INFORMATION BRIEF (RAPID REVIEW)

RIGID STERILISATION CONTAINER IN REDUCING CARBON EMISSION AND CONTAMINATION

Malaysian Health Technology Assessment Section (MaHTAS)
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Ministry of Health Malaysia
001/2025

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Available online via the official Ministry of Health Malaysia website: http://www.moh.gov.my

eISSN:

SUGGESTED CITATION: Fatin NM, Nurkhodrulnada ML and Izzuna MMG. Rigid Sterilisation Container in Reducing Carbon Emission and Contamination. Information Brief. Ministry of Health Malaysia: Malaysian Health Technology Assessment Section (MaHTAS); 2025. 20 p. Report No.: 001/2025. eISSN: ……

DISCLOSURE: The author of this report has no competing interest in this subject and the preparation of this report is entirely funded by the Ministry of Health Malaysia.

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PURPOSE

To provide brief information on the effectiveness, safety and cost-effectiveness of rigid sterilisation container in reducing carbon emission and contamination.

BACKGROUND

It is well recognised that the healthcare industry contributes significantly to environmental contamination. The healthcare sector accounts for 5.5% of a nation's overall carbon footprint on average, with wealthy nations like the United States, Belgium, Japan and the Netherlands leading the pack with 7.6 to 8.1%.[1] It was estimated in 2013 that the environmental effects of the United States healthcare system caused 614,000 disability-adjusted life years (DALY) each year worldwide.[2] Given the paradox that healthcare has indirect negative impacts on public health, steps must be taken to enhance the healthcare sector's environmental performance through waste and pollution reduction, energy conservation and other measures.[3] The operating room, a very resource-intensive department of the hospital, is one where carbon dioxide emission reduction strategies might have a significant effect. The use of inhalation anaesthetics, the energy consumption of the heating, ventilation and air conditioning system, the supply chain and waste generation are the main factors influencing the operating room’s carbon footprint.[4]

The increased reliance on disposable items over the past 20 years is a key factor driving the rise in operating room waste. Disposables have become standard in healthcare, replacing reusable products. This shift is attributed to convenience, cost savings, and enhanced infection control. Many reusable items previously used in the operating room, such as laparoscopic tools, surgical gowns and drapes, and anaesthetic supplies like breathing circuits and facemasks, have been replaced by disposable alternatives. Disposing of these items after use generates substantial waste, with an average of 12 kg of waste produced during a single surgery, highlighting the operating room's significant role in overall hospital waste generation.[4]

Globally, around 313 million surgeries are carried out each year, and the market for surgical equipment is expected to increase by 7.8% yearly to reach a value of €16.8 billion by 2025.[5,6]. The greenhouse gases related to surgical items and supporting activities may be evaluated using a carbon footprint. During a procedure, surgical equipment is usually a significant surgical carbon hotspot,[7] and using more reusable equipment instead of single-use items has been found to be a crucial approach for minimising environmental damage overall.[8] Comprehending the best practices for decontaminating and packing reused surgical instruments would assist surgical teams in achieving healthcare carbon reduction goals.[9]

Aside from these pragmatic obstacles to recycling, it is critical to understand that recycling is essentially the down cycling of plastics, which make up the majority of packaging materials and throwaway items utilised in operations. Recycled materials are rarely utilised in the operating room as raw materials for comparable goods. Accordingly, it is preferable to minimise waste from an environmental standpoint by implementing the other waste reduction pillars of "reduce," "reuse," and "recycle" first. In a circular economy, recycling is a crucial strategy to guarantee that priceless raw materials are not squandered. But first and foremost, the greatest method to lessen the environmental effect is to prevent waste from being created.[10]

One of the main contributors of operating room waste is the use of blue wrap as a disposable wrapping material for sterile surgical tools **(see Figure 1a)**.[11] In the United States alone, an estimated 115 million kilogrammes of blue wrap are thrown annually.[10] It is made from sheets of polypropylene, and this wrap is a multilayer non-woven packaging material. Similar to how shipments are packaged, surgical instrument nets are wrapped in the sheets. A special polypropylene trilaminate that is durable, resistant to germs and able to tolerate the high temperatures required for sterilisation is created via the production processes of spun bonding and melt blowing.[12] Blue wrap packaging is thrown away once sterile surgical tools are unpacked, accounting for 11.5% of all operating room waste.[13]

