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Segregation and Recycling in the Operating Room. An Intervention to Accelerate the Decarbonisation Process in the Health Sector

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ABSTRACT

Aim: To evaluate the impact of a multilevel intervention in a surgical department on the segregation of non-hazardous healthcare waste (plastic and paper) during the perioperative period as well as its effect on the carbon footprint of the healthcare organisation.

Methods: A prospective before–after interventional study without a control group was carried out in the operating room of the Universitary Hospital Mútua Terrassa in Catalonia (Spain). A multilevel programme to improve the segregation process during the surgical interventions was implemented in several phases from May 2023 to December 2024. Data collection was conducted in each phase of the study through questionnaires addressed to the professionals along with calculations of the carbon footprint and the volume of waste segregation. The study is framed within the socio-ecological model and employs a collaborative design. The study population included all professionals working in the operating room ($n = 320$).

Results: A multidisciplinary team was formed with consideration for all stakeholders. The project phases were implemented consecutively. A total of 141 professionals (44.4%) completed the baseline questionnaire. As a result of the project's development, the carbon footprint has been reduced to 79.1 kg CO2 eq/week, representing an 85% reduction in emissions.

Conclusion: The implementation of the recycling project has led to significant reductions in the amount of waste generated and it has been positively evaluated by the professionals.

The benefits of fostering a behavioural change among the professionals, coupled with the implementation of a well-designed segregation and recycling system, lead to significant benefits for the institution in carbon footprint.

Implications for the Profession and/or Patient Care: Nurses can lead this type of project with a clear impact on both the institution and the environment.

Impact: Reduction of the carbon footprint in the operating room increased satisfaction among professionals for contributing to environmental improvement.

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Reporting Method: The reporting of intervention evaluation studies using nonrandomized designs: the TREND statement Des Jarlais et al. (2004) was used to evaluate the quality of the study.
Patient or Public Contribution: N/A. Only professionals are involved in this study.

1 | Introduction

At the heart of the 21st century, the Climate Crisis is the greatest threat currently facing humanity. The increasingly explicit evidence of the impact that Climate Change has on people's health and our environment highlights the inseparability of the concepts of human health and the environment, as well as the importance of preserving our surroundings to protect our own health (Adhanom Ghebreyesus et al. 2023).

Paradoxically, the healthcare sector, which is responsible for the well-being and health of citizens, is also one of the most polluting sectors globally. In fact, if it were a country, it would rank fifth among the most polluting countries, accounting for approximately 5% of global annual emissions.

The healthcare sector contributes to carbon emissions through energy consumption (electricity, steam, cooling, heating), transportation, and the manufacturing, use, and disposal of products. Additionally, it is important to highlight the high generation of waste due to the continuous use of medical materials, as well as other types of products (Grupo del Banco Mundial 2017).

The surgical areas are known to be resource-intensive as they require significant resources to ensure the asepsis of the materials used on patients. Products used in clinical and healthcare practice are all packaged, with many being single-use items. This results in a large amount of waste that needs to be managed, much of which is comparable to urban waste (WHO 2024).

The improper disposal of healthcare waste incurs both economic and environmental costs. This is particularly true for low-risk waste, which is treated as hazardous waste, as the processes involved in handling hazardous materials are costly and require significant resources and energy (Plezia et al. 2024). In this regard, many authors highlight that faulty waste segregation is a global issue and emphasise the importance of creating interventions tailored to each specific context (Shinn et al. 2017).

Hospital Universitari Mútua Terrassa (Catalonia, Spain), as an organisation committed to the fight against climate change, launched the *Compromís Verd* program in 2020. The program aims to achieve three key objectives: decarbonising the healthcare activities carried out by the organisation, defining lines of adaptation to climate change, and serving as a catalyst for raising societal awareness.

The environmental commitment of the healthcare professionals has led to an action plan spearheaded by the nurses in the operating room aimed at minimising, segregating, packaging, storing, transporting, treating and disposing of all generated waste adequately.

2 | Background

Some countries have begun to comprehensively measure the carbon footprint of the healthcare sector. Notably, two studies conducted in the United States found that healthcare sector emissions accounted for 8% and 9.8% of the national total, respectively (Chung and Meltzer 2009). The latest of these estimates corresponds to 655 million metric tons of carbon dioxide equivalent (CO2eq) (Eckelman and Sherman 2016).

In the United Kingdom, the National Health Service (NHS) and Public Health England estimated that their carbon footprint in 2017 was 27.1 MtCO2 eq, accounting for 6.3% of the country's total. Similar findings have been reported in Australia (Malik et al. 2018) and Canada (Eckelman et al. 2018).

Equivalent figures have been reported in Europe, specifically in France, where healthcare centres account for 7% of greenhouse gas emissions (Pichler et al. 2019) and generate 700,000 tons of waste each year, 3.5% of the amount generated nationally (ANAP. Agence Nationale de la Performance Sanitaire et Medico-Sociale 2021). They also contribute significantly to industrial pollution (Lenzen et al. 2020).

