FROM DATA TO ACTION:
DESIGNING A DATA-DRIVEN TOOL FOR THE ICU

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"In der Beschränkung zeigt sich erst der Meister"
~Johann Wolfgang von Goethe

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PROJECT OVERVIEW

The healthcare industry is responsible for 6-7% of the Netherlands' national carbon footprint, with Intensive Care Units (ICUs) having three times the environmental impact of general hospital care. At Erasmus Medical Center (EMC), each ICU patient generates 17kg of waste daily, translating to 12kg CO2-equivalent emissions. This project addresses the challenge of reducing the ICU's environmental footprint through a data-driven approach to meet EMC's sustainability targets of 55% CO2 reduction and a 100% circular ICU by 2030.

PROBLEM

The Erasmus MC ICU needs to reduce its environmental footprint but lacks the data insights to effectively measure, monitor, and improve its impact. Current sustainability data is fragmented across departments, making it difficult for the ICU Green Team to execute their established workflow of identifying hotspots, setting goals, and implementing interventions.

RESEARCH FINDINGS

Our research identified two distinct user groups with different needs:

1. Green Team IC-V: Requires detailed analytics for intervention management
2. General ICU Staff: Needs simple, actionable insights that don't compete with patient care priorities

Key barriers to sustainable practice included:

- Limited awareness of small-scale impact
- Perceived conflict between sustainability and patient care
- Protocol-driven workflows that prioritize clinical care
- People-focused culture resistant to data-driven approaches
- Lack of incentives for sustainable behaviour

Data discovery revealed that medical products data offered the most complete dataset for initial implementation, combining procurement records with environmental impact factors.

SOLUTION: GERDA

GERDA (Green ERasmus Data Assistant) is a data-driven sustainability dashboard designed to help the ICU Green Team identify environmental hotspots, set reduction targets, and monitor progress. The solution consists of two complementary dashboard views:

Analysis View

Enables environmental hotspot identification through product category visualization, interactive filtering, usage trends, and environmental impact metrics.

Goal Setting View

Supports intervention planning and progress tracking with target configuration, progress visualization, and flexible time range monitoring

GERDA connects to the hospital's Health Data Platform through SAS Viya, automating data collection that previously required manual effort and allowing the Green Team to focus on analysis and action.

IMPLEMENTATION & IMPACT

User testing confirmed GERDA successfully meets core requirements for environmental hotspot identification, goal setting, and data filtering. Testing with ICU staff demonstrated that product-specific metrics (like gloves per patient day) are significantly more effective for communication than abstract environmental measures. The implementation roadmap provides a structured path forward:

- Short-term: Complete environmental dataset, establish live data connection
- Medium-term: Expand to additional emission sources and departments
- Long-term: Integrate with hospital-wide sustainability management

RECOMMENDATIONS

1. Standardize environmental data collection across departments to enable consistent measurement
2. Develop integrated metrics that combine clinical outcomes with environmental impact
3. Tailor communication strategies to clinical contexts, using concrete work-related metrics rather than abstract environmental measures
4. Establish centralized governance for sustainability data standards to enable meaningful benchmarking

By bridging the gap between environmental data and clinical practice, GERDA demonstrates how data-driven approaches can effectively support sustainability progress in healthcare settings while respecting clinical priorities.

1. Introduction

This chapter aims to introduce the project by first presenting an overview of sustainability challenges in healthcare, with specific focus on the Intensive Care Unit at Erasmus MC. Second, it identifies the key stakeholders involved and their distinct roles in sustainability efforts. Finally, it presents the central challenge of fragmented sustainability data and introduces the research question that will guide the development of a data-driven solution to reduce environmental impact in the ICU.

1.1. CONTEXT

In this section the context of the research is established by providing background on sustainability in healthcare and its relevance. It also identifies the key stakeholders in this project and their interests. This context is important for understanding the initial assignment and research question.

1.1.1. SUSTAINABILITY IN HEALTHCARE

The healthcare industry worldwide is increasingly recognizing the importance of sustainability and the need to reduce their environmental impact.
To understand the scale, it is important to note that globally, the healthcare industry is responsible for a significant portion of global greenhouse gas emissions, estimated at 4.4% (Karliner et al., 2020). This has led to a growing number of studies exploring methods and actions to reduce healthcare's environmental footprint, including material use, energy consumption and waste (McGain & Naylor, 2014). These efforts are driven by the recognition that reducing the environmental impact of healthcare can positively impact both planetary and public health (Lenzen et al., 2020).

The Dutch healthcare industry is responsible for 6% - 7% of the national footprint of the Netherlands (Gupta Strategists, 2019; Health Care Without Harm & ARUP, 2019). The sector also accounts for 13% of national material extraction and 4.2% of national waste generation. Annually, this translates in the extraction of 33,801 kilotons of materials, 17 575 kilotons of CO_2 eq. (Carbon Dioxide equivalent) emissions and 4803 kilotons of waste (Steenmeijer et al., 2022). With the increasing demand and pressure healthcare in the Netherlands (Stand Van De Zorg 2024 - Nederlandse Zorgautoriteit, 2024) due to the ageing population these numbers are likely to grow.
Within the healthcare sector, Intensive Care Units (ICU's) are particularly resource-intensive (Huffling & Schenk, 2014). Globally, studies have shown that ICU's emit approximately three times more CO_2 per hospitalization day and generate 30% more waste compared to general acute hospital care (Prasad et al., 2021). These figures highlight the urgent need for a shift from a linear system to a circular system in healthcare, starting with the resource intensive ICU.

1.1.2. STAKEHOLDERS

The project takes place in the Erasmus MC, with a lot of sub-groups that have their own expertise and needs, for a full overview, see Figure 1.

ERASMUS MC

Erasmus Medical Centre (EMC) is an academic medical centre in Rotterdam, the biggest hospital in the Netherlands with 1350 beds, it is focussed on research, education, and specialist care. Among other objectives, the EMC is committed to developing sustainable healthcare practices and advancing data-driven healthcare delivery.
Erasmus MC has committed to the National Green Deal for Sustainable Care ("GREEN DEAL: Samen Werken Aan Duurzame Zorg," 2022) and furthermore set up their own sustainable strategy (Een duurzaam Erasmus MC et al., 2022). Key objectives include:

1. Identifying & Monitoring:
   Mapping out emissions and material usage to target environmental hotspots areas and evaluate progress over time.
2. Reduce CO_2 Emissions:
   A 55% reduction by 2030 (compared to 2018 levels) and net-zero emissions by 2050.
3. Material Circularity:
   Achieving a 50% reduction in raw material consumption and transitioning to a 100% circular ICU by 2030.
4. Collaboration and Communication:
   Partnering with manufacturers and creating awareness among employees and patients about sustainability efforts.

These organisation-wide sustainability goals are particularly relevant for departments with high resource intensity, making the ICU an interesting focus area.

INTENSIVE CARE UNIT

As one of the most resource- intensive departments of the hospital, the ICU manages 56 beds and over 3,000 patients annually. A team of intensivists, nurses and support staff provides critical care 24/7.

To understand the environmental impact at this ICU, a material flow analysis was conducted in 2019 revealing a significant environmental footprint: Each ICU patient generated 17 kg of waste. This translates into 12 kg CO2 eq (emissions, 300 L water and required 4 m2 of agricultural land occupation per day (N. Hunfeld et al., 2022).
In response to these findings, the ICU has initiated interventions to reduce the environmental footprint These efforts are coordinated by the Green Team IC-V.

GREEN TEAM IC-V
The Green Team IC-V is a group of staff members of the IC for adults that are taking responsibility for the sustainability. They implement initiatives such as waste segregation protocols and reduction of single-use products. Focussed on the identified hotspots (big emission sources), first steps have been made toward circular healthcare practices (N. Hunfeld et al., 2023).

DE GREEN ICU
The Green ICU is a research group specialized in sustainable healthcare practices, focusing on reducing the ICU's ecological footprint and generating knowledge on that. They work closely with the Green Team IC-V to translate research into practical implementations.

THE DATAHUB
The DataHub is a research group in the EMC with the aim to make date-driven healthcare scalable and clinically applicable in the hospital, with a big focus on the ICU. To this end they are developing Artificial Intelligence models and Dashboards to assist ICU staff in their work. The

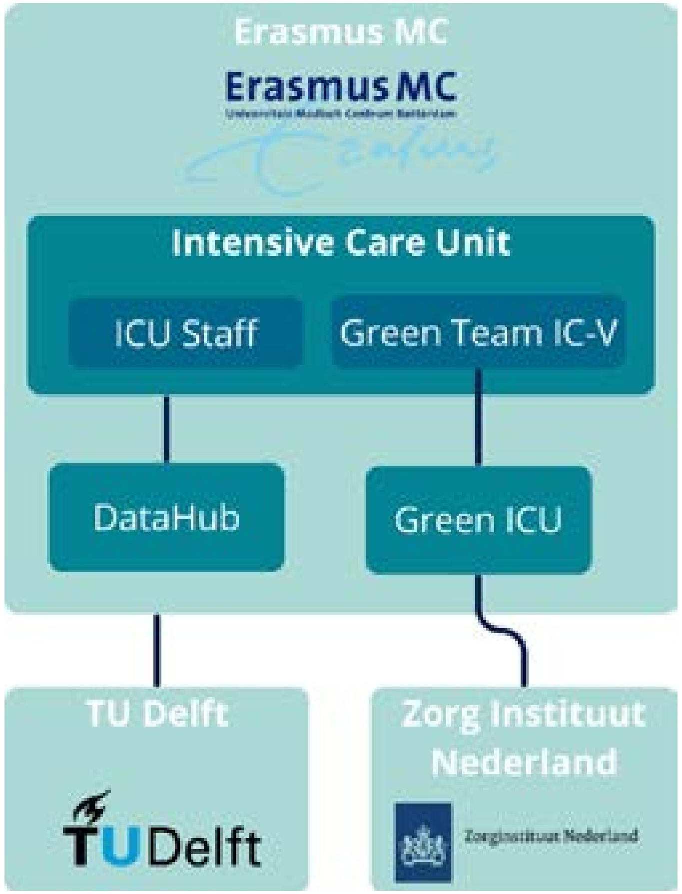


Figure 1: Stakeholder overview

DataHub has knowledge on and experience with data sourcing, data processing, AI development, dashboarding, and operating data-driven products.

ZORG INSTITUUT NEDERLAND
Zorg Instituut Nederland (ZIN) started the initiative 'Sustainable Data-Driven ICU Care' aiming to scale sustainable care practices nationally through standardized data collection and the development of an ontology. Their goal is to contribute to the development of knowledge about sustainable care nationally (Ministerie van Volksgezondheid, Welzijn en Sport, 2024). The ZIN is involved in this project is facilitated through my supervisor at the Erasmus MC who is employed by the ZIN.
This research can serve as a proof of concept for ZIN's national initiative on sustainable healthcare data standards.

1.2. INITIAL ASSIGNMENT

This master's thesis project was initiated by stakeholders at the Erasmus MC from the DataHub and Green ICU to address key challenges in the ICU's sustainability efforts. There are plenty of initiatives by the green team and ambitious sustainability targets have been set by the EMC. However, despite this, there are some barriers to reducing environmental impact. This section outlines the main issues identified by the initiating stakeholders, which form the initial basis for this project.

1.2.1. CURRENT CHALLENGES

The ICU at Erasmus MC faces a big challenge in its efforts to reduce environmental impact: the lack of a unified data infrastructure to track and visualize environmental impact. Without standardized accessible data on CO2 emissions and material waste, it is a big challenge to effectively monitor progress towards sustainability targets or for ICU staff to understand how their daily actions contribute to environmental outcomes.
This data fragmentation hinders both the evaluation of current sustainability interventions, and the ability to motivate interventions to the ICU staff.
This challenge, as identified in conversations with stakeholders at Erasmus MC, underscores the need for a data-driven, integrated solution. By centralizing and visualizing sustainability data, this could both enable progress monitoring and empower ICU staff to make better informed, environmentally aware decisions. This leads to the following research question:

"How can a data-driven decision support tool be designed to enable ICU staff to reduce environmental impact in the Erasmus MC?"

1.2.3. SCOPE

This project consists of two main components: first, a research phase to understand the problem space and identify influencing factors in reducing environmental impact in the ICU and second, the design of a data-driven solution that addresses the identified needs. A data-driven approach was chosen because it enables objective measurement of environmental impact, supports systematic identification of environmental hotspots, and can leverage Erasmus MC's existing technical infrastructure. Both research and design components will be documented in this master thesis report.
The project is limited to environmental sustainability at the adult ICU at Erasmus MC and does not cover other departments, organisations or hospitals, though the method and findings might also be applicable to other situations.

1.2.3. SIGNIFICANCE

This research & design can be justified because it has implications for both the Erasmus MC and the broader field of sustainable healthcare. By organising the data and developing a data-driven tool the project directly contributes to Erasmus MC's sustainability objective of 'Identifying and monitoring' to target environmental hotspots areas and evaluate progress. Furthermore, this project can support 'Communication' about environmental efforts, another one of EMC's sustainability objectives, and thereby motivating staff to work along.
The insights and outcomes from this project could also inform sustainability efforts in other healthcare contexts and can provide a case study for national standardized sustainability data.

Figure 2: Waste after 24 hour care at the ICU

1.3. KEY TAKEAWAYS

- Healthcare has a significant environmental footprint (4.4% of global emissions), with ICUs being three times more resource-intensive than general hospital care. At Erasmus MC's ICU, this means 17kg waste and 12kg CO_2-eq. emissions per patient daily.
- Erasmus MC has set ambitious 2030 targets (55% CO_2 reduction & a 100% circular ICU) and in the ICU these 3 groups collaborate to achieve them:
    a. Green Team IC-V: Implements practical sustainability changes
    b. DataHub: Provides data expertise
    c. Green ICU: Contributes research
- The Erasmus MC ICU faces challenges in reducing environmental impact, including unclear impact of current sustainability interventions and decentralized, and inconsistent data on emissions and waste.
- This leads to the research question: "How can a data-driven decision support tool be designed to enable ICU staff to reduce environmental impact in the Erasmus MC?"

2. Literature Review

This chapter reviews existing knowledge in three domains essential for designing a sustainability tool for the ICU environment. By examining data-driven decision support in healthcare, sustainability monitoring approaches, and behavioral change theories, we identify key insights and knowledge gaps that inform our research questions. The review focuses on balancing information needs, automating data collection, and understanding context-specific factors that influence sustainable behavior in critical care settings.

2.1. REVIEW FRAMEWORK

The research question leading this project is:

How can a data-driven decision support tool be designed to enable ICU staff to reduce environmental impact in the Erasmus MC?"

Understanding how to design a data-driven sustainability tool for ICU environments requires knowledge from multiple domains. This chapter examines three domains that form the theoretical foundation for the rest of this research:

1.Data-Driven Decision Support in Healthcare
As the designed tool needs to integrate with existing ICU systems and workflows, current practices and lessons learned from healthcare tools are explored.

2. Sustainability Monitoring in Healthcare
To effectively reduce environmental impact, it is important to understand existing sustainability monitoring approaches, particulary in healthcare settings.

3. Motivating Sustainable Behaviour
Successfully enabling ICU staff to reduce their environmental impact requires understanding on how to effectively motivate sustainable behaviour in clinical environments.

For each domain, the chapter systematically reviews current practices, analyses barriers and facilitators, and aims to identify gaps in research. These three domains are inherently interconnected in the context of this research—creating an effective sustainability tool for the ICU requires understanding how to present data meaningfully (data-driven decision support), what environmental factors to measure (sustainability monitoring), and how to encourage adoption among staff (behaviour change). The chapter concludes by highlighting the gaps that translate to the sub-questions guiding the rest of this study.

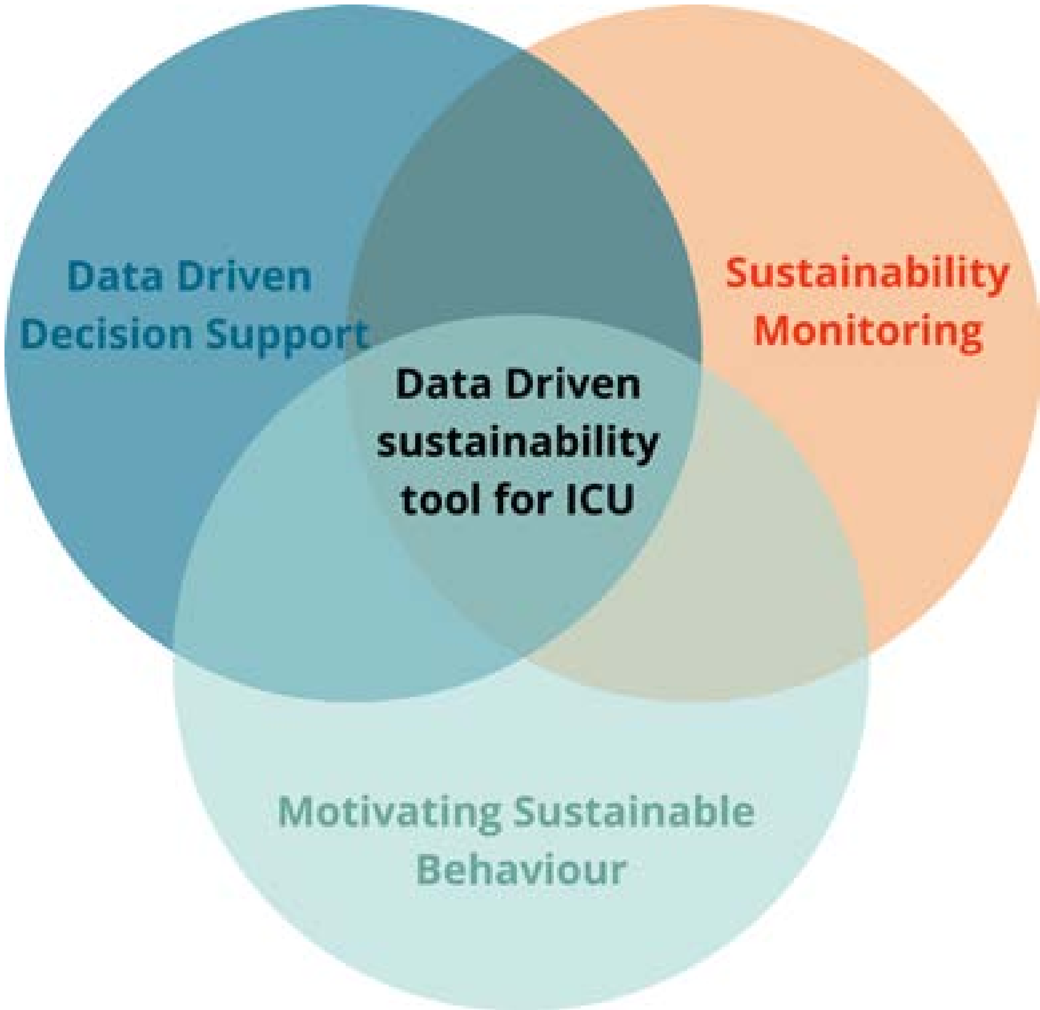


Figure 3: Literature review framework

2.2. DATA-DRIVEN DECISION SUPPORT IN HEALTHCARE

To design new data-driven tools for the ICU setting, it is important to understand both the current landscape and the lessons learned from existing implementations. This section examines the academic knowledge on data-driven tools in ICUs, exploring the barriers that hinder and the facilitators that enable their effectiveness in healthcare environments.

Current practice

The ICU environment is inherently data-driven, with staff continuously monitoring and interpreting patient data through Key Performance Indicators (KPIs) (Citerio et al., 2015). However, the increasing volume of available data has begun to exceed human cognitive processing capacity (Stead et al., 2010), highlighting the critical need for effective data presentation tools in healthcare settings.

Barriers

Several key barriers affect the effectiveness of data-driven tools in healthcare environments. The primary challenge is cognitive overload, where the volume of data surpasses staff's cognitive capacity (Stead et al., 2010). This is especially relevant in the ICU context, where physicians can face up to 32,120 data points per shift (Asgari et al., 2024).
Furthermore, studies show 50% of tools fail to involve end users in development, leading to poor adoption (Helminski et al., 2024). Technical integration with existing systems presents another barrier (Culler et al., 2010), this can be the result of tools lacking systematic implementation strategies and frameworks (only 20.3% use any framework) (Helminski et al., 2024). Finally, data quality issues can undermine tool effectiveness and user trust (Carra et al., 2020; Van De Sande et al., 2021) and these early technical problems during implementation can create lasting mistrust that stay even after issues are resolved.

Facilitators

Research has identified several factors that enable successful implementation of data-driven tools. The most effective implementation strategies found by Helminski et al. (2024) combine educational sessions, audit & feedback and stakeholder engagement. Effective data visualization can significantly improve interpretation efficiency and decision-making speed, reducing the cognitive burden and even improving the decision quality, compared to tabular information (Park et al.,2021; Lai et al., 2022; Wac et al., 2023).
Large screen visualizations enhance communication accuracy during multidisciplinary rounds (Lai et al., 2022; Bersani et al., 2020). User involvement in the design process and continuous improvement based on feedback are crucial for successful implementation (Bersani et al., 2020; Wac et al., 2023; Goldstein et al., 2020). Creating personas based on professional roles could be a method that helps address user needs and improve tool adaptation (Jalilian & Khairat, 2022; Goldstein et al., 2020).

Conclusion

These insights show that any new data-driven tool must prioritize user-centred design and consideration of cognitive load. This means balancing the amount of information while maintaining decision quality. While information overload is a significant challenge, research shows that successful implementations depend on user involvement, education and effective data visualisation.
Between the found literature, a gap emerged on how to effectively integrate new data tools into existing ICU workflows. Specifically when applied to sustainability monitoring in this setting, this leads us to the next section; exploring current approaches to environmental impact monitoring in healthcare.

2.3. SUSTAINABILITY MONITORING IN HEALTHCARE

As healthcare organizations move from recognizing their environmental impact to taking more concrete action, monitoring becomes important to validate and improve these initiatives. This section is about existing tools in healthcare and the barriers and facilitators in implementing sustainable monitoring in healthcare to inform the design of an effective tool for the EMC ICU.

Current practice

Healthcare organizations employ various tools to monitor environmental impact.
Promeza, for example, is a data management tool where users manually input data about medical materials used (type, quantity, disposal method) to gain insights into environmental impact. However, this manual data entry makes the process time-consuming.
The 'Barometer Groene OK' takes a different approach, using questionnaires to assess operating room sustainability practices and providing hospitals with tailored advisory reports. The tool has identified key actions that could reduce OR emissions by up to 75%.

Barriers

The implementation of sustainability monitoring tools faces several significant challenges. The lack of comprehensive regulatory mandates makes it difficult to standardize sustainability reporting across healthcare institutions (Collins & Demorest, 2022). Existing tools often require manual data collection and entry, creating a significant time burden for staff (Chiara, 2024). Additionally, data privacy concerns and integration issues with hospital systems complicate implementation. The lack of standardization in sustainability metrics and reporting methods makes it challenging to compare and benchmark performance across institutions (Collins & Demerest, 2022).

Facilitators

Several factors enable effective sustainability monitoring in healthcare. Standardized reporting frameworks, when available, facilitate consistent measurement and comparison (Collins & Demerest, 2022).
The identification of environmental hotspots, as demonstrated in the Erasmus MC- based study, provides focused areas for intervention (N. Hunfeld et al., 2022). Regular evaluation and monitoring of these hotspots enables effective goal-setting and progress tracking (Saviano et al., 2018; Bhonagiri et al., 2023).
The 10 R strategies framework provides a structured approach to implementing and monitoring sustainable interventions (Reike et al., 2017). Research emphasizes that effective sustainability data visualization should balance analytics with engagement and communication, to make complex environmental more accessible to diverse users. Involving healthcare staff in tool development can improve this balance (Mahyar, 2024).

Conclusion

The current landscape of sustainability monitoring in healthcare is young, with many opportunities for improvement. Current monitoring tools demonstrate the potential for monitoring environmental impact but are limited by their reliance on manual data collection and lack of standardized metrics. The design of a monitoring tool should prioritize automated data collection and focus on making environmental data actionable by identifying hotspots and tracking progress. However, knowledge on how automated sustainability data could be collected is very limited. This is essential for developing tools that operate without adding administrative burden. A good reason to look into this further.

