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Implementing a Green ICU Pathway Across a Large U.S. Health System: An Observational Study

Faisal N. Masud, MD, FCCP, FCCM[1]
Adel H. Khan, MBBS[1]
Jason F. Fischer, MBA[2]
Alisha F. Estay, MSN[1]
Megan E. Gooch, MD[1]
Laura M. Blackburn, PharmD, BCPS, BCCCP, FCCM[3]
Coral Lozada, PhD[2]
Farzan Sasangohar, PhD[1,4]

IMPORTANCE: ICUs contribute substantial environmental impact within the healthcare industry, yet few practical solutions have been published to implement environmentally sustainable practices.

OBJECTIVES: To describe the implementation of a systemwide Green ICU initiative using a previously published sustainability pathway and to report early outcomes and lessons learned.

DESIGN, SETTING, AND PARTICIPANTS: Observational implementation study within a large, multihospital U.S. healthcare system with adult ICUs. The initiative focused on operational and systems-level ICU processes rather than individual participant outcomes.

MAIN OUTCOMES AND MEASURES: A coordinated sustainability infrastructure was established through partnerships among ICU clinicians, the Office of Sustainability, supply chain, and a multidisciplinary "Critical Care Sustainability Work Group." External engagement was expanded through the creation of a national "Green ICU Collaborative." Pilot projects were developed across the "reduce, rethink, recycle" framework. All emissions calculations were done using the Greenhouse Gas Protocol, the U.S. Environmental Protection Agency's U.S. Environmentally-Extended Input-Output modeling framework, and the Intergovernmental Panel on Climate Change accounting principles. The methodology uses large language models for classification to enable scalable, consistent categorization of procurement activities. Key outcomes included medication waste reduction, supply use optimization, and recycling.

RESULTS: Medication waste transitioned to on-demand preparation which reduced IV medication waste from 4.8% to 1.4%. Reduction in unnecessary supplies entering ICU rooms diverted an estimated 3401 metric tons of carbon dioxide equivalent annually across 350 ICU beds. A saline flush recycling program collected more than 1600 lbs of recyclable material in its first year. Implementation revealed critical lessons, including the need for early verification of material composition, the incorporation of patients and families into sustainability workflows, and the development of adaptable metrics that align unit-level initiatives with systemwide emissions baselines.

CONCLUSIONS AND RELEVANCE: Operationalizing a Green ICU pathway in a large health system is feasible and produces measurable environmental and financial benefits. Establishing strong partnerships, structured processes, and adaptable evaluation strategies is essential for scaling sustainability efforts. This work provides a detailed implementation roadmap to advance Green ICU initiatives and contributes the guidance needed to a growing yet underdeveloped field.

KEYWORDS: critical care; environmental policy; environmentalism; intensive care units; sustainability

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KEY POINTS

Question: This article examines whether a structured "Green ICU pathway" can be successfully implemented in a large health system to reduce environmental impact through measurable sustainability initiatives.

Findings: In this observational implementation study, on-demand medication preparation and revised storage practices were suitable for reducing infusion waste by two-thirds. This prevented an estimated 200 metric tons of carbon dioxide equivalent (mTCO_2e) annually and yielded substantial cost avoidance, while additional supply-reduction and recycling programs diverted thousands of mTCO_2e and over 1600 lbs of material.

Meaning: Implementing a structured "Green ICU pathway" is feasible and produces meaningful environmental and financial benefits for health systems.

Efforts toward environmental sustainability in healthcare are increasingly being considered as imperative for the fight against climate change. It is well documented that the healthcare sector has a significant impact on environmental pollution, with reports indicating that its contribution to net global emissions is as high as 4.4% (1). Despite growing efforts, numerous challenges persist in achieving environmental sustainability in healthcare, particularly in intensive care. ICUs are known to consume substantial energy, including that required for continuous monitoring equipment, and rely heavily on single-use disposable items for patient care and safety (2). This makes ICUs significant contributors to resource consumption, leading to higher waste output and carbon emissions per patient than in other healthcare settings (3).