These figures are alarming, and hence, many countries have already started to implement specific programs in the healthcare areas to reduce their carbon footprint. In Spain, to address the current climate crisis, the Healthcare ministry has launched the Strategic Plan for Health and Environment (PESMA) intending to promote environments to improve the health of the population and reduce the health risks associated with exposure to environmental factors. Moreover, it defines actions targeting the main environmental factors impacting health and identifies synergies with policies from other departments and administrations (Ministerio de Sanidad and Ministerio para la Transición Ecológica y el reto Demográfico 2021).

The document also formally establishes how to deal with the challenge of waste. There are different policies on waste management from activities and services at a European, national and/or autonomic level which impose a series of limits for the protection of the environment and the public. (Ley 7/2022 https://www.boe.es/eli/es/l/2022/04/08/7/con; Royal Decree 553/2020 https://www.miteco.gob.es/content/dam/miteco/es/calidad-y-evaluacion-ambiental/sgecocir/normativa-y-planificacion/240606_RD553-2020_EN_vfinal(2).pdf; Decree 27/1999, https://portaljuridic.gencat.cat/ca/document-del-pjur/?documentId=187544; Decree 152/2017 https://portaljuridic.gencat.cat/eli/es-ct/d/2017/10/17/152, Decree 93/1999, https://portaljuridic.gencat.cat/ca/document-del-pjur/?documentId=184377).

The regulations allow waste to be treated according to its type, characteristics and hazardous nature. This enables appropriate treatment and final disposal for each type of waste, minimising

Summary

- What problem did the study aim to address?
  - Healthcare facilities generate significant amounts of waste, leading to a large carbon footprint. While hospitals have well-established protocols and regulations for managing biomedical waste, other materials are not always properly segregated.
  - Interventions aimed at healthcare professionals are needed to raise awareness of the importance of separating waste in the perioperative period as well as, in order to help slow climate change.
- What were the main findings?
  - It is possible to improve the process of segregation in the operating room during the perioperative period by means of a motivational intervention aimed at health professionals. Segregation implies an increase in time during the perioperative period.
- Where and on whom will the research have an impact?
  - This research has implications for one of the most waste-generating areas, the surgical areas of hospitals, where large quantities of plastic are generated in addition to biological waste.
  - To segregate clinical waste from general waste in the operating room has an impact on the carbon footprint.

the environmental and health impact through a recycling-centred approach (Abdallah et al. 2024).

Waste can create different risks to people and the environment, such as infections, chemical dangers, or radiation, depending on where it comes from (Decree 27/1999, 1999). Because of this and based on the characteristics of the waste, it is essential to follow the different protocols established by health authorities, which detail the actions required to handle waste safely and responsibly. This practice primarily involves separating waste into different categories according to its type, characteristics and hazard level to minimise the environmental and health impact, with a focus on recycling and a circular economy perspective (Abdallah et al. 2024).

In this context, hospitals play a key role in promoting sustainable practices, minimising waste production, and optimising its segregation and recycling. Segregation of healthcare waste is the first essential step for proper management (WHO 2024).

Waste generation is particularly high in operating rooms, where 20% to 30% of hospital waste is produced (McGain et al. 2009; Azouz et al. 2019). The primary reason for this is the necessity for a wide range of sterile, often single-use medical devices in surgical interventions, coupled with the significant amounts of water and energy consumed (MacNeill et al. 2017).

In surgical environments, due to the meticulous need to maintain a sterile and aseptic setting for surgical practices, the use of disposable and carefully packaged materials generates a higher volume of waste (Fraifeld et al. 2021). These packaging materials are typically made of paper, cardboard and/or plastic and are only used to contain the materials. Once opened, the packaging is discarded as waste. Consequently, 40% of this waste may be classified as potentially recyclable (McGain et al. 2009).

Various frameworks and strategies have been proposed to reduce waste in operating rooms. In Australia, the 2018 National Waste Policy (NWP) (Department of Climate Change, Energy, the Environment and Water 2018) provides a framework to guide investments and sustainable action by businesses, governments, communities and individuals. The National Waste Policy Action Plan (NWPAP) includes five circular economy principles to implement: avoiding waste, improving resource recovery, increasing the use of recycled material, better managing material flows and improving information to support innovation, guide investment, and enable informed consumer decision-making (Department of Climate Change, Energy, the Environment and Water. National Waste Policy Progress Summary Report, 2021 https://www.dcceew.gov.au/sites/default/files/documents/national-waste-policy-progress-summary-2021.pdf). However, translating these general strategies to scalable healthcare implementation has its challenges. Perhaps for this reason, the identified studies implement interventions focused on improving the recycling protocol for Group III (biohazardous) and Group IV (chemical) wastes. Among these studies, the systematic review by Ashtari et al. (2020), stands out with a total of 27 intervention studies.

However, overall segregation at the point of waste generation appears to be the first and most important step in healthcare waste management (Basu et al. 2012). In this sense, many studies have identified some deficiencies in the knowledge, attitude and practices of the healthcare professionals in the organisations (Reddy et al. 2024).