Even though steam sterilisation seems effective on blue wrap packaging, it requires a porous barrier that introduces inefficiencies and risks. This barrier, typically made from polypropylene, allows steam to penetrate but also creates potential bacterial entry points. It is sensitive to moisture and fragile, requiring a carefully controlled environment for sterility. The cooling phase is particularly slow due to the porous nature of the barrier. Steam must escape gradually to avoid condensation, which can compromise sterility through bacterial wicking. Rapid cooling or premature handling can cause condensation, increasing the risk of contamination. Additionally, placing hot trays on cold metal surfaces may lead to droplet formation, potentially contaminating adjacent trays with wet spots and dripping **(see Figure 1b)**.[14]

(a) (b)

Figure 1: a) The [redacted] blue wrap[11] and b) rapid cooling can lead to droplet condensation, dripping and localised wet spots, which may allow bacteria to wick through the porous barrier and compromise the sterility of its contents.[14]

Perioperative disposables can be replaced with reusable alternatives to reduce operating room waste. A reusable rigid sterilisation container as shown in **Figure 2a**[15] can be used as a substitute to blue wrap. Most sterilisation departments in Europe (60.0%) utilise rigid sterilisation containers, however in North America, China and India, where blue wrap is used, this is far less common.[16] Both packaging systems have similar overall costs for both purchase and use, nevertheless, the containers demand more storage space **(see Figure 2b)**,[18] require relatively big capital commitments to purchase, and are less ergonomic due to their weight. These drawbacks of rigid sterilisation container are a possible explanation for the worldwide popularity of blue wrap.[17]

(a) (b)

Figure 2: a) Rigid reusable sterilisation container[15] and sterile area.[18]

Reusable surgical tools are usually arranged in trays or baskets in sets (inside the rigid sterilisation container) that include the tools needed for a particular surgery or series of procedures. Following usage, instruments are packed and undergo a decontamination procedure that includes cleaning and microbial inactivation by sterilisation and/or disinfection. Microbial inactivation is most often achieved using steam, although alternative low-temperature methods include use of ethylene oxide, vaporised hydrogen peroxide gas plasma, or ozone. Sterile barrier systems are used in the packaging of decontamination tools to keep them sterile until they are used. These systems allow the sterilising agent to pass through while blocking the entry of germs after treatment.[19]

In terms of local practice, the Policies and Procedures on Infection Prevention and Control (Third Edition; 2019) in Malaysia states that, at least three sections should ideally make up the core processing area or areas: packaging, decontamination, and sterilisation and storage. The decontamination room should be physically isolated from the other areas to keep used items from being contaminated. For the Central Sterilisation and Supply Unit, environmental cleaning needs to be done on a regular basis. Additionally, prior to being sterilised or disinfected, reusable medical devices and equipment must be completely cleansed in order to physically eliminate any pathogens. Physical inspection, lubrication, wrapping, washing, drying and pre-cleaning (disassembly, sorting, soaking) would all be part of the cleaning procedure.[20]

Several reputable brands offer rigid sterilisation containers designed to maintain the sterility of surgical instruments such as [redacted].[24] These brands offer a variety of sterilisation containers to suit different medical and surgical needs, ensuring the safe and effective sterilisation of instruments.

As things stand, the financial cost and carbon footprint of various procedures for cleaning and preparing reusable surgical tools, as well as how to optimise these procedures, have not yet been documented in any study. Due to the uncertainty regarding the sterilisation container, this information brief was requested to assess whether this technology can serve as an alternative for disposable sterilised surgical sets while simultaneously reducing carbon emissions and contamination.