2.4. MOTIVATING SUSTAINABLE BEHAVIOUR

Once the right data is available, the success of sustainability initiatives in the ICU depend for a big part on the motivation of staff and their behaviour. While tools can enable taking action in the most effective hotspot, the effectiveness of these actions relies on adaptation by ICU staff. This section examines how behavioural theories can inform sustainability interventions in healthcare and explore the barriers and facilitators that (de-) motivate sustainable behaviour in healthcare and ICU staff.

Current practice
Healthcare staff engagement in sustainable practices requires understanding of both individual and organizational factors. Behavioural change theories provide frameworks for analysing these factors. There are old and wide used examples to analyse behaviour such as the Theory of Planned Behaviour (Ajzen, 1985), which considers attitudes, perceived control, and social norms. More recently the COM-B model (2011) is developed to focuses on capability, opportunity, and motivation to understand behaviour, but also suggest most effective influencing strategies, based on the identified behavioural factors.

Barriers
Research has identified several barriers to sustainable behaviour in healthcare settings. Nurses often face high workload and competing priorities, which can make adopting new sustainable practices challenging (Kalogirou et al., 2021). The complexity and time required for tasks like waste segregation can discourage adoption, as found in the Operating Room (Wyssusek et al., 2018). A perceived conflict between patient safety and environmental goals creates additional resistance in critical care departments, as infection prevention practices often rely on disposable products (McGain et al., 2020). Research at Erasmus MC showed that simple interventions like using nudges to discourage unnecessary apron use did not result in behavioural change (Van Der Zee et al., 2024), though they are reported to work in other contexts. Teaching us to not copy paste proven concepts from other environments without testing them.

Facilitators
Studies have identified several factors that support sustainable behaviour adoption. Healthcare staff show willingness to learn and adapt when provided with appropriate tools and resources (Sürme et al., 2024). Research suggests that creating habits and fostering self-regulation supports long-term adherence to sustainable practices (Kwasnicka et al., 2016). Education among healthcare staff can help raise awareness and support implementation of sustainable interventions (Bennett, 2023; Slutzman et al., 2022; Cohen et al., 2023). Studies indicate that basic education and training can reduce waste volume (Mosquera et al., 2014).

Conclusion
Behaviour change in healthcare requires addressing both individual and systemic factors. Behavioural models can provide a good structure to guide the design of sustainable interventions. Education and habit formation are mentioned as the most influential factors, but must beware of adding more workload. A key insight is that introducing behaviour change interventions, even when proven elsewhere, might not have the same effect in the ICU and must therefore always be tested in context.
One gap in literature is the understanding how data visualization and metrics can support sustainable behaviour in healthcare settings. There remains limited evidence on which specific metrics and visual formats best communicate environmental impact to healthcare staff in high-stakes environments like the ICU, and motivate to action.

2.5 DISCUSSION & GAPS

The literature review reveals several important considerations for designing data-driven sustainability tools in ICU environments. Cognitive load emerges as a big concern, any new tool must carefully balance information density with decision support quality through effective presenting of the data. Furthermore, automated data collection and standardized metrics are crucial for successful sustainability monitoring as the implementation must not increase staff workload. Additionally, behavioural interventions require thorough testing in the specific ICU context, as solutions proven somewhere else might not be applicable to this unique environment. These findings highlight that successful implementation depend on user involvement throughout the design process and support through education and formation of habits.
In this review, three primary research gaps were found that inform the next steps in this study. Firstly the Integration with existing ICU workflows, there is limited evidence exists on how to effectively integrate new data tools into existing ICU workflows, particularly tools focused on environmental impact rather than patient care. Next, while organizations increasingly recognize the need to monitor environmental impact, research on how to efficiently collect and process this data in healthcare settings remains limited. And lastly there is limited understanding of which specific metrics and visual formats best communicate environmental impact to people in general, as well as in ICU settings.

These gaps translate into the following sub-questions:

SQ1: "What are the current sustainability prac tices and workflow patterns in the Erasmus M ICU?"

SQ2: "What user needs and preferences must be considered when designing sustainability metrics and visualizations for ICU staff?"

SQ3: "What data sources and infrastructure ar available for (automated) sustainability monito ring in the Erasmus MC ICU?"

Addressing these sub-questions will guide the methodology and following research phases.

2.5 KEY TAKEAWAYS

- Data-driven tools in the ICU environment must balance information density with decision support quality to reduce cognitive burden, while automated data collection is essential to avoid increasing workload.
- Sustainability monitoring in healthcare currently relies heavily on manual data collection and lacks standardized metrics, highlighting the need for automated approaches that identify actionable environmental hotspots.
- ICU-specific context is crucial for behaviour change. Solutions proven in other healthcare settings may not translate directly to the ICU environment, emphasizing the need for user involvement throughout the design and implementation process.
- Three key research gaps were identified that inform this study's approach:
    a. Integration of sustainability tools with existing ICU workflows
    b. Methods for automated sustainability data collection in healthcare
    c. Effective metrics and visualizations for motivating sustainable behaviour
- These gaps translate to three sub-questions which will methodologically be answered, as can be read in the next chapter.

3. Methodology

This chapter outlines the research approach used to address the gaps identified in the Literature Review. To effectively design a data-driven sustainability tool for the Erasmus MC ICU, a methodological framework was needed that could investigate both user needs and technical data possibilities in parallel. Three sub-questions presented in Section 2.4, guide this research, each requiring specific methods that complement each other. Before moving to the individual methods, the first section presents the overarching research design that connects these approaches into a coherent framework.

3.1. RESEARCH DESIGN

In this study, a structural approach is used, that combines both the ICU context and the data-driven nature of the project. The following sections will address the chosen research framework and explain how it guides both the investigation of user needs & context and technical possibilities.

3.1.1. TRIPLE DIAMOND MODEL

This research will follow the Triple Diamond model, an overarching framework that structures the research and design process when working with data. The model is an extension of the well-known Double Diamond Model with the Problem Discovery and Solution Exploration, but introduces a third, the Data Discovery phase (Schleith & Tsar, 2022) as seen in Figure 3.

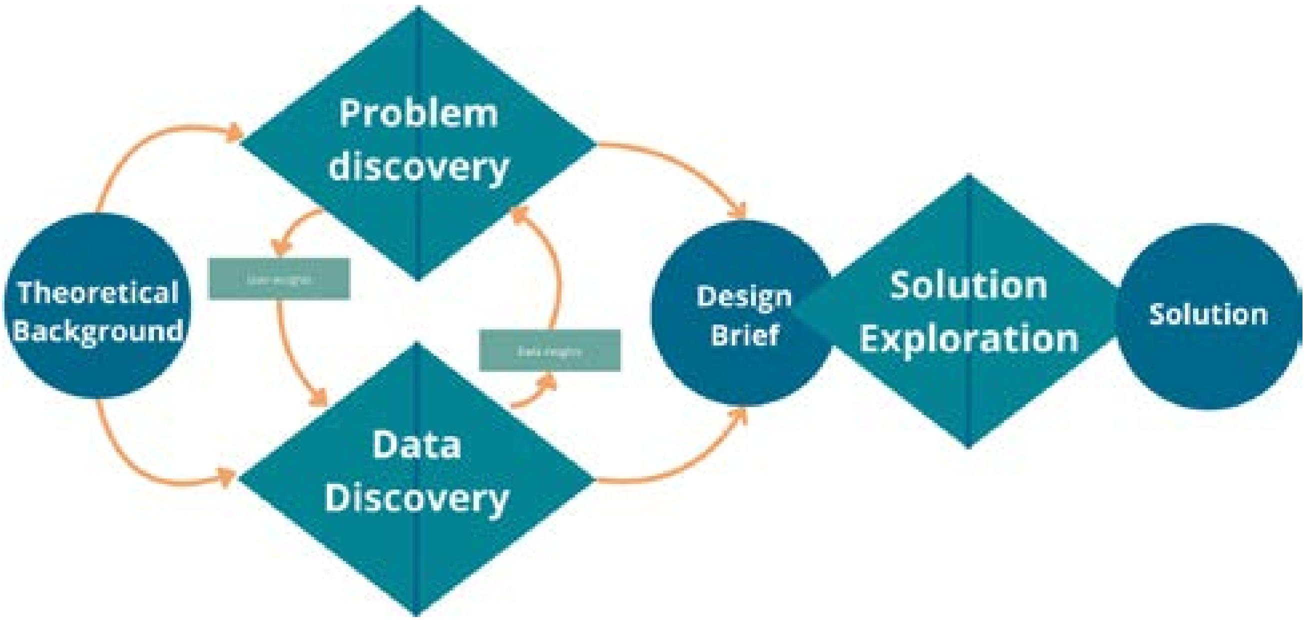


Figure 4: Triple diamond framework

All three diamonds stand for a different phase and purpose:

Problem Discovery
Explores user needs, challenges and current practices through user research and interaction.

Data Discovery
Examines available data sources, infrastructure, and technical possibilities.

The discovery phases interact with each other. Findings from the Data Discovery inform the Problem Discovery by providing stakeholders with examples of data visualizations to understand how they interpret and interact with the sustainability metrics. Vice versa, the Problem Discovery findings give context to the Data Discovery for interpreting data, by identifying which datasets are considered useful or reliable by staff.

This ensures that the resulting Design Brief is both technical feasible and meaningful to users; leading towards the last diamond:

Solution Exploration
Develops and iterates on potential solutions based on the design brief and its requirements. As a final step the chosen Solution is explained and implemented.

The Triple Diamond model was chosen for this project for the following reasons:

- It was specifically developed for data-driven contexts, making it ideal for designing a sustainability tool that relies on environmental metrics
- It provides a structured approach to parallel exploration of both user context and data infrastructure, which fits the complexity of implementing sustainability initiatives in the ICU environment
- It is a divergent-convergent process that balances thorough exploration with focused decision-making, helping identify meaningful sustainability metrics without contributing to information overload
- It reduces the risk of developing technically sound tools that fail to address actual user needs - a common pitfall in healthcare implementation

3.1.2. CONNECTION SUB-QUESTIONS AND RESEARCH METHODS

The research phases were designed to directly address the three sub-questions that emerged from the literature review.

The Problem Discovery addresses:

SQ1: What are the current sustainability practices and workflow patterns in the Erasmus MC ICU?

and

SQ2: What user needs and preferences must be considered when designing sustainability metrics and visualizations for ICU staff?
Observations and interviews were chosen methodologies here because they complement each other. Observations reveal the actual practices that may differ from reported behaviours while interviews uncover staff perceptions and preferences. These methods are detailed in section 3.2.

The Data Discovery addresses:

SQ3: What data sources and infrastructure are available for (automated) sustainability monitoring in the Erasmus MC ICU?

Environmental impact mapping, data source assessment and technical infrastructure analysis were the selected methods for this phase to identify emission sources, analyse the available datasets and understand how data can be accessed and integrated in existing systems. These methods are detailed in section 3.3.

3.2. PROBLEM DISCOVERY METHODS

The Problem Discovery chapter investigates current sustainability practices & user needs in the Erasmus MC ICU, answering SQ 1 and SQ 2 with two methods: direct observations and semi-structured interviews. These were selected to provide both objective insights into actual context and workflows and subjective insights from ICU stakeholders.

3.2.1. OBSERVATION METHODOLOGY

The observations consisted of two main components.
First direct observations were done through ICU visits. A full-day was spent shadowing ICU staff to gain empathy and insight into their daily work & experiences. This included witnessing & helping with patient care routines, staff interactions with monitoring systems, and resource usage patterns. Due to privacy reasons, there were no recordings, but field notes and pictures.
Secondly, 4 ICU Green Team were attended meetings. Here, context was gathered for existing sustainability initiatives and challenges. This provided insights into current priority areas and implementation approaches. A Green Team workflow documentation was made based on observed decision-making and intervention planning processes.

The field notes were categorized in three domains: sustainability practices, data usage patterns and Green Team workflow.

3.2.2. INTERVIEW METHODOLOGY

STUDY DESIGN
This part of the Problem Discovery made use of semi-structured interviews with two parts:
1. Questions regarding sustainability, and sustainable interventions at the ICU
2. Interaction with sustainability data

PARTICIPANT SELECTION
Participants for this study were selected using a combination of purposive sampling and considerations of reachability & availability of personnel. In collaboration with one of the staff managers, suitable participants were identified for a diverse representation of perspectives within the ICU.

- ICU Nurses: two nurses with varying interests. One nurse is part of the Green Team, while the other has experience in implementing a new education module.
- PhD Candidate: One PhD candidate, specializing in ICU pharmacology.
- ICU manager: One Intensivist who also manages the ICU and oversees both ICU and OR operations.

The sample size of 4 participants is small, but it was deemed sufficient for this exploratory research for the following reasons. First, the participants have diverse roles within the ICU ecosystem and second, the findings were triangulated with observational data to strengthen validity. The insights are intended to inform design direction rather than produce generalizable statistical conclusions.

DATA COLLECTION

The interviews lasted between 30 and 60 minutes, depending on participant's availability and data saturation. The interview guide (Appendix A) was designed to progressively explore key areas while maintaining flexibility for follow-up questions or participant input. The interview guide covered three main areas:

1. Context and daily operations, starting with easy questions providing understanding of daily routines.
2. Sustainability and change, participants were asked about their views on sustainability in the ICU, the associated changes and the expectations for ICU staff. They were also shown a picture with some of the biggest emission sources and asked which they thought was the biggest, and which they themselves could impact. The aim was to identify perceived barriers and facilitators to implementing sustainable change.
3. Data interaction: Participants were shown four types of plots (see Appendix A):
   a. The top 10 product categories by total weight
   b. Monthly data for the Operation Jacket
   c. The Number of laboratory tests done per day for 1 patient
   d. The transport choice of patients (see Figure 5)

These plots were generated fast from real ICU hospital data, and not polished prompt raw and real input; a commonly used design method to get quick first prototype feedback (Greenberg et al., 2012).

Figure 5: Interaction plot, transport choice employees

They were chosen for the different aspects fo sustainability data: categorical data, patterns, patient level metrics and staff metrics. This allowed assessment of the intuitiveness and meaningfulness of the diverse data formats to ICU staff.
For each plot, participants were asked to describe what they saw in the data, explain their interpretation and share their thoughts on the usefulness.
This allowed observation of how participants naturally interact with and interpret different types of data visualizations.

DATA ANALYSIS

Thematic analysis was employed to analyse the interview data, following the 7 steps as described by Clarke and Braun (2013). The process was done inductively, bottom up, to ensure high quality of data and minimum interference of existing theories or tunnel vision. The process included transcription with Word Transcriber, data familiarization, inductive coding using Atlas.ti software (resulting in 400 initial codes, see Appendix B), theme development, and validation. To ensure objectivity, external reviews were done by several people in different phases.

THEORETICAL FRAMEWORK

The first effort of developing themes was done bottom up, without an existing framework. However, this produced very broad themes (like 'sustainability in healthcare' or 'work challenge') that lost the information conveyed in the interviews. It failed to capture the interaction of personal feelings, specific sustainability views and motivational aspects that the participants did describe. Therefore I decided to use a theoretical framework, the COM-B model of behaviour change by Michie et al., (2011). The model identifies three essential components that together influence behaviour, as also seen in Figure 6:

- Capability (both psychological and physical ability to perform the behaviour),
- Opportunity (physical and social environment that enables the behaviour), and
- Motivation (automatic and reflective mechanisms that activate behaviour).

The COM-B model was selected over other

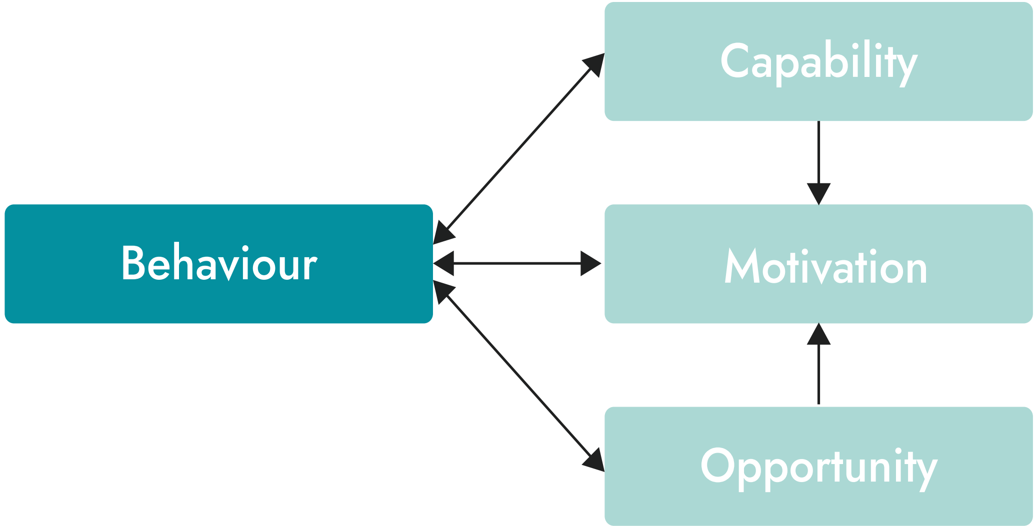


Figure 6: COM-B model and interactions

behavioural frameworks based on its successful application in similar healthcare contexts, such as the English Department of Health's tobacco control strategy and sustainable interventions among anaesthesiologists (Zaw et al., 2023). This last paper is used as example for the approach in this project. For the full list of themes and quotes, see Appendix C.

QUALITY MEASURES

Some triangulation measures were implemented to ensure the quality of the research:

- Multiple reviewer involvement
- Independent review of transcripts 4 fellow IDE master students, who verified coding consistency and gave some of their views on the topic to prevent bias.
- Collaborative theme creation with a PhD candidate specializing in sustainable behaviour in healthcare; providing domain expertise as a qualitative researcher.
- Validation of findings with 2 ICU Green Team members and my direct supervisor in the Erasmus MC.

Systematic Documentation

- Use of transcripts codes & themes
- Use of theoretical framework COM-B

3.3.DATA DISCOVERY METHODS

The Data Discovery phase uses three complementary methods to address SQ3:

'What data sources and infrastructure are available for (automated) sustainability monitoring in the Erasmus MC ICU?'

Together the environmental impact mapping, data souce assessment and technical infrastructure analysis provide a complete picture of the sustainability data in healthcare.

3.3.1. ENVIRONMENTAL IMPACT MAPPING

An overview was created of all the different environmental impact sources surrounding the ICU patient through two sessions Green Team IC-V and ecological experts. Additional input was gathered through interviews that were part of the Problem discovery phase. This resulted in an illustration mapping the emission sources, providing a visual framework for the following data source assessment. This mapping was also used to communicate with stakeholders.

3.3.2. DATA SOURCE ASSESSMENT

For each identified environmental impact source, available datasets, variables and sources were documented through conversations with Green Team and DataHub members and referrals to relevant departments (e.g., purchasing department).

Data gaps were identified where information about emission sources was either non-existent or challenging to obtain. The assessment focused on datasets that could provide information about the previously identified emission sources and documented in a structured matrix.

3.3.3. TECHNICAL INFRASTRUCTURE ANALYSIS

Insights into the data infrastructure of Erasmus MC and DataHub were gathered through consultations with two DataHub software engineers. These sessions focused on understanding the necessary steps and considerations for utilizing hospital data in a data-driven tool, including data access protocols and system integration requirements. These findings were documented

3.4. VALIDATION

with a system architecture diagram.
To ensure quality and validity of the research done, findings from both discovery phases were triangulated and verified.
The findings from both discovery phases (Problem Discovery and Data Discovery) will be combined to create a comprehensive Design Brief. This brief will translate the research findings into clear design direction and requirements for the data-driven sustainability tool. Initial findings were presented to Green Team members and DataHub engineers for verification, to confirm or refine interpretations.
The validated findings from both discovery phases were combined to create a comprehensive Design Brief. This brief translated the research findings into clear design direction and requirements for the data-driven sustainability tool.
Based on this Design Brief, the Solution Exploration phase will develop potential solutions, with iterations. After that prototypes were made and tested with ICU staff. As last step the solution is refined based on user feedback and presented in chapter 'Solution' and implementation is suggested.

3.5. KEY TAKE-AWAYS

- This research follows the Triple Diamond model. This enables parallel exploration of both user needs and technical possibilities, ensuring the Design Brief and following Solution Exploration is grounded in both spaces. The following research methods are used:
  a. Problem Discovery: Observations and interviews revealed current sustainability practices, workflow patterns, and user requirements.
  b. Data Discovery: Environmental impact mapping, data source assessment, and infrastructure analysis identified available sustainability metrics and integration possibilities.
- Research validity was strengthened through triangulation between complementing methods, multiple data sources, stakeholder verification, and systematic documentation using established frameworks like COM-B for behavioural analysis.
- This methodological approach directly addressed the research gaps and 3 sub questions identified in the literature review in the specific context of the Erasmus MC ICU

4. Problem Discovery:
Understanding the ICU Context

This chapter addresses two sub- research questions:
SQ1: *“What are the current environmental sustainability practices and data utilization in the Erasmus MC ICU?”*, and
SQ2: *“What are the key user requirements and considerations for a data-driven sustainability tool in the Erasmus MC ICU?”*
Through observations and interviews with ICU personnel, we explore existing monitoring systems, intervention workflows, and facilitators & barriers to environmental impact reduction.

4.1 CURRENT ICU MONITO-RING

The Erasmus MC ICU relies on data-driven tools to support clinical decision making and patient care. Observations revealed 2 there are primary monitoring systems operating and interviews provided insights into staff experiences with these systems.

HIX: ELECTRONIC HEALTH RECORD (EHR)

HiX, a software by ChipSoft, serves as the over-arching EHR platform, managing both high- and low-frequency patient data. There are multiple monitoring systems like the heart monitor in (Figure 7) plugged in. This includes everything from real-time vital signs like heart rate and oxygen level to clinical documentation such as letters from the physician and radiology appointments.

Strengths

- Integration capabilities with other hospital systems like the heart monitor
- One overarching platform containing all relevant patient data
- Security features for patient data protection

Figure 7: Heart monitor

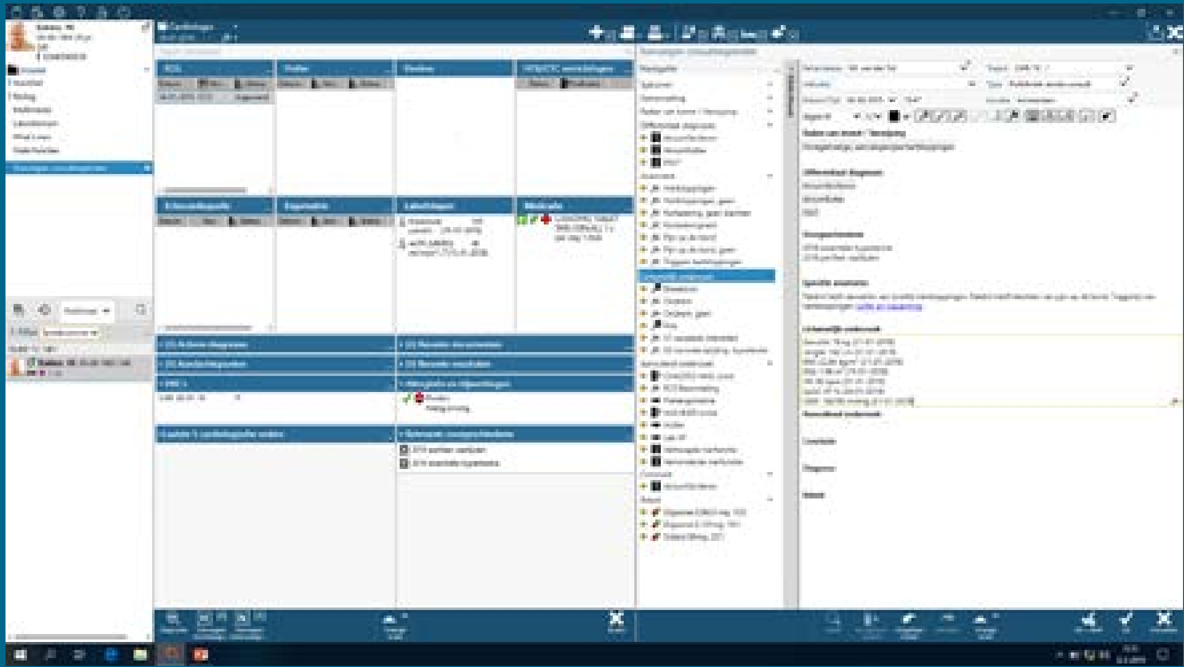


Figure 8: Interface HiX

Challenges

- User interface is complex and requires training
- Limited flexibility for specific department needs
- Can be rigid in terms of workflow adaptation

During conversations, ICU staff noted that while HiX is comprehensive, its complexity can be overwhelming.
'For 1 patient, there are between 100 and 150,000 unique data points per day , and those data points recorded in HiX... ...you can imagine that when you start at 8am in the morning, you look at that more freshly than after a night shift at 8am.'