In light of all this, this project presents an intervention aligned with the primary initiative for climate-smart healthcare: reducing the climate footprint of the healthcare sector (Grupo del Banco Mundial 2017). In this regard, a specific action plan was designed to reduce, in the operating room, the amount of waste sent to landfills and promote more sustainable practices within the healthcare sector.

2.1 | The Study

2.1.1 | Aim

The aim of the study was to implement a multimodal intervention to raise awareness of the importance of separation among professionals working in the operating room to contribute to the improvement of recycling and, consequently, to the reduction of the climate impact generated in the health sector.

2.1.2 | Objective

To evaluate the impact of a multilevel intervention on the segregation of non-hazardous healthcare waste (plastic and paper) during the perioperative period, as well as its effect on the carbon footprint of the healthcare organisation.

2.1.3 | Methods

2.1.3.1 | Study Design. A prospective before–after interventional study without a control group was carried out in the operating room of a university hospital in Catalonia (Spain). The report of this study adhered to the reporting of intervention evaluation studies using nonrandomized designs: the TREND statement (Des Jarlais et al. 2004) (File S1).

The project was carried out in several phases: **PRE period** with no segregation comprising **Phase 1**: May 2023, **Phase 2**: June–September 2023, and **Phase 3**: October–December 2023; and a **POST Period**: from February 2024 to the present (see Figure 1).

2.1.3.2 | Study Setting. The study was conducted in the surgical department of the University Hospital Mútua Terrassa (Catalonia, Spain). This hospital has 380 inpatient beds, a 20-bed intensive care unit (ICU) and a surgical block with 16 operating theatres for scheduled surgery and one emergency operating theatre. Additionally, the hospital has three post-surgical resuscitation units with a combined capacity of 25 patients.

Regarding the activity, a total of 27,990 scheduled surgeries were performed in 2023.

2.1.3.3 | Population and Sample. The multilevel intervention was targeted at all professionals employed in the surgical department ($n = 320$), which encompasses a range of professional categories, including nurses (96), auxiliary staff (8), surgeons (102), anaesthesiologists (33), health technicians (74), cleaning personnel (10) and middle managers (5). All professionals were included and informed to ensure the success of organisational change related to waste segregation. Participation was voluntary and participative.

2.1.3.4 | Variables and Data Collection Procedure. The independent variable in the study was the multilevel program aimed at improving the segregation process during the surgical interventions. This program is described in the intervention section.

Data collection was carried out according to each phase of the study using questionnaires addressed to the professionals, checklists during the perioperative process and measurement of the volume of material separation by type (plastic, paper, etc.). The carbon footprint and the volume of waste segregation were calculated along all the phases. The combination of these data collection methods provided a complete picture of the effectiveness of the intervention.

Prior to the start of the intervention, a baseline ad hoc questionnaire was used to assess the motivation for segregation in the workplace. The questionnaire comprised eight questions, two of which pertained to socio-demographic data (age and professional category), while the remaining six employed a numerical rating scale from 0 to 10 to assess respondents' levels of concern and involvement in recycling in their personal lives and interest

