Ecoresponsible actions in operating rooms: A health ecological and economic evaluation

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Health Economic Evaluation

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ABSTRACT

Background: In the current context of climate change, actions must be taken to improve the hospital's ecological footprint, particularly in the operating room, which is a major consumer of medical devices.
Methods: This prospective pilot study assessed the ecological and economic impacts of sustainable actions targeting medical devices designed by a multidisciplinary working group and implemented in the 24 operating rooms of a University Hospital over one year. The ecological analysis was based on the life cycle assessment method and categorized in seven impacts. The economic impact was assessed by a micro-costing analysis and divided in four main expense items: human and material resources, logistics, and waste management.
Results: In total, 13 actions were implemented with the aim of reducing waste volume, improving waste sorting, and increasing eco-responsible purchases. In one year, these 13 actions allowed avoiding the emission of 203 tons eq CO_2. The environmental and human toxicity benefits were 707.8 and 156.2 tons of 1.4 dichlorobenzene, respectively. Concerning non-renewable resources, these actions avoided the extraction of 9 tons of oil (petroleum) and 610 kg of copper per year. These actions led to a land occupation reduction of 1071.3 m^2year and to water saving of 552 m^3. From the economic side, the implementation of these actions brought a gain of €3747.9 for the first year and of €5188.2 for the following years.
Conclusion: The integration of sustainable measures in operating rooms leads to important ecological benefits and also generating savings. This more eco-responsible approach should be considered in all healthcare establishments that generate a significant annual volume of waste.

1. Introduction

The report on the 6th Intergovernmental Panel on Climate Change, published in August 2021, alerted on the many natural disasters that have occurred in recent years, and the conclusions are clear: the climate and ecological emergency must be a priority, in all sectors [1]. In 2009, Costello et al. already warned about climate change and its impact on the world population in the next decades [2]. Moreover, a 2019 study estimated an annual excess mortality of 659,000 people caused by pollution in the European Union [3]. In France, healthcare establishments produce ~700,000 tons of waste per year (i.e. 3.5% of the national waste production) [4], including many sterile medical devices (SMD). Considering all healthcare activities, the main SMD consumers are technical platforms, such as operating rooms (OR). Indeed, OR growing activity is accompanied by a continuous increase in the number and volume of consumed SMD that represent a major source of waste. One of the main causes of waste overproduction in OR is the many SMD that are removed from their packaging but not used during surgery, and that has significant ecological and financial impacts [5]. A study carried out at a French University Hospital (urology, gynecology, and digestive surgery) showed that wasted supplies represented up to 20.1% of the total costs allocated to surgical supplies. Different causes were

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identified: anticipation of the surgeon's needs, aseptic mistakes, comfort, wrong choice of supplies [6]. It is essential to reconsider how SMD are used, including reviewing the medical device circuit using an eco-responsible approach. Several additional factors must be considered when thinking about a sustainable approach in OR: water and energy savings, greenhouse gas reduction, waste management and also the work life quality, which represents an important part of the social aspect of sustainable development. A growing number of initiatives concerning sustainable development in OR have been developed. For example, some studies reported that harmonizing surgical practices decreases the number of stored references and so the overconsumption, leading to a reduction in costs [7,8]. A narrative review based on 81 articles found that reusable devices reduce costs, water consumption, energy consumption, waste, and greenhouse gas emissions compared to single-use devices. This study also showed the supposed benefit of single-use devices for infectious risk reduction is based on weak scientific arguments [9]. The environmental impact of single- and multiple-use SMD began to be studied few years ago. For example, Eckelman et al. demonstrated that the environmental impact of 40 uses of a reusable laryngeal mask airway device is lower than that of 40 disposable laryngeal masks. The worse ecological impact of disposable masks was mainly explained by their production, packaging, and waste management (*vs* washing and sterilization for reusable masks) [10]. Another study on reusable laryngoscope blades showed that single-use plastic blades generate 5–6 times more CO_2 equivalents than reusable steel blades treated by high-level disinfection. Reusable devices also decrease the CO_2 emissions related to transportation and waste [11]. Similarly, a study in an Australian healthcare facility with six OR showed a 46% of cost savings when converting from single-use anesthesia plastic drug trays to reusable equipment [12].

In this context of generalized SMD overconsumption and where suppliers are regularly announcing supply shortages (increased by the COVID-19 pandemic), a general awareness seems to emerge among health professionals about the ecological challenges of tomorrow.

To address these needs and to propose concrete solutions, the objective of this study was to evaluate the ecological and economic impact of the implementation of sustainable measures targeting SMD in OR.

2. Methods

2.1. Study design

We carried out a monocentric prospective pilot study in the OR of a French University Hospital from September 2020 to September 2021. This study was approved by the Institutional Review Board of the University Hospital (N° *blinded*) and has been reported in line with the CHEERS criteria.

