Life Cycle Assessment of Stainless Steel Surgical Tools (Reusable vs. Single-use) in the UVA Hospital

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Life Cycle Assessment of Stainless Steel Surgical Tools (Reusable vs. Single-use) in the UVA Hospital

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Abstract

This study conducts a life cycle assessment (LCA) to evaluate the environmental impacts of single-use versus reusable stainless steel surgical instruments within the University of Virginia (UVA) Health System. The research analyzes the impact of instrument reusability on three environmental factors, focusing on global warming potential (GWP), electricity usage, and water usage, as well as financial costs to the UVA Hospital. The investigation presents functional units, data acquisition encompassing weights, costs, usage metrics, and impact assessment across each life cycle stage, including production, utilization, and end-of-life. The breakeven analysis demonstrates substantial cost savings and reduced GWP associated with the increased adoption of reusable instruments while also showing challenges in high water consumption for autoclave sterilization. Sensitivity analysis highlights the financial benefits of three behavioral recommendations in excess use reduction, reusable instrument adoption in the Emergency Department, and implementation of a steel recycling program in the UVA hospital system. The findings showcase the potential for healthcare facilities to achieve significant economic savings while addressing environmental concerns by adopting reusable stainless steel surgical instruments.

Keywords: Life Cycle Assessment, Healthcare Sustainability, Medical Waste, Stainless Steel Surgical Instruments

Background

The unsustainable generation and management of hospital waste, particularly hazardous and non-recyclable materials, poses multifaceted environmental and sustainability concerns. Hospitals generate a vast volume of waste daily, making the healthcare industry the second largest contributor to landfill waste in the United States. Healthcare waste accounts for five million tons of waste per year and 14 thousand tons per day[28]. Globally, hospitals make up 4.4 percent of global greenhouse emissions. One of the biggest drivers of the trend of increasing hospital waste is the transition from reusable surgical instruments and materials to single-use alternatives. The market for single-use surgical tools is expected to grow 8.2 percent from 2023 to 2030 due to the increased prevalence of chronic diseases and the increased preference for single-use materials[6].

Single-use tools are used more frequently in the emergency department (ED) because they are often included in larger kits of materials, the entirety of which is opened regardless of the nuance of the case. Reusable instruments are used in the operating room because they are of a higher quality, and there is more time to select the instruments and prepare them for each surgical procedure. The surgical instrument waste stream was observed first-hand through two visits to the UVA Hospital in January and February 2024. Each visit included observations of the entire lifecycle of surgical instruments within the hospital, from inventory sourcing to eventual disposal. Single-use surgical tools carry significant costs and environmental burdens that are often overlooked by health systems for convenience; however, surgeons almost universally acknowledge this problem. A study by Dr. Matthew J. Meyer of the UVA Hospital found that 90% of surveyed surgeons agreed that waste is a significant problem, and 95% agreed to commit to significant waste reduction efforts[15]. To support growing concerns among hospital staff, we aim to explore the impact of disposable vs reusable steel instruments.

Additionally, disposable stainless steel surgical tools are of lower quality than their reusable counterparts. FDA Import Alert 76-01, a warning about imported disposable surgical instruments, notes that "the quality of the [disposable] instruments appear to fall below that which they were represented to possess. Documented analysis revealed great variability in chromium content" [10]. Chromium content in stainless steel dictates its strength and resistance to heat and corrosion; therefore, instruments with lower chromium content would be more susceptible to corrosion or fracture during use. This material disparity was brought up in numerous physician interviews, as they cited tools that arrived broken, rusted, or of obvious low quality. The paper aims to investigate the environmental impacts of replacing single-use instruments with a reusable equivalent to inform the UVA hospital on improving their environmental footprint.

Methods

Goal Statement and Scope Definition

The goal of this life cycle assessment is to analyze and compare the environmental impacts of single-use and reusable stainless steel surgical instruments in the University of Virginia Health System. Two functional units are used throughout this LCA. The first case compares 500 uses of a single reusable instrument and 500 individual single-use instruments, representing one reusable tool's estimated lifespan. The lifespan of the reusable tool was estimated through conversations with

UVA surgeons. The second functional unit is calculated by determining the maximum number of disposable products bought in one year by the UVA hospital between 2021 and 2023 and using that amount for all 3 years. This information we collected through UVA hospital inventory managers. We assume that this aggregated estimate represents the uses per year of the disposable instrument (since it is single-use). Thus, we aim to compare the case of a complete switch to an instrument's reusable equivalent. For example, between 2021 and 2023, the maximum number of disposable Iris scissors purchased over these 3 years was 1920 units in 2023. 1920 is thus the assumed number of uses per year every year (3*1920 = 5760 total) for both the disposable Iris scissors and the reusable equivalent.

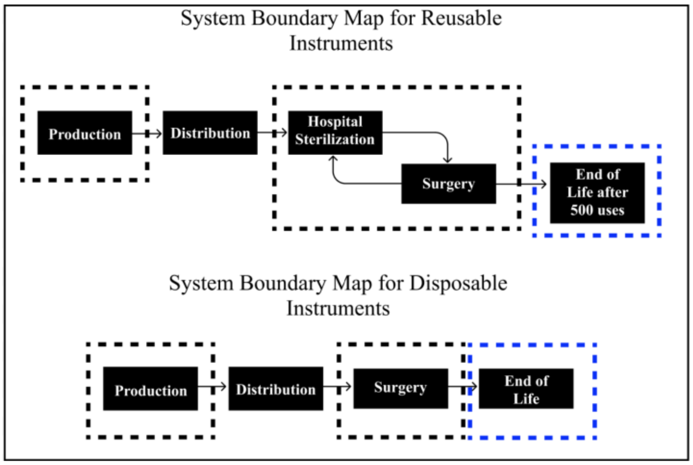

Fig. 1. System boundary maps for reusable and single-use instruments. Processes outlined in black are those considered in the analysis section.