From a solution standpoint, numerous barriers hinder sustainability practices in ICUs. Risks of cross-contamination and compromised patient safety, limited alternatives to standard single-use equipment, a lack of provider training and awareness of sustainability practices, limited funding, and regulatory compliance are among the documented barriers (4–6).

Despite these barriers, hospitals continue to implement sustainable practices. Our previous work (7) documented the gap in ICU sustainability in the United States and outlined a pathway for developing sustainable "green" ICUs (**Fig. 1**). This pathway included establishing baselines to quantify the current carbon footprint, forming strategic partnerships to implement targeted intervention programs, and standardizing a systemic approach to developing green ICUs.

Although sustainability in ICUs has gained some traction since the publication of this pathway, to date, there is still limited published work describing Green initiatives in U.S. ICUs. The Society of Critical Care Medicine (SCCM) Environmental Sustainability in the ICU Task Force published an article in 2025 outlining numerous opportunities to reduce emissions in intensive care and highlighting progress made by Houston-area health systems (3). However, widespread adoption of environmental sustainability initiatives in ICUs across the United States is not evident.

In this article, we describe the implementation of a systemwide Green ICU pathway and report early outcomes from pilot sustainability initiatives. We also document lessons learned from our preliminary implementation to inform future efforts to develop sustainable ICUs.

MATERIALS AND METHODS

Study Design and Setting

Our initiatives were conducted within ICUs at a large healthcare system in Texas. The health system comprises eight hospitals that accommodate over 30,000 patients annually, with over 400 ICU and Intermediate Care Unit beds systemwide and an additional virtual ICU. Staff includes more than 100 intensivists, 125 advanced practice providers, 900 nurses, and 250 trainees systemwide.

Implementation Framework

In our previous work (7), we proposed a three-step pathway for sustainable critical care. The first step was to measure the current carbon footprint and waste generation in ICUs, which required systemwide collaboration and clinician engagement. The second step focused on building partnerships to target major sources of emissions and waste through targeted reduction initiatives. The final step emphasized the grassroots engagement of ICU staff by embedding environmental