EVIDENCE SUMMARY

The systematic review was conducted. A total of 283 titles were retrieved through the Ovid interface: Ovid MEDLINE® All <1946 to 7 February 2025>, Embase and United States of Food and Administration. Google was used to search for additional web-based materials and information. There was no language limitation in the search and the last search was conducted on 14 February 2025. There were five comparative studies and one prospective study were found to be relevant and included in this review. The studies were conducted in United States, United Kingdom, Australia and Netherlands.

EFFECTIVENESS

Five studies reported on the effectiveness of sterilisation containers in reducing carbon emissions, while one study examined their implications for contamination.

a. Impact on carbon emission

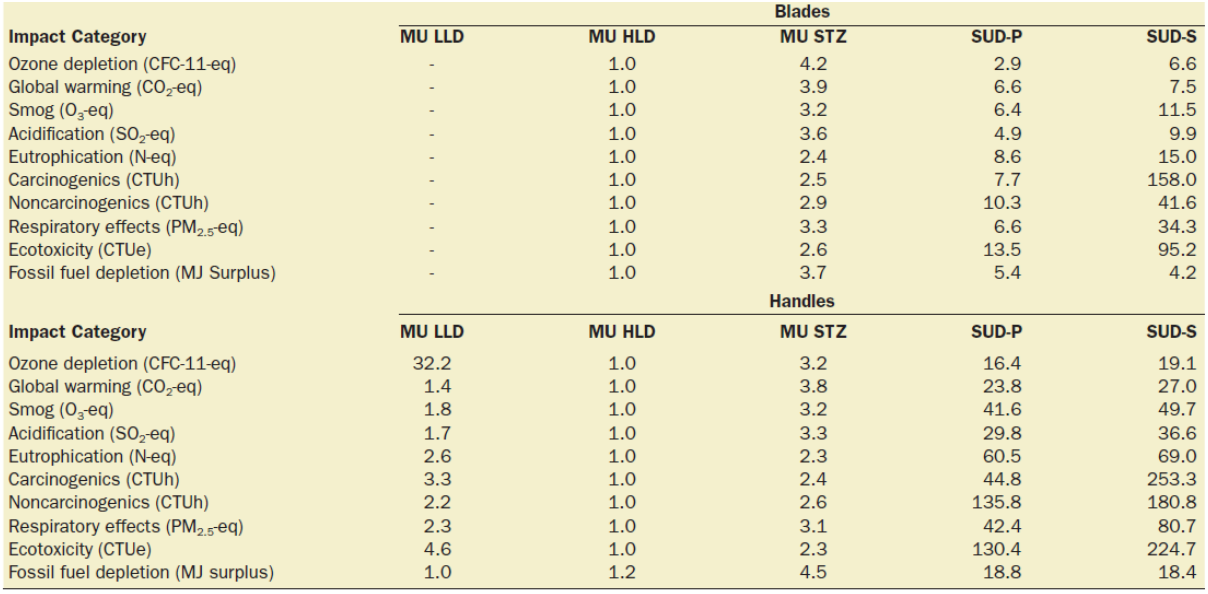
A comparative study was conducted by Friedericy HJ et al. (2022) in the Netherlands, to evaluate the environmental impacts of single-use polypropylene blue wrap versus reusable rigid sterilisation containers for packaging surgical instruments. The study utilised an in-depth life cycle assessment and applied three environmental indicators: carbon footprint (single issue method), ReCiPe (damage-based method; it was about damage in terms of human health, ecosystems and resource depletion, and had no separate score for global warming) and eco-costs (monetised prevention-based method). The functional unit was defined as the sterile packaging of a standard-format instrument tray over 5,000 sterilisation cycles. This implied that 5,000 blue wraps were equivalent to a single reusable rigid sterilisation container used for 5,000 cycles.[11]