This assessment encompasses every main process step in the product's life cycle, except for distribution. The simplified flow diagrams representing the system boundaries for both reusable and single-use tools are shown in Figure 1. The processes assessed in this work are enclosed in black dashed boxes. The system boundaries demonstrated in the flowchart include production, surgery, and end-of-life for both types of instruments, as well as sterilization and maintenance for reusable instruments. The black dashed boxes represent steps for which actual past data is used; the blue represents the predictions for the impacts of the different end-of-life procedures discussed later in the analysis as a distinct section.

Life Cycle Inventory Assessment (LCIA)

This LCA analyzes the effect on the cost to UVA Hospital, global warming potential (GWP), electricity, and water usage from each functional unit case comparing reusable vs. disposable surgical instruments. For this analysis, four reusable instruments and four single-use equivalent instruments used by the UVA hospital were chosen. The instruments were chosen after shadowing and interviewing UVA hospital staff. The weights, costs, and order volumes for 2021-2023 were gathered from these tools. These values are shown in Tables 2 & 3, respectively. The process by which these values were obtained is detailed in the Data Summary. Additionally, environmental impact data was gathered using OpenLCA and comparisons to other LCAs. The GWP, water usage, and electricity usage for 1 kg of stainless steel, are shown in Table 1. These values are used with the weights of the tools to calculate the environmental impact of each tool. Finally, data was collected from the UVA hospital on the load size of autoclaves, used to sterilize reusable instruments, as well as their model serial numbers. From there, water, GWP, cost, and electricity data were calculated for each autoclave cycle, shown in Table 5.

Impact Assessment and Interpretation of Results

To assess the impact of both disposable and reusable stainless steel surgical instruments from the perspective of the UVA Hospital, the surgical tool types will be compared based on four primary metrics: cost, global warming potential (GWP), water usage, and energy usage. The data collected will be used to create a breakeven point with respect to the number of uses in the UVA Hospital for both metrics that will determine the number of uses at which reusable surgical tools are advantageous. After this use case breakeven is determined, further exploration will be conducted to determine the potential benefits associated with the hospital altering its surgical tools use and exchanging disposable instruments for reusable counterparts.

Data Summary

The data summarized in this section comprises a comprehensive overview of previous stainless steel LCAs and collected data from UVA Health. Reviewing literature sources and life cycle assessment studies, this section presents data on the environmental footprint of producing 1 kg of steel and pertinent data on our selected stainless steel surgical tools used in UVA Health. The subsequent tables and figures offer insights into the variation in impact values across different studies, shedding light on the key factors influencing steel production.

Table 1 presents the environmental impacts of producing 1 kg of stainless steel derived from many literary and LCA sources. To reduce

Source	GWP (kg CO2 eq/kg steel)	Electricity (MJ/kg)	Water (L)
Alternate Routes to Stainless Steel-A Lifecycle Approach	4.9	49	
Review of Life Cycle Assessments for Steel and Environmental Analysis of Future Steel Production Scenarios	2.3	21	
Stainless Steel in Structures in View of Sustainability	3.2	31.7	
OpenLCA (Ecoinvent Chromium Steel 18 8 Hot Rolled production {RER} Ecoinvent from Agribalyse v301)	**4.84**	**12.83**	**30**
Purdue Quantification of Water Footprint			704.9

Table 1. Impact of Production of 1 kg of Steel from Literature Data.

complexity, stainless steel was chosen for both materials despite the reusable being labeled as German stainless steel and disposable as Pakistani stainless steel. Due to material differences observed in reusable vs single-use, future work is needed to compare how material composition affects environmental impact. The respective data comprises the GWP, electricity consumption, and water usage, which are all crucial factors in addressing the sustainability of stainless steel production processes. The approach to the subsequent data collection required sourcing information from previously established LCA sources available in the literature. Notably, the selected values used in our further analysis for GWP, electricity, and water use were derived from the OpenLCA source, as seen by the bolded values in Table 1. OpenLCA was chosen as the primary data source due to its coverage of all three parameters, which fall within the scope of our LCA study. The specific material and the database used to obtain the OpenLCA data are shown in Table 1. The only consensus value across LCA sources was GWP. Electricity had a wide range of values, and the water values differed significantly from different sources. OpenLCA allows this LCA to use all three parameters from a singular source, allowing for consistent calculations.

The data presented in Table 2 were collected through direct observation and measurement of weights during hospital shadowing sessions. This method involved physically examining and weighing each surgical tool commonly used in the OR and their disposable counterparts used in other hospital areas. As seen in Figure 2, each tool was weighed with its reusable or disposable counterpart while observing hospital use. By directly observing and measuring instruments in use, the data was accurately collected for future analysis. The reusable instruments and single-use instruments are both made from stainless steel. However, the reusable instruments are of noticeably higher quality upon observation, as the tools appear more finished and are significantly heavier and more balanced when held. Each disposable tool comes in a package to ensure sterility, while reusable tools are sterilized with an autoclave and delivered directly to the OR in sterile trays. Further work should be done to measure the impact of plastic packaging used for every single-use instrument.

Table 2 data shows standard reusable tools on the left side with their weights and comparative disposable counterparts on the right side of the table. It is noteworthy that specific tools, such as the straight hemostats and the disposable needle holder, were not used in further analysis due to the unavailability of comparable counterparts during our observation. We chose to compare these tools based on the use case in the hospital. This includes the dimensions and functions of these tools for surgical procedures. This is outlined by the fact that those specific tool weights are not bolded in Figure 2. This selective approach aims to create consistency when comparing reusable and disposable tools. The weight of the disposable scalpel was measured by taking the blade out of the plastic handle, so only the steel component was measured.