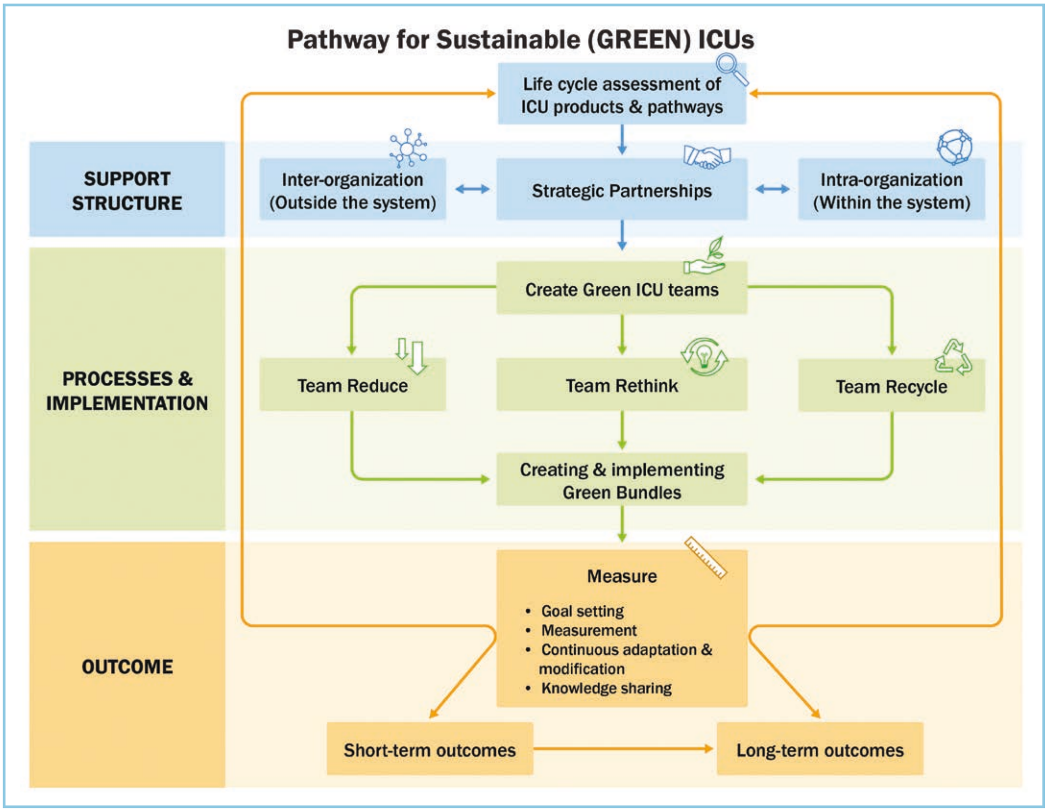

Figure 1. Implemented pathway for the development of sustainable "green" ICUs. Adapted from prior work (7) in accordance with CC-BY 4.0 licensing terms (https://creativecommons.org/licenses/by/4.0/).

awareness into daily practice to sustain the systemwide "Green ICU" culture.

The necessary condition for sustainable implementation was the establishment of a stable, committed support structure through strategic partnerships. The partnerships, in turn, promote organization, collaboration, and outreach both within and outside of our healthcare system.

Partnerships

Intraorganization Partnerships. While our healthcare system has made many efforts to advance sustainability practices, they have been conducted in silos, underscoring the need for a centralized, collaborative approach to unite and amplify impact across the system. To address this need, our hospital established an Office of Sustainability that oversees employee and community engagement in sustainability efforts and created a Systemwide Medical Director of Sustainability role. The ICU team partnered with the Office to enable knowledge exchange between the clinical and sustainability teams. One of the key outputs from this partnership was the quantification of the clinical greenhouse gas footprint. The ability to test various sustainability solutions and measure their impact using data-driven metrics was foundational to our pursuit of goals.

Another key intraorganizational partnership was established between the clinical team and the supply chain. This relationship enabled us to focus on the complete product lifecycle, from acquisition to disposal. Additionally, it allowed for vendor and supplier engagement in our initiatives.

In an extensive health system like ours, sustainability efforts often run in parallel. To avoid duplication, enable effective knowledge sharing, and create a unified strategy, it is necessary to establish a systemwide partnership. This initiative originated from the Center for Critical Care Sustainability Work Group's development. The group comprises key stakeholders, including nurses, physicians, pharmacists, key members of the supply chain, the Office of Sustainability, quality improvement, and administration. This multidisciplinary group holds bimonthly meetings, during which site projects are shared, data are collected for analysis, barriers are identified, and solutions are proposed.

Through these partnerships, we have been able to align system-level goals, resources, and metrics, scale our initiatives, and empower implementation. We regularly share the efforts and outputs of these partnerships through systemwide meetings and newsletters to raise awareness of sustainability and showcase the clinical, financial, and environmental benefits for stakeholders.

Interorganization Partnerships. Being that healthcare sustainability is not yet a universally accepted agenda, there was a dire need to establish a multicenter collaborative and further scale the initiative. To our knowledge, no such collaboration existed in the United States. With this in mind, we established the Green ICU Collaborative. The purpose of this initiative was to establish a shared vision for sustainability in intensive care worldwide and set a standard for sustainability practices in ICUs. Furthermore, it would promote the importance of intensive care sustainability through impactful initiatives, advocacy, education, and training programs.

Green ICU Initiatives

After establishing the foundation and support structure, we began defining and developing new processes for implementation. The implementation was spearheaded by dedicated "Green ICU teams" who were organized around the three key pillars of sustainability: "reduce," "rethink," and "recycle." A challenge was set before the ICUs within our system to develop their own "Green ICU" initiative in one or more of the 3R workflows (8). We also modified our internal seed-funding mechanism to reward and support innovative ideas with grants. We provided seed-funding sufficient to support the first stage of contribution. At the time of initial seed funding, formally published review criteria were still in development; however, funding decisions were made using agreed-upon priorities and a collaborative review to ensure consistency and alignment with program objectives/goals. Various multidisciplinary teams were formed in some ICUs, whose work is briefly summarized below.