ICU MAPS: OVERVIEW OF THE ICU

ICU Maps is a relatively new dashboard, originated in the ICU itself and developed by the researchers at the DataHub. On a centrally stationed monitor, the patients, responsible caregivers, and most vital care information are mapped out. It provides an overview and assists in multidisciplinary rounds and shift handovers, see Figure 5. The original tool used for this purpose was an Excel sheet.

ICU maps is built in SAS Viya an analytics platform that enables data processing, real-time visualisation and data analytics support. ICU maps sources its data from multiple sources: The work scheduling software for the responsible clinicians and HiX for patient data, e.g. whether the patients are on heart monitoring or dialysis.

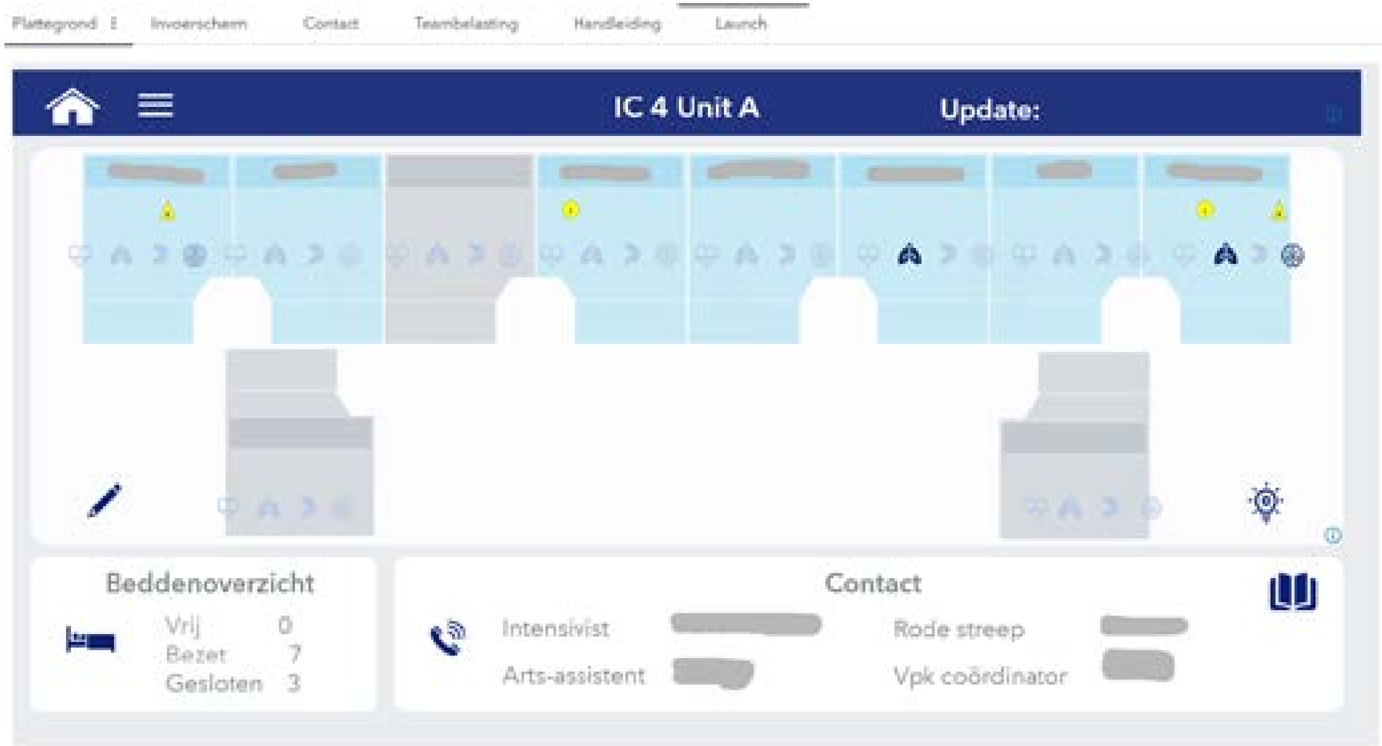


Figure 9: Monitor ICU Maps

Strengths

- Strong staff engagement during development
- Intuitive visualisation, not too complex like HiX
- Medical field expertise (developed by a PhD candidate with clinical background)

Challenges

- First version implementation issues caused loss of faith in staff
- Performance issues due to multiple data sources and limited capabilities of Sas
- Slow response times.

ICU maps is now also extended for further tooling like the respiration dashboard that monitors whether patients are being ventilated according to the protocol. It is used by the respiration team now with the aim of expanding to all the nursing staff.

4.2. SUSTAINABILITY AND THE INTERVENTION WORKFLOW

The Green Team IC-V is responsible for sustainability at the ICU in the Erasmus. Though management also bears some responsibility, the Green Team is active in organising the day-to-day for the ICU specifically and gets support from management where needed. The Green Team meets about once every 2 weeks and is typically led by Nicole Hunfeld, a pharmacist who combines practical expertise with academic research in sustainable healthcare. In her new paper 'The paracetamol challenge in Intensive Care' (N. Hunfeld et al., 2024), can give a nice insight into the workings of a Green Team and the setup of a sustainable intervention.

4.2.1. INTERVENTION WORKFLOW

The sustainable intervention workflow of the Green Team consists of four main steps, each with its own considerations:

1. **Identify hotspot**

The Green Team identifies a problem they want to look into and collect baseline data. Identifying a problem is often done intuitively or by learning from the medical network. For example, when a paper is published about inserting a catheter clean instead of sterile (Aarts, 2024), this is something the Green Team picks up.
Challenge:

- Environmental impact data (like CO2 emissions) require manual calculation and/or weighing.

- Data is not centralized, this makes data collection difficult
- Reliance on external departments (e.g. Pharmacist and inventory) for usage data can slow down the process

2. **Set goal**

A reduction target is set, some of those are included in the annual plan of the Green Team and the overall ICU.

Challenge:

- Limited historical data makes it difficult to set realistic reduction targets
- Goals need to be aligned across multiple stakeholders (Green Team, ICU management, general staff)
- Difficult to quantify the impact of proposed goal

3. **Motivate & Communicate**

In this step the Green Team thinks of a way to communicate the intervention to the rest of the ICU staff. For example this poster about 'Glove Week' in Figure 10.

Challenges:

- Information fatigue is mentioned as a limiting factor for effective communication
- Rotating staff and different communication channels

4. **Act**

The ICU staff implement the intervention in their daily work.

Challenge:

- Limited time and resources for staff to adapt to new procedures
- Difficulty in measuring the actual impact of implemented changes

Figure 10: Poster for the gloveweek campaign

4.2.2. RECENT INTERVENTIONS

In the Erasmus MC ICU, the green team has done several interventions, including:

- Reduce paracetamol IV (Intravenous) fluid by switching to oral medication when possible.
- Reduce non-sterile glove use, reduction was achieved by changing the use pattern/ behaviour with an awareness week & campaign.
- Replace disposable bedliners for washable towels, when possible.
- Implement new, protocol of non-sterile placement of catheter that needs less disposables.

Interviews with general ICU staff revealed varying levels of awareness about these initiatives, with gloves and paracetamol mentioned the most. One doctor explained:

"When I'm working now, I no longer put on those non-sterile gloves, because I can just wash my hands. So if I think 'oops, this is going to get very dirty,' then I do use them."

This shows the effectiveness of the campaign, but also the practical side of it.

4.3. USER GROUPS

During the visits and observations, two distinct different user groups became apparent.

GENERAL ICU STAFF

This group consists of everyone working on and around the ICU including nurses, intensivists, support staff, and management. These stakeholders are central to the project because their daily actions directly influence the ICU's environmental impact. Furthermore, these stakeholders fall under the ICU's management and are therefore easier to influence than external stakeholders. This general ICU staff group has little knowledge of the sustainability practices at the ICU, other than what is told to them by the Green Team.

“. Ik denk niet dat mijn gemiddelde collega er zich van bewust is op het moment dat hij een extra zeilstof matje uit de kast trekt. Wat voor milieu impact dat heeft.”

GREEN TEAM IC-V

This group is part of the ICU staff, but with a bigger interest and knowledge of the sustainable practices of the ICU. As they, together with management, are responsible for the decisions and sustainable interventions taken, they drive the sustainable change.

4.4. BARRIERS & FACILITATORS TO SUSTAINABLE PRACTICE

Understanding what hinders and what supports sustainable progress in the ICU is important for designing an effective tool to reduce environmental impact. This section presents insights from mainly the interviews, with some contextual observations, organized with the COM-B framework (Capability, Opportunity, Motivation), which provides a structured approach to analysing behavioural factors.

4.4.1. CAPABILITY

It was observed that awareness is a big factor in the capability of the user. More awareness can make people feel capable to act. People mention awareness on a big level, however, on an individual level or small-scale impact is something that is lacking.

“There is just a lot of waste, we can all see that”- Nurse 1

Next to that there is a perceived conflict between sustainability and both the patient care, and the protocols that are in place.

Barrier	Facilitator
Lack of small impact awareness	General awareness about sustainability & waste
Patient care & safety is a priority	Need for an actionable and effective process
Actions guided by protocols & regulations	

Table 1: Capability factors

4.4.2. OPPORTUNITY

When discussing ways data can be used, people really saw big opportunities for transparent & data informed decision making. They did mention that it must be user centric, it is important to avoid extra work and make the process and sustainable change as easy as possible. A barrier that has not been mentioned in literature is the people focus and soft culture that came up in several interviews. This people-centric culture may make it harder to push for something that feels "impersonal", similarly it is a culture that values positive relationships and avoiding direct confrontation.

Barrier	Facilitator
(Too) soft culture with focus on people	Need for user centric change (avoid extra work)
	Need for transparent & data informed decision-making

Table 2: Opportunity factors

4.4.3. MOTIVATION

Activating people's interest is found to be a main facilitator for the participants motivation. “If you can back it up with figures like: we can re-cycle 80% and it really does come back into the cycle and we save so much CO2. Then you really do get people on board, and they want to make an effort.” - PhD
This might be a good way to tackle the human condition that is resistant to change. Another big barrier is the lack of incentive. Activating interest and motivation could therefore best be facilitated with clear management support or incentives, according to the participants.

Barrier	Facilitator
Resistance to change	Activating drive & interest
Lack of incentive	Importance of management support

Table 3: Motivation factors

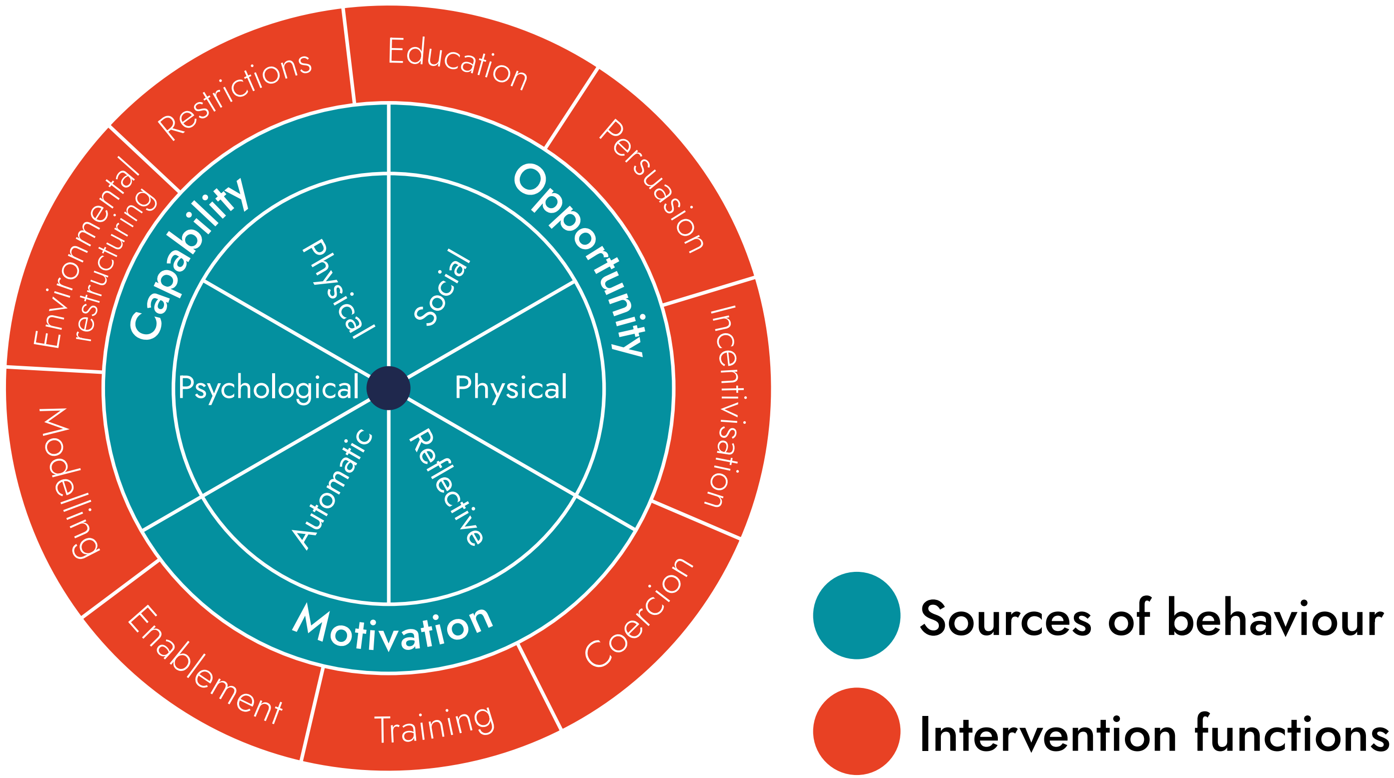


Figure 11: Behaviour Change Wheel

4.4.4. INTEGRATION WITH BEHAVIOUR CHANGE THEORY

The findings from the thematic analysis were mapped to the Behaviour Change Wheel (Figure 9) to identify which intervention functions are suggested to be most effective to guide our design.
Four key intervention functions were identified that could drive sustainable behaviour change in the ICU, each translated into a concrete recommendation.

Education & Persuasion
Address the gap between general and individual awareness by providing clear visualization of individual and collective impact.

Environmental Restructuring
Make sustainable choices more accessible within existing workflows and protocols to minimize disruption to critical care.

Incentivisation
Develop progress tracking and recognition systems that respond to the need for incentives and management support.

Enablement
Create easy-to-follow sustainable alternatives that make environmentally friendly choices the path of least resistance.
These proposed intervention functions can inform the further design brief and development of the tool.

4.5. DATA VISUALIZATION PREFERENCES

As part of understanding user requirements for a data-driven sustainability tool, participants of the interview interacted with various sustainability data visualizations. Four key patterns emerged in how ICU staff interacted with and interpreted the data:

Need for contextual information
Participants consistently asked questions about the context of the data, emphasizing their need for supporting information to make sense of the visualisations

Preference for specific over general
Individual product data had a higher engagement than category-level visualisations.

Confirmation or challenge
Participants used the data either to confirm their knowledge or to challenge their assumptions, always relating it to the context as they thought it to be.

Varied interpretations
Different interpretations were made for the same data patterns - for example, increased disposable jacket usage in the winter was attributed to both flu season by one participant and cold temperatures by another.

These insights can have direct implications for the design of any data-driven sustainability tool, particularly regarding the level of detail and contextual information provided.

4.6 DISCUSSION AND IMPLICATIONS

This research investigated sustainability practices and user requirements at the Erasmus MC ICU, revealing insights that address our two research questions.

SQ1: "What are the current environmental sustainability practices and data utilization in the Erasmus MC ICU?"

The ICU currently relies on targeted interventions led by the Green Team following a four-step workflow (Identify, Set Goal, Motivate, Act), with recent initiatives including paracetamol IV reduction and decreasing glove use. However, while sophisticated data systems (HiX and ICU Maps) support clinical care, there is no systematic sustainability data collection or monitoring. Environmental interventions often rely on manually gathered baseline data and intuitive decision-making.

SQ2: "What are the key user requirements and considerations for a data-driven sustainability tool in the Erasmus MC ICU?"

Two distinct user groups emerged with different needs: the specialized Green Team requires detailed analytics for intervention management, while general ICU staff need simple, actionable insights that don't compete with patient care priorities. Key requirements for a sustainability tool include: seamless integration with clinical workflows, interfaces tailored to different user groups, product-level specificity rather than broad categories, sufficient contextual information for data interpretation, respect for clinical priorities, and sensitivity to the ICU's people-focused culture.

The research confirms several patterns from existing literature, including the prioritization of patient care over sustainability and the importance of management support. However, it also revealed new insights specific to this context: a "soft" people-focused culture that may resist impersonal data-driven approaches, tension between medical protocols and sustainability efforts, and a gap between general environmental awareness and understanding of individual actions' impact.

The behaviour change analysis suggests interventions should focus on education (addressing awareness gaps), environmental restructuring (workflow integration), incentivization (progress tracking), and enablement (simplifying sustainable choices).

These insights, together with the insights from the next chapter, will inform the design brief and solution exploration, for other use they might be informative, but benefit from validation across different ICUs and more diverse participants in future research.

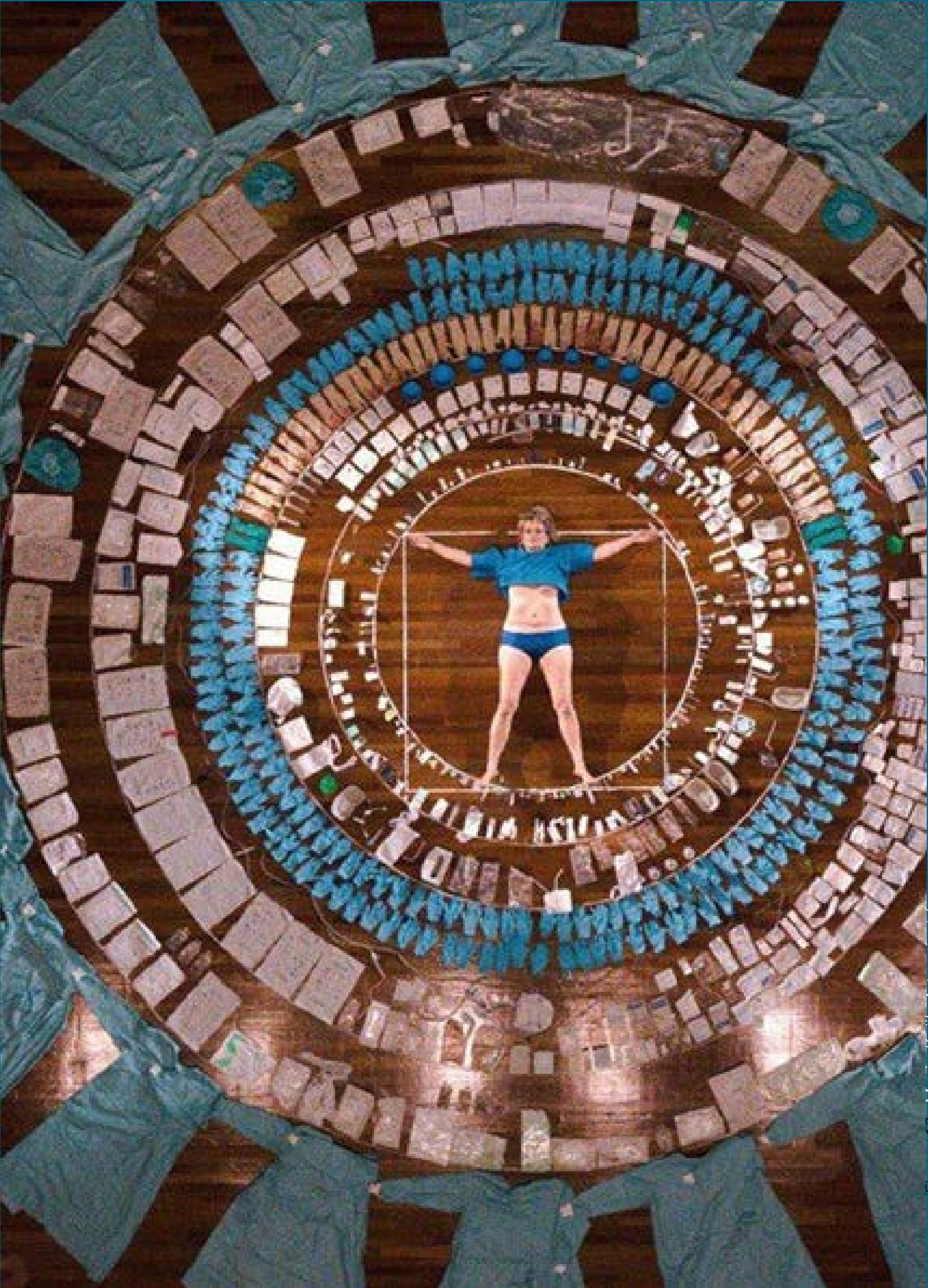


Figure 12: Maria Koijk, Artproject from

4.7. KEY TAKE-AWAYS

- There are two user groups with different needs: The Green Team requires detailed analytics for intervention management, while general ICU staff needs simple, actionable insights for daily decisions.
- The Green Team has established a four-step workflow (identify, set goals, motivate, act), but struggles with fragmented data and manual calculations.
- Staff insights reveal that sustainability efforts must work within clinical priorities & protocols and could focus on the limited awareness of small-scale impacts. Implementation needs to account for the ICU's people focussed culture.
- Implementation should include that any solution must integrate with existing systems (e.g. HiX or ICU Maps), and support the Green Team's workflow while minimizing disruption to clinical processes.
- Effective interventions should address awareness gaps, integrate with workflows, provide progress tracking, and make sustainable choices easier than unsustainable alternatives.

5. Data Discovery:
Environmental impact data & infrastructure

To design an effective data-driven decision support tool for reducing environmental impact in the Erasmus MC ICU, it is important to understand the available data and data sources. This chapter addresses SQ3:
“What data sources and infrastructure are available for (automated) sustainability monitoring in the Erasmus MC ICU?”
This chapter focuses on identifying available data sources, assessing their quality, and understanding the technical infrastructure that would support the final solution

5.1 ENVIRONMENTAL IMPACT FRAMEWORK

To be able to identify the right datasets, it is important to first know all potential environmental impact sources add up to the full emission surrounding the ICU patient. Through conversations with the Green Team and DataHub we mapped ten distinct emission sources that contribute to the ICU's environmental footprint:

- Medical Products.
- Medication
- Laboratory Tests
- Transport Patient
- Radiology Research
- Energy Use
- Cloud & Computing
- Medical Devices
- Commuting ICU Employees
- Food

All sources are mapped out around the ICU patient in Figure 10. This visual framework illustrates the complex environmental impact landscape. This framework served as a foundation for the data assessment, allowing us to systematically evaluate data availability across all environmental impact sources.