Fig. 2. Side-by-side comparison of a disposable (left) and reusable (right) pair of iris scissors, with their weights shown.

Table 3 displays the number of tools purchased by the UVA Hospital and the cost per tool for every instrument from 2021 through 2023. The instruments previously discussed without a suitable reusable or disposable alternative were excluded from the rest of the analysis and, therefore, not included in this table. This inventory data was obtained from a UVA Hospital administrator. This data anchors the LCA, as the number purchased and the cost per tool is used throughout the paper to build break-even graphs, make cost comparisons, and use forecasting.

Table 4 shows the combined three-year case functional units for case 2. This represents the raw data from Table 3 condensed to demonstrate the average uses across three years. For the reusables, the total number of instruments purchased is the sum of all three years. The total number of disposable instruments purchased was attained by taking the largest value across all three years and multiplying by three. This was

Reusable		**Disposable**	
Product Type	Weight (g)	Product Type	Weight (g)
Scissors (Mayo or Iris)	**65.77**	MediChoice 4.75" Straight Iris Scissor	**18.26**
Adson Forceps	**17.82**	MediChoice 4.75" Adson Serrated Forceps	**12.96**
Mosquito Curved Hemostat	**35.93**	MediChoice 5" Curved Mosquito Forceps	**24.58**
Scalpel Handle with Ruler	**29.97**	Myco Retractable Disposable Safety Scalpel	**6.25**
Kelly Straight Hemostat with Gold Handle	44.76	Sklar 5 1/2" Baumgartner Needle Holder	29.28
Mosquito Straight Hemostat	28.13		

Table 2. Instrument Types with Respective Weights

done so the data represents the maximum number of possible uses for each instrument. That number for each instrument is bolded in Table 3. As is evident in Table 3, there is a significant variation in the number of reusable tools purchased from year to year. It is hypothesized that this is because surgeons surveyed estimate that reusable tools often have a lifespan of over one year, so they do not need to be repurchased at the same volume yearly. This three-year analysis provides a more holistic picture of the number of reusable instruments purchased and the number of uses for them.

Reusable			**Disposable**		
Product Type	**# Bought in 2023**	**Cost/Tool**	**Product Type**	**# Bought in 2023**	**Cost/Tool**
Scissors (Mayo or Iris)	348	$10.91	MediChoice 4.75" Straight Iris Scissor	**1920**	$1.30
Adson Forceps	800	$30.47	MediChoice 4.75" Adson Serrated Forceps	**8,270**	$1.72
Mosquito Curved Hemostat	151	$49.48	MediChoice 5" Curved Mosquito Forceps	23,887	$1.30
Scalpel Handle with Ruler	6	$37.15	Myco Retractable Disposable Safety Scalpel	8,727	$0.92
Product Type	**# Bought in 2022**	**Cost/Tool**	**Product Type**	**# Bought in 2022**	**Cost/Tool**
Scissors (Mayo or Iris)	87	$10.91	MediChoice 4.75" Straight Iris Scissor	273	$1.30
Adson Forceps	79	$30.47	MediChoice 4.75" Adson Serrated Forceps	7,881	$1.72
Mosquito Curved Hemostat	0	$49.48	MediChoice 5" Curved Mosquito Forceps	23,785	$1.30
Scalpel Handle with Ruler	3	$37.15	Myco Retractable Disposable Safety Scalpel	**9,785**	$0.92
Product Type	**# Bought in 2021**	**Cost/Tool**	**Product Type**	**# Bought in 2021**	**Cost/Tool**
Scissors (Mayo or Iris)	172	$10.91	MediChoice 4.75" Straight Iris Scissor	210	$1.30
Adson Forceps	85	$30.47	MediChoice 4.75" Adson Serrated Forceps	6,451	$1.72
Mosquito Curved Hemostat	10	$49.48	MediChoice 5" Curved Mosquito Forceps	**27,223**	$1.30
Scalpel Handle with Ruler	2	$37.15	Myco Retractable Disposable Safety Scalpel	9,141	$0.92

Table 3. Hospital Raw Data 2021-2023.

Reusable				**Disposable**			
Product Type	**# Bought 2021-2023**	**Cost/Tool**	**Total Cost**	**Product Type**	**# Bought 2021-2023**	**Cost/Tool**	**Total Cost**
Scissors (Mayo or Iris)	607	$10.91	$6,622.37	MediChoice 4.75" Straight Iris Scissor	5760	$1.30	$7,508.51
Adson Forceps	964	$30.47	$29,368.26	MediChoice 4.75" Adson Serrated Forceps	24810	$1.72	$42,593.81
Mosquito Curved Hemostat	161	$49.48	$7,966.28	MediChoice 5" Curved Mosquito Forceps	81669	$1.30	$106,161.53
Scalpel Handle with Ruler	11	$37.15	$408.65	Myco Retractable Disposable Safety Scalpel	29355	$0.92	$26,906.79

Table 4. Combined 3-Year Case Functional Unit Table

Table 5 shows all the data collected using a STERRAD 10NX autoclave to sterilize instruments. This data determines the cost per use for each reusable instrument and is critical to calculating the impacts of reusable instruments. The table is divided into three resources: water, electricity, and GWP from electricity. Under each resource, some values quantify the amount of that resource used for each sterilized tool and the cost of that resource for each instrument. This data was selected from a paper comparing steam sterilization to traditional water sterilization for hospital surgical instruments. It is worth noting that there is hardly any available data on autoclave resource usage. This is the only paper that has comprehensive data[14].

