.

Abbreviations

ANZICS	Australia and New Zealand intensive care society
ESICM	European society of intensive care medicine
EEIO	Extended economic input–output
HVAC	Heating, ventilation, and air conditioning
ICS	Intensive care society UK
ICUs	Intensive care units
LCA	Life cycle assessment
MFA	Material flow analysis
NVIC	Netherlands society of intensive care medicine
SusQI	Sustainability in quality improvement
WHO	World health organization

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13054-025-05316-8.

Additional file 1.

Author contributions

All authors have drafted the work and/or substantively revised the manuscript, and approved the final version.

Funding

Not applicable.

Availability of data and materials

Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

HB has received a grant from SBRI Healthcare Competition 24 for 'Delivering a Net Zero NHS for a Healthier Future'. FM has received royalties for a patented device for the treatment of patients with respiratory infectious diseases (the McMonty by Medihood). FM is also a founder of ReResp (developing a reusable N95 mask). JW has consulted for Biomerieux, Menarini, MSD, Pfizer, Roche Diagnostics, ThermoFisher and Viatris (fees and honoraria paid to institution). NH received grants from the Dutch Research Council for developing evidence-based Strategies to create Circular Hospitals through the 10-Rs framework (ESCH-R) and from the Netherlands Organization for Health Research and Development (ZonMw) to implement sustainability initiatives in Dutch hospitals. JDW is supported by a Sr Clinical Research Grant from the Research Foundation Flanders (FWO, Ref. 1881020N).

Received: 17 December 2024 Accepted: 9 February 2025
Published online: 19 February 2025

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