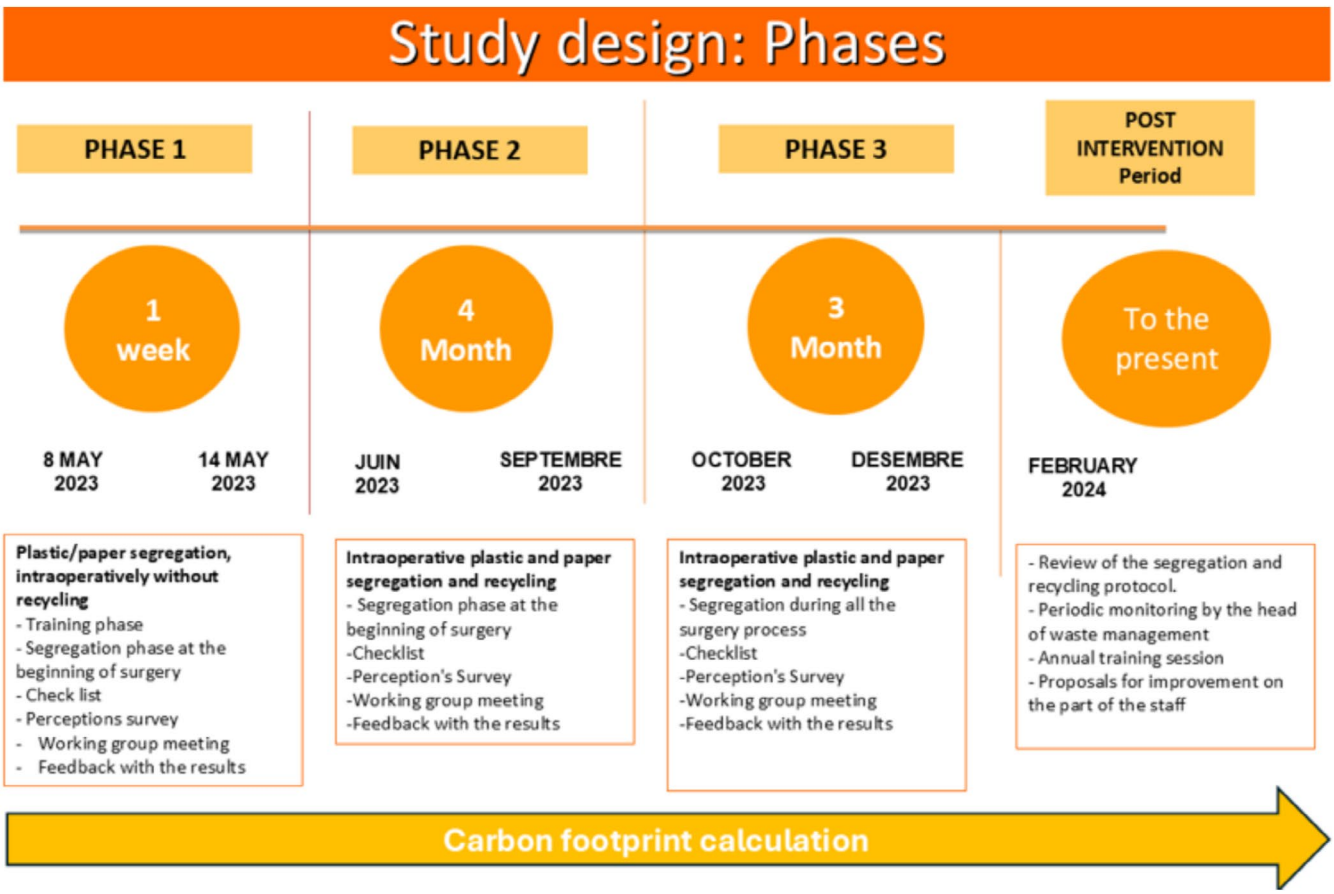

FIGURE 1 | Study design and project implementation phases.

TABLE 1 | The emission factors provided by the Catalan Office for climate change.

Emission factors			
Concept	**Type of treatment**	**Emission factors**	**Units**
Paper and cardboard waste	Paper and cardboard recycling	159.87	kg CO2 eq/t
Paper and cardboard waste	Paper and cardboard recycling	0.16	kg CO2 eq/kg
Plastic waste	Management through a Collection and Transfer Center	106.22	kg CO2 eq/t
Plastic waste	Management through a Collection and Transfer Center	0.11	kg CO2 eq/kg
Household and similar waste	Management through a Collection and Transfer Center	912.21	kg CO2 eq/t
Household and similar waste	Management through a Collection and Transfer Center	0.91	kg CO2 eq/kg

in applying recycling practices in their work environments. Follow-up questionnaires were administered during the implementation process to gather perceptions of the implemented segregation process. The final questionnaire also assessed overall satisfaction with the implemented recycling programme and the perceived need for its implementation in other hospitals.

To quantify the extent of segregation, we calculated the number of bags, kilograms per day, and kilograms per week for each material type.

2.1.3.5 | Carbon Footprint Calculation. The carbon footprint calculation focuses solely on the final stage of the life cycle of recycled plastic and paper since the only aspect that changes within the product's life cycle is the final waste management.

As there is no data on the total amount of waste generated in the areas, both for Group I and Groups II, III and IV, the carbon footprint calculation was made by comparing the emissions from the different waste management methods for the quantified waste.

The emission factors used for the carbon footprint calculation are those listed in the calculation guide provided by the Government of Catalonia, 2024 (Generalitat de Catalunya 2024). The emission factors (EF) are provided by the Catalan Office for Climate Change and represent the estimated value of Greenhouse Gas (GHG) emissions produced by a process or product (see Table 1).

The carbon footprint calculation is based on the volumes of waste recycled at each phase of the project (see Table 2).

2.1.4 | Study Intervention

The study is framed within the socio-ecological model. This model is founded upon five levels: intrapersonal, interpersonal, organisational, community and public policy (Sallis et al. 2006) (see Figure 2). The improvement project was designed using a collaborative project framework (Camarinha-Matos et al. 2008), an approach that brings people together to co-create and develop solutions to complex problems.