Tools/cycle	21
Water	
Water/cycle (L)	670.49
Water/tool (L)	**31.92809524**
Cost of water ($/L)	$0.00036425
Cost of water/cycle	$0.24422598
Cost of water/tool	$0.01162981
Electricity	
Electricity/cycle (kWh)	0.09
Electricity/tool (kWh)	**0.004286**
Cost of electricity ($/kWh)	$0.11000000
Cost of electricity/cycle	$0.00990000
Cost of electricity/tool	$0.00047143
Total cost per tool	**$0.012**
GWP From Electricity	
Electricity/tool (kWh)	**0.0042857**
GWP equivalent (kg CO2 eq)	0.3730000
Total GWP/tool/cycle (kg CO2 eq)	0.0015986

Table 5. Cost per Use for Sterilization from STERRAD 100NX

Results

The results of the LCA are broken down into two use cases, each with its own functional unit. Case A compares the use of one reusable instrument 500 times to 500 uses of its single-use counterpart. This is meant to represent the entire life cycle of a reusable instrument and will be used as the functional unit for the analysis and comparison. Case B examines the total number of reusable instruments bought over the three-year period. The number of uses for reusable and disposable instruments is represented by the maximum number of disposable instruments purchased in one year over three years. This case is anchored by the actual purchasing behavior of the UVA Health System. The three-year period accounts for the large variation in the yearly purchasing quantity of reusable instruments due to life spans longer than one year. The equations used for analyzing Case A and Case B are seen in Figure 3.

Case A	Case B
Reusable Impact = Impact of single tool + (impact of autoclave cycle)(X uses)	Reusable Impact = ((Impact of single tool)(number of tools purchased)) + (impact of autoclave cycle)(X uses)
Disposable Impact = (Impact of single tool)(X uses)	Disposable Impact = (Impact of single tool)(X uses)

Fig. 3. Equations for the impact assessment of each instrument.

Test Case A

After calculating the data from Case A, that data was analyzed in a break-even graph between a reusable Iris scissor being used 500 times versus 500 single-use tools being used. This number of uses before repair/disposable was obtained from surveyed surgeons. For each graph in Figure 4, the breakeven for the reusable and disposable scissors were compared based on four different parameters. These parameters include cost to UVA hospital, GWP, electricity, and water usage. To calculate the equation of the line for the reusable Iris scissors, the y-intercept was set at the initial cost of the tool, where the slope is the cost of autoclaving the tool after each use. The line for the disposable tool increases with the price of each disposable tool. Figure 4 shows that the cost break-even occurs after 9 uses for Iris Scissors. A similar paradigm was used to calculate the equations of the lines for GWP and electricity usage. To calculate the equation of the line for the reusable Iris scissors, the y-intercept was set at the initial GWP, and electricity used to produce one tool, where the slope is the GWP and electricity usage of autoclaving the tool after each use. The disposable equation was calculated using the same process as the cost breakeven graphs. The GWP and electricity use graphs show that both parameters have a breakeven time after 3.6 uses. Finally, the reusable and disposable equations for water were calculated using the same processes as before. However, due to the massive amount of water needed to autoclave reusable tools after each use, compared to the amount required to produce one disposable instrument, there is no breakeven time on water use. This data shows that while reusable tools have an attractive breakeven time when it comes to cost-cutting, GWP reduction, and electricity reduction, there is still a massive increase in water usage, which will require further research into autoclave efficiency in hospitals.

After creating the breakeven graphs, the total impact for 500 uses was calculated and is displayed in bar graph format in Figure 5. Each metric has a set of side-by-side bars comparing the total impact of 500 uses of a disposable instrument and its reusable counterpart. The bar graph demonstrates that 500 disposable uses have significantly higher impacts on cost, GWP, and electricity usage than their reusable counterparts. Based on the calculations, the total savings among all the tested instruments for cost, GWP, and energy are $2,467.99, 146.24 kg CO_2-eq, and 555.21 MJ, respectively. However, water usage is much higher for reusable instruments, with an increase of 62,929.93 L than for disposables. This is to be expected, as autoclaves use copious amounts of water. This could also be predicted by the breakeven graph for water, where a breakeven never happens.

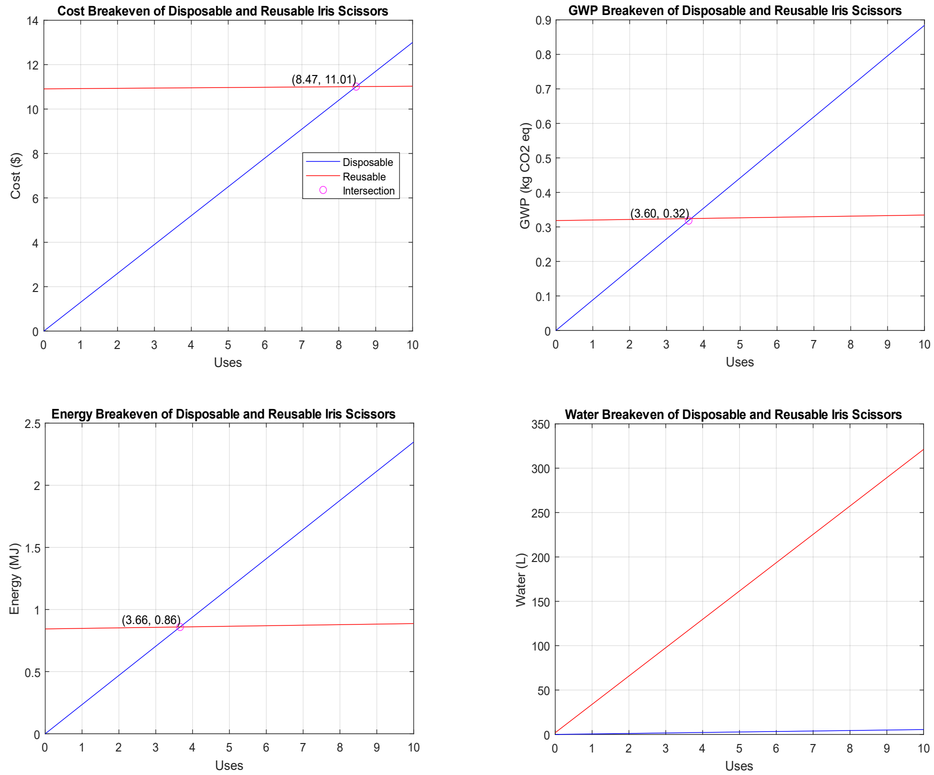

Fig. 4. Impact breakeven point for iris scissors based on cost, GWP, energy usage, and water usage.