Findings revealed that reusable rigid sterilisation containers had significantly lower environmental impacts; 85.0% less in carbon footprint, 52.0% less in ReCiPe, and 84.5% less in eco-costs as compared to blue wrap packaging. The study also determined that the environmental break-even point for reusable rigid sterilisation containers occurred after 67, 98 and 228 use cycles, respectively, depending on the indicator applied. Moreover, the primary contributor to the environmental impact of the reusable rigid sterilisation containers system was power consumption during its use phase at the hospital, totalling 1,996 MJ per 5,000 cycles. This raised the potential environmental benefits of installing solar panels on the hospital's roof. Compared to the EU-27 electricity mix (the baseline scenario), using locally generated solar power could reduce the eco-cost of the rigid sterilisation containers system by €28 per 5,000 cycles; a 74.0% reduction. In contrast, the electricity consumption for blue wrap during the use phase is minimal, amounting to just 103 MJ per 5,000 cycles.[11]

Another comparative study (Davis NF et al., 2018) was explored in Australia, to evaluate the environmental impacts of single-use and reusable flexible ureteroscopes (endourological equipment set which was stored in a sterilised container). The analysis considered the entire lifecycle of both devices, including manufacturing, usage, maintenance and disposal. The findings revealed that the total carbon footprint per procedure was approximately 4.43 kg of carbon dioxide (CO_2) for the single-use ureteroscope and 4.47 kg of CO_2 for the reusable ureteroscope, indicating comparable environmental impacts. The study highlighted the importance of considering the lifecycle emissions of medical instruments to make informed decisions regarding their environmental sustainability.[25]

Sherman JD et al. (2018) in another comparative study, aimed to assess the environmental impacts and total costs associated with reusable and single-use disposable laryngoscopes. Researchers conducted a cradle-to-grave life-cycle assessment and life-cycle costing analysis at Yale-New Haven Hospital, United States, focusing on both metal and plastic laryngoscope handles and blades. The study utilised the United States Environmental Protection Agency's TRACI method to assess environmental impacts, including greenhouse gas emissions. The results revealed that, the single-use disposable plastic handle was found to generate approximately 16 to 18 times more life cycle CO_2-equivalents (CO_2e) than the reusable steel handle undergoing traditional low-level disinfection. Similarly, the single-use disposable plastic blade produced about five to six times more CO_2e than the reusable steel blade treated with high-level disinfection. The single-use disposable metal components exhibited even higher emissions compared to all other alternatives **(see Table 1)**.[26]

Table 1: Life-cycle assessment results, scaled to the lowest alternative for each impact category.[26]



			Blades		
Impact Category	**MU LLD**	**MU HLD**	**MU STZ**	**SUD-P**	**SUD-S**
Ozone depletion (CFC-11-eq)	-	1.0	4.2	2.9	6.6
Global warming (CO_2-eq)	-	1.0	3.9	6.6	7.5
Smog (O_3-eq)	-	1.0	3.2	6.4	11.5
Acidification (SO_2-eq)	-	1.0	3.6	4.9	9.9
Eutrophication (N-eq)	-	1.0	2.4	8.6	15.0
Carcinogenics (CTUh)	-	1.0	2.5	7.7	158.0
Noncarcinogenics (CTUh)	-	1.0	2.9	10.3	41.6
Respiratory effects ($PM_{2.5}$-eq)	-	1.0	3.3	6.6	34.3
Ecotoxicity (CTUe)	-	1.0	2.6	13.5	95.2
Fossil fuel depletion (MJ Surplus)	-	1.0	3.7	5.4	4.2
			Handles		
Impact Category	**MU LLD**	**MU HLD**	**MU STZ**	**SUD-P**	**SUD-S**
Ozone depletion (CFC-11-eq)	32.2	1.0	3.2	16.4	19.1
Global warming (CO_2-eq)	1.4	1.0	3.8	23.8	27.0
Smog (O_3-eq)	1.8	1.0	3.2	41.6	49.7
Acidification (SO_2-eq)	1.7	1.0	3.3	29.8	36.6
Eutrophication (N-eq)	2.6	1.0	2.3	60.5	69.0
Carcinogenics (CTUh)	3.3	1.0	2.4	44.8	253.3
Noncarcinogenics (CTUh)	2.2	1.0	2.6	135.8	180.8
Respiratory effects ($PM_{2.5}$-eq)	2.3	1.0	3.1	42.4	80.7
Ecotoxicity (CTUe)	4.6	1.0	2.3	130.4	224.7
Fossil fuel depletion (MJ surplus)	1.0	1.2	4.5	18.8	18.4