Outcome Measures

Accounting Software. To establish the carbon footprint, some preliminary data were collected from the ICUs and pharmacy units across the system. Methods described below for carbon emissions accounting use various data points, such as the "Supply Chain Greenhouse Gas Emission Factors v1.2 NAICS-6 Datasets," as compiled by Wesley Ingwersen (9). Following the practices of the Environmental Protection Agency, the Office of Sustainability uses NetZero Cloud by Salesforce (10) as a data aggregator and emissions factors applicator and reporting tool. All information and calculations below were pulled from NetZero Cloud (Salesforce, San Francisco, CA), Epic electronic health records (Epic Systems Corporation, Madison, WI), and Excel (Microsoft, Redmond, WA) documents that project teams used to track supplies.

Preliminary Data. Over a 6-month period, ICU teams across the hospital system collaborated on various sustainability projects. The "Go Green" project documented the items most used in the ICU. Items were collected over 2-week intervals and tracked in an Excel document, with collection dates noted, along with room numbers, the number of each item, and the cost associated with each item. Cost for the items was assigned using the Epic-designated number and then the associated unit price for that item. These items included 10 mL 0.9% sodium chloride flushes, irrigation trays, Mepilex (Mölnlycke Health Care, Mölndala, Sweden & Indianapolis, IN), gauze 2 × 2, 10 mL syringes, vacutainer blue, vacutainer pink, butterfly needles, suction tubing 3/16, suction tubing ¼, band aids, alcohol prep pads, tourniquets, restraints, sequential compression devices, perineal pads, briefs, tape white, and sterile cups. At the end of the 2-week intervals, the top five wasted items were categorized by the amount collected.

Cost Saving Accounting. Using the total dollar amount collected for those items, a cost savings was calculated as "total savings/number of of rooms observed daily" to determine average potential savings per stay. Annual savings could then be calculated using the formula: "total savings per bed × total system-wide ICU beds (350)." To calculate total CO_2 emissions, the U.S. Environmentally-Extended Input-Output (USEEIO) v1.2 by North American Industry Classification System (NAICS) 2023: Medical, Dental and Hospital Equipment and Suppliers Merchant Wholesalers dataset (11) was used to identify the most appropriate emissions factor for these items. The factor was 0.85 with a unit of kg $CO_2e/2$. Calculations are shown below for kg CO_2 emissions that were calculated: 1) per number of bed days (13-d total for this pilot), 2) per standard 32-bed unit for the year, and finally, 3) for the 350-bed systemwide ICU annual savings (**Table 1**).

Reducing Medication Waste. A 6-month period was used to collect data on medication waste in coordination with the pharmacy team. Similar to the "Go Green" project methodology, an emissions factor was determined using the USEEIO v1.2 by NAICS 2023 dataset factor for Pharmaceutical Preparation Manufacturing NAICS title (11). This factor was 107, with a unit of tons of carbon dioxide equivalent (tCO_2e) per million dollars. The pharmacy team calculated spend amounts for the following categories: "total spend," unusable

TABLE 1.
Overview of Cost Saving Per Bed, Per Unit, and Per System

Scale	Emission Savings	Unit	Cost Savings	Metric	Calculation
Per bed	26.6	kg CO_2e/bed/day	$45.24	/bed/day	Total savings divided by number of bed days observed (12) to get total per day per room
Per unit	310,945.20	kg CO_2e/32 bed ICU/year	$528,359.40	/32 bed unit/year	Total savings per room per day multiplied by standard 32 bed unit per day for annual savings per unit
Per system	3,400,963.08	kg CO_2e/350 ICU beds across HM system	$5,778,930.94	/350 beds across HM system	Total 32 bed annual savings divided by 32, multiplied by 350 for total annual savings across systemwide ICU beds

CO_2e = carbon dioxide equivalent, HM = Houston Methodist.