The sustainable actions concerning SMD were implemented in the 24 OR (among which 4 ambulatory rooms), 3 preoperative rooms, 3 post-anesthesia care units, and the Sterile Processing Department (SPD). All surgical specialties (neurosurgery, otolaryngology, ophthalmology, orthopedic, plastic, vascular, gynecology, urology, and digestive surgery) and anesthesia were included in the study to involve all the professionals working in the OR and SPD.

2.2. Creation of the working group and staff survey

First, a multidisciplinary working group composed of representatives from all health professionals working in the OR and SPD was created (e.g. surgeons, anesthetists, OR nurses, nurse anesthetists, auxiliary nurses, SPD pharmacist and pharmacy technicians, clinical pharmacists with strong expertise in medical devices, health managers). The hospital hygiene unit also was represented by a pharmacist and a nurse. Lastly, the hospital environmental engineer and sustainable development technician were included in the working group to assess the feasibility of some actions and to ensure the link with the other hospital departments. The working group members were included on a voluntary basis after a call for candidature. Every month, the working group met to define sustainable actions that could be implemented in the OR, to assess their feasibility, and to discuss the feedback concerning the previously implemented activities. In these meetings, the working group also validated the monthly newsletter that included highlights on ecology in health, and the main results of this study. The monthly newsletter was sent to all OR, SPD and pharmacy employees ($n = 650$). Before the study start, a short survey was sent to all OR and SPD staff to assess their awareness and interest on sustainable development. It included questions about their general awareness on sustainable development, its role in their personal and professional life, and motivation to get professionally involved in its implementation at their workplace. The results were collected and analyzed with the REDCAP® software (v11.1.0).

2.3. Sustainable actions and their feasibility

The first objective of the working group was to define sustainable actions that could be implemented in the OR and/or SPD. Multiple sources were used to identify sustainable actions, such as a literature data, exchanges with other healthcare establishments and with learned societies (e.g the French Society of Anesthesia, Critical Care and perioperative Medicine, SFAR). Moreover, many interviews with hospital employees (e.g. nurses and surgeons) were performed. Once an action was identified, an analysis of the technical, economic and human resource feasibility was performed by the working group. An action was considered as technically feasible if its implementation did not involve major works that would have taken several months to complete (small changes works were acceptable). For the economic feasibility, since no specific budget was allocated for the realization of this study, if the action generated a budgetary investment up to € 3,000, the hospital financial director was solicited for approval. Concerning human resources, the action was validated if no additional staff was needed, or if the increased workload created by the task was considered acceptable by the working group and the health managers in charge of its application. Once the feasibility of an action was validated, relevant data were collected before its implementation (before scenario). Then, training or information on the action was given during its implementation. Finally, relevant data were collected again after its implementation (after scenario). The actions were numbered in order of analysis and then grouped into 3 categories (Table 1). The annual consumptions were calculated from the averages of the last 3 years consumption (2017–2019) of medical devices or based on the surgical activity before the COVID-19 pandemic began (2019) (Fig. 1).

2.4. Data collection

Due to the diversity of the implemented actions (Table 1) that concerned different employees and hospital departments, many different data were collected (e.g collection of suppliers data, weighing of packages, time for intervention preparation). For each action, the before and after scenario data were collected by the same pharmacist (Table 1).

2.5. Ecological impact

The ecological impact was evaluated using the life cycle assessment (LCA) method with the SimaPro® v9.2.0.1 software. The LCA is a quantitative method based on a multi-criteria environmental analysis. It considers all the life phases of a product or a process/activity: raw material extraction, product manufacturing, transport and distribution, use, and end of life. For this study, some criteria, such as manufacturing processes, were not considered, due to the lack of information. For each action, the results obtained by the LCA method were then summarized and classified in seven categories: global warming (climate change impact) (kg eq CO_2), occupied land (m^2 year crop eq), human toxicity

Table 1
Sustainable actions and data collected.