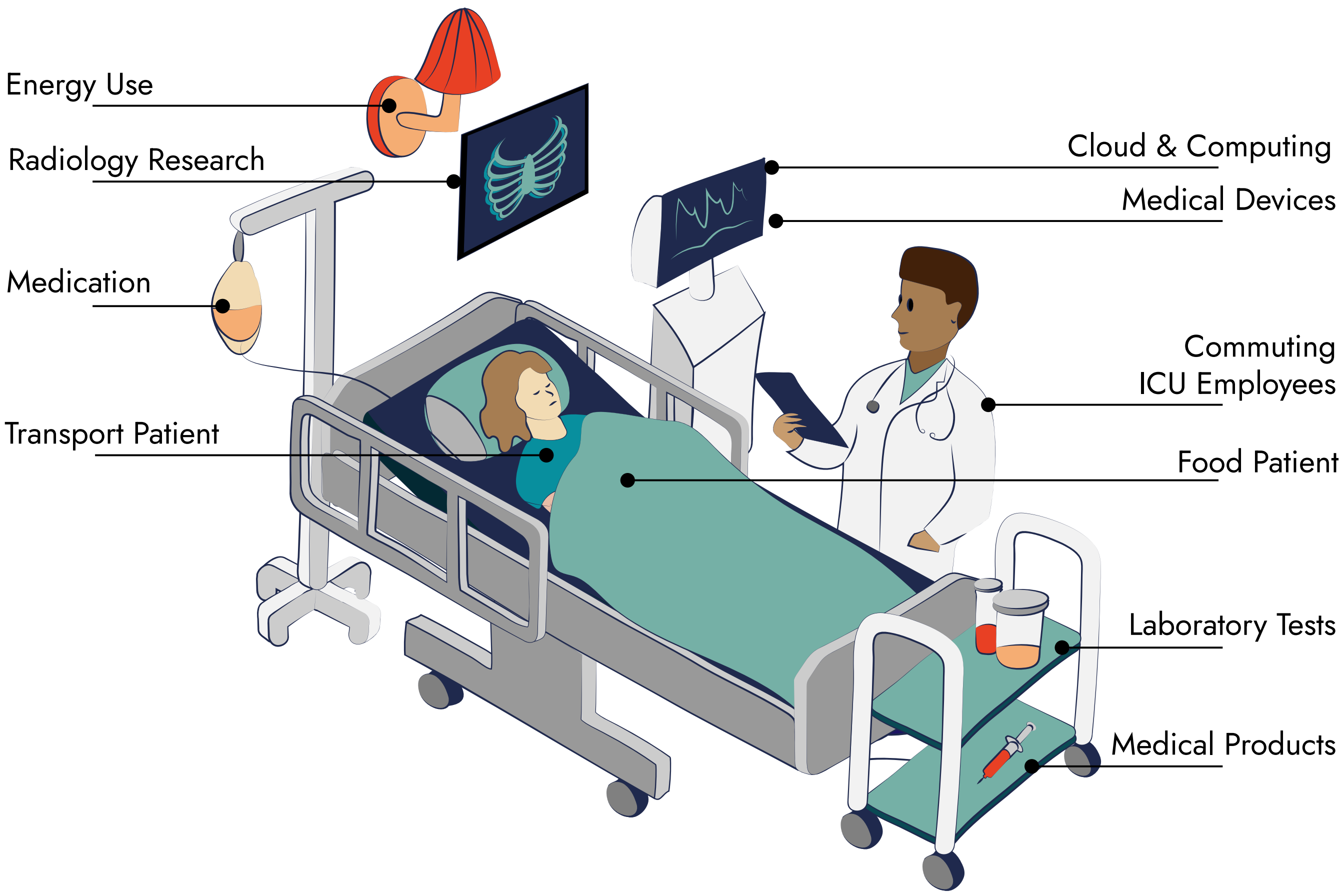


Figure 13:: Environmental impact sources around ICU patient

5.2 DATA AVAILABILITY, STRUCTURE AND QUALITY

Using the environmental impact framework as a guide, an overview was made of all available datasets.

5.2.1. DATA STRUCTURE

The analysis identified three different categories of data variables needed for sustainable monitoring:

1. **Usage Data:**
   Base measurements of consumption with variables like 'Amount Ordered', or 'Consumption levels'. These provide base measurements and are captured in units like [n], [mL], [kWh] & [kg].
2. **Emission Factors:**
   Factors needed to convert the usage data into environmental impact metrics. These are variables like CO2 equivalents [kg-CO_2-eq/kg], Water- [m^3/kg] or Land use [m^2/kg].
3. **Contextual Data:**
   Temporal variables (timestamps) and categorical information (product categories or device types) provide the necessary context for analysing patterns and meaningful interpretations.

By combining these three variables, standardized comparisons can be made for example across time or between different products.

5.2.2. DATASETS OVERVIEW

In Table 4 key datasets and their most important variables are shown for two of the Emission sources; Medical Products and Medication along with their descriptions, key variables, units of measurement, data sources, and the frequency of data collection. For the other emission sources see Appendix D. The Emission sources are ordered by completeness, from most complete (Medical Products) to no data currently available at all (Patient transport). We can clearly see that there is not enough data to give a good emission sum of the total. However, for some of the emission sources there is enough data to create insights into environmental impact and identify areas for improvement. This is the case for medical products, and energy consumption where there are both usage data and emission factors available. In terms of n * kg and therefore kg waste. Medication is also an interesting emission source to consider as there is data on both the prescribed amounts in kg, as well as the packaging waste in numbers and kilograms.

Source of Emission	Description	Key Variables	Unit	Source data-set(s)	Frequency of Data Collection
Medical products	Emissions & purchase data from medical products	Product Name, Category, Amount Ordered	[n]	Inventory purchasing dataset (query)	Monthly
		Mass, Emission Factor (per Category)	[kg] [kg-CO2-eq / kg]	2019 Material flow analysis (N. Hunfeld et al., 2022)	Manual
		Mass	[kg]	Manual Weighing	Manual
		Emission factor	[kg-CO2-eq / kg]	LCA Sources	-
MEDICATION	Emissions & waste data from medication production and use	Medication Type, time, patient, Amount prescribed	[mL], [mL/h]. [mg], [nr]	Electronic Health Record (HiX)	Live
		Medication Mass, packaging Mass	[kg]	Research done by PhD cand. (not published yet)	-

Table 4: Dataset overview (selection: Medical Products & Medication

5.2.3. DATA QUALITY AND LIMITATIONS

The analysis of available data revealed some limitations and quality considerations:
Completeness gaps: For several emission sources (particularly Patient Transport and Food), data is entirely missing or too fragmented for meaningful analysis.
Standardization challenges: Limited standardization of emission factors across sources makes comparative analysis difficult.
Collection methods: Some metrics require manual data collection (e.g., product weighing), creating potential for inconsistency and limiting scalability.
Time lag: Most data is available monthly rather than in real-time, creating delays in impact assessment.
Processing requirements: Some datasets require significant processing before they can be meaningfully analysed.

5.2.4. EXPERIMENTAL VISUALISATION

To get some visual understanding of what these datasets can show us, a few visualisations were made, for example in figure 10 the top 10 most used medical product categories per patient day is plotted. Here you can see that per patient day in 2023, 91 gloves were used.

Further visualisations can be found in Appendix A, developed for the data interaction part of the interviews in Chapter 4.

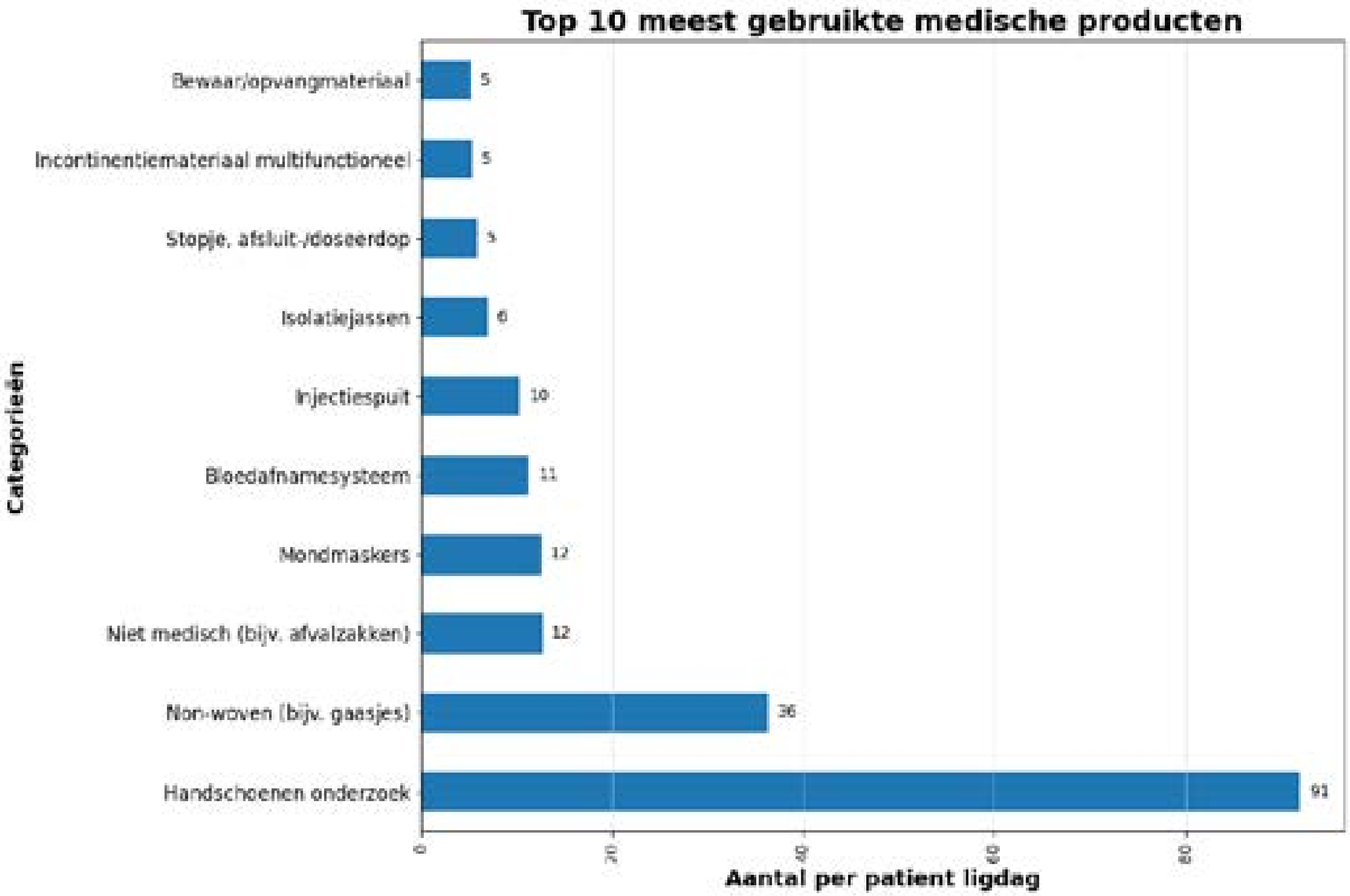


Figure 14: Most used medical product categories per patient day in 2023

5.3 TECHNICAL INFRASTRUCTURE

Understanding the technical infrastructure at Erasmus MC is important for designing, processing and implementing a data-driven tool. This section looks at the existing data systems and flow processes that can support this.

SOURCE

HiX (Chipsoft) is the electronic health record system that captures patient-related clinical data, including medication administration and medical procedures

Oracle Purchasing System manages the procurement data for medical products and materials for the whole Erasmus MC

Environmental data: Research-based impact factors and manually collected measurement.

DATA PROCESSING

Health Data Platform (HDP) extracts data from source systems (e.g. HiX, lab data and others) within Erasmus MC and models this data to international standards before publication to other secure systems.

SQL Server Management Studio (SSMS) is a development environment where database queries are written and executed to retrieve and manipulate data from the Health Data Platform.

Azure DevOps is a development tool manages the version control and deployment of code used for data processing and analysis in the infrastructure.

SAS Viya is the analytics platform that combines SAS Visual Studio for analytics and dashboard creation and SAS Server for keeping the dashboard live to end users (the DataHub often also uses SAS for running models).

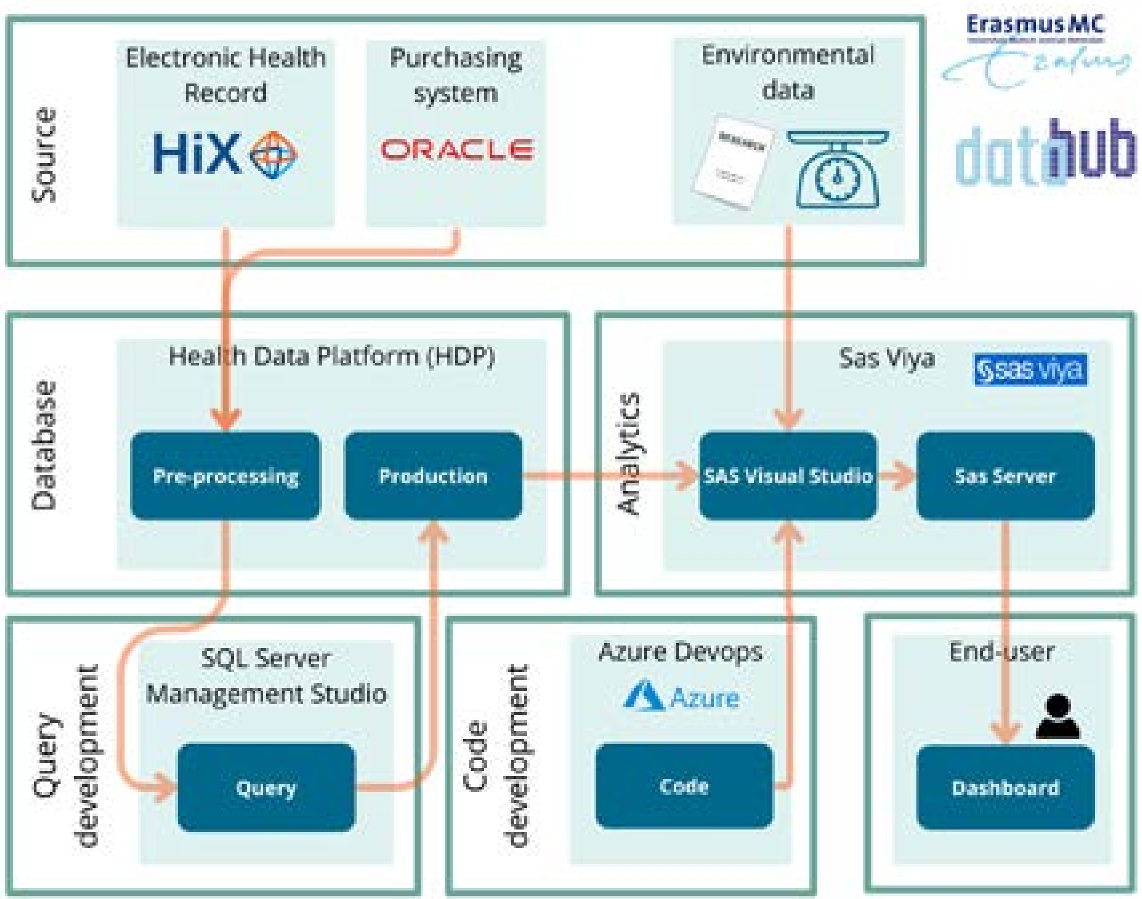


Figure 15: Data Infrastructure Erasmus MC & DataHub

Figure 12 illustrates the dataflow from source through processing to a data-driven tool for the end-user. Two source systems (HiX and Oracle) feed the HDP, which preprocesses this data to fit certain standards. It is worth noting that inventory data has only been available in this system since September 2024, and is thus only recently available for processing.
To extract the right data from the HDP a query needs to be developed, this is done by a combination of the researcher/developer and the HDP-team. In this case my colleagues from the DataHub helped me with this. With a query, data can be accessed in a different environment, in this case SAS Viya. With additional input of non-Erasmus MC specific environmental data as well as some code that translates the query generated data into a format that SAS Viya can work with, we have all the input needed to create a data-driven tool or dashboard which is then put live at the SAS Server and can be accessed by the end-user.

5.3.2. TECHNICAL INTEGRATION CHALLENGES

Through collaboration with DataHub engineers, several key technical challenges were identified that can affect sustainability data integration:
Data integration mapping: Combining procurement and environmental data requires collaboration across multiple systems
Security requirements: Healthcare data is surrounded by privacy regulations and access restrictions.
External data integration: Environmental impact factors from external sources must be manually updated as they aren't part of standard hospital data flows.

5.4 DISCUSSION

This chapter addressed the third research sub-question "What data sources and infrastructure are available for (automated) sustainability monitoring in the Erasmus MC ICU?"
Our assessment supports prioritizing Medical Products for initial implementation based on three factors: superior data completeness, established infrastructure for access, and alignment with staff awareness (as found in Chapter 4).
This approach allows for focused development while establishing processes that can extend to other emission sources as data improves.
The findings suggest a phased implementation approach, beginning with medical products, then expanding to energy consumption and medication, and eventually incorporating more challenging sources like laboratory tests and transportation.

The technical infrastructure assessment confirms that the existing DataHub systems can support automated sustainability data collection, though implementation challenges remain in combining clinical, procurement, and environmental data within healthcare's security constraints.
These insights can directly inform the design brief and solution with concrete technical guidelines and limitations.

5.5. KEY TAKE-AWAYS

- Ten emission sources were identified and mapped, creating a framework for assessing sustainability data availability
- Medical Products was found to have the most complete dataset combining both usage metrics (procurement records) and emission factors.
- Data falls into three categories: Usage Data, Emission Factors, and Contextual Data, which together enable meaningful environmental impact analysis.
- The existing DataHub infrastructure provides a foundation for automated data collection through a series of connected systems (Oracle -> HDP -> SAS Viya)
- Some implementation challenges remain, these include data completeness gaps, standardization issues, and the need for manual environmental data updates.

6. Design Brief

This chapter translates the findings from the literature review, problem discovery and data discovery together in one Design Brief for the data-driven sustainability tool for the Erasmus MC ICU. While the research identified 2 user groups with different needs, this brief strategically refocuses on supporting the Green Team as the primary user of the product. Through the Design challenge, Strategic direction and Requirements, this chapter establishes the foundation for developing a decision support dashboard that enables data-driven sustainability decision support.

6.1 DESIGN CHALLENGE

6.1.1. PROBLEM STATEMENT

After the research that has been done, we can present a refined problem statement which is not only built on the initial assignment given by stakeholders but is based on the insights gathered:

The Erasmus MC ICU needs to reduce its environmental footprint to meet its 2030 sustainability targets, but lacks the data insights to effectively measure, monitor, and improve its impact. The current fragmented sustainability data makes it difficult for the Green Team to execute their established workflow of identifying hotspots, setting goals, and implementing interventions. While the research identified two distinct user groups with different needs, this project focuses on the Green Team as the primary user. Due to time constraints it was deemed better to focus on one user group, especially as the needs are quite different. By enabling the Green Team to manage data-driven interventions through transparent sustainability metrics, they can more effectively guide and motivate general ICU staff toward sustainable practices, while ensuring patient care remains the priority.

6.1.2. CORE CHALLENGES

To address the problem statement effectively, three key challenges must be overcome:

Information Integration
Currently, relevant sustainability data is scattered across different departments and systems, requiring manual collection and calculation. This fragmentation makes it difficult for the Green Team to identify environmental hotspots, set realistic goals, and measure intervention success. As one Green Team member noted during interviews:
"We spend more time gathering data than acting on it."

Clinical-Sustainability Balance
Any solution must operate within an intensive care medical environment, where strict protocols and patient care are the absolute priorities. The research revealed a perceived conflict between sustainability initiatives and clinical requirements, particularly around infection prevention practices and disposable products. The Green Team needs data tools that acknowledge and work within these clinical constraints.

Data-Driven Decision Making
While the Green Team has established a workflow for sustainability interventions, they currently rely heavily on intuition and limited manual measurements rather than comprehensive data analysis. Improving their capability to make evidence-based decisions requires not just data access, but also meaningful visualization and context that supports their intervention planning process.

6.1.3 DESIGN OPPORTUNITIES

The research guides us toward the following design opportunities:

Enhanced Green Team Workflow
The Green Team's established intervention process (identify, set goals, motivate, and act) provides a framework that can be strengthened through integrated data support. A data-driven tool that aligns with this workflow can transform sustainability management from intuitive to evidence-based.

System Integration
Building on existing Erasmus MC data infrastructure (HiX, Oracle, and SAS Viya) provides an opportunity to automate data collection that currently requires manual effort, allowing the Green Team to focus on analysis and action rather than data gathering.

Data-Driven Communication
Findings from the research done, showed that transparent metrics and product-level data visualization can effectively engage staff in conversations about sustainability. By equipping the Green Team with clear, contextual data visualizations, they can more effectively communicate interventions and progress to general ICU staff. These opportunities directly address the challenges identified in this research. Figure 16 illustrates how each design opportunity connects to specific challenges in the ICU sustainability context. Ensuring that the design direction is purposefully aligned with solving the core problems faced by the Green Team in their sustainability efforts.

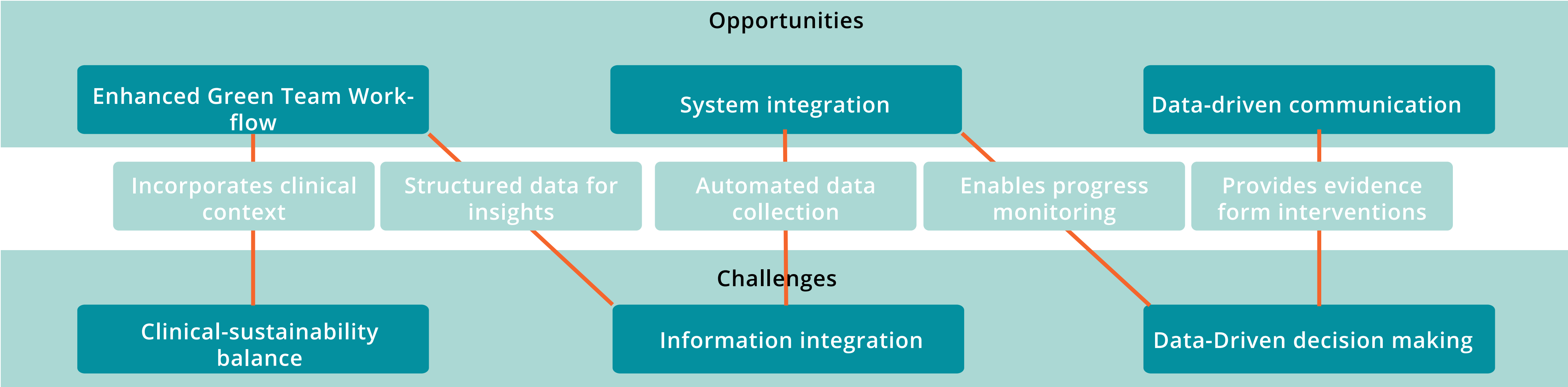


Figure 16: Connection between challenges & opportunities

6.2. DESIGN DIRECTION

Building on the identified Design Challenge, the design direction presents guidance for the data-driven tool through an analogy, product vision and requirements. The design direction primarily focuses on the Green Team as the identified main user, but will

6.2.1. THE FOOTBALL TEAM

To better understand the role of the Green Team and their relationship to the product's functionality, and the ICU staff, and analogy can be useful. In this project, the main stakeholders and their interactions can be compared to that of a football team and its coach, see Figure 17.

The coach
The coach oversees the bigger picture. They analyse the past performance, review the data of their team and develop a gameplan to improve team performance. Similarly, the Green Team uses sustainability data to identify areas for improvement and create focussed campaigns to drive change, following their workflow from analysis to implementation. The green team provide the direction and insights needed for the general ICU staff to perform effectively.

The players
The football players are the ones that are actively playing on the field, taking actions that directly impact the outcome. Their combined efforts lead to success. Like players who need a clear gameplan and coaching support, ICU staff need guidance to understand how their actions contribute to sustainability goals. By focusing on one key change at a time, they can work together toward meaningful progress.

This analogy illustrates that by empowering coaches with better information and planning tools, players receive more effective guidance and feedback, ultimately improving team performance.

6.2.2. VISION

Based on the analogy and research findings, the vision for the users, the function of and interaction with the product is outlined.
Green Team
"Facilitating a moment of reflection, acknowledging the team's progress, and looking ahead to build the next winning strategy. Like a football coach, the Green Team uses data insights to identify key areas for improvement, and guide the ICU staff toward impactful, focused actions for a more sustainable future."