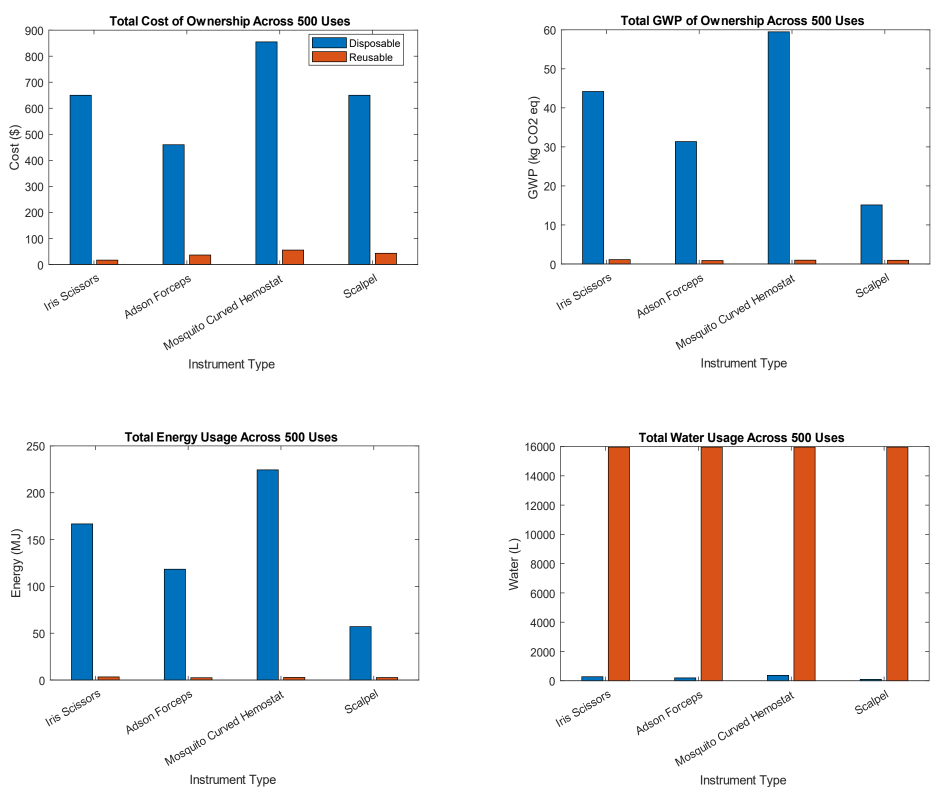

Fig. 5. Total impact of ownership for 500 uses.

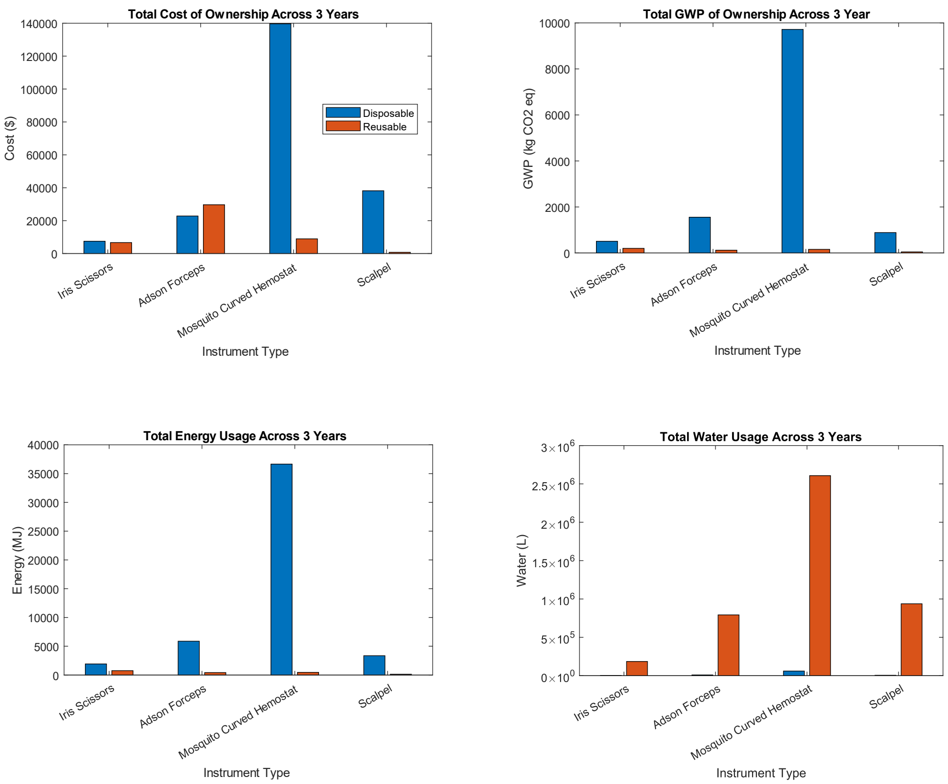

Fig. 6. Total impact of ownership over 3-year timespan for each individual tool tested.