(expired medications), nonpatient-specific waste, and central pharmacy carousel accounting.

RESULTS

Governance and Infrastructure Outcomes

The collaborative currently comprises a dozen institutions from around the country, with members supporting the movement regardless of whether it aligns with their institutional policies. Members represent leaders in the field of critical care, from both clinical and academic sectors. In addition to this collaboration, we developed a joint statement on environmental sustainability in critical care, providing essential leaders in care with the opportunity to publicly commit to the sustainability movement. There are currently over 50 signees affiliated with more than 30 institutions across 13 states and six countries, and the list continues to grow. The collaborative team is also involved with programs, such as the SCCM Environmental Sustainability in the ICU Task Force. It engages with larger sustainability-centered associations, including Practice Greenhealth (13), HealthCare without Harm (12), and the Medical Society Consortium on Climate and Health (14). These efforts informed the inaugural Houston Methodist Green ICU Conference, which was held in Houston this year.

Team Reduce

Reducing Medication Waste. IV medications can be prepared in batches in advance, based on documented patient flow rates in electronic health records. This can lead to medication expiration and waste in dynamic settings like the ICU, where needs are constantly changing. In this project, an alternative "on demand" approach to preparing IV medications was explored. In particular, angiotensin II was switched from batch preparation to on-demand preparation, reducing waste from 4.8% to 1.4%.

Additionally, alternative methods to medication storage were explored. Medications prepared in sterile compounding areas have a relatively short beyond-use date (BUD) when stored at room temperature. The BUD can be extended if medications are stored in a refrigerator. Dexmedetomidine and vasopressin storage was moved from room temperature to refrigeration, reducing medication waste from 60 infusion bags per month to 20 per month. During a 6-month monitoring period, it was determined that, on an annualized basis, medication waste is equivalent to 200 metric tCO_2e (mTCO_2e) and has a potential cost avoidance of $1,870,000 annually.

Other Projects. Other projects related to the "reduce" workflow include reducing unnecessary supplemental oxygen use in ICU patients, decreasing the number of supplies brought into patient rooms in the cardiovascular ICU, and reducing laboratory and imaging orders in the ICUs. For example, reducing the number of supplies brought into an ICU room was found to divert, on average, 26.63 kg CO_2e per ICU bed per day. This is extrapolated to 311 mTCO_2e per 32-bed ICU unit per year or 3401 mTCO_2e per 350 ICU beds across the Houston Methodist system on an annual basis.

Team Rethink

Intubation Tackle Box. A preorganized airway management kit was created to reduce reliance on traditional crash carts. This kit ensures rapid accessibility of airway supplies during emergencies while reducing unnecessary waste. By standardizing the items included and minimizing overstocking, this initiative improves both clinical efficiency and inventory control.

Procedure Cart. The procedure cart (**Fig. 2**) is a structured, standardized cart system designed to streamline access to procedural supplies. It helps reduce waste by ensuring that only essential and frequently used items are stocked. This approach not only reduces the overuse of consumables but also lowers the cost of unused or expired materials.

ICU Reoptimization Program. A comprehensive program aimed at minimizing the ICUs environmental footprint by implementing dedicated reprocessing bins for materials. The initiative raises staff awareness, encourages responsible disposal habits, and diverts a significant portion of ICU waste from landfills. This effort directly contributes to sustainability goals and supports regulatory compliance with environmental health standards. The goal is to optimize the use of reprocessed equipment through key vendors. By extending the life cycle of medical instruments and materials, the ICU significantly reduces its carbon footprint and lowers costs. This initiative also includes careful contract review and procurement practices that favor the use of recyclable and renewable supplies.

Team Recycle

Recycling Saline Flushes. In this project, recycling receptacles were added to all ICU inpatient rooms in one of our large sites to enable staff to recycle empty saline flushes. Additionally, we provided education to ICU staff to build team buy-in and cooperation. In-services on recycling were conducted each shift to improve compliance. Frequent rounding after initiation was crucial for gaining the team's insight into what was working well and identifying opportunities for improvement after implementation. Given the promise shown by the preliminary results, expansion is planned to include other sites, as well as the emergency department, operating rooms, and the infusion center.

