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Reducing the Environmental Impact of Syringes at the Intensive Care Unit

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Abstract This research project, part of the Green Intensive Care Unit (ICU) initiative at the Erasmus University Medical Center (EMC), is focused on reducing the environmental impact of syringes at the ICU by designing solutions based on circular economy principles. Based on a Material Flow Analysis of the EMC ICU, syringes and their packaging have been identified as one of the main environmental impact hotspots. Therefore, this project aimed to redesign the syringes, their packaging, and their use, according to circular design strategies suitable for medical products to decrease their environmental impact, while remaining convenient and safe in use for the healthcare staff and patients. Research was executed to understand the context from multiple perspectives. The outcomes demonstrated that decreasing the impact of syringes is not only related to the design of the syringe itself. Manufacturing, preparation, use and disposal, all contribute to the environmental impact of the syringe. Various possible interventions were derived to reduce its impact:

1. Adapting the infection prevention protocol and behaviour of the staff;
2. Separating infectious waste from general hospital waste;
3. Redesigning the syringe itself;
4. Optimising the filling process of syringes.

The final design is an optimised filling process for prefilled sterilised syringes (PFSs), based on circular strategies such as reduce, reuse, rethink and repurpose. Interventions include: eliminating a redundant sterilisation phase, reducing residual medication and changing from steam to gamma sterilisation. This resulted in decreasing the amount of waste, material, energy and water consumption, while offering similar convenience and safety for the staff and patients of the ICU.

Keywords Circular healthcare · Syringe · Environmental impact · Design

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1 Background

The healthcare sector has a high environmental impact, contributing to 4.4% of the global net greenhouse gas emissions and toxic air pollutants (Karliner et al. 2020). In the Netherlands, 5.9% of the national ecological footprint is associated with the healthcare sector. The majority (71%) of these emissions come from the production, use, transport, and disposal of medical products used in the hospital (Browne-Wilkinson et al. 2021). Single-use and disposable products are commonly used in the healthcare sector as a procedure to reduce (cross-)infections and have resulted in better health outcomes (Kane et al. 2017).

The ICU of EMC produces an excessive amount of waste. In the existing situation, to a large extent, the products used are disposables. After one time use, they are disposed of and incinerated. The current state of the ICU is therefore not sustainable nor circular since it is based on single-use devices, disposables, and a linear economy. The reason for this is the fact that safety, sterility, and infection prevention have been prioritised above sustainability.

Based upon the Material Flow Analysis (MFA) of the ICU at EMC, syringes and their packaging have been defined as an environmental impact hotspot. Meaning that it is a product group causing significant environmental impacts, due to the product properties, extensive use (24 syringes per patient per day), and the fact that it is a single-use disposable product (Browne-Wilkinson et al. 2021). The syringes (50 ml) are used to administer medication to the patient. They are connected to the patient via an extension line and placed in an infusion pump for automated administration of the fluid. After single-use, the syringe is disposed of. Some syringes are even disposed of unused, due to limited shelf life or due to the infection prevention protocol. Furthermore, the syringe is an assembly of components made of different materials (polypropylene (PP) and bromobutyl). The packaging, to keep the syringe sterile, is made of a laminate of two plastic (namely polyamide 6 (PA6) and low-density polyethylene (LDPE)) which is hard to separate at the disposal stage (for recycling). This packaging laminate contributes significantly to the carbon footprint of the syringe.

The main underlying problem of the relatively high environmental impact of syringes is that the current life cycle is "linear". The impact at the end-of-life of a syringe and its packaging has not been taken into account in the design. This results in syringes being used only once (or not even), disposed of afterwards and being incinerated. To limit the amount of waste and reduce the use of natural resources, the current linear system needs to be transformed into a "circular" one (Ellen MacArthur Foundation 2019). Design can play an important role here, since designing products from a circular economy perspective prevents the production of waste and pollution in the first place. The materials and products used can be designed to be circulated back into the loop instead of ending up in incineration.