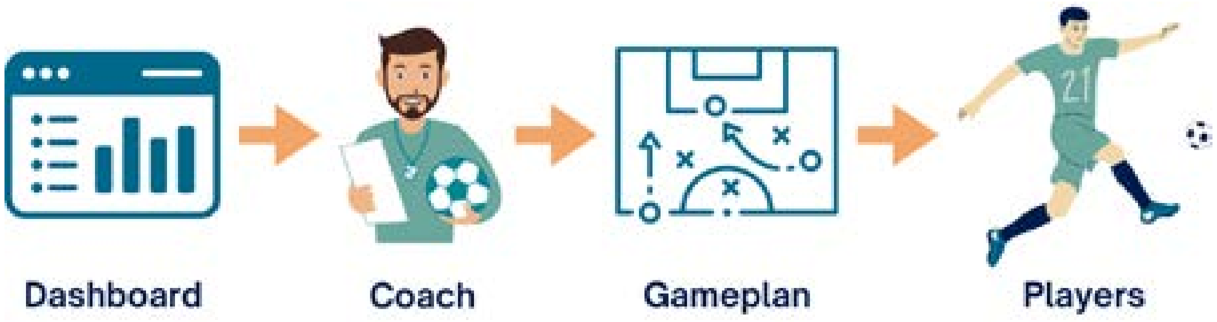


Figure 17: The Football team interaction analogy

All findings from our research can be summarized in these two user personas shown in Figure 14, with the dashboard solution focusing primarily on the Green Team IC-V. The clear distinction between these groups' needs reflects the different roles they play in sustainability initiatives. Understanding both perspectives ensures the dashboard effectively supports the Green Team while remaining mindful of how their decisions impact frontline staff.

6.2.3. TARGET USERS

Product
The football team analogy translates into two key product components that have different but complementary roles:

- The dashboard:
  Designed for the green team, the dashboard provides reliable, data driven insights throughout all the steps they take. It helps to identify sustainability hotspots, monitor progress and focus interventions on where there is most to win in environmental reduction on the ICU.
- A campaign:
  The research also revealed potential for campaign format, based on the dashboard insights they wish to focus on, that communicates one specific area for improvement to the ICU staff. This ensures actionable and motivating communication and creates a positive sense of teamwork and progress.

This campaign aspect, while valuable, is identified as a future development opportunity beyond the scope of the current implementation.

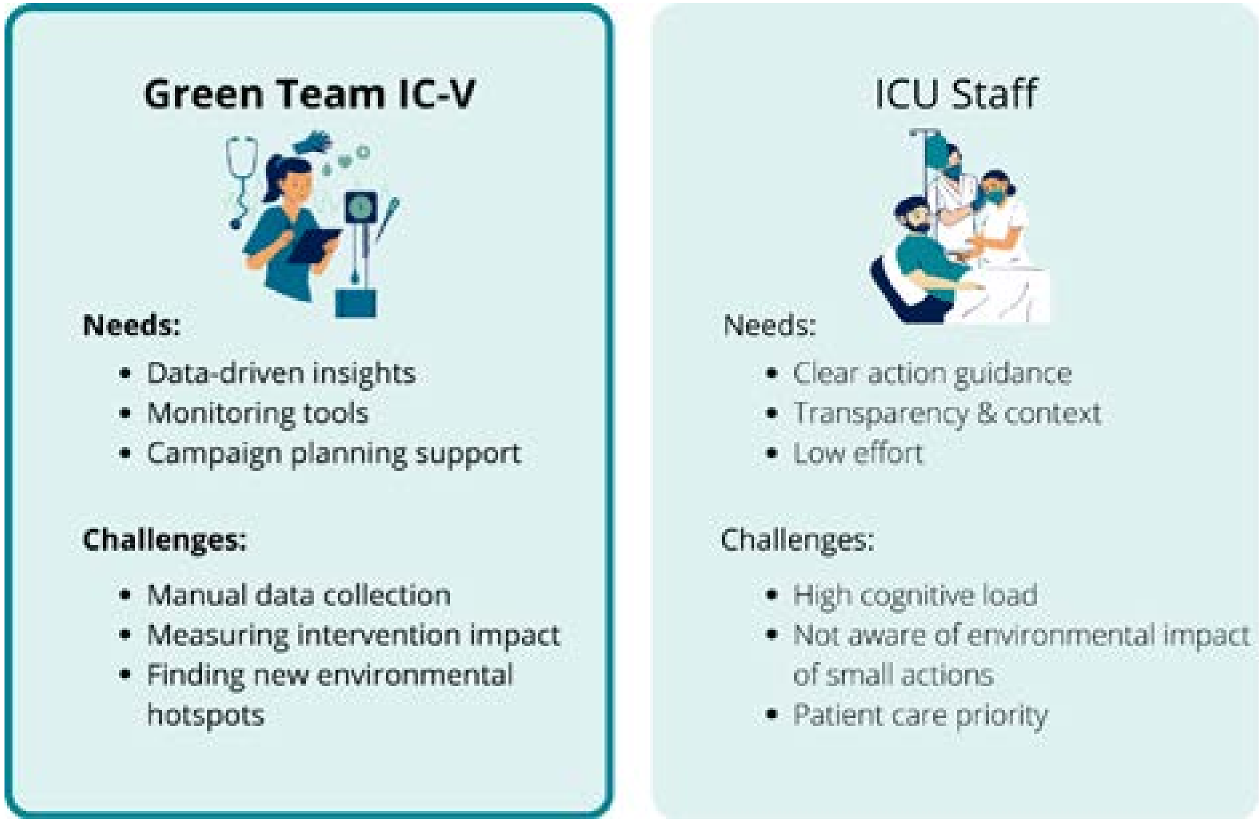


Figure 18:Target users with needs and challenges

6.3 REQUIREMENTS

Building on the design goal and research insights, this section outlines a list of design requirements that will serve as guidelines for the design and evaluation of both the dashboard and the derived campaign.

The requirements have been verified with both the client and the end-user and with their input altered and put in the correct order, from most to least important. The requirements are organized in:

- Functional
  Outlines what the product does and which user needs it adresses
- Technical
  Describes how the infrastructure and capabilities need to function.
- Operational
  Deals with the usability, training and real-world application, making it human-centric.

The following requirements have been reviewed and supplemented by the Green Team and its manager. The requirements in bold are the most important in their view.

6.3.1. DASHBOARD

FUNCTIONAL

1. **The dashboard must reveal environmental impact hotspots for improvement.**

Justification: Problem Discovery revealed the Green Team spends significant time identifying where to focus sustainability efforts. Data analysis showed medical products as the most complete dataset to begin with.
Validation metric: Green Team members can identify top 5 environmental impact categories in 10 seconds.

2. **The dashboard must enable goal-setting and target tracking for interventions**

Justification: Observations of the Green Team workflow showed they establish reduction targets but are not able to track progress without consistent metrics.
Validation metric: The system allows setting numerical reduction targets and visualizes progress against these targets.

3. The dashboard must support filtering and sorting of data by different parameters (product type, department, time period)

Justification: Interviews revealed the need for contextual understanding of data, including temporal patterns and product-specific details.
Validation metric: Users can successfully filter by at least three parameters (time period, product category, and department).

TECHNICAL

1. **The system must provide transparency by giving the source of data and explaining the calculations made, enabling quality checks & comparisons**.

Justification: Literature review identified trust in data as crucial for adoption, and interviews confirmed users need to understand data origins.
Validation metric: All visualizations include data source citations and calculation explanations accessible within one click.

2. The system must integrate with the Erasmus MC Data infrastructure data retrieval and connection with existing monitoring systems;

Justification: Data Discovery identified existing hospital systems (HiX, Oracle) as potential automated data sources through the Health Data Platform.
Validation metric: Data retrieval process functions through established infrastructure without requiring manual export/import steps.

3. The tool must support access to Green Team members, for updating the manual retrieved data (e.g. product weight or emission factors).

Justification: Data quality assessment revealed gaps in emission factors that require regular updates as new information becomes available.
Validation metric: Green Team members can update product weights and emission factors on a quarterly basis.

4. The tool must be compliant with data privacy and information security policies.

Justification: Hospital context requires adherence to strict data governance standards.
Validation metric: Solution passes the DataHub's security review process.

OPERATIONAL

1. The tool must be intuitive to use and view for Green Team members, requiring minimal training to operate.

Justification: Observations revealed time constraints and competing priorities among Green Team members.
Validation metric: New users can complete basic tasks after a short introduction.

2. The tool must fit in the workflow of the ICU Green Team;
Justification: Workflow analysis identified key intervention stages (identify, set goals, motivate, act) that the tool must support.
Validation metric: Tool functionality aligns with and enhances each step of the Green Team's established process.
3. The tool should use simple visualizations and language to ensure sustainability data is easily understood by all users.
Justification: User testing in Problem Discovery showed varied data interpretation skills among stakeholders.
Validation metric: Visualizations follow established data visualization best practices and avoid technical jargon.
4. The tool must support collaborative analysis sessions with medical experts
Justification: Observations showed Green Team decisions involve multiple perspectives, including clinical expertise.
Validation metric: Dashboard can be effectively used during team meetings with multiple viewers

6.3.2. FUTURE DEVELOPMENT: CAMPAIGN

While the initial implementation focuses on the dashboard for the Green Team, the research identified requirements for a potential future campaign component. These requirements are documented to guide subsequent development phases:

- Materials that highlight specific sustainable actions and their measurable impact
- Templates that focus on one intervention area at a time
- Progress feedback mechanisms
- Formats compatible with ICU communication channels
- Designs that respect clinical priorities and minimize cognitive load

These future campaign requirements will be revisited after the dashboard implementation, with potential integration of dashboard data exports into campaign templates.

6.4. KEY TAKEAWAYS

- This Design Brief focuses on supporting the Green Team as the main user of the data-driven tool. Like giving football coaches better analysis tools to improve team performance, we prioritize enhancing the Green Team's capabilities.
- The three main challenges are: combining scattered sustainability data, working within ICU clinical priorities, and supporting the Green Team's process of planning and implementing sustainability initiatives.
- Critical requirements include identifying environmental hotspots, setting and tracking reduction goals, and connecting with existing hospital systems while ensuring data is transparent and easy to understand.
- The design recognizes the dynamic between the Green Team and ICU staff, with potential future development of communication materials to help staff understand and act on interventions.

7. Solution Exploration

This chapter documents the development of a data-driven sustainability dashboard that meets the requirements from the Design Brief. The solution exploration follows an iterative approach that will support the Green Team's established workflow with data access. The chapter progresses from design iterations to technical implementation, communication strategies, and validation through user testing., with each decision connected to the requirements identified.

7.1 DESIGN ITERATIONS

Building on the Design Brief's requirements, this section documents the iterative development of the dashboard solution. The design process focused on creating a tool that serves the Green Team's role as "coach" while integrating into their established workflow.

7.1.1. WORKFLOW INTEGRATION

The first step in the design process was mapping how the dashboard would enhance the Green Team's intervention workflow. Figure 19 illustrates the expanded workflow, showing how each step is supported by dashboard functionality. The enhanced workflow expands the Green Team's current four step process to six steps, adding two critical components:

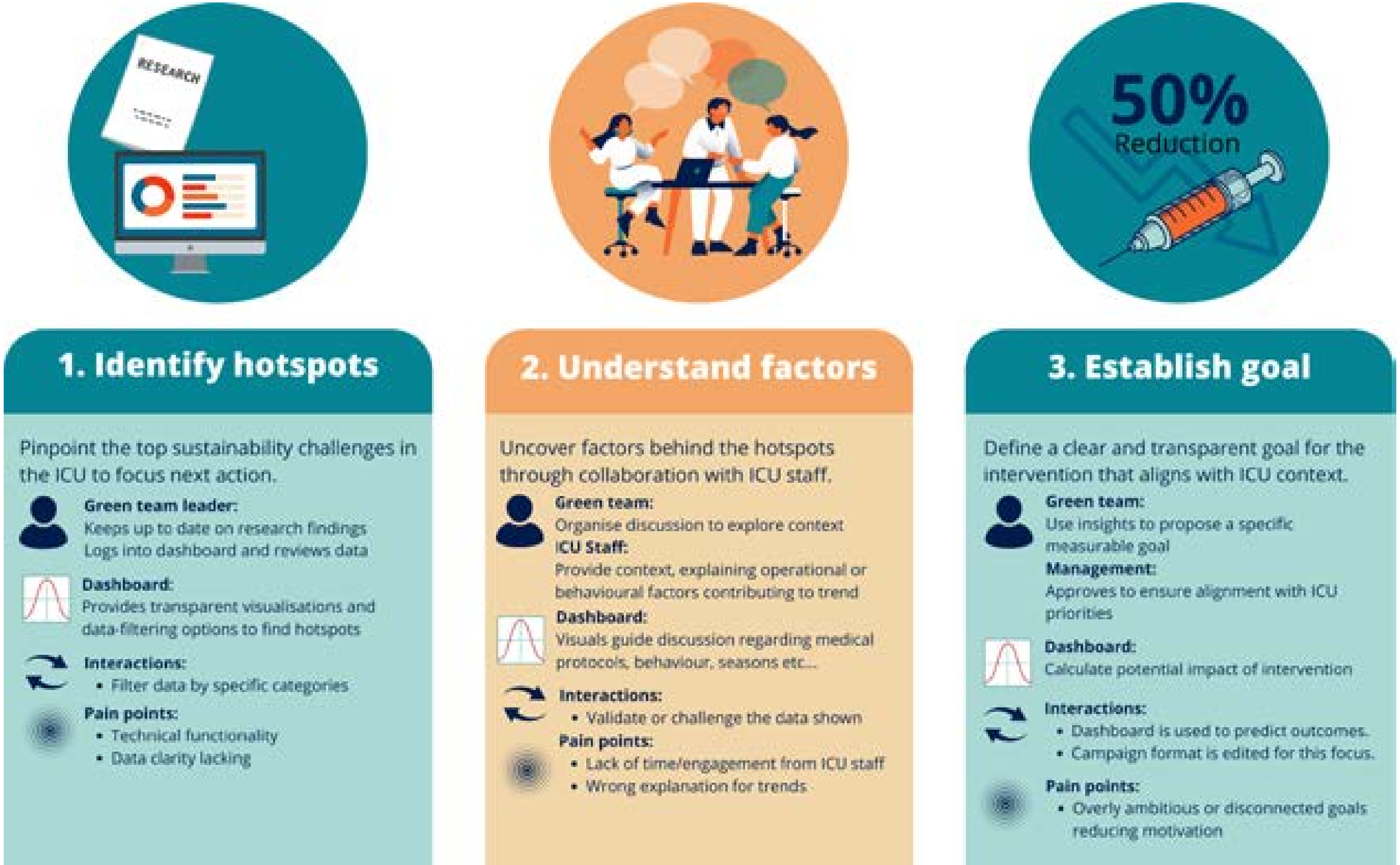


Figure 19: Workflow with dashboard interaction

- Understand factors: Understand factors: Added to provide context and explore the medical implications of potential interventions, ensuring changes respect patient care priorities
- Measure progress: Added to use the available data for tracking outcomes and motivating continued engagement

The dashboard provides continuous data support at each stage, from identifying hotspots through automated data collection to measuring outcomes with standardized metrics.

The visualizations evolve throughout the process—beginning with broad category overviews for initial analysis and transitioning to specific product-level details and progress tracking for implementation. The workflow guides the clear integration points, ensuring that the data insights result in action.

7.1.2. DATA VISUALIZATION DESIGN

To develop effective visualizations for each workflow stage, a systematic evaluation approach was implemented. This process began with the development of approximately 50 different data plots visualizations, which were then assessed using a requirements-based scoring framework.

The best 3 of these visualizations were selected and evaluated with a scoring framework, based on the requirements from Chapter 6:

- Functional Requirements (F): Effectiveness in serving user needs
- Technical Requirements (T): Data clarity and system integration
- Operational Requirements (O): Usability and workflow fit

Each visualization was scored on a 1-5 scale for these categories to determine which plot would be selected for the prototype.

EVALUATION EXAMPLE

The following visualizations were evaluated for the "Identify Hotspots" workflow step:

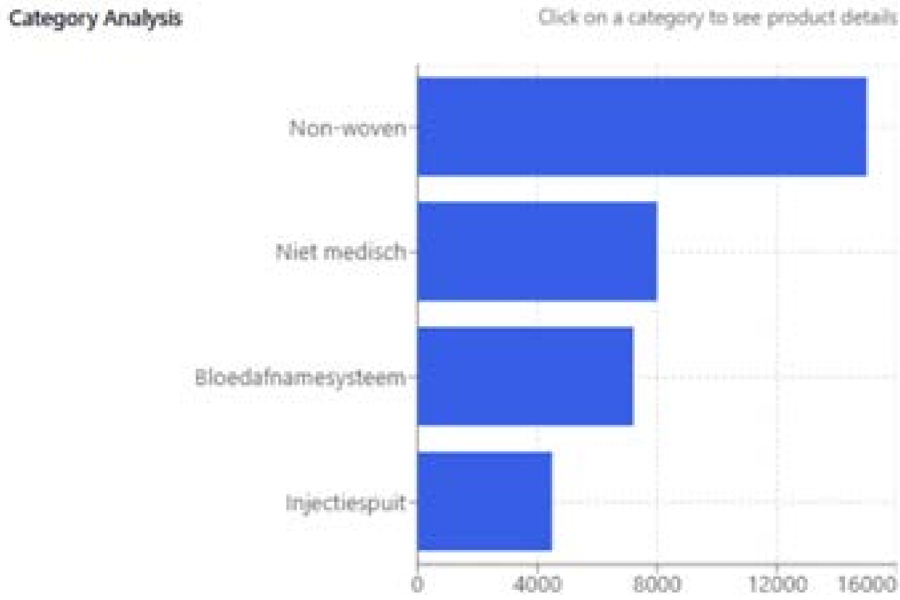


Figure 21: Identify Hotspot lot A

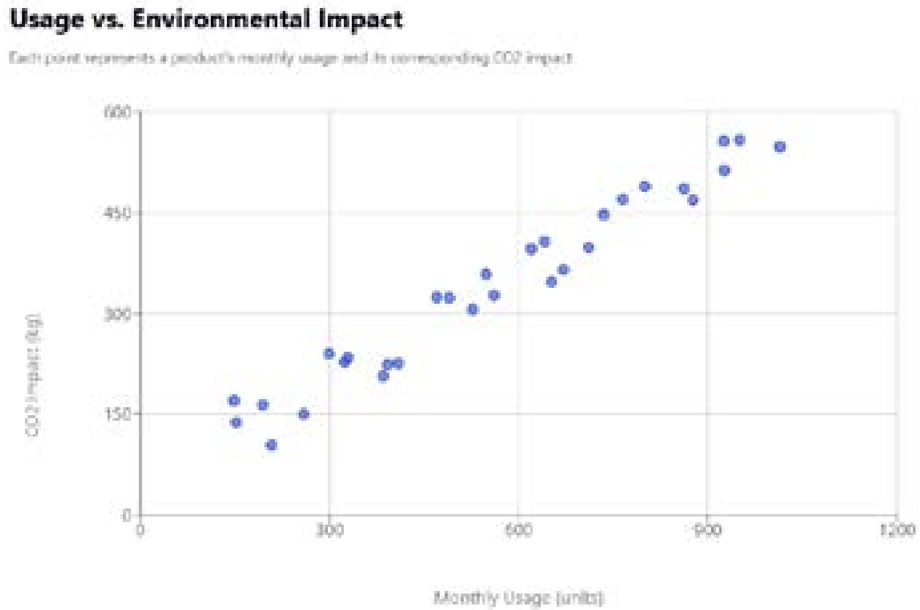


Figure 22: Identify Hotspot lot B

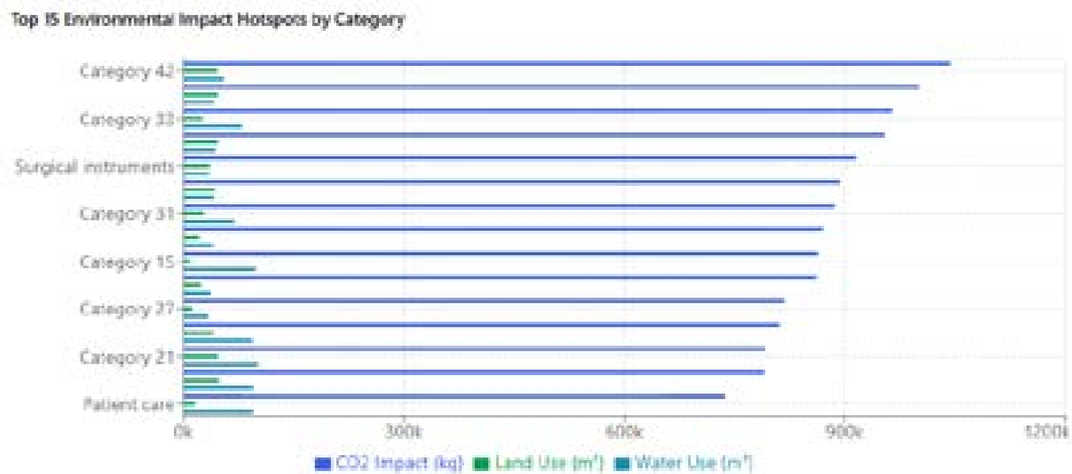


Figure 20: Identify Hotspot lot C

Visualization	F	T	O	Total	Key strength
A	5	4	5	14/15	Clear impact comparison
B	3	4	3	10/15	Temporal patterns
C	4	4	3	11/15	Multiple metrics

Table 5: Hotspot plot evaluation

Visualization A scored highest because of its clear presentation of comparative data, directly supporting requirement F1 'reveal hotspots'. The design allows users to quickly identify the highest-impact categories, with the interactive button element to explore product-level details by clicking on a category bar.
Similar evaluation processes were conducted for visualizations supporting each workflow stage in Appendix E.

7.1.3. FINAL DASHBOARD STRUCTURE

This evaluation process revealed that while the workflow has 6 steps, the data visualization needs could be effectively met with two dashboard views that support the different types of Green Team/Dashboard interactions:

- Analysis & Plan: Deep data exploration during the 'Hotspot Identification' and 'Understand Factors' steps.
- Set & Track Goals: Supporting "Establish Goal" and "Measure Progress" steps.

This simplified approach addresses the need for intuitive use (O1) while still providing the data necessary throughout the workflow.