DISCUSSION

Outcomes and Evaluation

Moving Beyond the Pilot. When evaluating outcomes, projects must quantify and use language that supports ongoing capability. For example, running an effective pilot and quantifying savings and emissions mitigation are significant steps. To truly bring about organizational change, ensure the validity of sustainability claims, and have a sustainable impact, we established various protocols, including educational materials, policies and procedures, standards of work, and quality assurance practices.

Energy Savings Quantification. While one can perceive energy savings as low-hanging fruit for evaluation, measuring their impact can be challenging for any pilot or project. Unfortunately, the cost of measuring energy usage down to a unit level, let alone a room level, can

Figure 2. A sample procedure cart. The most used supplies are displayed up front to avoid supply and time waste. Shelves are labeled to avoid contamination and wastage of nonessential supplies.

prove daunting and costly. However, we identified other opportunities in addressing this gap. One strategy is to investigate various energy-consuming tools and equipment in isolation. For example, when reducing the time computer monitors are left on, a wall-plug meter can be used to measure the reduction across a sample of computer stations and extrapolate the results to estimate the overall impact. Another strategy is to compare the product specifications to identify “Greener” alternatives. For example, traditional LED lights use 110-volt electrical wiring, compared with the smaller, less resistive speaker wiring. Assumptions can then be made based on power usage specifications to estimate energy-consumption reductions and cost savings.

Comparison With Baseline Data and Targets. Setting microlevel goals, whether unit-based or service line-based, was an excellent start for our initiatives; however, we need to link them to what is measured at the system level. To achieve such a macrolevel goal, we established baselines for scope 1 (direct emissions from sources we control or own, such as transportation and distribution costs), scope 2 (indirect emissions from sources we purchase and use, such as electricity) emissions, and waste stream baselines. This was necessary to provide a deeper understanding of the data constructs and to move the needle. Although scopes 1 and 2 account for 20% of our annual emissions, scope 3 (supply chain and business activities) comprises the majority, at 80%. At such a significant level, this underscores the importance of a wide range of mitigation efforts to achieve effective reductions. Systematizing reduction efforts and implementing projects ranging from waste reduction to alternative supply choices and process improvements is necessary to achieve a lasting environmental impact.

Lessons Learned: Challenges and Opportunities for Green ICU Initiatives

Operationalizing our Green ICU pathway in a large health system presented both significant challenges and promising opportunities. Here, we discuss some of these lessons learned.

Organizational and Cultural Differences. The pathway discussed in this article was implemented in a large urban health system, led by ICU leadership, and supported by a culture that fostered positive energy and enthusiasm for sustainability by providing the necessary resources for growth. Unfortunately, not all health systems may enjoy the same level of commitment, support, resources, or readiness to support green ICU initiatives. Differences in cultures, decision-making styles, and risk tolerance may pose significant barriers that either prevent such initiatives from forming or slow progress. However, our experience with the Green ICU Collaborative has led us to believe that a great deal can be achieved when passionate individuals come together and achieve quick wins through small but impactful projects, which, in turn, build momentum and organizational trust.

Initial Assumptions Are Often Data-Limited. In many of our initiatives, our initial plans were based on either incomplete or secondhand information, leading to wasted effort or misguided strategies. For example, one challenge we faced during the implementation of recycling saline flushes was the initial assumption that the plastic in the syringes was polyvinyl chloride, but after further investigation, it was determined to be a nonrecyclable plastic. This necessitated rethinking the process entirely. To address this, we suggest including direct supplier verification and material audits explicitly in the implementation planning process for recycling initiatives.