Therefore, this project aimed to redesign the syringes, their packaging, and their use, according to circular design strategies suitable for medical products to decrease their environmental impact. Precondition is the fact that the use of syringes should remain convenient and safe for the healthcare staff and patients.

2 Methodology

The research project is divided into four phases: discover (understanding the problem), define (scoping of the project), develop (idea finding and developing concepts) and deliver (design conceptualisation). This is an iterative process, in which different methods are used per phase and each phase can be performed multiple times. Research questions are answered using different methods (as stated in Table 1) and are executed from three different perspectives: a user perspective, a product perspective and an end-of-life perspective. Results from these analyses will identify starting points for design solutions and interventions.

3 Results

3.1 User Perspective

The main users are the staff of the ICU, a team of medical specialists. Four nurses, two care assistants and one pharmacy technician were interviewed. The observations involved all of the staff members of the ICU. A use scenario, user journey and a workflow analysis are made to process the insights.

- **The workflow** analysis visualised the interaction between staff members using syringes. The staff members interact with the syringes in different ways. The intensivists only communicate about the syringe by prescribing the order. The pharmacy technician (PT 1) checks the order and arranges the logistics. Next, a second PT (PT 2) prepares the syringes if needed. Thereafter, PT 1 ensures that the syringe is placed in the drawer of the patient. The nurses interact with the syringes and the patient, and the care assistant only interacts with the syringe before use and the cleaners after use.
- **The use scenario** showed that filling a syringe with medication at the ICU and connecting it to the patient requires several other products in addition to the syringe itself. All these additional products needed to fill the syringe are single-use disposable items, such as gauze pads, gloves, needles, stoppers and packaging. These are needed per syringe since each syringe is filled one by one per specific patient.
- **The flow model** showed that there are different storage locations to store new syringes. One of these locations is the patient's room where strict infection prevention protocols are in place. This means that when a patient leaves after a stay that exceeded 24 h, the entire inventory, including unused syringes in the room needs to

Table 1 Research questions and accompanying methods used

Research question	Method	Explanation method
How much waste is disposed (differentiating between used and unused) on the paediatric intensive care (PICU), and what does it consist of? How many syringes are disposed of (unused)?	Waste audit	General hospital waste of the PICU is collected for four consecutive days. The PICU consists of four units; each day one unit is analysed. Waste is collected per unit for 24 h. The next morning, all bags of one unit are weighed and opened, and next all items are sorted and counted. Each item is classified as 'used' or 'unused' and sorted into one of the 14 product categories. All the categories are weighed separately at the end. One of these categories is "syringes". Besides the general hospital waste, there are also containers for specific hospital waste (SZA). These containers are left out, due to safety reasons and available time. They are only weighed and opened to see what is generally in there
How are syringes used by the staff in the ICU?	User analysis	Use scenario: observe all the steps of using a syringe in the user environment and interview the users about the use process
		User journey (user-centred design): observe different users and their emotions and frustrations during the use process. Afterwards, ask questions about the frustration and general use of the syringe
		A workflow analysis is performed to understand the human context of using a syringe. Two traditional contextual design models are used: the flow model and the physical model. The contextual design models help to understand the workflow of the users. The flow model shows the interaction between the different users. The physical model shows where and by who the products are used (Holtzblatt and Beyer 2017)
What are the product specifications of a syringe?	Product analysis	Analyse the product on materials, different parts, and weight. The weight of the different parts is measured using a KERN & SOHN GmbH 572 Precision balance. The material specifications are retrieved from the technical datasheet of BD Medical, the manufacturer, and by doing desk research

(continued)

be disposed of. These are disposed of without being used and end up being incinerated (Browne-Wilkinson et al. 2021). Furthermore, the user journey showed that certain nurses have the habit of picking up multiple syringes when they only need one.

The main barriers to decreasing the impact of syringes are the infection prevention protocol and behaviour of the staff, causing syringes to be disposed of unused.