ANALYSE & PLAN
This view answers the question: "*What are our biggest environmental reduction opportunities, and what drives them?*"

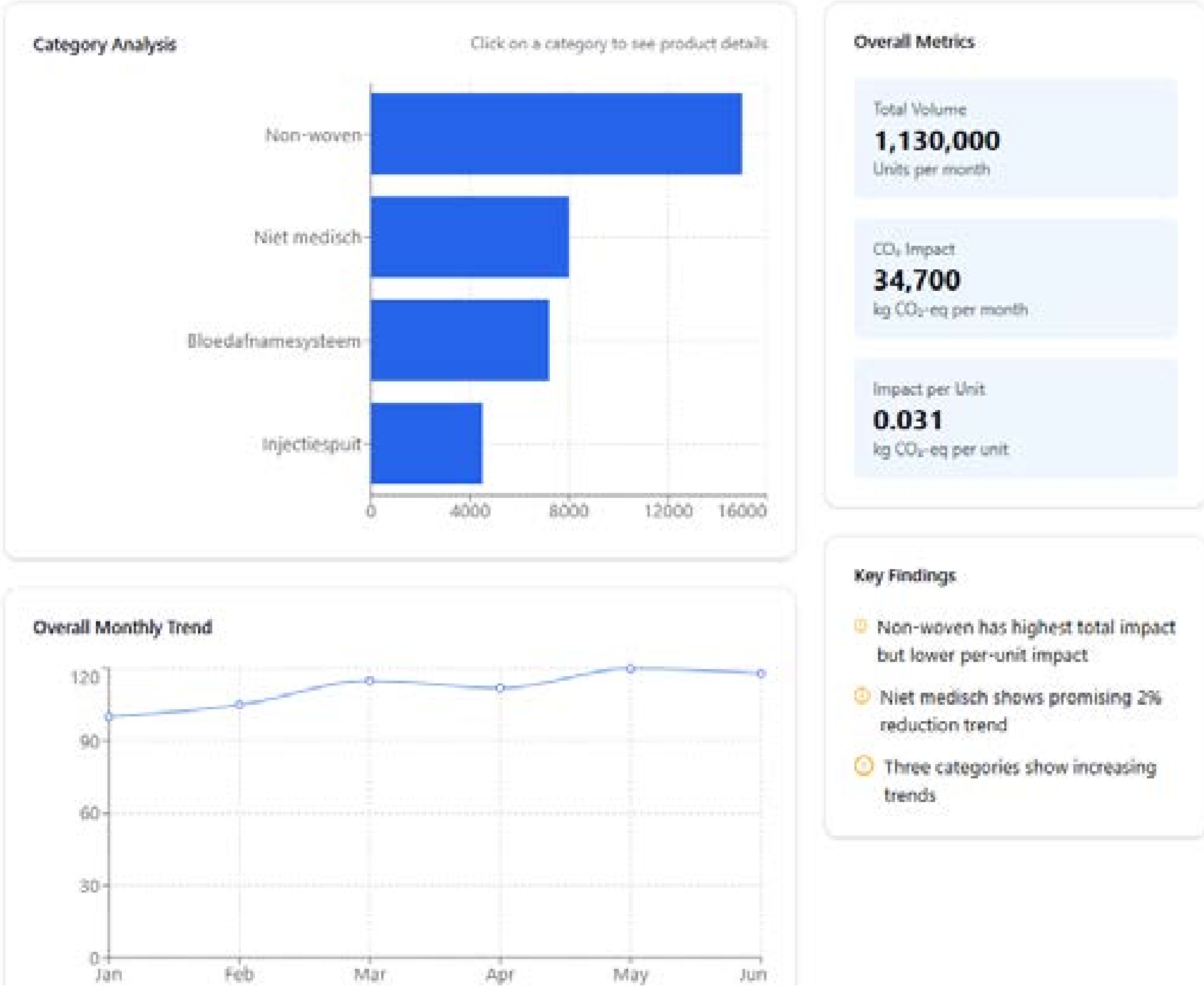


Figure 23: View 1 Dashboard Prototype

Key elements are:
- Category and product impact overview & comparison (Req. F1)
- Usage pattern over time
- Multiple environmental impact indicators
- Interactive filtering and zoom in capabilities (Req. F3)

SET & TRACK GOALS

This view answers the question: "What is a realistic target and how are we doing?"
Key elements are:
- Target setting interface for reduction goals (Req. F2)
- Progress tracking with target path comparison (Req. F2)
- Environmental savings calculations
- Status indicators for goal achievements

The systematic steps made in this section show how design decisions were guided by insights from the research and requirements, resulting in a prototype that is a balance of both functionality and usability. The next section will focus more on the technical side of the prototype.

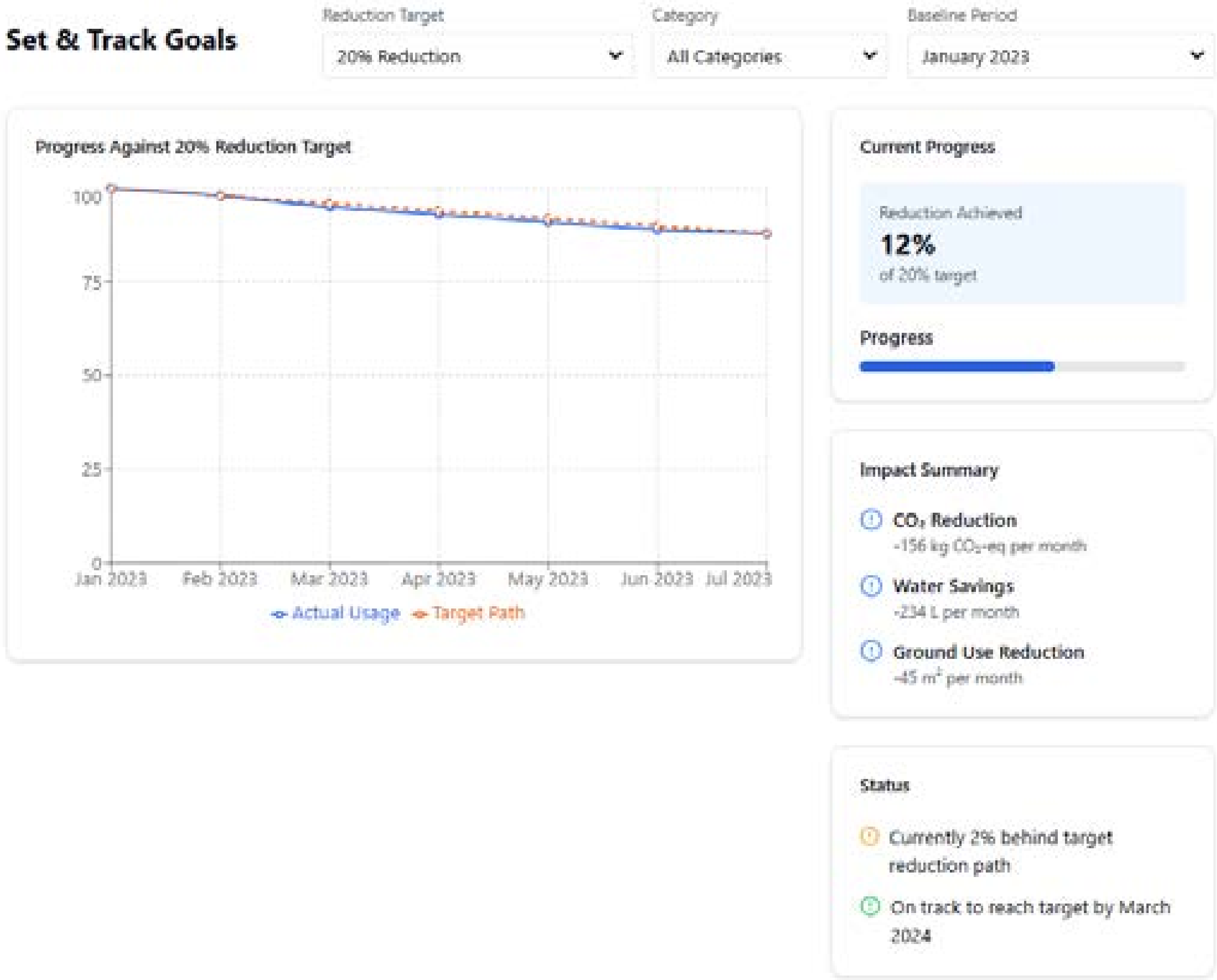


Figure 24: View 2 Dashboard Prototype

7.2 TECHNICAL PROTOTYPE DEVELOPMENT

Several technical decisions were made to ensure the functionality worked well for user testing.

7.2.1. DEVELOPMENT APPROACH

The prototype was developed in SAS Viya Visual Analytics to leverage existing infrastructure and expertise at the DataHub, as explained in chapter 5. This enabled faster development of a functional prototype that could connect to real hospital data sources while meeting security requirements.
The initial prototype focused on implementing the two key dashboard views that emerged from the design process:

- The Analysis & Plan view for exploring environmental impact hotspots
- The Set & Track Goals view for monitoring intervention progress

These views were first made with real procurement data from the ICU for evaluation purposes, initially using .csv files of the year 2023 for fast iteration cycles.

7.2.2. KEY ITERATIONS

The prototype underwent several iterations to address initial technical challenges:

1. **Data preprocessing**
   Significant effort went into transforming procurement data into suitable formats for SAS Viya, for example conversion to long format datasets that could be properly processed.
2. **Standardized metrics**
   Calculations were incorporated within SAS Viya to normalize data (e.g., "usage per patient day"), enabling meaningful comparison across time periods with varying patient volumes
3. **Interactive filtering:**
   Additional filter mechanisms were implemented to allow Green Team members to explore data by different dimensions including time period, product category, and environmental metric
4. **Reduction tracking:**
   A technical solution was developed for the goal tracking feature, using the average monthly usage from the previous year as a baseline to calculate reduction percentages
5. **Clear labelling:**
   Comprehensive titles and explanatory text were added throughout the interface to improve clarity and usability

Each iteration focused on implementing the core requirements identified in the Design Brief while preparing the prototype for user testing.

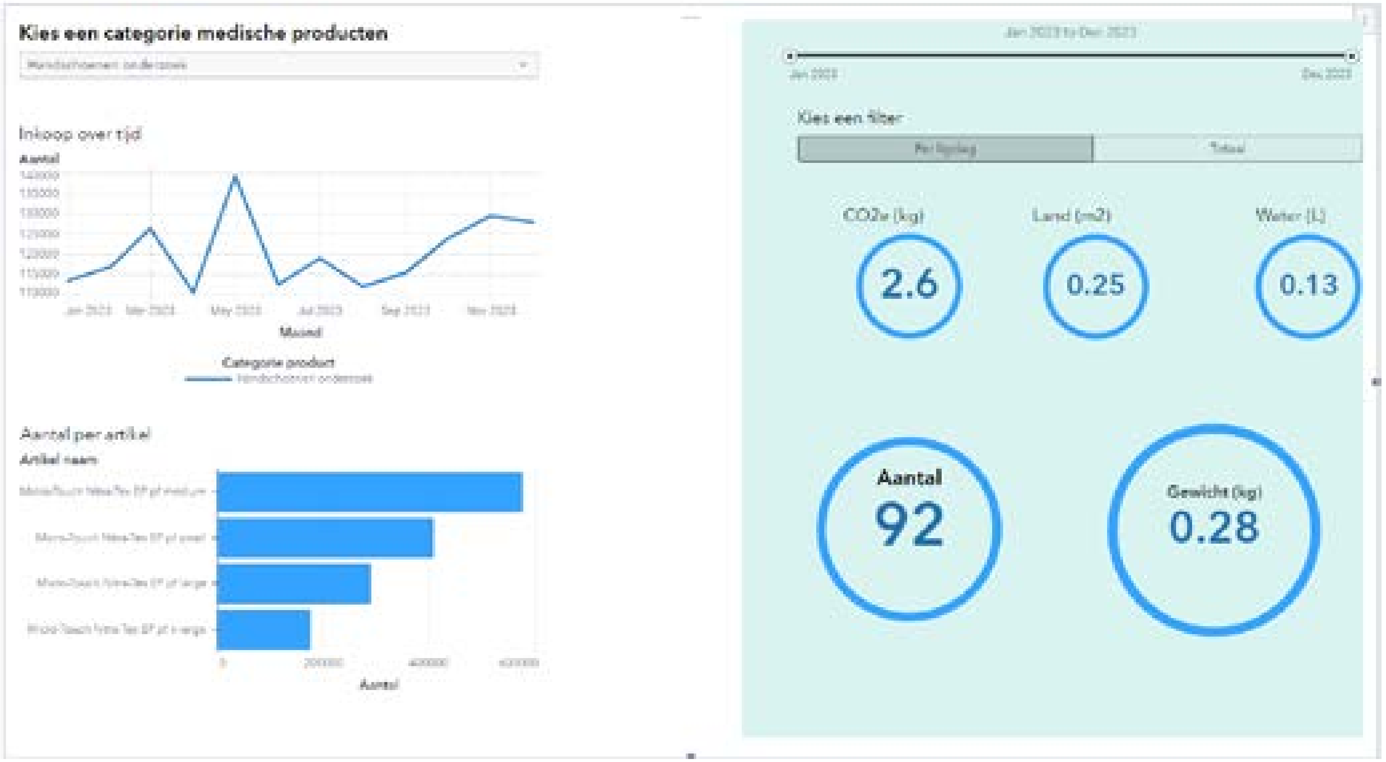


Figure 25: Prototype in SAS Viya

7.3 USER TESTING

7.3.1 TESTING METHODOLOGY

PARTICIPANTS
Testing involved six participants representing different stakeholder perspectives:

- Three Green Team members: one nurse, 2 medical researchers.
- One Green Team leader & pharmasist
- One PhD researcher with sustainability expertise
- One student with experience in Erasmus MC sustainability initiatives

This diverse participant selection ensured representation across different roles, and as the Green Team is not that big, it seemed a good idea to get some external feedback.

7.3.2. TEST STRUCTURE

The evaluation followed a three-part structure:

1. **Contextual introduction**
   Participants were introduced to the Green Team's enhanced six-step workflow as the foundation for the dashboard design, providing context the dashboard
2. **Task-based usability testing**
   Participants completed specific tasks representing typical dashboard use cases, including:
   a. Identifying environmental impact hotspots
   b. Exploring specific product information
   c. Setting and interpreting reduction goals
   d. Analyzing trend data for selected categories

   This portion of the test was designed to identify usability issues and familiarize participants with the dashboard interface.
3. Open feedback discussion Participants were asked open-ended questions about their expectations, perceived usefulness, and desired improvements. This approach encouraged candid feedback beyond the predefined requirements. The test guide can be found in Appendix F

7.3.3.KEY FINDINGS FROM USER TESTS

The testing revealed several important insights about the prototype's effectiveness and areas for improvement. For effective implementation, the insights have been divided in three groups; Errors to fix, User experience improvements and Future enhancements. All feedback is categorized by priority, providing a foundation for an implementation roadmap that addressed both the quicker fixes and longer term opportunities. This roadmap is presented in detail in Chapter 8.

ERRORS TO FIX

- Navigation issue: Unable to return to category view after drilling down into products
- Calculation issues with per-patient day metrics
- Product filters not functioning consistently for every visible metric
- Future year projections needing adjustment in goal tracking view

USER EXPERIENCE IMPROVEMENTS

- Add clear source attribution for all environmental impact factors
- Display number of products within each category (in parentheses)
- Improve time period display (month names instead of numbers)
- Add titles to filter section in view 1
- Set y-axis to start at zero for more accurate visual representation
- Make clearer distinction between procurement data and actual usage
- Add percentage indicators showing an article's proportion of its category total
- Add tooltips for explaining visualization elements

FUTURE ENHANCEMENT OPPORTUNITIES

- Integration with Microsoft Teams environment used by Green Teams
- Year-to-year comparison capabilities in a single view
- Trendlines to smooth procurement fluctuations
- Cost saving calculations alongside environmental metric savings
- Automatic detection of significant trend changes
- Progress notifications and positive feedback when goals are achieved
- Database of sustainability best practices

Figure 26: ICU Nurse at work (Beeldbank EMC)

7.4. KEY TAKEAWAYS

- The solution exploration process resulted in a dashboard prototype with two complementary views that support the Green Team's enhanced six-step workflow.
- The Analysis & Plan view enables identification of environmental hotspots and contextual understanding
- The Set & Track Goals view provides goal setting and progress monitoring capabilities.
- Technical iterations focused on data preprocessing, standardized metrics, and interactive filtering.
- User testing with six participants identified specific improvements across three categories: errors requiring immediate fixes, user experience enhancements, and future development opportunities.
- The testing confirmed that the prototype successfully meets core requirements for environmental hotspot identification, goal setting, and data filtering, while revealing opportunities to enhance data transparency and visualization clarity.

8. Solution: GERDA

This chapter introduces GERDA and it’s components and features, demonstrates the practical application, explains its technical implementation and outlines future development possibilities with a roadmap. Building on research findings, the design brief and design iterations, Gerda addresses the core need of enabling the Green Team to effectively measure, monitor and reduce environmental impact.

8.1. GERDA: THE GREEN ERASMUS DATA ASSISTANT

8.1.1. PRODUCT OVERVIEW

GERDA (Green ERasmus Data Assistant) is a data-driven sustainability dashboard designed to help the ICU Green Team identify environmental hotspots, set reduction targets, and monitor progress.
The name GERDA—an old-fashioned Dutch female name—was chosen to give the tool a personified, assistive character, reinforcing its role as a helpful companion in sustainability work. Building on the football coach analogy from Chapter 6, GERDA equips the Green Team with the data needed to effectively guide ICU staff toward more sustainable practices while integrating seamlessly with existing hospital infrastructure and connecting to procurement data through the Health Data Platform.

8.1.2. KEY FEATURES & COMPONENTS

GERDA consists of two complementary dashboard views, see Figure 27, each supporting different stages of the Green Team's sustainability workflow:

ANALYSIS VIEW ("ONDERZOEK")
The Analysis view, shown in Figure 28, enables environmental hotspot identification and exploration through several key components:

- Product Category Visualization: A horizontal bar chart displays product categories by volume, with examination gloves ("Handschoenen onderzoek") clearly identified as the highest-volume category at nearly 8 million units, followed by face masks and injection equipment.
- Interactive Filtering: Users can filter by product category and time period using the selection controls at the top of the interface, allowing focused analysis of specific areas of interest.
- Usage Trends: A time series graph displays procurement patterns over the selected time (2019-2023), revealing fluctuations in ordering behaviour and potential seasonal patterns.
- Environmental Impact Metrics: Key figures prominently display total product volume, total CO_2 emissions, and per-unit environmental impact providing multiple perspectives on sustainability performance.
- Drill-down Capability: The "klik door voor product details" (click for product details) option allows users to explore specific products within a category, supporting detailed analysis.

GOAL SETTING VIEW ("DOEL & MONITOR")
The Goal Setting view, shown in Figure 29, supports intervention planning and progress tracking:

- Target Configuration: Sliders allow users to set specific reduction targets (shown as 10%) and timeframes (January 2022 to December 2024), establishing measurable goals for sustainability interventions.
- Progress Visualization: The time series graph displays actual usage (blue line) against the target reduction path (yellow dashed line), providing immediate visual feedback on performance relative to goals. The yellow line starting value is the average monthly use of the 12 months before the starting time.
- Product Selection: Dropdown menus enable focusing on specific product categories (with "Mondmaskers" or face masks selected in the example) or individual products, allowing targeted intervention tracking.
- Flexible Time Range: The configurable time period allows for both short-term tactical monitoring and long-term strategic assessment of sustainability initiatives.

Figure 27: Dashboard views 'Analysis' & 'Goal Setting'

Figure 28: Dashboard view 'Analysis'

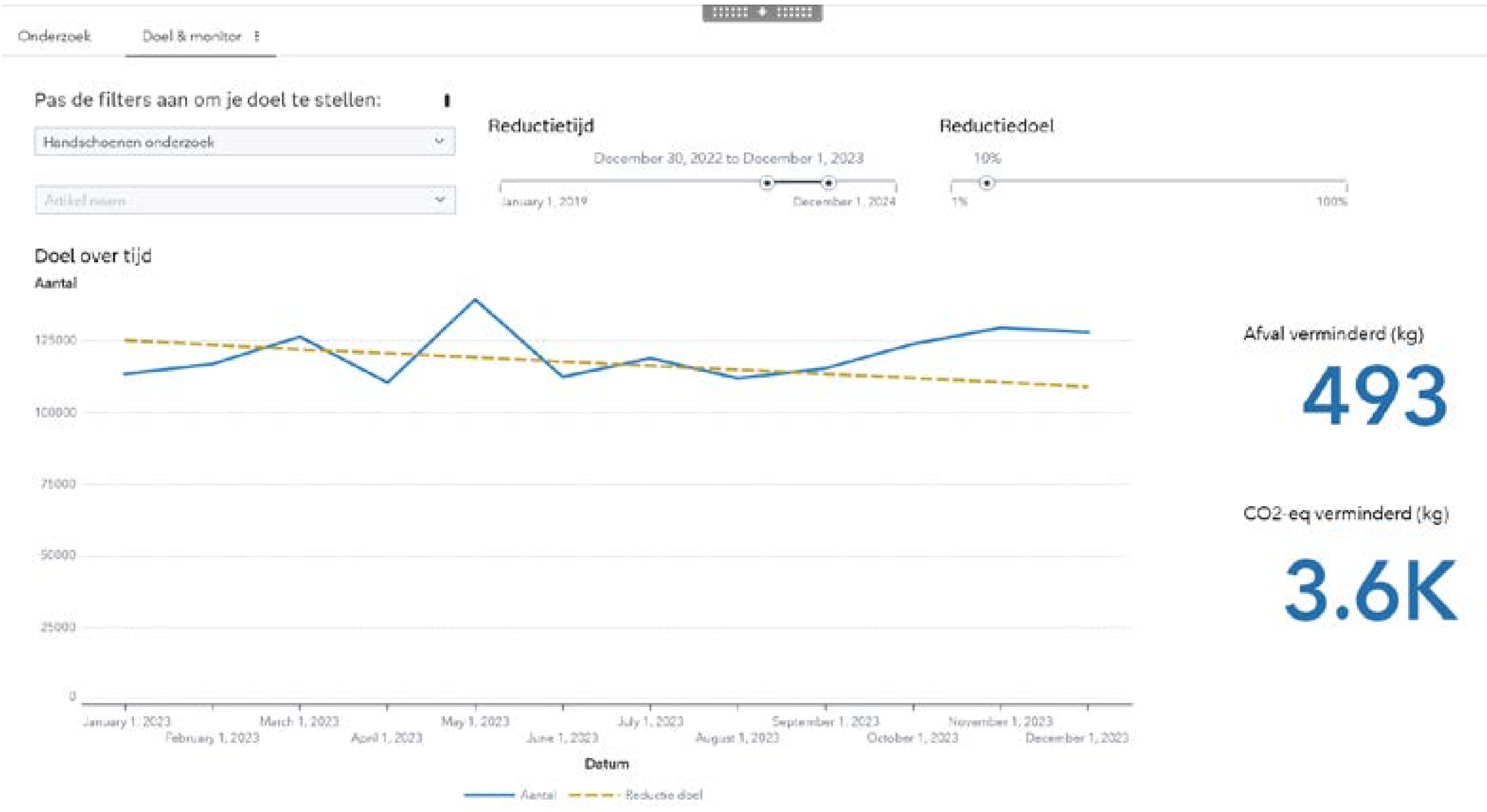


Figure 29: Dashboard view 'Goal Setting'

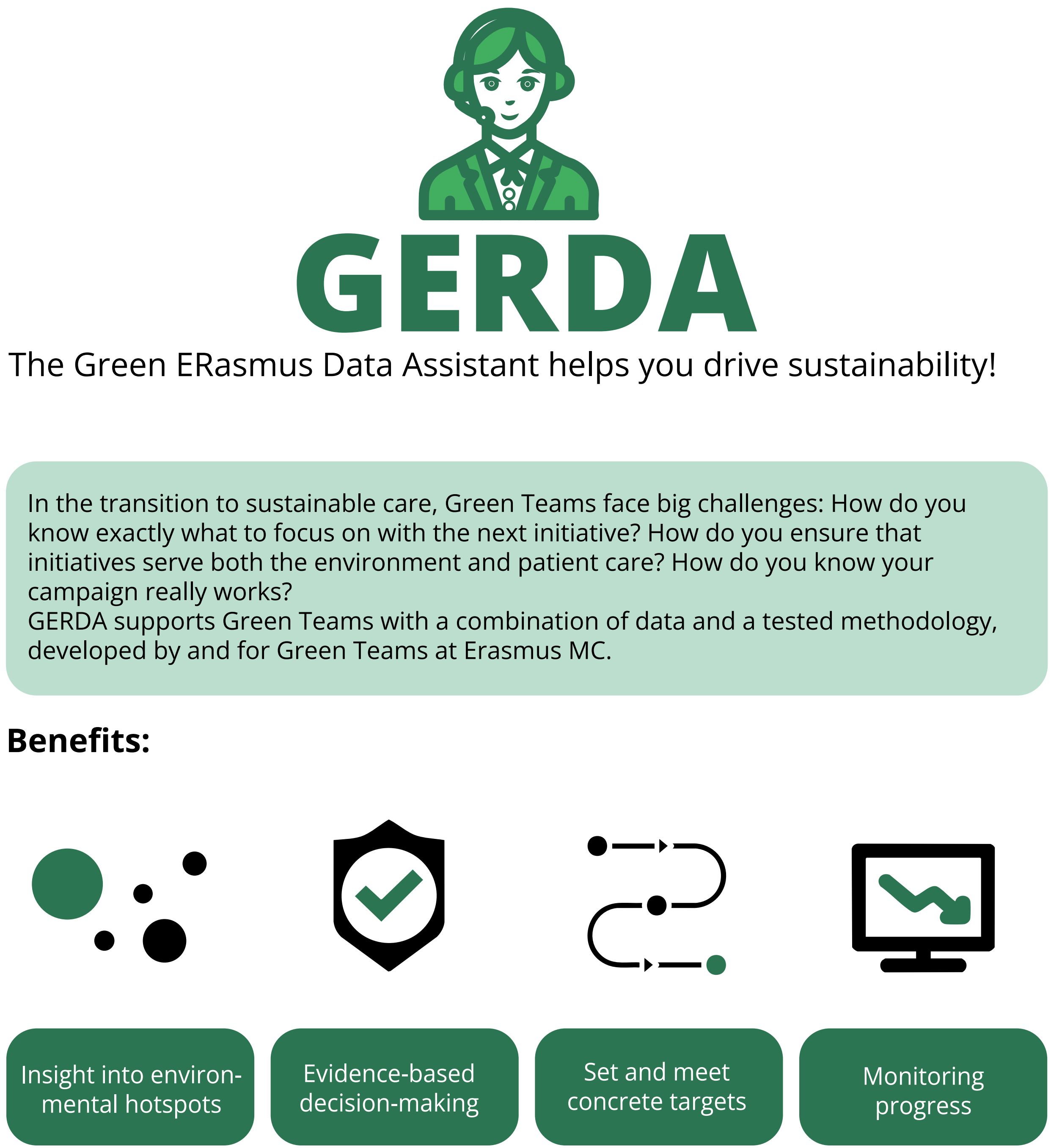
Together, these views support the Green Team throughout their entire workflow—from identifying the most significant environmental impact sources to setting realistic reduction targets and monitoring intervention outcomes. The simple interface design minimizes training requirements, allowing the Green Team to focus on environmental impact reduction rather than dashboard operation.