	Description of the action	Functional unit (before scenario)	Functional unit (after scenario)	Specialty concerned	Annual consumption	Data collected
a. Waste reduction actions						
1 2	Custom brain surgery pack Custom coelioscopy pack	Individual packaging for each SMD[a]	All needed SMD in one package	Neurosurgery Digestive/ Gynecological surgery	220 units 1200 units	• Waste weight/waste type. • Time for intervention preparation. • Purchasing costs. • Waste management costs
3	Change of anesthesia face masks to a version without plastic hook	Anesthesia mask with plastic hook	Anesthesia mask without plastic hook	Anesthesia	16,000 units	• Waste weight/waste type • Purchasing costs • Waste management costs
4	Redon drain without pre-mounted needle for robotic urological surgery	Pre-mounted needle on the Redon drain systematically wasted (ICW[b]) during robotic surgery	Redon drain without pre-mounted needle	Urological robotic surgery	130 units	• Weight of avoided waste (ICW) • Purchasing costs • Needle composition • Waste management costs
6	Change from single-use to reusable laryngoscope blades	Single-use laryngoscope blades	Reusable laryngoscope blades	Anesthesia	17,184 units	• Waste weight • Purchasing costs • Sterilization costs • Logistic costs • Blade composition • Waste management costs
10	Implementation of a movable irrigation fluid recovery system for wastewater	Evacuation of surgical fluids to the ICW with a classic system using flexible bags	Evacuation of surgical fluids with a movable suction system connected to the wastewater	Urological/orthopedic surgery	400 interventions	• Waste weight • Purchasing costs • Handling time • Waste management costs
13	Single-pack surgical kits	Using double packaged surgical kits	Using single-pack surgical kits	Urology and some general surgeries	2000 + 1850 units	• Waste weight/waste type • Purchasing costs
b. Waste sorting actions						
5	Recycling the aluminum blisters of surgical sutures	Aluminum blisters wasted in NICW[c]	Aluminum blister recycling	All surgery specialties	76,500 units	• Waste weight of one blister • Waste management costs
7	Optimization of selective waste sorting in OR	No recycling channel in OR	Setting up a recycling channel in OR		21,000 interventions	• Weight of recycled, NICW and ICW waste • Purchasing costs of garbage bags • Logistic costs • Set up/training time. • Waste management costs
8	Metal waste recycling at the SPD[e]	Defective SMD not eligible for repair wasted in NICW	Recycling of defective SMD not eligible for repair	SPD	54 kg	• Weight of recycled waste • Purchasing cost of storage boxes • Handling time • Waste management costs
9	Rationalization of the use of triclosan-coated surgical sutures	Widespread use of triclosan-coated sutures	Use of not triclosan-coated sutures when possible	All surgery specialties	8172 units	• Purchasing costs • Suture composition
12	Recycling of ES[d] wires	ES wires wasted in NICW	Recycling of ES wires		10,000 units	• ES weight • Disinfection costs • Purchasing costs of disinfection boxes • Waste management costs
c. Eco-responsible purchasing action						
11	Creating a sustainable development questionnaire for medical device suppliers	The final score when referencing a medical device was based on the technical (60%) and economic (40%) scores	Addition of a sustainable development score (5%) to the final score	Surgical medical devices referenced in the hospital database	200 references	• Human resources to create the questionnaire and exploit the data

[a] SMD: sterile medical device.
[b] ICW: infectious clinical waste.
[c] NICW: non-infectious clinical waste.
[d] ES: electric scalpels.
[e] SPD: sterile processing department.

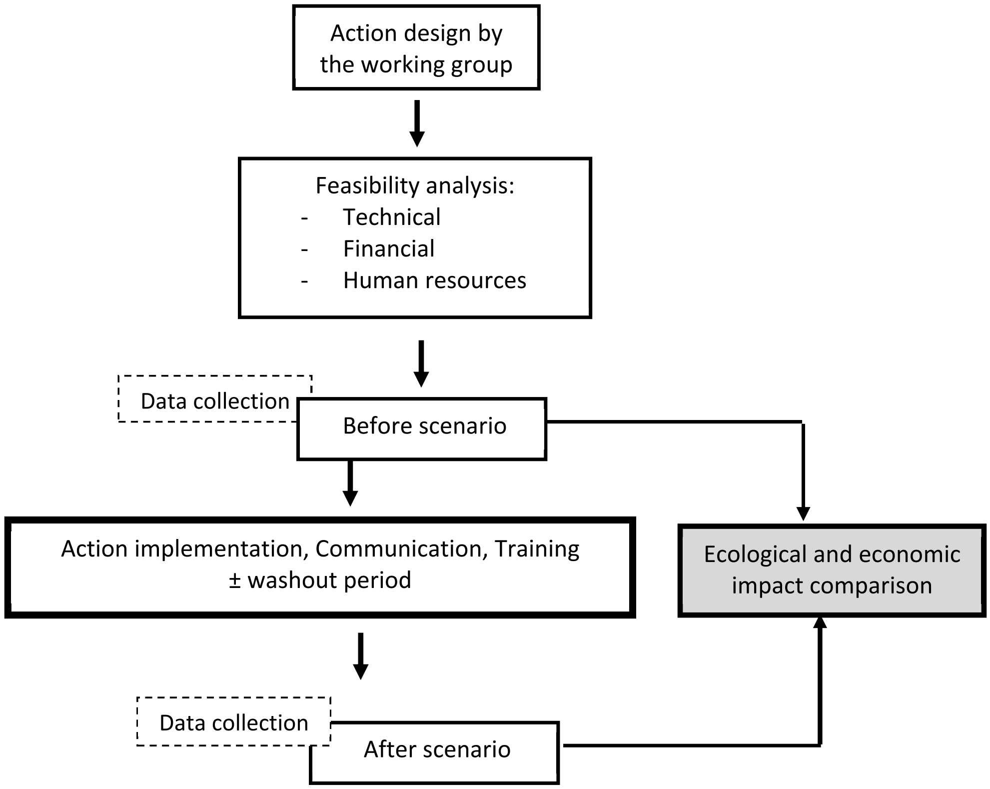

Fig. 1. Study flowchart.