Test Case B

The functional unit, shown in Table 4, used to analyze the impact of reusable and disposable surgical instruments across the three-year period was the approximated total number of disposable instruments purchased during that time span. Over the three-year period, the largest number of surgical instruments bought in a single year was used to represent the average per year, which was then multiplied by three to estimate the uses over 3 years. Therefore, in the case of disposables, the impact assessment relies solely on the quantity for each metric. Meanwhile, reusable instruments are calculated based on the total number of reusable instruments purchased over three years, which were then assumed to be used an equivalent number of times as their disposable counterparts. As shown by the impact assessment in Figure 6, over the three-year time span, the cost burden for the UVA hospital proved to be greater for disposable tools than their reusable equivalent, except for the Adson forceps. In this case, the total savings for cost, GWP, and energy over 3 years for the reusable instruments tested was \$162,875.87, 12,136.91 kg CO_2-eq, and 46,036.34 MJ, respectively. However, Adson forceps were the only instrument type for which the reusable option was more expensive. The Adson Forceps may have been the only more expensive instrument due to hospital buying trends and needing more specific tools for that year. For example, the reusable mosquito curved hemostat was 93.59% less expensive than the disposable alternative. Additionally, the GWP and electricity usage over the 3-year time period was less for the reusable version of each instrument type. The total water usage over 3 years was much greater for all reusable instruments at an increase of 4,444,195.61 L due to the process of sterilization using an autoclave requiring a significant amount of water for each cycle. More accurate information on use numbers for reusable instruments as well as complete reusable buying history would increase the accuracy of our UVA hospital model.

Based on single instrument impact (Case A) and historical buying habits (Case B), reusable instruments have a lower impact on GWP, electricity, and cost compared to disposable instruments.

Analysis

Case 1: Reduce Waste from Excess Instruments in the Operating Room

The first case concerns a reduction in the usage of surgical tools in the operating room. By reducing the number of excess tools in the OR, we hypothesize that UVA Health can reduce the environmental effects of autoclaves and extend the life of underutilized reusable instruments. In a study conducted at UVA, Dr. Matthew Meyer installed cameras in operating rooms to assess the frequency of use for each surgical tool. The aim was to establish a method for removing tools that showed little to no interaction over multiple observations within a single OR. The study quantifies that 26% of reusable tools opened during observed cases were thrown out despite not being used[15]. Reducing this number of wasted reusable instruments will bring significant water and GWP savings to the UVA Hospital. Figure 7 demonstrates that not wasting 26% of these instruments will bring water usage and GWP savings of 1,175,415 L and 58.85 kg CO_2-eq, respectively. When this reduction is applied across multiple hospitals, the total savings increase. The third graph in Figure 7 represents the increase in cost savings as the number of hospitals increases. While this case is simple in nature, it shows that there is potential to reduce the environmental impacts of hospitals through the identification and removal of wasteful instrument use. After reducing wasteful use, the hospital system needs behavioral changes to reduce the environmental impact of essential material use. Case 2 explores the recommendation of switching from single-use steel instruments to reusable ones in the UVA Emergency Department. In contrast, Case 3 investigates the potential benefits of recycling the single-use steel instruments that are used in the hospital.

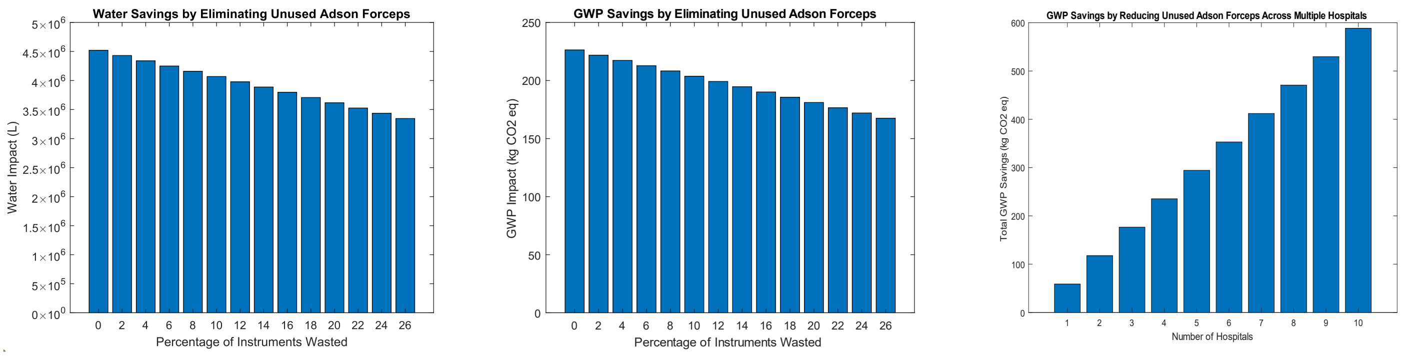

Fig. 7. Percentage of water savings, GWP savings as the percentage of wasted instruments increases, and total GWP savings as more hospitals implement the reductions.

Case 2: Switch to Reusable Steel Instrument in UVA Emergency Department

By transitioning from disposable to reusable surgical instruments, the UVA Hospital emergency department can save substantial money due to the lower cost per use of reusable instruments. As shown in Figure 8, if the emergency department only used the disposable version of the Adson forceps, the total cost over the three-year period would be $22,825.20. However, as the percentage of reusable instruments adopted increases, the total cost decreases. If the hospital used only reusable instruments, the total cost over the same time span would be only $7,868.22. This represents a total savings of 65.53% for this tool type alone for a transition from disposable to reusable tools, so when this same idea is applied across all surgical instruments, it can prove highly financially beneficial for the UVA Hospital.

The relative impact of reusable instruments on GWP and energy is significantly lower. This makes the effect of the full transition much larger. A complete transition to reusable represents 96.62% savings for GWP and 97.35% for energy. The impact on water usage is much higher for reusable instruments, so the transition to reusable will have a negative impact. The complete transition to reusables would result in an 8,112.8% increase in water usage. This data is summarized in Table 6.