First, a promotion team was set up that included all the stakeholders: nurses and technicians from the operating room, the service manager, the waste distribution and management officer, the *Compromís Verd* team and the center's communications manager. Through this promotion team, different actions and phases of the project were designed to drive structural changes and encourage behavioural change among professionals regarding the separation of Group I waste:

1. **Segregation process**: Before the project was implemented, paper/cardboard and packaging were treated as Group II waste and were sent to the collector. During the project, the on-site waste management process was modified to classify paper/cardboard and packaging as Group I waste, thereby enabling their reincorporation into the value chain through recycling.
2. **Basal motivation**: To identify the motivations driving professionals' waste segregation efforts, an ad hoc questionnaire comprising eight questions was designed and distributed to professionals via a QR code. A total of 142 professionals completed the questionnaire.
3. **Training/sensitization**: An awareness-raising session was conducted for all members of the surgical team. The session covered essential recycling concepts on waste classification in the perioperative process and its impact on the carbon footprint and global climate change. Three sessions were held across different work shifts, with a total of 200 professionals participating.
4. **Visual Campaign**. The communication team designed posters with clear information on the types of waste and proper segregation practices. These were strategically placed in high-traffic areas, including rest areas, operating rooms and resuscitation rooms.
5. **Segregation Guidelines**. A list detailing the primary types of medical waste generated in the operating room and their proper segregation methods was created and made available in the operating rooms. The list was updated as new requirements and concerns arose during the implementation of the project.
6. **Infrastructure**. The operating rooms were equipped with 23 containers for paper segregation and 23 containers for plastic segregation. The equipment of each operating room before and after the implementation of the project is shown in Images 1 and 2.

TABLE 2 | Carbon Footprint Calculation according to the Catalan Office for Climate Change (Government of Catalonia 2024).

Type of material	Carbon footprint calculation process
Paper and cardboard recycling	Calculation performed by multiplying the weight of the recorded paper and cardboard waste by the emission factor (EF) associated with the waste treatment process through recycling **kg CO_2; eq** = Weight of paper and cardboard waste × Paper and cardboard recycling emission factor
Packaging Recycling	Calculation performed by multiplying the weight of the recorded plastic waste by the emission factor (EF) associated with the waste treatment process through recycling **kg CO_2; eq** = Weight of paper and cardboard waste × Paper and cardboard recycling emission factor
Treatment of municipal and similar waste	Calculation performed by multiplying the weight of the recorded paper and cardboard waste and plastic waste by the emission factor (EF) associated with the waste treatment process Group II The calculation reflects the emissions that would have been generated if the waste had been treated in the same way as before the project was implemented **kg CO_2; eq** = Weight of paper and cardboard waste × Waste treatment emission factor (Group II) **kg CO_2; eq** = Weight of packaging waste × Waste treatment emission factor (Group II)

Additionally, end-point containers and the necessary compactors (for paper, cardboard and plastic packaging) were purchased to ensure proper storage of the segregated waste.

7. **Intraoperative Implementation of Segregation**. This Was Carried out in three phases.

Phase 1

Learning period. Over the course of 1 week, we simulated the segregation process. A questionnaire was administered to the surgical team to assess the effectiveness and challenges encountered.

The ad hoc questionnaire consisted of 9 questions with a response scale of 0 to 10. If the total score of the survey was ≥ 7, it was moved to PHASE 2. If the score was < 7, it continued in PHASE 1 for an additional week.

The members of the working group met to review the results of the questionnaire and proposed new guidelines to promote engagement, participation and success.

Phase 2

Intraoperative separation of clean plastic/paper for subsequent recycling. Separation is completed at the start of surgery (during the incision) to ensure that waste does not come into contact with biological debris typically found in surgical procedures. The professionals gain hands-on experience in handling and segregating materials.

The same questionnaire is administered to the professionals to assess effectiveness and identify challenges. If the total score of the survey was ≥ 7, it was moved to PHASE 3. If the score was < 7, the process continued in PHASE 2 for an additional week.

Duration of the phase: 4 months.

The members of the working group met to review the results of the questionnaire and proposed new guidelines and the new phase.

Phase 3

Segregation is performed throughout the intraoperative period. By this stage, professionals have gained both practical experience and advanced knowledge, allowing them to segregate waste safely throughout the surgery. A checklist was used during the process to ensure its correct implementation. A new questionnaire was administered to evaluate the effectiveness of the implemented process.

Duration of the phase: 3 months.

The working group met with the professional teams to evaluate the new guidelines and thank them for their participation and commitment to the programme.

8. Creation of an action and follow-up protocol.

2.1.5 | Data Analysis

A descriptive analysis was conducted on the data collected from the various questionnaires utilised. Frequencies and proportions were employed for categorical variables, while means and standard deviations were used for continuous variables. The carbon footprint and the volume of plastic and paper resulting from segregation were calculated as specified in the methodology section. Finally, the results were compared regarding the carbon footprint and volume of plastic and paper segregated before, during and after program implementation.

2.1.6 | Ethical Considerations

Since no interventions were performed on the patients in the study, the study did not require approval and was exempt from ethical review.