Participatory Approach Involving Patients and Family Members. Stakeholders for Green ICU initiatives extend beyond ICU staff to include patients and their family members. In the same saline-flush recycling effort, the bins were initially placed on the ICU floor; however, despite their distinct colors and labels, patient family members continued to put trash in them. We addressed this issue by placing the bins on top of the workstations in each patient room, which improved compliance. However, a more systematic approach to addressing such issues may be to use a participatory method, in which family members are included in awareness campaigns within the ICU. Visual displays explaining green initiatives, specific orientation materials aimed at educating family members about these goals, seeking suggestions, and explicitly asking for ideas to make ICUs greener may contribute to improved implementation outcomes.

Need for Evolving Metrics. There is no one-size-fits-all metric for determining the effectiveness of pilot projects, and the needs or capabilities of measurement may change over the lifetime of a project or initiative. When assessing outcomes, each entity will have different needs, expectations, and abilities. When determining which green ICU project to adopt, an organization may consider a range of qualitative measures related to its mission and organizational values. For example, weighing visibility, cost/value, volume, and barriers (such as change management) may provide the right perspective for an organization to determine which project to pursue and to evaluate it upon implementation.

Linking Microlevel Initiatives to Systemlevel Impact. Successful green initiatives are the foundational building blocks for a successful Green ICU. However, as the organization develops and collects success stories and data, the sustainability movement should begin to consider how such successes connect to a bigger picture in terms of quality, performance improvement, and patient safety measurements. Working with a physician champion to translate the importance of initiatives and their downstream impacts may be key to sustaining project growth. Leading discussions with quality executives and presenting the bigger picture will help advance the mission and educate a broader audience beyond grassroots champions. For example, connecting the dots internally on how the installation of circadian-based lighting may reduce energy consumption and patient delirium, and shorten length of stay, can have a powerful effect. Measuring and reporting hospital waste streams on a per-equivalent-patient-day basis may also help drive a sustainability mindset. Finally, triangulating various high-impact measures, such as climate impacts, community health outcomes, and admission rates, can provide a more holistic view of how efforts, both internally and externally, are making a positive environmental difference.

Ensuring Accuracy and Transparency in Reporting. Given the limitations in outcomes and evaluation, reporting sustainability outcomes is challenging and may require due diligence to ensure accurate disclosure. It often takes many institutions across industries multiple years before reporting data at an internal level. Validation from various parties and across numerous pilots can help assess accuracy and readiness for disclosure. Institutions should be prepared to scope, challenge, and revisit baseline data to ensure transparent and accurate disclosure, thereby gaining buy-in and support.

Limitations

Our study was not without limitations. Although these efforts spanned several centers, they were all within a single system with shared practices. This may limit the generalizability of our work and its reproduction at other centers that may not use the same techniques or workflows. Additionally, for several of our initiatives, cost and energy savings are difficult to measure and quantify. This leaves some proposed initiatives without sufficient data to determine their success. Future work will focus on finding ways to more effectively measure quantitative outcomes and to use continuous monitoring behaviors. Additionally, our initiatives focused on solutions that we had immediate control over, such as scopes 1 and 2. Because we recognize that most emissions arise from supply chain and business partnerships (scope 3), we must also develop initiatives that extend beyond our control and across the entire lifecycle of supply development and use.

CONCLUSIONS

Despite the overall increase in awareness and the emergence of Green ICU initiatives, the knowledge base in this domain remains sparse, and documentation of successes and implementation guidelines remains a gap in the literature. In this article, we address this gap by documenting our operationalization of the stages of the Green ICU Pathway, as well as the lessons learned, challenges faced, and practical solutions developed across our extensive healthcare system. The ICU sustainability field is in dire need of shared knowledge to support its growth, and we hope this article contributes by outlining how this pathway translates into tangible, sustainable projects. Although much work is warranted to validate the generalizability of our approach, we hope that, given the scarcity of published work, this article will inform future efforts and contribute meaningfully to the knowledge base in this area.

1 Center for Critical Care, Houston Methodist, Houston, TX.

2 Office of Sustainability, Houston Methodist, Houston, TX.

3 System Pharmacy Services, Houston Methodist, Houston, TX.

4 Department of Industrial and Systems Engineering, Texas A&M University, College Station, TX.

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For information regarding this article, E-mail: fsasangohar@houstonmethodist.org

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