Impact category	Impact of all disposables	Impact of all reusables	Percentage savings
Cost	$22,825.20	$7868.22	65.53%
GWP	1,555.59	52.59	96.62%
Electricity	5,870.05	155.15	97.36%
Water	9,646.13	792,216.00	-8112.79%

Table 6. Summary of Sensitivity Analysis Data for Case 2.

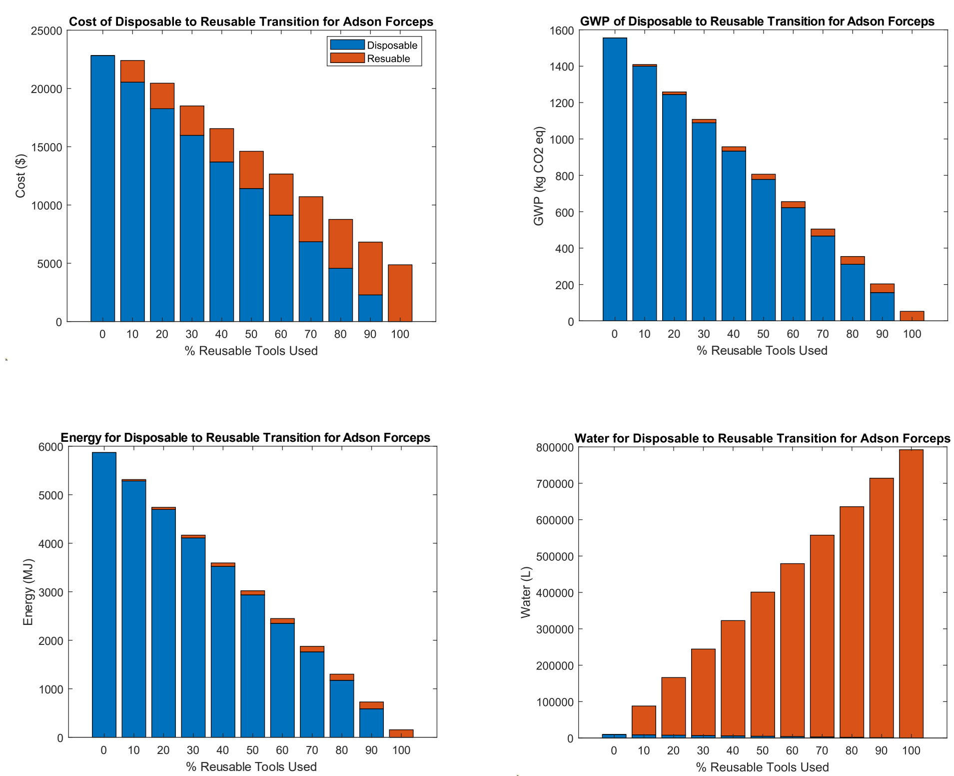

Fig. 8. Sensitivity analysis of all impact categories for Adson forceps.

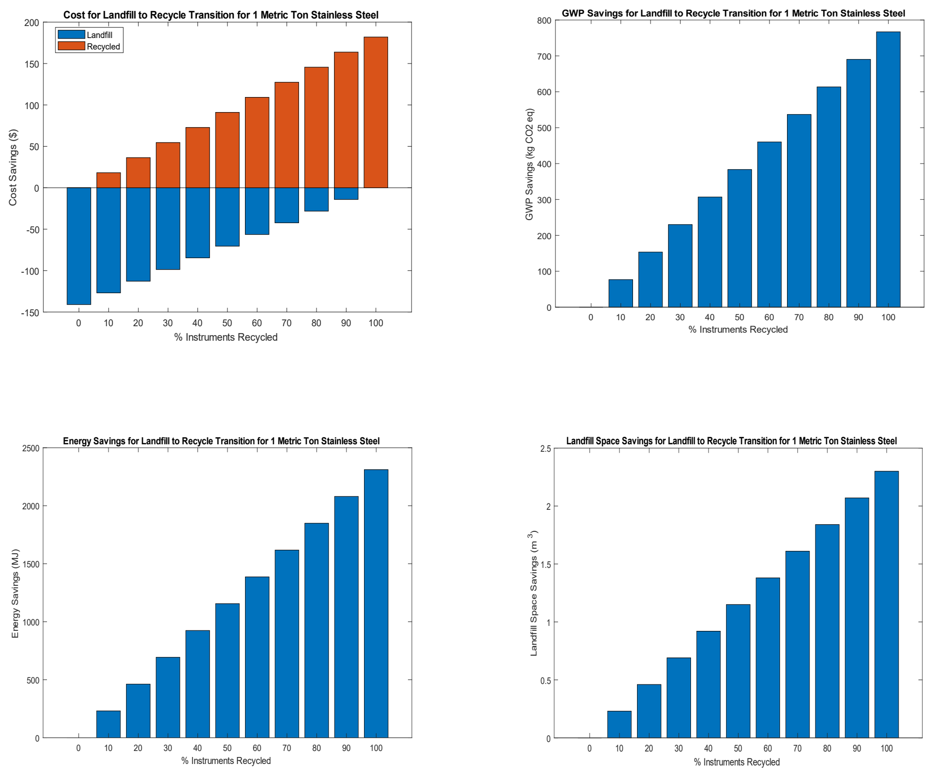

Fig. 9. Impact of switching from landfill disposal to recycling of stainless steel.