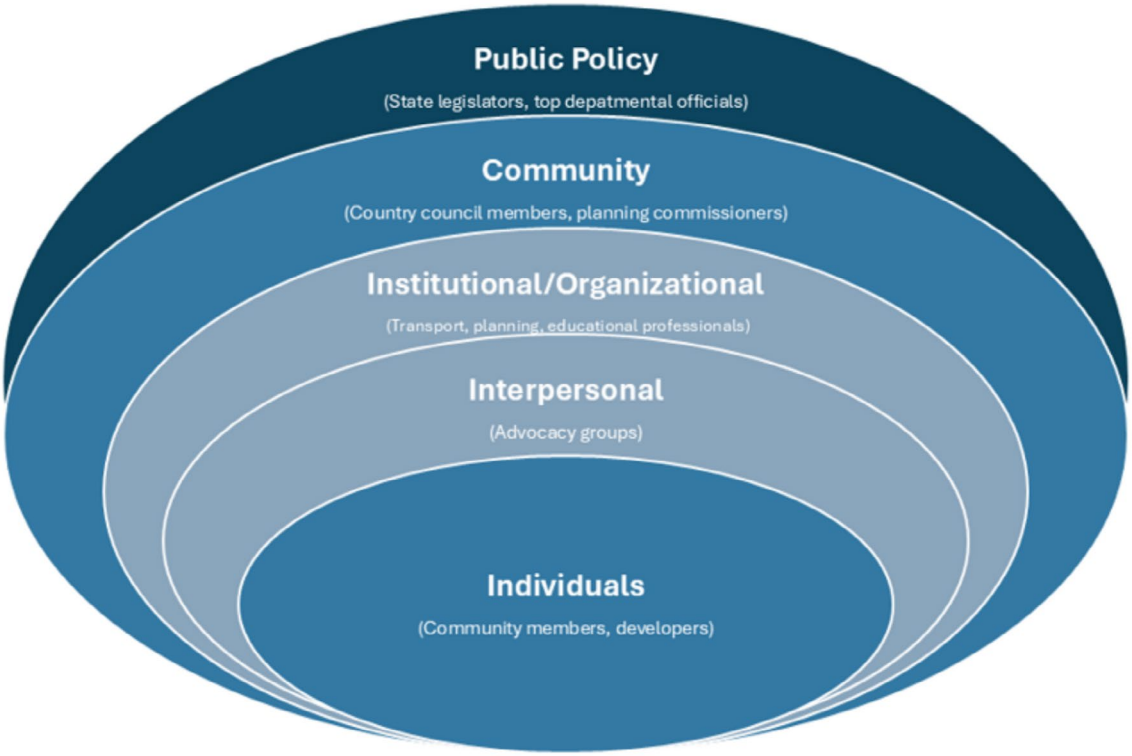

FIGURE 2 | Levels of the socio-ecological model. (Sallis et al. 2006).

IMAGE 1 | Operating room containers for segregation.

IMAGE 2 | Recycling bins on theatre trolleys.

All the professionals involved were informed of the purpose of the study and agreed to participate.

3 | Results

The results are presented by sections.

3.1 | Segregation and Footprint Calculation

The quantity of waste bags, broken down by material type, collected in each phase of the project, along with the associated carbon footprint, is presented in Table 3.

A carbon footprint of 534.6 kg CO2 eq/week would have been generated if the project had not been carried out, i.e., if the waste had been treated as Group II, without being recycled into the appropriate fraction.

Thanks to the project, the carbon footprint has been reduced to 79.1 kg CO2 eq/week, representing a reduction percentage of 85%.

Moreover, it has allowed for an 82% reduction in the carbon footprint associated with the final disposal of each kilogram of recycled paper/cardboard. For plastic, emissions associated with its final disposal have been reduced by 88%.

Throughout the project, a carbon footprint reduction of 85% and 86% was achieved through the recycling of the studied

TABLE 3 | Results of segregation by waste type (bags/weight/carbon footprint) and final disposal management.

					With segregation	Without segregation	With segregation	Without segregation
PHASE 1								
	Bags/day	Bags/week	Kg/day	Kg/week	kg CO2 eq/day	kg CO2 eq/day	kg CO2 eq/week	kg CO2 eq/week
Paper	0	0	0	0	—	—	—	—
Plastic	0	0	0	0	—	—	—	—
TOTAL	0	0	0	0	—	—	—	—
PHASE 2								
Paper	63	315	50,6	253	8.1	46.2	40.4	230.8
Plastic	77	385	56,8	284	6.0	51.8	30.2	259.1
TOTAL	140	700	107,4	537	14.1	98.0	70.6	489.9
PHASE 3								
Paper	57	285	63	315	10.1	57.5	50.4	287.3
Plastic	59	295	54.2	271	5.8	49.4	28.8	247.2
TOTAL	116	580	117.2	586	15.8	106.9	79.1	534.6

waste, resulting in a reduction of 419 kg CO2 eq per week during the second phase and 455 kg CO2 eq per week in the final phase.

3.2 | Behavioural Change

The implementation of the improvement plan involved all staff members from the surgical department ($n = 320$).

A total of 141 professionals: 60 nurses, 41 surgeons, 23 auxiliaries, 2 radiology technicians, 10 cleaning staff, 2 technical services and 3 others responded to the baseline questionnaire, accounting for 44.4% of the population. It is noteworthy that all responses had an average score above 7, except for whether they believe recycling during surgical procedures could affect the duration of the process (see Table 4).