and environmental toxicity (aquatic and terrestrial ecosystems) (kilogram equivalent of 1,4-dichlorobenzene; kg eq 1,4-DCB), depletion of mineral resources (non-renewable resources) (kilogram of copper equivalent; kg eq Cu), depletion of fossil resources (non-renewable resources) (kilogram of oil equivalent; kg eq Oil), and depletion of water resources (m^3 of water).

The material composition of all studied devices was retrieved from the manufacturer's data sheets. The weight of each small device or packaging was measured using the same calibrated scale, and the weight of garbage bins was measured with a dedicated scale. Data on the consumption of water, electricity and chemical products necessary for the washers and autoclaves were collected through the suppliers. The before and after scenario waste management also was evaluated.

2.6. Economic impact

The costs of each action were estimated and the before and after scenario costs were compared using a bottom-up micro-costing methodology based on the unitary costs from a hospital perspective. This methodology identifies action-specific resource use and hospital-specific unit costs. Input data (quantity) were provided by the concerned teams. Costs (human, material and logistic resources, and waste) per unit were calculated using 2020 data from the hospital human resources and administrative departments from the city where the study was conducted. The used data came from the ordering and invoicing software programs (CPAGE® v.208.010 and PHARMA® v.5.9), and from the operative traceability software (OPERA® v.5.1).

3. Results

3.1. Awareness survey

Before the study start, 239 of the 650 (36.8%) OR and SPD employees filled in the survey: n = 51 (21.3%) surgical nurses, n = 41 (17.2%) nurse anesthetists, n = 42 (17.6%) surgeons, n = 27 (11.3%) residents, n = 24 (10%) anesthetists, n = 21 (8.8%) auxiliary nurses, n = 14 (5.9%) SPD agents, n = 7 (2.9%) pharmacy preparators, n = 3 (1.3%) healthcare executives, n = 3 (1.3%) pharmacists, and n = 6 (2.5%) others. To the question "How aware are you about sustainable development?", most participant (n = 165, 69.0%) replied "very aware" or "aware". Moreover, 204/239 (85.4%) respondents implemented environmentally responsible approaches in their daily routines. Most responders (n = 231, 96.7%) thought that environmentally responsible actions should be implemented in their work environment, and 84.1% would have liked to be involved in this. Some obstacles were also highlighted by the responders, such as the lack of time and human resources, the difficulty to change habits, and the lack of communication.

3.2. Sustainable actions

Thirteen actions were evaluated: seven concerned waste reduction (actions 1, 2, 3, 4, 6, 10, 13), five concerned waste sorting (actions 5, 7, 8, 9, 12), and one concerned eco-responsible purchases (action 11) (Table 1). Seven actions concerned all the hospital OR, one concerned both OR and SPD, one concerned neurosurgery, one concerned coelioscopic surgery, one concerned urological robotic surgery, and one concerned the urological and orthopedic surgery departments.

3.3. Ecological impact

Overall, for each action, the ecological impacts were positive, with annual savings of 203 tons CO_2 eq (global warming impact), which represents a car journey of 2,841,790 km (equivalent to 71 trips around the world by car). Concerning environmental toxicity, the annual savings amounted to 707 tons of 1,4 DCB, which is the estimated quantity needed to cause the death of all fish in a 203 million m^3 lake. The other annual gains were 156 tons of 1,4 DCB (human toxicity), 1071.3 m^2 year crop eq (land occupation), 610 kg eq Cu (mineral resources), 8.9 tons eq Oil (fossil resources), and 551.3 m^3 (water consumption) (Table 2). Considering the overall annual ecological impact (all categories

Table 2
Annual ecological impact of the 13 actions.