Assumes standard United States waste disposal mix.
CFC-11-eq, trichlorofluroromethane equivalents; CO2-eq, carbon dioxide equivalents; CTUe, comparative toxicity units, ecotoxicity equivalents; CTUh, comparative toxicity units humans equivalents; HLD, high-level disinfection; LLD, low-level disinfection; MJ surplus, megajoule (energy) surplus; MU, multiuse/reusable; N-eq, nitrogen equivalents; O3-eq, ozone equivalents; PM2.5 eq, particulate matter (<2.5 micron aerodynamic diameter) equivalents; SO2-eq, sulfur dioxide equivalents; STZ, sterilization; SUD, single-use disposable (-P/-S, plastic/steel).

Rizan C et al. (2022) conducted a prospective study in the United Kingdom to assess the environmental and financial impacts of decontaminating and packaging reusable surgical instruments. The study examined various sterilisation methods, including individually wrapped instruments and instrument sets housed in single-use tray wraps or reusable rigid containers. They also modelled alternative practices such as optimising machine loading, adjusting instrument set compositions, utilising different energy sources for decontamination, and implementing alternative waste management strategies. Modelling of loading efficiencies as shown in **Figure 3** showed that, increasing the number of instruments per set (or per slot for individually wrapped instruments) reduced the carbon footprint, with further reductions achieved by enhancing loading efficiency (the proportion of slots utilised). The carbon footprint was highly associated with the number of slots used and the amount of instruments per slot ($R^2=0.678$, $p<0.001$).[27]

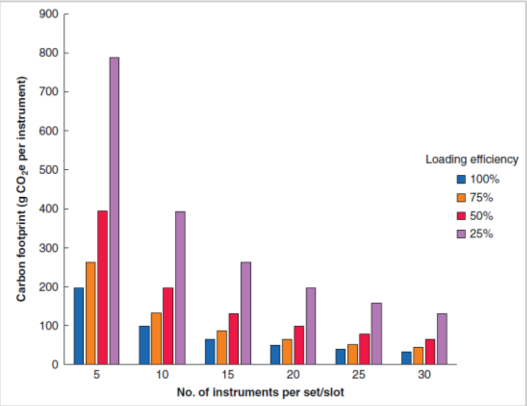
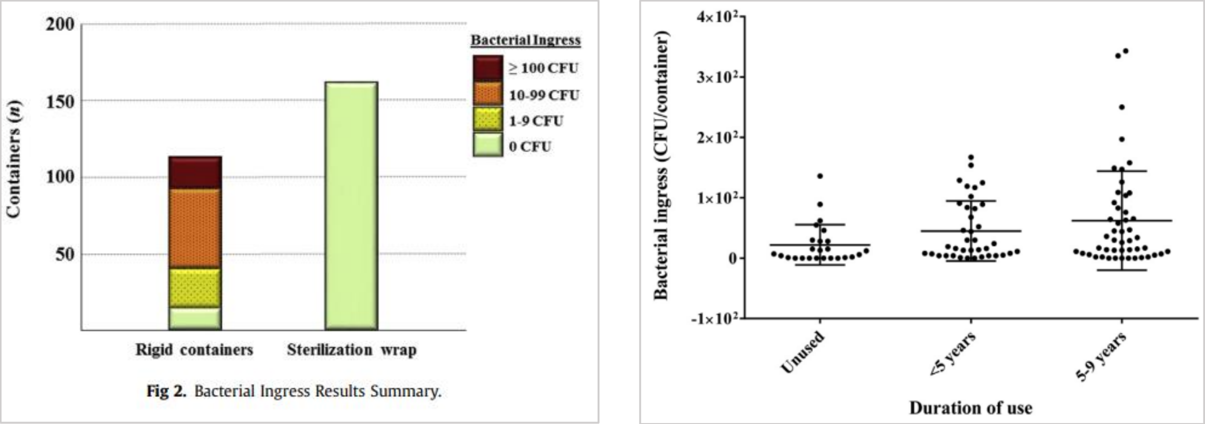