Table 1 (continued)

Research question	Method	Explanation method
What process does the syringe go through during its life cycle?	Life cycle analysis and product journey mapping	Product journey: map the journey of the product from beginning to end with accompanying stakeholders
		The life cycle of the product is mapped in a flow chart. All materials and consumables needed to produce and fill a syringe are included. Impact hotspots in the process are determined by looking at energy consumption and materials needed per step A single score indicator, the ReCiPe Endpoint, is used to assess the impact of the (material) hotspots. This indicator combines 18 different impact categories concerning damage to human health, resource scarcity, and ecosystems (Huijbregts et al. 2020). The values of the endpoints can be found in the EcoInvent V3 database. The specific values of the hotspots have been identified by calculations. When the values of specific processes are not present in the database, existing information from comparable situations in scientific papers is used to determine a value
What are alternative life cycle scenarios for a syringe to reduce its impact?	Comparing life cycles	Comparing different life cycle scenarios by doing a literature study. This is done to investigate to see what possible interventions could be of interest

3.2 *End-of-Life Perspective*

A waste audit at the Paediatric Intensive Care Unit (PICU) of the Erasmus MC was done to quantify the waste. The analysis was not performed at the adult ICU, due to logistic reasons. During four days, a total of 570 syringes were collected from the waste bags. There were 5–6 children in each unit, so on average, approximately 27 syringes were used per child per day. Around 2% of the syringes were disposed of unused, most of the time because they were out of date. All syringes were disposed of in the general hospital waste bins, some still containing fluids like blood or medication. This was remarkable since these are supposed to be disposed of in the specific hospital waste containers dedicated to infectious waste.

3.3 *Product Perspective*

The life cycle of the 50 ml Luer-Lok syringes, the type of syringes that are used most in the ICU, was analysed resulting in the following environmental impact hotspots:

The sterilisation process (ethylene oxide): ethylene oxide sterilisation has a significant impact on the environment, but sterilisation is required to deliver sterile syringes to the hospital.

Additional products needed per syringe during the filling process. All the protective products needed at the ICU pharmacy (alcohol swab, sterile gloves, tip cover) are there for preserving the sterility of the syringes. Each syringe is filled one by one per specific patient. Cooled storage (fridge) at the ICU pharmacy until use.

Comparing the life cycle of the original manually filled syringe to new possible life cycle scenarios showed various possibilities to adapt the linear product life cycle towards a more circular life cycle:

- Using prefilled sterilised syringes (PFSs).
- Changing the end of life from incineration to recycling.
- Sterilise the syringes after use for reuse.
- Using other materials; change the material from petroleum-based PP to recycled or bio-based PP or another more sustainable material.

This study looked further into the scenario of PFSs since PFSs are assumed to have a lower impact than manually filled syringes (Cheetham and Johnson 2013). PFSs are prefilled sterilised syringes that are filled and sterilised in large batches by an external provider, in our case Apotheek A15. Comparing the life cycle scenario of PFSs to manually filled syringes showed the following:

- The filling process of PFSs saves a lot of products and materials during the filling process compared to manually filled syringes, as PFSs are produced in large batches (5000 per batch). Needing fewer additional products to prepare a syringe reduces the environmental impact.
- PFSs do not need to be stored in a fridge, as manually filled syringes do.
- Prefilled syringes have a higher impact on a product material level since the syringe is made of materials with a higher ReCiPe endpoint than the manually filled syringe.
- The production process of PFSs involves an energy and water-consuming sterilisation process after filling, which is not the case for manually filled syringes.

4 Discussion

User and product research demonstrated that decreasing the environmental impact of syringes is not only about the product itself. Manufacturing, preparing, using and disposing of the syringe all contribute to the environmental impact. The following possible interventions were identified based on the results:

- The flow model and user journey showed that the storage of new syringes in the ICU rooms could be revised, as well as the infection prevention protocol. Decreasing the stock inside the ICU rooms of the patient would lead to a decrease in unused disposed items. The user journey presented that the amount of disposed of unused syringes could be decreased by changing the habits of staff. Teaching the staff to only pick the amount you are going to use could decrease the disposal of unused syringes.