GERDA's visualization approach follows best practices identified in Chapter 2, balancing information density with clarity and providing context for meaningful interpretation. The design addresses the key user requirements identified in Chapter 4, particularly the need for specific product-level data over general categories and clear contextual information for proper interpretation.

8.2. GERDA IN USE

8.2.1. GREEN TEAM INSTRUCTION

The following instruction guide was developed to support the Green Team in implementing GERDA within their sustainability workflow. This booklet was read by five Green Team members and refined based on their feedback to ensure it accurately represents their way of working and use of terms and language. The illustrated format in demonstrates how GERDA supports each step of the six-stage process, from identifying hotspots to monitoring progress.



GERDA

The Green ERasmus Data Assistant helps you drive sustainability!

In the transition to sustainable care, Green Teams face big challenges: How do you know exactly what to focus on with the next initiative? How do you ensure that initiatives serve both the environment and patient care? How do you know your campaign really works?
GERDA supports Green Teams with a combination of data and a tested methodology, developed by and for Green Teams at Erasmus MC.

Benefits:

Figure 30: Information Booklet for the ICU Green Team

1. Identify hotspots

Nicky, the Green Team manager in the ICU, sits at her computer and reviews the environmental hotspots in her department, the ICU, with GERDA. She has read an article on disposable coats and is now checking the status on her department in preparation for the Green Team meeting.

Working method

- View environmental indicators across product categories
- Zoom in from overview to specific products
- Track patterns over time
- Prepare insights for team discussion

GERDA features:

- *Usage numbers and environmental*
- *impact measurements*
- *Time-based trends*
- *Products & categories*

2. Understand factors

In a meeting room, Nicky discusses the gown hotspot with the Green Team, consisting of nurses, physician-researchers, and intensivists. They discuss protocols and possible actions to reduce the use of disposable gowns in the ICU. On the ICU, Nicky also asks her colleagues when and why they use disposable gowns.

Werkwijze:

- Bring up new potential hotspot for intervention
- Discuss patterns and causes (e.g., protocols, medical procedures, or behavior), with data context
- Compare alternative solutions
- Document insights & possible actions

Gerda features:

- *Data visualization zoom-in for group discussion*
- *Product environmental impact comparison*
- *Time-based trends*

3. Set Goal

When all information is collected for the next Green Team meeting, the Green Team reviews the trends and usage numbers shown by GERDA alongside the underlying factors. They discuss what would be a realistic goal. Using GERDA's goal function, they simulate different scenarios and set a 20% reduction as their target for the next six months.

Working method:

- Review all collected knowledge
- Set specific measurable goals
- Connect actions to these goals
- Calculate potential impact of reduction:
  - Environmental impact
  - Financial impact
- Align goals with annual targets

GERDA features:

- *Goal-setting interface*
- *Progress monitoring*

4. Motivate & communicate

Working method:

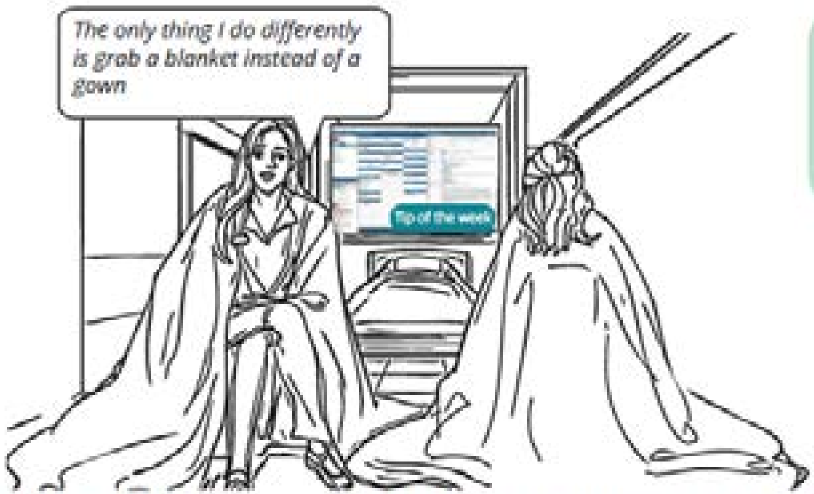
- Create campaign material
- Choose effective communication channels
- Prepare department heads

GERDA features:

- *Campaign material template*

After setting their goal, the Green Team creates a campaign for the new gown reduction guidelines. They create materials showing when isolation gowns are medically necessary and when they are not, and introduce reusable blankets as a sustainable alternative for warmth. They decide to display reminders on department screens and ask team leaders to share the message during handovers.

5. In action



Working method:

- Staff implements new guidelines
- Initial use and feedback is reviewed
- Provide progress updates
- Document successes & challenges

On the ICU, staff begins implementing the new guidelines. People remind each other to grab a blanket when they're cold, and the screens sometimes display a reminder of the goal or an update on progress.

6. Monitor progress

Two months later, Nicky and the Green Team evaluate the impact of the intervention. GERDA shows a declining trend in gown usage. No incidents have been reported in patient care. Staff is positive about the blanket alternative. A poster is created showing the reduction achieved so far and complimenting the department. The team shares their approach with other departments to support similar initiatives.

Werkwijze:

- Check progress against the set goal
- Discuss staff feedback
- Adjust where needed
- Communicate progress positively to staff
- Share success with other departments

GERDA features:

- *Progress updates*

8.3. TECHNICAL IMPLEMENTATION

8.3.1. SYSTEM ARCHITECTURE

The integration of GERDA with existing hospital systems ensures that it is easily accessible and reliable. Furthermore it is important to use the right foundation for data accuracy, security and maintenance.

PLATFORM SELECTION

The infrastructure is based on the DataHub infrastructure as described in chapter 5.
HDP Connection
The dashboard connects to the Health Data Platform through an SQL query, developed in collaboration with DataHub software engineers. This enables extraction of only the necessary data while complying with hospital data governance policies.

Sas Viya
The decision to use SAS Viya Visual Analytics as the development platform was made for a few reasons. Firstly the ICU & Datahub already use SAS Viya for other dashboards (ICU Maps & the Respiration Dashboard), making it a proven implementation path. Secondly, the DataHub's expertise with SAS Viya ensures the right environment for maintenance of GERDA. Lastly the already established connection with the HDP simplifies data access.
While there are other platforms like Power BI (also used in other departments of the Erasmus MC) and open source solutions that were considered, SAS Viya was the most practical software; especially considering the project's implementation timeline and support requirements.

DATA PROCESSING

Gerda connects and processes data through a pipeline from procurement records to actionable sustainability insights. This section outlines the journey of the data through the system, illustrate d with the example of disposable gloves, the biggest hotspot (in usage numbers) at the Erasmus MC's ICU.
The system integrates two primary sources:
Purchasing System (Oracle): Monthly procurement data for all medical products
Environmental Dataset: Manually collected sustainability metrics for product categories

1. **Data extraction**
   The query returns records form the HDP like in Table 6.
2. **Data enrichment**
   Next the data is enriched with environmental metrics from the manually maintained environmental dataset like in Table 7. Both datasets are joined on the 'article names' as the identifier and create a complete record with both usage and environmental data.

Category products	Product name	Net Weight per unit (kg)	Carbon footprint [CO2-eq / kg]	Use agricultural ground [m2 / kg]	Water use [m3 / kg]	Source:
Handschoenen onderzoek	Micro-Touch Nitra-Tex EP pf large	0.003	9.31	0.92	0.48	Metabolic 2019 (disposable gloves)
Handschoenen onderzoek	Micro-Touch Nitra-Tex EP pf medium	0.003	9.31	0.92	0.48	Metabolic 2019 (disposable gloves)

Table 7: Data enrichment

3. Environmental calculations
   Within the SAS Viya then calculations are performed to derive the environmental impact metrics, e.g:
   a. Total weight of products = Amount ordered * Weight per unit
   b. CO2 emissions = Total weight * CO2 equivalent factor

By use of filters that can be controlled by the user of the dashboard, the system aggregates these calculations across various dimension like time period and product categories. Similarly it can create a sum of or a total. This creates the interactive visualisations presented by GERDA.

Category product	Artikel name	Month	Amount
Handschoenen onderzoek	Micro-Touch Nitra-Tex EP pf large	JAN23	20500
Handschoenen onderzoek	Micro-Touch Nitra-Tex EP pf medium	JAN23	44000

Table 6: Data extraction

All data processing occurs within Erasmus MC's secure environment. The access to the final dashboard is granted per individual, through the hospital's authentication system, guarantying data safety.

8.3.2. DATA MANAGEMENT

Getting the architecture right is important to get the tool running. However, the right data management is required for GERDA's reliability and long-term operation. This section will outline the procedures for maintaining data integrity, updates, and the system governance.

DATA UPDATE PROCEDURES

Procurement Data
GERDA's procurement data is refreshed weekly through the query, automated, so no manual steps required. Monthly updates would be sufficient for operational needs, but weekly cycles ensure continuous data availability.
Environmental Data

The environmental dataset needs to be updated manually, as it is not automatically updated by query. A quarterly update cycle is suggested where:

1. The datahub team sends a product inventory list with the last updated list of environmental factors
2. The green team reviews the list to identify:
   a. New products requiring environmental factors
   b. Existing products with either no or outdated environmental factors for which new researched values are available
3. Environmental factors are updated with source documentation
4. The Datahub implements the updates

In this collaboration, the DataHub holds responsibility over the maintenance and the Green Team's sustainability expertise is leveraged. The citation of the environmental data's source (e.g. Metabolic, 2019) is important to maintain transparency and scientific validity. The new filename includes the latest update date to ensure version control.

DATA GOVERNANCE

Data governance is important to make sure that the right rules, procedures and roles are in place to make sure that GERDA's data stays accurate and secure. It defines who can access different types of data, how changes are implemented and documented, and what measures protect the quality of the data.

Access
Viewing access is only available to Green Team members with their secure hospital authentication and provided by the DataHub software engineer in control of GERDA.
The system architecture is maintained, and accessible by the DataHub team only. The environmentl data can be edited only in quarterly updates.

Quality assurance
There are a few mechanisms in please to ensure GERDA's data quality. Firstly, missing values are labelled as such, rather than defaulting to zero, preventing misinterpretation. Next, calculations and summed numbers are only visible when complete data is available. At last, source documentation of all environmental factor makes it verifiable by the Green Team.

Documentation
The GERDA introduction booklet serves as the primary training resource. This document has been user-tested and provides guidance on following the sustainability workflow with GERDA, and not relying on data only, but gathering information from the medical context is needed to implement the right sustainable interventions. An additional explainer about the calculation methodologies could still be added.
In governance, the balance between the need for data quality, and the practical hospital reality is balanced. This ensures that GERDA remains reliable in an efficient way.

8.3.3. IMPLEMENTATION CHALLENGES

With the development and efforts to implement GERDA, several challenges were encountered. Both technical and organizational challenges, which are listed below.

TECHNICAL CHALLENGES

Environmental Data
A critical aspect of providing sustainable data-driven insights is the availability of reliable sustainability data itself. The limited availability of product-specific environmental impact data is a big challenge to this project. For many medical products, CO2 equivalent factors simply don't exist. Another useful metric, the mass, is also not readily provided by suppliers. This was approached by:

- Applying generic category-level environmental factors (for example, 1 value for all Injection needles) across the entire category, even though in reality these values likely vary per product.
- Manually weighing items in the ICU generated mass values the top 25 categories of medical products.
- Due to project scope constraints, there are several external sources for Life Cycle Assessment (LCA) data, that have not been looked into yet. These sources remain available for future dashboard development to enhance data completeness.

Data Mapping
Erasmus MC's medical product procurement classification system was not designed with sustainability in mind.
Firstly, the standardized AOC-coding system used (Productinformatie | AOC-codering.nl, n.d.) has some inconsistent categories. Some, like 'Gloves Research' contain similar items, while others like 'Blood collection system" contain diverse products with different materials and environmental impacts.
Secondly, regular tendering by the EMC leads to frequent supplier and product changes, this requires continuous reassessment of environmental values like weight and CO2-eq. factor. Finaly, without standardized sustainability information from manufacturers, matching products with environmental values is done manually.

Platform
GERDA was developed with SAS Viya Visual Analytics; a platform that offers advantages for integration with the system, and an efficient way of designing the dashboard. However it also imposes some limitations. There are limited user input options; preventing direct updates to environmental factors by Green Team members, or saving & exporting certain views. Additionally, the visualizations are also restricted by platform capabilities.

Data quality
Transparency and reliability of data-driven tools in the ICU environment is crucial, as also mentioned in literature and this projects findings. User testing of GERDA revealed that staff want to see where each number comes from, highlighting the need for transparent data sources. However, ensuring the reliability of the data remains a challenge, there are some concerns for reliability:

- The procurement data is not the same as usage data, it's a close proximate. However, not exact, it is visible in the data that high-volume ordering months are typically followed by lower volumes.
- The applicability of environmental factors to specific products has a certain uncertainty level. Next to that, manual work on product weighting and mapping can introduce mistakes or inconsistencies.
- Variations in data formatting and updates over time require flexibility for adjustments; for example, the AOC coding system mentioned before, is recently implemented.

ORGANISATIONAL CHALLENGES

The development and implementation of GERDA required collaboration of not only the initial stakeholders mentioned in the introduction. Next to the technical support from the DataHub, successful implementation also depended on the input from the Procurement department and the Health Data Platform team. Communication with these departments was challenging, especially with the development of the query for live data access, this process is still ongoing.
As the project was conducted by a masters student, new to the Erasmus MC. Establishing the necessary connections, gaining access to the right software's and understanding organisational practices required some additional time and effort.

8.4. CAMPAIGN SOLUTION IDEATION

While developing GERDA primarily focused on the dashboard for Green Team use, a key research question remained unanswered: which types of environmental metrics would most effectively communicate impact to general ICU staff? This question directly addresses a gap identified in the literature review, where limited evidence exists on metric effectiveness in high-stakes clinical environments.
It was decided with the chief sustainability officer in the Green Team to test different metrics using their most successful intervention to date - medical gloves reduction - as a case study. This targeted testing would provide valuable insights for future campaign development even as the project's immediate focus remained on the dashboard.

8.4.1. CONCEPT TESTING

The test plan explored four different ways of communicating the intervention's impact. The base metric was percentage reduction, which is the standard measure used in ICU sustainability reporting. To complement this, we tested three additional metrics that relate to the reduction in different ways:

1. Number of gloves reduced per patient day (inventory) This value provides concrete numbers that directly relate to daily ICU work
2. Total yearly CO2-equivalent emissions saved (emission factor, Metabolic 2019). This shows the broader environmental impact in measurable units
3. Environmental impact expressed as equivalent number of trees per 10 years (Greenhouse Gas Equivalencies Calculator | US EPA, 2024). This aims to make the impact more relatable by comparing it to something familiar.

For the full test plan see Appendix G.
The test was conducted during the coffee break at the ICU, with both Intensivists and nurses. In total 13 people participated, both doctors (3) and nurses (10).
The test used a poster that displayed all four metrics together, see Figure 31.

Figure 31: Poster Environmental Metric test

RESULTS AND INSIGHTS
The testing revealed varying responses to each metric format, see Table 5 and Table 6:

	Demotivating	Neutral	Motivating
A	0	8	5
B	5	5	2
C	5	4	3

Table 8: Motivation results environmental metric

	Not more aware	Little more aware	More aware
A	0	8	5
B	5	5	2
C	5	4	3

Table 9: Awareness results environmental metric

Staff feedback provided some valuable background in conversation:

"Can you show the infection rates alongside the glove reduction? I need to see both to understand the full picture."

Promoting environmental reduction alone, is a one-sided approach that could benefit from more medical context for more meaning to the ICU staff.

While most staff preferred concrete, work-related metrics, individual preferences varied significantly. As one staff member noted:

"I always think about trees when I throw away paper, so that comparison really resonates with me."

The result of this test are clear. A, the amount of gloves per patient day is the most motivating and aware-making metric to the ICU staff (n=13). The other two metrics did not mean a lot to the participants of this test, according to their explanations. Those were hard to compare and imagine metrics, too vague.

8.5. IMPLEMENTATION

8.5.1. ROADMAP

Building on feedback from user testing and technical feasibility assessment, a structured three-horizon approach was developed to guide GERDA's evolution over time (Figure X). This roadmap balances immediate functionality with long-term ambition, ensuring sustainable development and adoption.
The roadmap visualizes development across five key dimensions (Users, Data, Integration & Infrastructure, User Experience, and Communication) through horizons spanning from concrete actions for fast implementation to long-term vision ideas.

HORIZON 1: FOUNDATION & CORE PRODUCT

To get some sense of what this Roadmap is built on, the context of steps on horizon one is explained:
The immediate focus is on establishing GERDA's core functionality for the ICU Green Team, with several concrete initiatives already underway:

- **Completing the environmental dataset**
  The Green Team has begun systematically weighing high-volume medical products to expand mass data, while researching literature sources for additional emission factors. For example, work has started on weighing different types of syringes and mapping their materials to develop more precise environmental impact estimates.
- **Live query connection**
  Collaboration with the DataHub is progressing toward automating data retrieval, replacing the current manual export process. A prototype query has been developed and is undergoing security review before implementation.
- **Data lineage transparency**
  User testing revealed strong demand for understanding data origins. In response, source documentation for emission factors has been standardized, with plans to incorporate this information directly into dashboard tooltips for immediate reference.
- **Clinical context integration**
  The user test finding that staff requested infection rate data alongside glove reduction metrics has prompted development of a framework for integrating clinical outcomes with sustainability metrics. This ensures interventions are evaluated holistically rather than solely on environmental impact.

These first-phase initiatives focus on establishing GERDA as a reliable decision support tool for the Green Team while building the technical infrastructure and data governance practices needed for sustainable operation and future expansion.

	Horizon 1: Foundation & core product 0-6 months	Horizon 2: Enhancing user group & capabilities 7-18 months	Horizon 3: Advanced system 1.5-3 year
Users	Green Team ICU ICU staff Green Team child- ICU	Other departments within EMC Individuals	Hospital management National hospitals
Data	Complete Environmental Dataset for medical products as far as factors are available. Include real-time medication usage data from HiX	Expand to additional emission sources beyond medical products & medication, such as energy use, transport, food & computing Lay data foundation for a department comparison platform with standardized metrics	Implement predictive analytics for intervention impact estimates. Integrate sustainability data from all departments & standardize metrics across all 9 emission sources for hospital scale insights.
Integration & infrastructure	Establish connection to the live query with a weekly refresh cycle Provide clear data lineage information for all metrics showing source, calculation method, and update frequency	Integrate with daily ICU staff activities through embedded micro-insights in existing systems Develop solution to integrate LCA and Research findings directly in GERDA Implement data validation protocols for manual inputs	Create personalized dashboards for each user Implement chatbot interaction
User experience & interface	Optimise dashboard after a few months of use by the ICU Green Team Add contextual link(s) to explain clinical and medical context to the environmental data.	Build custom view for general department staff, with educational purpose Implement mobile view for quick progress checks	Connect Corporate Social Responsibility's goals on hospital scale to department sustainability goals Develop product & data standardisation (based on an ontology?) for expansion and collaboration on national scale
Communication & adoptation	Create templates for campaign materials for introduction, reminder, update and finalisation of a sustainable intervention Develop a training module Integrate clinical context in communication & reporting (so e.g., we did this without any more infections)	Create a platform for communication of successful interventions with quantified outcomes and replication guidelines Develop automated progress report messages Implement "small impact awareness" reminders or visualisations across communication channels	Implement digital recognition/reward system for sustainable practices

Figure 32: Implementation Roadmap

8.5.2. SCALING CONSIDERATIONS

The development of GERDA provided valuable insights that extend beyond the ICU context. During this project, I also contributed knowledge and data analysis expertise to a related initiative for Zorg Instituut Nederland (ZIN), which focused on standardizing sustainability data approaches nationally. This experience, combined with GERDA's implementation learnings, informs the following considerations for scaling sustainability monitoring across healthcare settings.

DEPARTMENTAL DIFFERENCES

Expanding GERDA beyond the ICU requires adaptations for different clinical environments:

- **Purchasing System Variations**
  Not every department has a centralized purchasing system. Some collaborate with others on procurement, making it significantly harder to track department-specific data or even impossible to disaggregate usage. This fundamental data access challenge must be addressed before implementation.
- **Green Team Readiness**
  The Children's ICU represents an ideal next implementation target due to their active Green Team that has already requested collaboration. However, not every department has an equally active or successful sustainability team. Some may require organizational development support before a data-driven tool would be effective.
- **Operating Rooms**
  Higher material intensity with specialized supplies requires additional environmental factors and potentially different visualization approaches, building on foundations like the "Barometer Groene OK" initiative.
- **Outpatient Settings**
  Lower resource use per patient but higher patient volumes create different measurement challenges, requiring per-visit rather than per-day metrics.

CROSS-HOSPITAL IMPLEMENTATION REQUIREMENTS

For GERDA to scale nationally, as envisioned in ZIN's sustainable data-driven care initiative, several critical elements must be established:

- **Standardized Data Architecture**
  A common sustainability data platform should begin with sharing environmental factors across institutions, reducing duplicate research effort and building toward standardized calculation methodologies.
- **Sustainability Ontology Development**
  Building an ontology that extends existing medical coding systems (like AOC) to include sustainability dimensions would enable meaningful cross-institutional comparisons while respecting different clinical contexts.
- **Centralized Governance**
  There is a clear need and gap for a single coordinating entity to take responsibility for sustainability data standards. Without this central authority, fragmented approaches will likely continue, limiting the potential for meaningful benchmarking.

The recommendations presented in the roadmap and scaling considerations transform GERDA from a department-specific tool to a potential component in Dutch healthcare's broader sustainability infrastructure. By addressing standardization needs while respecting institutional differences, GERDA's approach can contribute to both local environmental impact reduction

8.5. KEY TAKEAWAYS

- GERDA's technical architecture successfully integrates procurement data with environmental metrics through a four-stage process: data extraction, enrichment, environmental calculations, and interactive aggregation
- The data management framework establishes sustainable governance practices with weekly automated procurement updates and quarterly environmental data reviews, balancing rigor with practical hospital realities.
- Implementation revealed critical challenges including limited product-specific environmental data availability, procurement classification systems not designed for sustainability tracking, and platform constraints that influenced the final solution.
- The three-horizon roadmap provides a structured path forward, with immediate plans for data enrichment and query automation, medium-term expansion to additional emission sources and departments, and long-term vision for hospital-wide integration.
- Concrete testing with ICU staff demonstrated that product-specific metrics (like gloves per patient day) are significantly more effective for communication than abstract environmental measures, informing future campaign development.
- Scaling considerations identified specific departmental differences (purchasing systems, Green Team readiness) and cross-hospital requirements (standardized data architecture, ontology development, centralized governance) that must be addressed for wider implementation.