Annual gain before/after	Global warming	Environmental toxicity	Human toxicity	Land occupation	Mineral resources	Fossil resources	Water consumption
Units	kg CO2 eq (%)	kg 1,4 DCB (%)	kg 1,4 DCB (%)	m^2 year crop eq (%)	kg Cu eq (%)	kg oil eq[a]	m^3[a]
ACTION 1 (n = 220)	1230 (0.6)	3826.5 (0.5)	1036.3 (0.7)	247.7 (23.1)	1.6 (0.3)	338.2	41.9
ACTION 2 (n = 1200)	586.6 (0.3)	907 (0.1)	339.8 (0.2)	72.5 (6.8)	0.9 (0.3)	156.5	11.8
ACTION 3 (n = 16,000)	0.1	0.2	0.4E-01	2.2E-04	0.2E-04	0.4E-01	3.9E-04
ACTION 4 (n = 130)	8.3	172.3	14.3	0.27	0.9 (0.1)	2	0.04
ACTION 5 (n = 76,500)	1.5	11.5	28	0.2	0.014	0.7	−0.3E-01
ACTION 6 (n = 17,184)	26,460.2 (13.0)	117,782.9 (16.7)	37,447.1 (24.0)	626.3 (58.5)	579.3 (94.9)	6601.6	221.6
ACTION 7 (n = 21,000)	169,933 (83.7)	105,991 (15.0)	110,962 (71.0)	56 (5.2)	19 (3.1)	721	250
ACTION 8 (n = 54)	0.8	5.7	14.2	0.1	0.01	0.3	−1.1E-03
ACTION 9 (n = 8172)	0.2E-01	0.5E-01	0.2E-01	0.5E-03	0.5E-03	0.7E-02	0.4E-04
ACTION 10 (n = 400)	4240.3 (2.1)	11,960.3 (1.7)	2285.2 (1.5)	34 (3.2)	7.5 (1.2)	1089	26.2
ACTION 11 (n = 200)	NE	NE	NE	NE	NE	NE	NE
ACTION 12 (n = 10,000)	13.3	465,544 (65.8)	3756.9 (2.4)	3.3 (0.3)	0.1	7.1	−0.9
ACTION 13 (n = 2000 + 1850)	511 (0.3)	1604 (0.2)	340 (0.2)	31 (2.9)	0.9 (0.1)	−1.9	0.7
GLOBAL IMPACT	202,985.1	707,805.5	156,223.8	1071.3	610.2	8914.5	551.3
REPRESENTING	2,841,790 km by car = 71 trips around the world by car	Death of all fishes in a 203 millions m^3 lake	32 millions of anti-moth balls	1071 m^2 year crop eq of occupied land	610 kg of copper	8.9 tons of oil (petroleum)	2 municipal swimming pools

NE: not evaluable data.
[a] The percentage for these ecological categories was not calculated due to positive and negative data.

together), actions 6 and 7 had the highest environmental impact (45.9% and 33.1% of all environmental gains) (Fig. 2). Specifically, action 7 was responsible of most of the annual decrease in global warming, human toxicity and water consumption (Table 2). Action 12 had the greatest impact on environmental toxicity (65.8%), whereas action 6 had the greatest impact on land occupation (58.5%), mineral resources (94.9%) and fossil resources. When the impact per unit and not the annual impact was considered, the distribution changed because it did not depend on the annual hospital volume (Table 1S). For example, action 10 had a higher impact on "global warming" than actions 7 and 8.

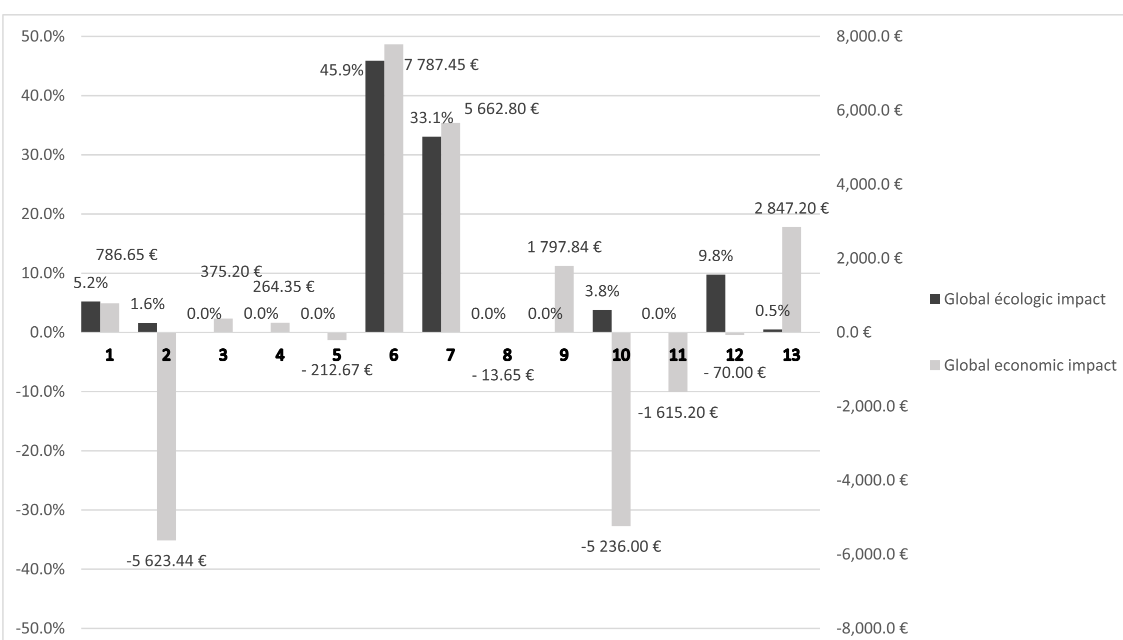

Fig. 2. Contribution of the different sustainable actions to the annual environmental and economic gains
Fig. 2: Numbers (1–12) correspond to the different actions (see Table 1 for their description). For action 11 (creation of a sustainable development questionnaire for medical device suppliers) only the economic impact was included (the ecological impact have not been evaluated).