Case 3: Benefits of Recycling Disposable Instruments

By altering the end-of-life treatment of surgical instruments, the UVA Hospital can save money and reduce its carbon footprint, energy usage, and landfill output. Figure 9 shows the potential savings for one metric ton of stainless steel by recycling instruments at the end of their lifespan instead of discarding them for landfill disposal. The cost for disposing of a metric ton of stainless steel in a landfill is $141, while the hospital could instead sell the stainless steel for scrap, which could be sold for $182 in Virginia. Therefore, transitioning from disposable to selling for scrap and future repurposing would constitute a net profit of $323 per metric ton of stainless steel. Applying this model across all surgical devices, the UVA Hospital could save thousands of dollars yearly while putting less waste in landfills, as the total weight of single-use Adson forceps disposed of each year was 321.54 kg. Figure 9 also demonstrates the potential savings of recycling stainless steel based on energy savings, GWP savings, and landfill volume savings. By transitioning to 100% recycling for end-of-life, the UVA Hospital would contribute to the reduction of 776 kg CO_2-eq and 3,211.2 MJ through recycling and save 2.3 cubic meters of landfill space for every metric ton of stainless steel. Therefore, changing the overall disposal process for stainless steel surgical waste would be beneficial based on all considerations, as it would increase hospital profits, lessen the GWP produced and energy used, and decrease the landfill output.

Discussion

Based on the results and discussions outlined above, transitioning away from single-use stainless steel instruments toward a more reusable future carries significant implications for both environmental sustainability and economic efficiency for the UVA Health System. The LCA underscores the significant benefits of adopting reusable instruments by increasing cost savings and reducing global warming potential and electricity use. According to the Life Cycle Assessment (LCA) analysis, implementing comprehensive behavioral changes in line with Dr. Meyer's work to reduce the usage of unused instruments could result in significant environmental benefits. Specifically, this initiative could lead to total water savings of 1,175,415 liters and a reduction in Global Warming Potential (GWP) of 58.85 kg CO_2-eq over 3 years. Moreover, transitioning to reusable instruments in the Emergency Department (ED) could yield substantial environmental gains, including a 96.62% decrease in GWP (1,504 kg CO_2-eq) and a 97.35% decrease in energy consumption (5,714.9MJ). However, this transition is accompanied by an 8,112.8% increase in water usage. Furthermore, recycling disposable instruments at the end of their life cycle offers additional benefits for UVA Hospital. This practice could result in a reduction of 776 kg CO_2-eq emissions, a decrease in energy usage by 3211.2 MJ, and a saving of 2.3 cubic meters of landfill space for every metric ton of stainless steel recycled. The results of the reusable behavior recommendation also reveal the challenges associated with increased water usage due to the substantial increase in autoclave use in the hospital. This metric emphasizes the need for future research surrounding increasing autoclave efficiency in hospitals or investing in autoclaves that promote more sustainable water usage.

Future Work

Autoclave

To enhance the accuracy of future projects and data collection, groups should focus on more direct monitoring of water and energy consumption during the autoclave sterilization process at the UVA Hospital. Additionally, hospital officials at UVA Health can collaborate with autoclave manufacturers to gather data on different autoclave models that would improve water and energy efficiency for the hospital sterilization processes. Efforts should include collecting data from various autoclaves to understand the most cost-efficient and water-efficient processes for the ideal systems to accommodate the increased use of reusable surgical tools. Additionally, further investigations should be conducted into optimizing autoclave efficiency and exploring alternative sterilization methods that use less water. However, potential pitfalls with these future improvements include upfront investment costs to replace old or unsustainable equipment and UVA Health resisting change due to the current established healthcare processes used in the hospital system. Additionally, this LCA did not examine the added employment cost for technicians who operate the autoclaves. Future work that factors in this additional cost would be more accurate.

Instrument Sourcing

In the realm of instrument sourcing, conducting X-ray fluorescence (XRF) analysis is essential. This comprehensive assessment will show the material composition disparities between single-use and reusable steel instruments, allowing for more accurate analysis of environmental impact. Moreover, partnering with surgical instrument manufacturers ensures that UVA Health promotes the ethical sourcing of surgical instruments by upholding social responsibility standards within the healthcare supply chain. Child labor used to make surgical tools is a significant problem in the Sialkot region of Pakistan, where almost all Pakistani tools are manufactured[4]. UVA Health must prioritize partnerships that avoid sourcing tools that may come from these damaging child labor practices. Finally, implementing rigorous quality checks on incoming instrument batches holds newly sourced manufacturers accountable and reinforces ethical sourcing practices.

Product Use Data

Finally, expanding the scope of product use data analysis is pivotal in optimizing instrument utilization. Future work should work more closely with hospital administrators to obtain more accurate usage data for reusable tools and more accurate data around the real lifecycle of each reusable tool. Developing standardized methodologies for measuring the usage of reusable instruments will provide valuable insights into their lifecycle and effectiveness. Moreover, stakeholders within the hospital, including waste management specialists and operations specialists, must collaborate with autoclave equipment manufacturers and regulatory bodies to innovate more sustainable practices to reduce stainless steel waste. Future research should also explore the broader implications of transitioning to reusable instruments across multiple healthcare facilities using different tools in their analysis. Broadening the Life Cycle Assessment to encompass a broader range of instruments, including tools made of plastic, blue wrap sterile packaging, or other stainless steel tools, will offer a comprehensive understanding of the environmental implications associated with different product types. This future research can also examine these proposed reusable instruments' long-term durability and maintenance requirements to promote more sustainable sourcing and procurement practices. By addressing these future considerations, UVA Health and other healthcare facilities across the country can work to provide a holistic change regarding sustainability practices, facilitating informed decision-making while also living up to their high standards of care.

End Matter

Author Contributions and Notes

C.G.M, J.M.N, M.D.S designed research, performed research, analyzed data, wrote the paper, and designed the poster.
M.J.M guided through hospital shadowing and data collection.
Z.T.L and L.M.CP advised undergraduate team throughout project entirety.
The authors declare no conflict of interest.

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