In phase 1, a total of 25 professionals responded: 9 nurses, 3 auxiliaries and 13 surgeons. In phase 2, a group of 64 professionals responded: 31 nurses, 16 auxiliaries, 2 radiology technicians, 10 surgeons and 5 others. In phase 3, there were 33 responses: 20 nurses, 12 auxiliaries and 1 radiology technician.

Notably, only values below 7 on a scale of 0–10 appeared for the question regarding whether they believe all staff properly segregated waste during the surgical intervention, with an average score of 6.1 (see Table 4).

Additionally, the professionals believe that the segregation process does not slow down the work pace (7.33). The average overall satisfaction with the project was 8.8 (SD = 1.3). The question regarding the belief that all hospitals should segregate waste received the highest possible score (100).

As required by each phase of the project, the self-assessment tests were positive (scoring above 7) and allowed progression to the next phase of the programme.

On a global level, the use of the socio-ecological model enabled the identification of the program's impact at different levels. At the individual level, each professional actively participated in the segregation project, gaining an understanding of the process. At the group level, all members of the surgical department (surgeons, auxiliaries, nurses, cleaning staff) worked as a team to implement the new segregation circuits and processes. At the organisational level, the managers of the surgical department, general services staff and waste management technicians created shared circuits. Finally, at a global level, the institution contributed to reducing environmental impact.

4 | Discussion

The results of the study demonstrate that the multimodal project "Segregation and recycling in the operation room" was successful in terms of participation, acceptance, and effectiveness in reducing the institution's carbon footprint.

Before the project began, professionals in the surgical department demonstrated a high level of awareness regarding domestic recycling. Other French authors, such as Tordjman et al. (2022), found through a questionnaire on "Environmentally Sustainable Practices at Home" that 99.5% of participants reported efforts to limit their environmental impact in their personal lives. Similarly, on a global scale, with a majority of European participants, the study by Chang et al. (2023) also concluded that most professionals were concerned about global warming and climate change. This awareness is crucial for achieving high levels of

TABLE 4 | Responses from the questionnaires used in each phase of the project.

Items	Study Period			
	Pre-intervention $n=141$ mean (SD)	**Phase 1 $n=25$ mean (SD)**	**Phase 2 $n=64$ mean (SD)**	**Phase 3 $n=33$ mean (SD)**
Concern about the environmental impact of waste	8.80 (SD 1.6)			
Recycle at home	9 (SD 1.7)			
Correct recycling in the common areas of the surgical block	7.36 (SD 2.2)			
Impact of intraoperative waste segregation on work pace	6.8 (SD 2.5)			
Importance of intraoperative recycling	9.32 (SD1.4)			
Satisfaction with the segregation and recycling project	9.24 (SD 1.6)			
Intraoperative waste segregation		8.04 (SD 2.7)	8.4 (SD 1.3)	8.67 (SD 1)
Correct segregation		8.6 (SD 2)	8.84 (SD 1.4)	9.12 (SD 0.9)
Confirmation of staff segregation		5.96 (SD 1.9)	6.52 (SD 1,4)	6 (SD 2,4)
Necessary infrastructure		7.2 (SD 2.1)	7.68 (SD 2.4)	7.5 (SD 2.2)
Impact on work pace				7.33 (SD 1.9)
Ability to move to the next phase		8.88 (SD 1.8)	8.57 (SD 1.9)	
Activity satisfaction level				8.78 (SD 1.3)
Belief that all hospitals should segregate				100% Yes

professional participation and may contribute to minimal resistance to change.

In this regard, the maximum score for the question asked at the end of the project about the "belief that all hospitals should segregate waste" reflects a strong commitment to sustainability and the reduction of environmental impact by the staff.

Regarding the program's ability to motivate the surgical block staff, the multidimensional program successfully promoted a global and positive behavioural change towards waste management in the workplace. Similar experiences have been reported in Australia (Wyssusek et al. 2016) with encouraging results. Specifically, the literature supports the implementation of projects based on behavioural change theories that impact both the individual and organisational levels (Schulte 2007).

The theoretical framework of the project, based on the socio-ecological model (Sallis et al. 2006), proved effective in identifying the impact at the individual, group, organisational, and community levels of action, with the added benefit of reducing the carbon footprint.

Additionally, the collaborative design approach facilitated the design, implementation, deployment and analysis of the project. In the field of recycling projects, other models, such as the Plan-Do-Study-Act (PDSA) model for improvement (Wyssusek et al. 2016), have also been successfully applied. Other studies have reached similar conclusions, suggesting that specifying the need for continuous, mandatory education in hospitals, led by a dedicated "green team," might improve the framework to encourage behavioural change (Pillay et al. 2024).

The barriers and facilitators to reducing waste generated in the operating room reported in the literature are extensive (Pillay et al. 2024; Azouz et al. 2019). Therefore, taking them into account when designing the study was crucial for achieving success in the stated objective.

The focus of this study is not on a quality programme aimed at improving the correct recycling process for hazardous medical waste, a topic extensively covered in the literature (Amariglio and Depaoli 2021), nor on improper segregation in the operating room. Rather, it focuses on segregating paper and plastic materials during the intraoperative period that can be treated as urban waste, and hence, reducing costs.