3.4. Economic impact

From the hospital perspective, the implementation of the 13 actions generated an annual gain of €3747.70 the first year. For the following years, the gains were estimated at €5188.20 (Table 3). Actions 6 and 7 generated the most benefits (€7787.40 and €5662.80), whereas actions 2 and 10 were the most expensive for the hospital (-€5623.40 and -€8236) (Fig. 2). Annually, profits were generated on three expense items: human resources (€5134.80), logistics (€12,048), and waste management (€16,383.90). Conversely, costs increased for material resources (-€29,819.10 per year).

The impact per unit also was studied for each action by expenditure (Table 2S). This analysis showed for each action, the major expense item and how expenses changed between the before and after scenario (Fig. 3). For actions 1, 2, 3, 6, 10 and 13, material resources were the most important expense item in both scenarios. For action 8, in the before scenario, all expenses were due to waste management costs (100.0%), while in the after scenario, these were mainly due to human resource costs (86.9%). For action 2, which generated a significant annual extra cost for the hospital, its implementation led to a decrease in costs in terms of human resources (10.4% *vs* 0.5%), and almost all costs in the before scenario were due to material resources (99.3% vs 89.3%). Action 1 had a low impact when considering the annual gains, but led to the highest profit (€3.58 per unit) when the before/after scenario differences per unit were considered.

4. Discussion

The implementation of 13 targeted sustainable actions related to SMD in the OR and SPD led to significant ecological benefits in terms of limiting global warming, environmental and human toxicity, land occupation, mineral resources, fossil resources, and water consumption. The study also showed economic benefits for the hospital that will progressively grow in time.

One of the strong points of this study was to use the LCA that is considered the most exhaustive method to assess ecological impacts [13]. Indeed, this analysis took into account seven environmental categories to obtain a global view. This is crucial because, depending on the type of action, there may be beneficial effects on some environmental categories and some damaging effects on others. For instance, action 12 (i.e. electric scalpel wire recycling) increased water consumption in the after scenario. Moreover, this action had a very high impact on environmental toxicity, but a low impact on the other six environmental categories. To make these results understandable to the widest possible audience, the environmental impacts were summarized in an easy way.

To ensure the generalizability of our results, we considered both the annual and unit impact to allow other hospitals interested in implementing similar actions to estimate the possible gains according to their activity volume. In this study, actions 6 and 7 (reusable laryngoscope blades and selective waste sorting optimization) had the greatest annual environmental impact. This was in part explained by the fact that these two actions concern all OR (17,184 and 21,000 units/year, respectively). Moreover, action 7 had the greatest annual impact on global warming (83.7%; n = 21,000), whereas action 10 had the greatest impact per unit (55.8%; n = 400).

Some studies have compared the ecological and economic impact of reusable and single-use SMD, but it is important to keep in mind that the ecological impact depends also on the type of energy used. Indeed, an Australian study showed that 300 uses of reusable central venous catheter insertion kits emit 3 times more CO_2 and consume 11 times more water than producing 300 single-use kits, mainly due to the sterilization step. These results are explained by the fact that Australia uses brown coal-sourced electricity. The results would have been different if the study had been carried out in Europe or USA, where electricity production is not based mainly on coal. In this configuration, CO_2 emissions are similar for reusable and single-use kits [14]. Yet, the source of electricity as well as the fragility of reusable devices and losses/breakages are rarely taken into account despite their environmental impact, especially at the beginning of use [9].

Besides the environmental gains, reusable SMD also allow better anticipating the needs. Indeed, the COVID-19 pandemic has led to an important consumption of SMD, resulting in an increase in the waste quantity and also in shortages when manufacturers could not cope with the increased demand [15]. In this study, the majority of the actions carried out were not directly impacted by the pandemic, so the pandemic impact on data collected was considered negligible. The main data collections were conducted during lulls in the pandemic when the surgical activity was still constant.

For each action, the ecological and economic results of a unit were projected on the annual consumption estimated from the average of the last 3 years (before the pandemic). Some cost data could have been impacted by the pandemic, especially for actions n°1 and 2, as the crisis led to significant increases in the cost of certain consumables, such as draping. In our study, the costs had been negotiated with providers at the beginning of the pandemic, so there was no impact on this work.