- From the waste audit, it can be concluded that the separation of general and specific hospital waste is not always done correctly. This makes mechanical recycling of general waste impossible since infectious waste cannot be mechanically recycled. However, the bags from the pharmacy and the bags which only contained food-related waste showed that separating regular waste from (infectious) specific hospital waste is certainly possible in specific areas of the hospital. This creates an opportunity for recycling general hospital waste. Lastly, it was observed that there is no separation of waste based on materials. Changing the environment by placing different waste bins, in for example the pharmacy, to separate waste.
- The system of the syringe was investigated and different lifecycle scenarios were analysed. It turned out that prefilled sterilised syringes (PFSs) require fewer additional products for filling, and are therefore assumed to be more environmentally friendly. However, an impact hotspot analysis of PFSs showed that the materials used, sterilisation and leftover products contribute significantly to the environmental impact. This makes it less environmentally friendly than existing studies assumed. In conclusion, the PFSs are more sustainable than manually filled syringes in terms of less waste. But the PFSs impact hotspots such as the sterilisation process, leftover medication and materials are points of improvement to make the PFSs an actual sustainable alternative for manually filled syringes.
- A cause of these environmental product hotspots is the need for safety and sterility. Sterility and preventing infections during the production and the filling process are the main barriers to decreasing the environmental impact of the production and filling process of syringes.

4.1 Final Design

The final design, therefore, is focused on optimising the entire filling process of PFSs to reduce the environmental impact of these impact hotspots. All steps in the filling process of PFSs have been reviewed and 10 different interventions based on circular design strategies have been proposed (see Fig. 1), resulting in:

- Reduction of waste (interventions number 4. deliver from stock, 5. decrease the amount of drug solution, 6. improve stopper machine, 7. repurpose packaging, 8. reuse plungers and 10. reuse syringes).
- Reduction of energy and water usage (interventions number 1. double sterilisation and 8. steam to gamma).
- Reduction of material impact (intervention number 2. change to a sustainable material).

The proposed interventions have been evaluated with the relevant stakeholders.

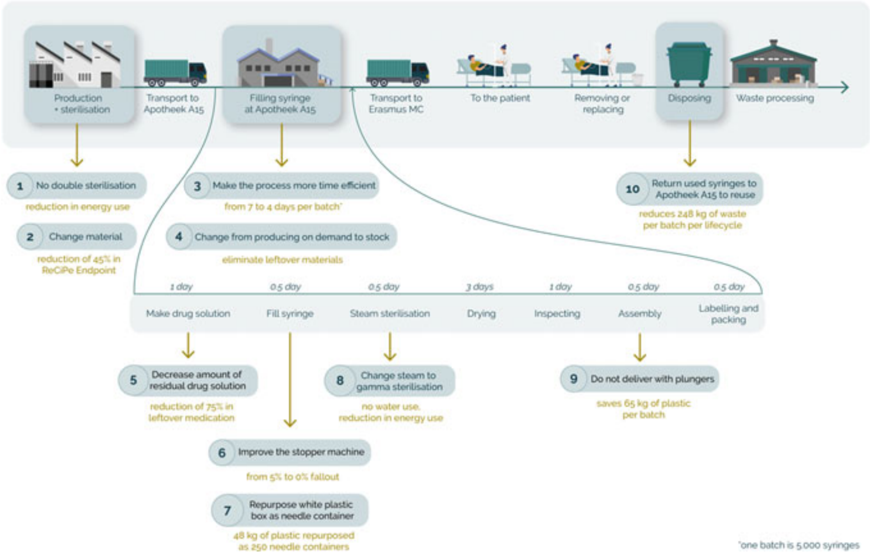

Fig. 1 Overview of interventions to decrease the impact of the filling process of PFSs, visualised on the product journey

This resulted in a holistic concept based on circular design strategies that reduces the environmental impact of syringes without increasing the workflow of the staff in the ICU. Compared to the original manual filling process in the ICU, the concept has an added value by decreasing the workload of the staff in the pharmacy. The workflow of the nurses, care assistants, intensivists, and cleaners will remain the same. The environmental impact of syringes is therefore reduced by optimising the filling process of syringes.