9. Discussion

This chapter connects the findings of this research back to the literature, discusses theoretical contributions and practical implications, acknowledges limitations, and suggests directions for future research.This research addressed the challenge of designing a data-driven sustainability tool for the Erasmus MC ICU, focusing on the question:
“How can a data-driven decision support tool be designed to enable ICU staff to reduce environmental impact?”

9.1. CONNECTIONS TO LITERATURE

The findings both confirm existing literature and provide new insights across three domains:

DATA-DRIVEN DECISION SUPPORT IN HEALTHCARE

. GERDA's design process addressed the cognitive overload concerns identified by Stead et al. (2010) by carefully balancing information density with usability. The implementation challenges encountered regarding data quality and trust echo Carra et al.'s (2020) observations, reinforcing the importance of transparent data sources for clinical environments.

New insights include the identification of a people-focused culture in the ICU that influences how data tools are received—suggesting that technical solutions must be balanced with personal approaches in healthcare environments.

SUSTAINABILITY MONITORING IN HEALTHCARE

This project confirms Collins & Demorest's (2022) findings regarding standardization challenges in sustainability monitoring. However, it extends their work by demonstrating that focused environmental monitoring can be implemented even with incomplete data by prioritizing high-impact areas like medical products. The research reveals that procurement data, while imperfect, can serve as a valuable proxy for usage when direct measurement is impractical—an insight not prominently discussed in existing literature on healthcare sustainability monitoring.

MOTIVATING SUSTAINABLE BEHAVIOUR

The user testing of sustainability metrics provided important new insights into effective communication strategies. While the literature suggests various behavioral change approaches (Michie et al., 2011), this research found that ICU staff respond most positively to concrete, work-related metrics (gloves per patient day) rather than abstract environmental measures—a critical consideration for future intervention design.

This finding extends Kalogirou et al.'s (2021) work on barriers to sustainable healthcare practices by demonstrating that communication strategies must be tailored to clinical contexts, with staff preferring metrics directly related to their daily practice.

9.2. LIMITATIONS AND FUTURE RESEARCH

Several limitations should be acknowledged. First, the study was conducted at a single institution with a small sample of participants, potentially limiting generalizability. Second, data availability constraints, particularly regarding environmental impact factors for specific medical products, necessitated using category-level estimations that reduce precision.

Technical limitations of the SAS Viya platform restricted some desired functionality, including direct user updates to environmental factors and customizable export options. Additionally, the focus on the Green Team as primary users means that engagement strategies for general ICU staff were not fully developed.

Future research could explore:

- Standardized sustainability metrics across healthcare institutions
- Integration of clinical outcomes with environmental metrics
- Effective motivation strategies for healthcare staff balancing clinical and environmental priorities

9.3. PRACTICAL IMPLICATIONS

This research demonstrates that effective sustainability monitoring in healthcare requires:

1. Integration with established clinical workflows.
2. Transparent data sources and calculation methods to build trust
3. Focus on specific, actionable product-level data rather than general categories
4. Recognition of clinical priorities alongside environmental goals

The roadmap and scaling considerations provided in Chapter 8 offer concrete guidance for extending this approach to other departments and institutions, contributing to the broader goal of standardized sustainability monitoring in Dutch healthcare.

This work represents a step toward Erasmus MC's ambitious sustainability targets while offering valuable insights for the healthcare sector's transition toward more sustainable practices.

By bridging the gap between environmental data and the practice in the ICU Green Team, GERDA demonstrates how data-driven approaches can support sustainability progress at the ICU; Data in Action.

9.4. KEY TAKEAWAYS

- This research bridges theory and practice by addressing identified literature gaps in healthcare sustainability monitoring through GERDA, demonstrating how data-driven tools can effectively support environmental impact reduction while respecting clinical priorities.
- While GERDA successfully integrates automated data collection with the Green Team's workflow, limitations in environmental data standardization and platform flexibility highlight the need for broader healthcare industry collaboration on sustainability metrics. Practical testing revealed that concrete metrics directly related to clinical work (like gloves per patient day) are more effective for staff engagement than abstract environmental measures, providing valuable insights for future sustainability communication in healthcare settings.

PERSONAL REFLECTION

This project at Erasmus MC expanded my perspective on sustainability and systemic change in significant ways. Coming from the energy transition field, I expected some comlexity and definitely found it; balancing environmental goals with the importance of patient care while also dealing data limitations.

Working in a large hospital's organizational structure proved challenging. Connecting with the right people and accessing appropriate data was more difficult than anticipated.
Another significant challenge was balancing the practical needs of my client at Erasmus MC with the academic requirements of my thesis. The hospital needed an immediately useful tool while the university expected theoretical depth and academic rigor. Finding the sweet spot between practical implementation and academic contribution required careful navigation and sometimes compromise. If I were to start over, I would use more visual communication earlier in the process to bridge gaps and clarify complex concepts.
This experience of writing a thesis and being part of the DataHub changed my perception of research from something dry to something valuable, though still challenging to execute well.

On a personal level, this project built my confidence in working among specialized professionals and taught me to balance in trusting my perspective as a designer while respecting domain expertise. Green team members commented that the Gerda information booklet was very user-friendly, it confirmed that bringing design thinking to healthcare technology makes a meaningful difference. I think that often healthcare tools are developed without sufficient consideration for care paths or user perspectives.
As I continue implementing GERDA more broadly across Erasmus MC, I hope to be better equiped to tackle the complex systemic challenges and always design for human needs. I look forward to the next steps!

REFERENCES

Aarts, F. (2024). Katheter schoon inbrengen in plaats van steriel. *Nursing*, *30*(4), 42–45. https://doi.org/10.1007/s41193-024-1158-3

Asgari, E., Kaur, J., Nuredini, G., Balloch, J., Taylor, A. M., Sebire, N., Robinson, R., Peters, C., Sridharan, S., & Pimenta, D. (2024). Impact of electronic health record use on cognitive load and burnout among clinicians: Narrative review. *JMIR Medical Informatics*, *12*, e55499. https://doi.org/10.2196/55499

Bennett, K. (2023, July 24). *Achieving sustainability in healthcare: Trends and practices (YEL2022) - IHF*. IHF. https://ihf-fih.org/news-insights/achieving-sustainability-in-healthcare-trends-and-practices/

Bersani, K., Fuller, T. E., Garabedian, P., Espares, J., Mlaver, E., Businger, A., Chang, F., Boxer, R. B., Schnock, K. O., Rozenblum, R., Dykes, P. C., Dalal, A. K., Benneyan, J. C., Lehmann, L. S., Gershanik, E. F., Bates, D. W., & Schnipper, J. L. (2020). Use, Perceived Usability, and Barriers to Implementation of a Patient Safety Dashboard Integrated within a Vendor EHR. *Applied Clinical Informatics*, *11*(01), 034–045. https://doi.org/10.1055/s-0039-3402756

Bhonagiri, D., Pinder, M., & Huckson, S. (2023). Environmental sustainability in the intensive care unit: A toolkit to counter futility! *Critical Care and Resuscitation*, *25*(2), 61–62. https://doi.org/10.1016/j.ccrj.2023.04.001

Carra, G., Salluh, J. I., Da Silva Ramos, F. J., & Meyfroidt, G. (2020). Data-driven ICU management: Using Big Data and algorithms to improve outcomes. *Journal of Critical Care*, *60*, 300–304. https://doi.org/10.1016/j.jcrc.2020.09.002

Chiara. (2024, November 4). *Promoting circularity in Dutch healthcare*. Metabolic. https://www.metabolic.nl/projects/promoting-circularity-in-dutch-healthcare/

Citerio, G., Park, S., Schmidt, J. M., Moberg, R., Suarez, J. I., & Roux, P. D. L. (2015). Data collection and interpretation. *Neurocritical Care*, *22*(3), 360–368. https://doi.org/10.1007/s12028-015-0139-4

Clarke, V., & Braun, V. (2013). *Succesful Qualitative Research: A practical guide for Beginners* (1st ed.). Sage Publications. https://www.researchgate.net/publication/256089360_Successful_Qualitative_Research_A_Practical_Guide_for_Beginners/citations

Cohen, E. S., Kouwenberg, L. H. J. A., Moody, K. S., Weiland, N. H. S., Kringos, D. S., Timmermans, A., & Hehenkamp, W. J. K. (2023). Environmental sustainability in obstetrics and gynaecology: A systematic review. *BJOG an International Journal of Obstetrics & Gynaecology*, *131*(5), 555–567. https://doi.org/10.1111/1471-0528.17637

Collins, A., & Demorest, S. (2022a). How should we respond to health care generating environmental harm? *The AMA Journal of Ethic*, *24*(10), E1004-1012. https://doi.org/10.1001/amajethics.2022.1004

Collins, A., & Demorest, S. (2022b). How should we respond to health care generating environmental harm? *The AMA Journal of Ethic*, *24*(10), E1004-1012. https://doi.org/10.1001/amajethics.2022.1004

Culler, S. D., Jose, J., Kohler, S., & Rask, K. (2010). Nurses' perceptions and experiences with the implementation of a medication administration system. *CIN Computers Informatics Nursing*, *29*(5), 280–288. https://doi.org/10.1097/ncn.0b013e3181fcbe7e

Davis, R., Campbell, R., Hildon, Z., Hobbs, L., & Michie, S. (2014). Theories of behaviour and behaviour change across the social and behavioural sciences: a scoping review. *Health Psychology Review*, *9*(3), 323–344. https://doi.org/10.1080/17437199.2014.941722

De Waele, J. J., Hunfeld, N., Baid, H., Ferrer, R., Iliopoulou, K., Ioan, A., Leone, M., Ostermann, M., Scaramuzzo, G., Theodorakopoulou, M., Touw, H., Citerio, G., Derde, L. P. G., Donadello, K., Juffermans, N. P., Galarza, L., Grasselli, G., Maggiore, S. M., Martin-Loeches, I., . . . Azoulay, E. (2024). Environmental sustainability in intensive care: the path forward. An ESICM Green Paper. *Intensive Care Medicine*, *50*(11), 1729–1739. https://doi.org/10.1007/s00134-024-07662-7

Een duurzaam Erasmus MC, Burdorf, L., Schilte, H.-P., Hunfeld, N., & Poot, C. (2022). *Duurzaamheidsdoelstellingen 2023-2024*.

Erasmus MC. (n.d.). *Green Teams - Erasmus MC*. https://www.erasmusmc.nl/nl-nl/duurzaamheid/green-teams

Goldstein, B. A., Cerullo, M., Krishnamoorthy, V., Blitz, J., Mureebe, L., Webster, W., Dunston, F., Stirling, A., Gagnon, J., & Scales, C. D. (2020). Development and performance of a clinical decision support tool to inform resource utilization for elective operations. *JAMA Network Open*, *3*(11), e2023547. https://doi.org/10.1001/jamanetworkopen.2020.23547

GREEN DEAL: Samen werken aan duurzame zorg. (2022). In *greendealduurzamezorg.nl* (C–238). https://www.greendealduurzamezorg.nl/files/1-green-deal-samenwerken-aan-duurzame-zorg-c238.pdf

Greenberg, S., Carpendale, S., & Uxton, B. (2012). *Sketching User Experiences: The Workbook* [Online]. Elsevier. https://doi.org/10.1016/C2009-0-61147-8

Greenhouse Gas Equivalencies Calculator | US EPA. (2024, December 12). US EPA. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator#results

Gregory, L. R., Lim, R., MacCullagh, L., Riley, T., Tuqiri, K., Heiler, J., & Peters, K. (2021). Intensive care nurses' experiences with the new electronic medication administration record. *Nursing Open*, *9*(3), 1895–1901. https://doi.org/10.1002/nop2.939

Gupta Strategists. (2019). *Een stuur voor de transitie naar duurzame gezondheidszorg.* Retrieved August 27, 2024, from https://gupta-strategists.nl/studies/een-stuur-voor-de-transitie-naar-duurzame-gezondheidszorg

Health Care Without Harm & ARUP. (2019). Health care climate footprint report | Health Care Without Harm. In *https://global.noharm.org/*. https://global.noharm.org/resources/health-care-climate-footprint-report

Helminski, D., Sussman, J. B., Pfeiffer, P. N., Kokaly, A. N., Ranusch, A., Renji, A. D., Damschroder, L. J., Landis-Lewis, Z., & Kurlander, J. E. (2024). Development, implementation, and evaluation methods for dashboards in health care: Scoping Review (Preprint). *JMIR Medical Informatics*, *12*, e59828. https://doi.org/10.2196/59828

Huffling, K., & Schenk, E. (2014). Environmental sustainability in the intensive care unit. *Critical Care Nursing Quarterly*, *37*(3), 235–250. https://doi.org/10.1097/cnq.0000000000000028

Hunfeld, N., Diehl, J. C., Timmermann, M., Van Exter, P., Bouwens, J., Browne-Wilkinson, S., De Planque, N., & Gommers, D. (2022). Circular material flow in the intensive care unit—environmental effects and identification of hotspots. *Intensive Care Medicine*, *49*(1), 65–74. https://doi.org/10.1007/s00134-022-06940-6

Hunfeld, N. G. M., Diehl, J. C., Van Der Zee, S., & Van Raaij, E. (2023). The Green Intensive Care: from environmental hotspot to action. *ResearchGate*. https://www.researchgate.net/publication/371069211_The_Green_Intensive_Care_From_Environmental_Hotspot_to_Action

Hunfeld, N., Tibboel, D., & Gommers, D. (2024). The paracetamol challenge in intensive care: going green with paracetamol. *Intensive Care Medicine*. https://doi.org/10.1007/s00134-024-07679-y

Jalilian, L., & Khairat, S. (2022, January 1). *The Next-Generation Electronic Health Record in the ICU: a focus on User-Technology interface to optimize patient safety and quality*. https://pmc.ncbi.nlm.nih.gov/articles/PMC9013229/

Kalogirou, M. R., Dahlke, S., Davidson, S., & Yamamoto, S. (2021). How the hospital context influences nurses' environmentally responsible practice: A focused ethnography. *Journal of Advanced Nursing*, *77*(9), 3806–3819. https://doi.org/10.1111/jan.14936

Karliner, J., Slotterback, S., Boyd, R., Ashby, B., Steele, K., & Wang, J. (2020). Health care's climate footprint: the health sector contribution and opportunities for action. *European Journal of Public Health*, *30*(Supplement_5). https://doi.org/10.1093/eurpub/ckaa165.843

Kwakye, G., Brat, G. A., & Makary, M. A. (2011). Green surgical practices for health care. *Archives of Surgery*, *146*(2), 131. https://doi.org/10.1001/archsurg.2010.343

Kwasnicka, D., Dombrowski, S. U., White, M., & Sniehotta, F. (2016). Theoretical explanations for maintenance of behaviour change: a systematic review of behaviour theories. *Health Psychology Review*, *10*(3), 277–296. https://doi.org/10.1080/17437199.2016.1151372

Lai, C., Li, K., Hu, F., Su, P., Hsu, I., Huang, M., Huang, Y., Liu, P., & Shen, M. (2022). Integration of an Intensive Care Unit Visualization Dashboard (i-Dashboard) as a platform to facilitate multidisciplinary rounds: Cluster-Randomized Controlled Trial. *Journal of Medical Internet Research*, *24*(5), e35981. https://doi.org/10.2196/35981

Lattanzio, S., Stefanizzi, P., D'ambrosio, M., Cuscianna, E., Riformato, G., Migliore, G., Tafuri, S., & Bianchi, F. P. (2022). Waste Management and the Perspective of a Green Hospital—A Systematic Narrative Review. *International Journal of Environmental Research and Public Health*, *19*(23), 15812. https://doi.org/10.3390/ijerph192315812

Lenzen, M., Malik, A., Li, M., Fry, J., Weisz, H., Pichler, P., Chaves, L. S. M., Capon, A., & Pencheon, D. (2020). The environmental footprint of health care: a global assessment. *The Lancet Planetary Health*, *4*(7), e271–e279. https://doi.org/10.1016/s2542-5196(20)30121-2

Mahyar, N. (2024, September 5). *Reimagining data visualization to address sustainability goals*. arXiv.org. https://arxiv.org/abs/2409.03611

Masud, F. N., Sasangohar, F., Ratnani, I., Fatima, S., Hernandez, M. A., Riley, T., Fischer, J., Dhala, A., Gooch, M. E., Keeling-Johnson, K., Moon, J., & Vincent, J. (2024). Past, present, and future of sustainable intensive care: narrative review and a large hospital system experience. *Critical Care*, *28*(1). https://doi.org/10.1186/s13054-024-04937-9

McGain, F., Muret, J., Lawson, C., & Sherman, J. D. (2020). Environmental sustainability in anaesthesia and critical care. *British Journal of Anaesthesia*, *125*(5), 680–692. https://doi.org/10.1016/j.bja.2020.06.055

McGain, F., & Naylor, C. (2014). Environmental sustainability in hospitals – a systematic review and research agenda. *Journal of Health Services Research & Policy*, *19*(4), 245–252. https://doi.org/10.1177/1355819614534836

Mehra, R., & Sharma, M. K. (2021). Measures of sustainability in healthcare. *Sustainability Analytics and Modeling*, *1*, 100001. https://doi.org/10.1016/j.samod.2021.100001

Michie, S., Van Stralen, M. M., & West, R. (2011). The behaviour change wheel: A new method for characterising and designing behaviour change interventions. *Implementation Science*, *6*(1). https://doi.org/10.1186/1748-5908-6-42

Ministerie van Volksgezondheid, Welzijn en Sport. (2024, December 3). *Duurzame zorg*. Over Ons | Zorginstituut Nederland. https://www.zorginstituutnederland.nl/over-ons/organisatie/duurzame-zorg

Mohanty, V., Filipowicz, A. L. S., Bravo, N. S., Carter, S., & Shamma, D. A. (2023). Save A Tree or 6 kg of CO2? Understanding Effective Carbon Footprint Interventions for Eco-Friendly Vehicular Choices. *Save a Tree or 6 Kg of CO2? Understanding Effective Carbon Footprint Interventions for Eco-Friendly Vehicular Choices*, 1–24. https://doi.org/10.1145/3544548.3580675

Park, S., Bekemeier, B., Flaxman, A., & Schultz, M. (2021). Impact of data visualization on decision-making and its implications for public health practice: a systematic literature review. *Informatics for Health and Social Care*, *47*(2), 175–193. https://doi.org/10.1080/17538157.2021.1982949

Potera, C. (2012). Strategies for Greener hospital operating rooms. *Environmental Health Perspectives*, *120*(8). https://doi.org/10.1289/ehp.120-a306a

Prasad, P. A., Joshi, D., Lighter, J., Agins, J., Allen, R., Collins, M., Pena, F., Velletri, J., & Thiel, C. (2021). Environmental footprint of regular and intensive inpatient care in a large US hospital. *The International Journal of Life Cycle Assessment*, *27*(1), 38–49. https://doi.org/10.1007/s11367-021-01998-8

Productinformatie | AOC-codering.nl. (n.d.). AOC-codering.nl. https://aoc-codering.nl/product/

Reike, D., Vermeulen, W. J., & Witjes, S. (2017). The circular economy: New or Refurbished as CE 3.0? — Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options. *Resources Conservation and Recycling*, *135*, 246–264. https://doi.org/10.1016/j.resconrec.2017.08.027

Saviano, M., Bassano, C., Piciocchi, P., Di Nauta, P., & Lettieri, M. (2018). Monitoring viability and sustainability in healthcare organizations. *Sustainability*, *10*(10), 3548. https://doi.org/10.3390/su10103548

Schleith, J., & Tsar, D. (2022). Triple Diamond design Process. In *Lecture notes in computer science* (pp. 136–146). https://doi.org/10.1007/978-3-031-17615-9_9

Schluep, M., Minheere, M., Baus, M., Machielse, S., Donkers, A., & Vroman, H. (2024). Reducing plastic waste in intensive care from longer use of intravenous administration and invasive monitoring sets: A before-and-after study. *Journal of Critical Care*, *84*, 154900. https://doi.org/10.1016/j.jcrc.2024.154900

See, K. C. (2023). Improving environmental sustainability of intensive care units: A mini-review. *World Journal of Critical Care Medicine*, *12*(4), 217–225. https://doi.org/10.5492/wjccm.v12.i4.217

Sijm-Eeken, M., Jaspers, M., & Peute, L. (2023). Identifying Environmental Impact Factors for Sustainable Healthcare: A scoping review. *International Journal of Environmental Research and Public Health*, *20*(18), 6747. https://doi.org/10.3390/ijerph20186747

Slutzman, J. E., Bockius, H., Gordon, I. O., Greene, H. C., Hsu, S., Huang, Y., Lam, M. H., Roberts, T., & Thiel, C. L. (2022). Waste audits in healthcare: A systematic review and description of best practices. *Waste Management & Research the Journal for a Sustainable Circular Economy*, *41*(1), 3–17. https://doi.org/10.1177/0734242x221101531

Stall, N. M., Kagoma, Y. K., Bondy, J. N., & Naudie, D. (2013). Surgical waste audit of 5 total knee arthroplasties. *Canadian Journal of Surgery*, *56*(2), 97–102. https://doi.org/10.1503/cjs.015711

Stand van de zorg 2024 - Nederlandse Zorgautoriteit. (2024, October 8). Retrieved January 15, 2025, from https://puc.overheid.nl/nza/doc/PUC_775407_22/

Stead, W. W., Searle, J. R., Fessler, H. E., Smith, J. W., & Shortliffe, E. H. (2010). Biomedical Informatics: Changing what physicians need to know and how they learn. *Academic Medicine*, *86*(4), 429–434. https://doi.org/10.1097/acm.0b013e3181f41e8c

Steenmeijer, M. A., Rodrigues, J. F. D., Zijp, M. C., & Loop, S. L. W. D. (2022). The environmental impact of the Dutch health-care sector beyond climate change: an input–output analysis. *The Lancet Planetary Health*, *6*(12), e949–e957. https://doi.org/10.1016/s2542-5196(22)00244-3

Strechen, I., Herasevich, S., Barwise, A., Garcia-Mendez, J., Rovati, L., Pickering, B., Diedrich, D., & Herasevich, V. (2024). Centralized Multi-Patient Dashboards' Impact on ICU Clinician Performance and Satisfaction: A Systematic review. *Applied Clinical Informatics*, *15*(03), 414–427. https://doi.org/10.1055/a-2299-7643

Sürme, Y., Maraş, G., & Akbuğa, G. A. (2024). Environmental sustainability, medical waste management, energy and medicine consumption of the surgical intensive care nurses: A qualitative study. *Nursing in Critical Care*. https://doi.org/10.1111/nicc.13150

Van De Sande, D., Van Genderen, M. E., Huiskens, J., Gommers, D., & Van Bommel, J. (2021). Moving from bytes to bedside: a systematic review on the use of artificial intelligence in the intensive care unit. *Intensive Care Medicine*, *47*(7), 750–760. https://doi.org/10.1007/s00134-021-06446-7

Van Der Zee, S., Verhoog, T., Post, T., Garcia-Gomez, P., Van Raaij, E. M., Diehl, J., & Hunfeld, N. (2024). Nudging intensive care unit personnel towards sustainable behaviour. *Nursing in Critical Care*. https://doi.org/10.1111/nicc.13086

Wac, M., Craddock, I., Chantziara, S., Campbell, T., Santos-Rodriguez, R., Davidson, B., & McWilliams, C. (2023). Design and evaluation of an intensive care unit dashboard built in response to the COVID-19 Pandemic: Semistructured Interview study. *JMIR Human Factors*, *10*, e49438. https://doi.org/10.2196/49438

Wyssusek, K. H., Keys, M. T., & Van Zundert, A. a. J. (2018). Operating room greening initiatives – the old, the new, and the way forward: A narrative review. *Waste Management & Research the Journal for a Sustainable Circular Economy*, *37*(1), 3–19. https://doi.org/10.1177/0734242x18793937

Zaw, M. W. W., Leong, K. M., Xin, X., Lin, S., Ho, C., & Lie, S. A. (2023). The perceptions and adoption of environmentally sustainable practices among anesthesiologists—a qualitative study. *Canadian Journal of Anesthesia/Journal Canadien D Anesthésie*, *70*(3), 313–326. https://doi.org/10.1007/s12630-022-02392-0