In addition, action 7, which consisted of setting up an additional channel in the operating room (recycling of packaging), could also have been impacted by the pandemic. Indeed, a reduction in waste was expected due to the cancellation of many surgical procedures. In order to avoid this bias, all waste weighing was related to the number of surgical

Table 3
Annual economic impact of the 13 actions.

Annual gain before/after	Human resources € (%)	Material resources € (%)	Logistics € (%)	Waste management € (%)	Global impact (before - after, €)
ACTION 1 (n = 220)	596.30 (75.8)	184.70 (23.5)	NE	5.60 (0.7)	786.60
ACTION 2[a] (n = 1200)	2568	−8208	NE	16.60	−5623.40
ACTION 3 (n = 16,000)	NA	320 (85.3)	0	55.20 (14.7)	375.20
ACTION 4 (n = 130)	NA	264 (99.8)	0	0.45 (0.2)	264.50
ACTION 5 (n = 76,500)	NA	NE	NE	−212.70 (100)	−212.70
ACTION 6[a] (n = 17,184)	NA	−5361.5	12,888	260.90	7787.40
ACTION 7[a] (n = 21,000)	−805.20	−3570	−840	10,878	5662.80
ACTION 8[a] (n = 54)	−25.10	−1.0	NA	9.60	−16,50
ACTION 9 (n = 8172)	NA	1797.80 (100)	NE	NE	1797.80
ACTION 10[a] (n = 400)	4416	−17,800	NE	5148	−8236
ACTION 11 (n = 200)	−1615.20 (100)	NA	NA	NA	−1615.20
ACTION 12 (n = 10,000)	NA	−70 (100)	NA	0	−70
ACTION 13[a] (n = 2000)	NA	960	0	29.60	989.6
ACTION 13 bis *(n = 1850)*	NA	1665 (89.6)	0	192.60 (10.4)	1857.60
GLOBAL IMPACT	5134.80	−29,819	12,048	16,383.90	3747.70
GLOBAL IMPACT Y+1					5188.20

NE: not evaluable/NA: not applicable.
[a] For some actions, the percentage by expenditure item was not calculated because of positive and negative data.

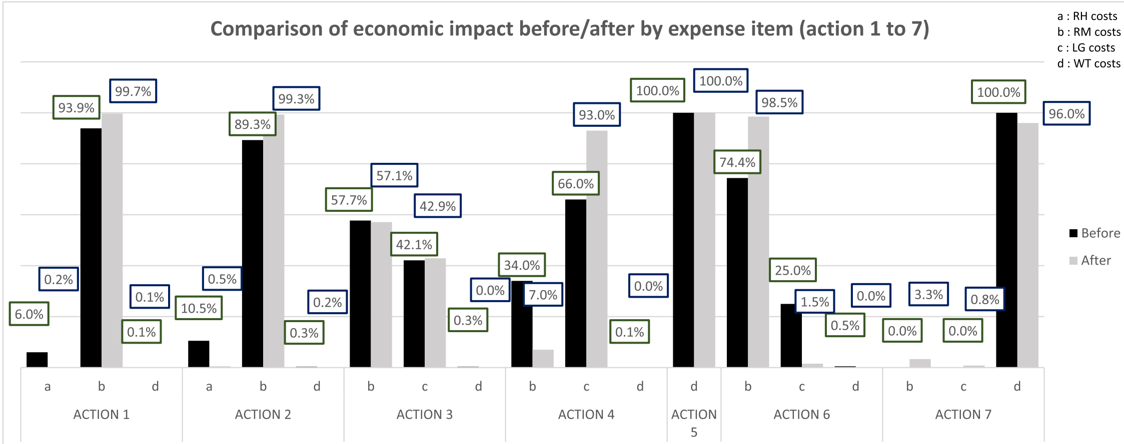

Fig. 3a. Comparison of the before/after scenario economic impact by expense item (action 1 to 7).

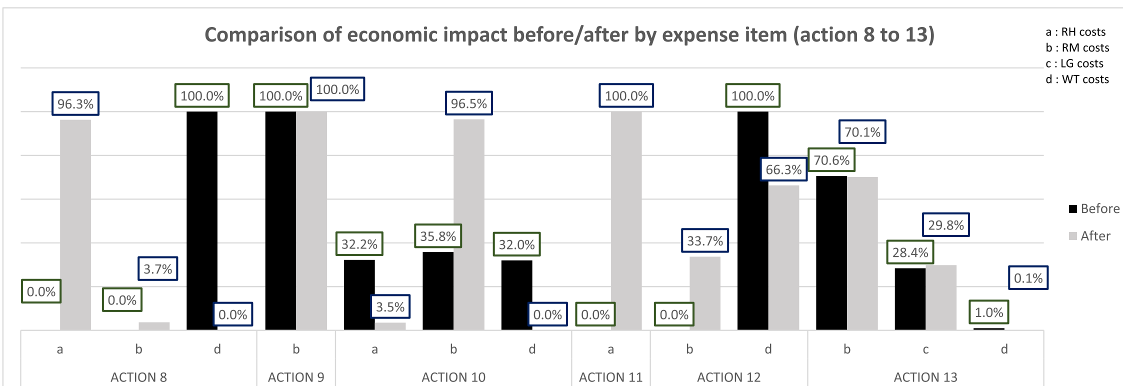

Fig. 3b. Comparison of the before/after scenario economic impact by expense item (action 8 to 13).

procedures over a given period.