The final design is not the only answer to the main research question and is not the only valuable contribution of this project. The research from different perspectives has revealed a range of pain points and possible solutions that could further decrease the impact of syringes. These insights from the analysis are also valuable for Erasmus MC and the transition to a circular ICU.

5 Conclusions

This project aimed to redesign the syringes, their packaging, and their use, according to circular design strategies suitable for medical products to decrease their environmental impact, while remaining convenient and safe for the healthcare staff and patients.

The outcomes of the research demonstrated that decreasing the impact of syringes is not only related to the design of the syringe itself. Manufacturing, preparation, use and disposal, all contribute to the environmental impact of the syringe. Various possible interventions were derived from this research:

1. Adapting the infection prevention protocol and behaviour of the nursing staff could lead to a decrease in unused disposed syringes.
2. Separating infectious waste from general hospital waste in a proper way could result in opportunities for recycling.
3. The syringe itself can be redesigned to reduce its impact by changing the material to a sustainable alternative and redesigning the shape for (partial) reuse.
4. The impact of the filling process could be reduced. Research concluded that prefilled sterilised syringes (PFSs) are more environmentally sound than manually filled syringes since they are produced in large batches and, therefore, have fewer by-products per syringe. However, a life cycle analysis of the filling process of PFSs showed various impact hotspots in this filling process, such as the sterilisation phase, materials used, and residual medication. The final design is a process optimisation for batch-produced PFSs, based on circular strategies such as reduce, reuse, rethink and repurpose. Interventions include: eliminating the first sterilisation phase, reduction of residual medication and changing from steam to gamma sterilisation.

In conclusion, this study showed how the environmental impact of syringes can be reduced. Replacing manually filled syringes with PFSs saves additional products, and thus saves waste (see Fig. 2). However, the PFSs come with new significant impact hotspots, such as double sterilisation, materials used and left-over medicine. The impact of these hotspots is decreased by the final design, a process optimisation of the PFSs. In the end, the optimised process reduces the amount of waste, energy and water usage and material impact per syringe.

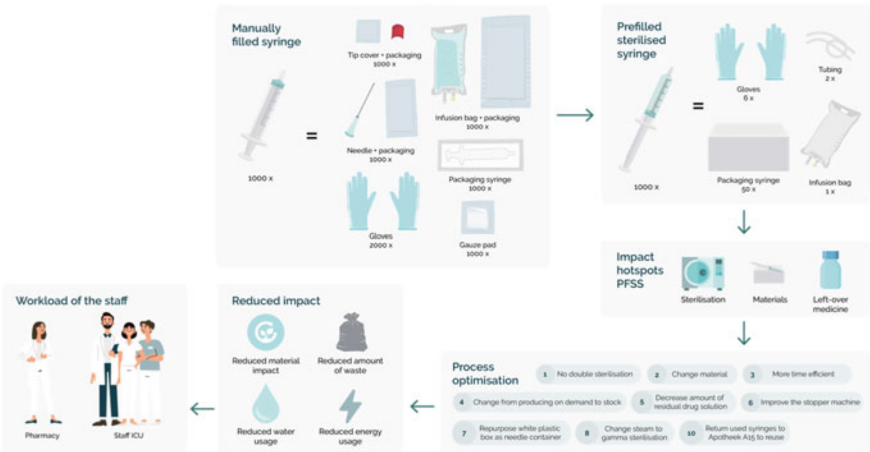

Fig. 2 Visualization of the conclusion of the project

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