Thus, this project demonstrates the importance of multidisciplinary collaboration throughout the development and implementation of quality initiatives. Healthcare professionals can reduce waste in the healthcare system and contribute to the global ecology of the planet. In particular, in the present study, the role of the surgical block nurses was fundamental to the continuity and success of the project. In this sense, some authors argue that nurses, in particular, should be at the forefront of these efforts (Harris et al. 2009).

In this program, the carbon footprint was measured, and the results were shared as feedback with the professionals. This action may have helped sustain behavioural change over time by allowing them to see themselves as drivers of contribution to the planet's sustainability.

The results of this study once again highlight the impact of indirect emissions caused by healthcare activities on the carbon footprint (Rodríguez-Jiménez et al. 2023; Eckelman et al. 2018) and propose a successful strategy to reduce them. However, among all indirect emissions, it only addresses the fraction related to waste. The results of this improvement in the carbon footprint are difficult to compare to those of other studies, which analyse different phases of the surgical process and identify medical devices and consumable materials as the main contributors to the carbon footprint (Robinson et al. 2023). Therefore, a key aspect of the present study is that it calculates how changing the treatment of waste generated in the perioperatory period drastically reduces the carbon footprint associated with its end-of-life management—an aspect rarely addressed in the reviewed literature.

Last but not least, our project which was implemented in a specific area of the hospital—the surgical department—could be extrapolated to other healthcare facilities, including clinics, hospitals and primary care centres. The lessons learned and best practices developed in the hospital setting can be replicated and tailored to meet the specific needs of each context, offering the potential to significantly enhance waste management and promote environmental sustainability within the healthcare sector.

In this respect, it will be necessary to collect more precise data to assess the waste generated by different groups in each care area. This will shed light on more detailed and specific results to track the evolution of the carbon footprint over time.

The present study shows some limitations. The first limitation stems from the study design. The absence of a control group limits the potential to generalise the results to other populations. However, this type of design is common in pilot studies and provides valuable information on the effectiveness of the intervention within the surgical department, making it transferable to other healthcare settings.

Another limitation is that the response rate to the questionnaires was not homogeneous, and in some phases, it was lower than desirable. However, the project implementation was followed by the majority of the professionals in the operating room. Moreover, we used an ad hoc questionnaire to assess the sensitivity and willingness of the professionals towards home recycling and its applicability in the workplace.

Finally, we do not have specific baseline data on the number of bags in Group II generated in the studied area. We only have global data from the entire hospital, and therefore, the results obtained cannot be compared with the situation prior to the project implementation. Furthermore, a relative comparison is provided of the volume of segregated and quantified waste that, in the baseline situation, would have been treated as Group II waste.

5 | Conclusions

The waste segregation project in the operation room has been a resounding success accomplishing significant reductions in the amount of waste generated, as well as having a positive response from the healthcare staff. Additional improvement proposals will further reduce the waste and make the project even more sustainable.

Generating a behavioural change in the professionals, as well as implementing a well-designed segregation and recycling system, could benefit the institution itself and help reduce the carbon footprint in the healthcare system.

As future recommendations, we propose to continuously monitor the results to assess the long-term impact of the project and keep exploring new ways to reduce waste and improve the sustainability of the surgical department. Future initiatives could involve exploring strategies such as optimising surgical packs, re-evaluating single-use items, and promoting the adoption of reusable materials where feasible. Moreover, collaboration with suppliers to enhance the sustainability of medical products and packaging could further contribute to minimising waste at the source. These considerations will be addressed in the next phase of our sustainability efforts within the surgical department.

We also propose to intensify the cross-disciplinary training in sustainability for all healthcare professionals, as well as to focus efforts during the onboarding of new employees to instill a culture of proper waste segregation and recycling practices. Proper training in this area is essential to guarantee the efficient and sustainable management of hospital waste, which in turn contributes to the protection of the environment, public health and safety of the staff.

Author Contributions

Barbara Carmona-Pomada: conceptualization, investigation, methodology, supervision, validation, formal analysis, writing – original draft. **Laura Diaz-Co:** conceptualization, investigation, methodology, supervision, validation, formal analysis, writing – original draft. **Hamid Azaroual El Bachiri:** conceptualization, investigation, methodology, supervision, validation, formal analysis, writing – original

draft. **Núria Nieto-Lorente:** conceptualization, supervision, validation, supervision. **Gemma Muriel-Serrano:** conceptualization, supervision, validation, formal analysis, writing – original draft. **Laia Zarza-Sánchez:** conceptualization, supervision, validation, formal analysis, writing – original draft. **Conxi Caro-Benito:** data curation, methodology, resources, supervision, writing – review and editing. **Olga Monistrol:** investigation, methodology, supervision, validation, formal analysis, writing – original draft, writing – review and editing.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are openly available in CORA. Repositori de Dades de Recerca at https://doi.org/10.34810/data2060.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.