From the economic perspective, implementing eco-responsible actions did not seem to generate additional costs for the hospital. These economic data were obtained with a micro-costing analysis that took into account the maximum number of criteria available at the time of the study. The additional costs and saving varied in function of the action type. The overall impact was encouraging, but the impact per unit of each action also must be considered. For example, in the overall economic analysis, action 1 (custom brain surgery kit) had a low impact (€786.60 per year) due to its low use per year (n = 220). However, by considering this action per unit, it had the highest economic gain (€3.58 per unit). On the other hand, action 6 (reusable laryngoscope blades) had the greatest annual impact, resulting in a gain of €0.45 per unit (n = 17,184). The precision of the micro-costing analysis highlighted the significant part of material resources in the hospital expenses. Concerning actions 2 and 10 (the most expensive for the hospital), almost all costs were due to material resources, but the data from the study could be used to renegotiate prices with suppliers. The initial implementation of the actions generated significant costs, particularly in human resources; however, these costs should not be present in the next years. For instance, human resources expenses for actions 7 (selective waste sorting optimization) and 11 (sustainable development questionnaire) should concern only the first year because they were caused by the time spent for the creation of the supports (training, questionnaire) that will not be required each year.

Our study presents some limitations due to its design (monocentric study) and the use of an experimental methodology because of the lack of similar previous studies. It was difficult to globally evaluate the economic gains linked to SMD because some costs were difficult to estimate, for example the logistic costs of some actions that were not evaluated. Similarly, some ecological sides require a precise methodology to be studied, such as the quality of life at work (QLW). Some actions influenced the QWL, such as actions 1 and 2 (custom packs), which significantly reduced the number of times the SMD were opened, and action 10 (implementation of a movable irrigation fluid recovery system), which considerably reduced the time and weight handled by OR personnel. These data were collected and quantified, but their impact on QWL will be assessed in another study. Moreover, it was not possible to involve all the staff in this sustainable approach and some were reluctant, especially if the implementation of actions entailed a significant change in their professional habits, as highlighted in the preliminary survey.

Some actions were studied but could not be completed. For example, a market study was realized with suppliers of sterilizable sheets to find sheets made of recyclable materials. But after multiple enquiries, it turned out that even when sheets were made of recyclable material, they could not actually be recycled because of the lack of an adapted channel. These sheets are widely used and therefore, constitute an important source of waste nationwide. Suppliers should consider the end of life of the products they put on the market to develop adapted recovery channels. This example and many others require the engagement of suppliers in these environmentally responsible approaches. Legal regulations in this field should push suppliers to become involved. These 13 actions are a first step, but the working group is still working to integrate new actions into professional practices.

To conclude, it is urgent to work on the consumption mode in OR. Indeed, one surgical operation generates more waste than a family of four people in one week [16]. At the hospital level, the OR is a major consumer of SMD that lead to important costs and waste volumes. Our study showed that by implementing sustainable actions in the OR, it is possible to generate significant ecological savings without additional costs for the health institution. Currently, these initiatives are implemented on a voluntary basis, but they may become mandatory in the coming years. All hospital staff must be aware of the importance of climate change, and this study illustrates some of the initiatives that can be taken to move in this direction.

Ethical approval

This study was approved by the Institutional Review Board of the University Hospital (N° 21.00.60).

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CRediT authorship contribution statement

N. Rouvière: Conceptualization, Data collections, Investigation, Writing – original draft, Responses to the reviewers and manuscript revision. **S. Chkair:** Methodology, Formal analysis, Responses to the reviewers and manuscript revision. **F. Auger:** Methodology, Formal analysis. **C. Alovisetti:** Data collections, Validation, Visualization. **MJ. Bernard:** Data collections, Validation, Visualization. **P. Cuvillon:** Data collections, Validation, Visualization. **J-M. Kinowski:** Validation, Visualization. **G. Leguelinel-Blache:** Methodology, Validation, Visualization, Responses to the reviewers and manuscript revision. **V. Chasseigne:** Conceptualization, Supervision, Writing – review & editing, Responses to the reviewers and manuscript revision.

Declaration of competing interest

All the authors have declared no potential conflicts of interest regarding this study.

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Appendix A. Supplementary data

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