Figure 3: Carbon footprint of decontaminating instruments under different loading scenarios.[27]

Additionally, the carbon footprint of the sterile barrier system per typical instrument was higher for reusable aluminium containers as compared to single-use tray wraps (25 g CO_2e vs. 13 g CO_2e). Compared to baseline (that utilised low-temperature incineration using waste energy), high-temperature incineration had shown higher carbon footprint increment in single-use tray wrap by 33.0%, followed by reusable rigid containers (3.0%). Decontaminating and packaging instruments as part of sets resulted in a lower carbon footprint (66 to 77 g CO_2e per instrument) compared to individually wrapped instruments (189 g CO_2e per instrument).[27]

b. Microbial contamination

A comparative study assessed the effectiveness of two sterilisation packaging systems; rigid containers and sterilisation wraps in maintaining sterility of surgical instruments post-sterilisation. The study was **conducted by Shaffer HL et al. (2015)** in United States, utilising a custom aerosol chamber to simulate dynamic environmental conditions, and challenging the packaging systems with aerosolised *Micrococcus luteus* bacteria. A combination of used rigid containers sourced from the active inventories of various healthcare facilities across diverse regions in the United States and Canada, along with new containers purchased from the open market, were tested in this study. For evaluation purposes, the test packages were classified based on their duration of use. Approximately 87.0% (97/111) of the rigid containers allowed significant bacterial ingress under the test conditions ($p<0.0001$). In contrast, all 161 wrapped trays maintained sterility, showing no detectable bacterial ingress, regardless of the wrap grade used **(see Figure 4a)**. Notably, containers with five to nine years of use were significantly more prone to contamination than unused ones, suggesting a decline in barrier efficacy over time **(Figure 4b)**.[28]



(a) (b)

Figure 4: a) Bacterial ingress results summary and b) bacterial ingress found in sterilised rigid containers based on duration of use.[28]

These results indicated that sterilisation wraps might offer superior protection against bacterial contamination compared to rigid containers, especially as the latter age. The study highlighted the importance of evaluating the long-term efficacy of sterilisation packaging systems to ensure the sterility of surgical instruments.[28]

Table 1: Effectiveness of rigid sterilisation container in reducing carbon emission and contamination.

Study	***Country***	***Intervention***		***Findings***
		Treatment	**Control**	
Friedericy HJ et al./2022/ CS[11]	Netherlands	Rigid sterilisation container	Single-use polypropylene blue wrap	• The treatment group had significantly lower environmental impacts as compared to control. • Primary contributor to the environmental impact of the treatment system was power consumption during its use phase at the hospital (1,996 MJ vs. 103 MJ per 5,000 cycles).
Davis NF et al./2018/ CS[25]	Australia	Reusable flexible ureteroscopes	Single-use flexible ureteroscopes	• The total carbon footprint for both groups were comparable (4.47 kg vs. 4.43 kg of CO_2).
Sherman JD et al./2018/ CS[26]	United States	Reusable disposable laryngoscopes	Single-use disposable laryngoscopes	• The treatment group generated lower life cycle CO_2e for low-level disinfection in steel handle and for high-level disinfection in steel blade, as compared to control. • The treatment group exhibited lower emission.
Rizan C et al./2022/ Prospective[27]	United Kingdom	Reusable rigid sterilisation container	Single-use tray wraps	• The carbon footprint, number of slots used and the amount of instruments per slot were highly correlated ($p<0.001$). • The carbon footprint of the sterile barrier system per typical instrument was higher in the treatment group (25 g vs. 13 g CO_2e).
Shaffer HL et al./2015/ CS[28]	United States	Reusable rigid sterilisation container	Single-use tray wraps	• The treatment group allowed significant bacterial ingress ($p<0.0001$) as compared to control. • Containers with longer use were significantly more prone to contamination.

CS, comparative study; CO_2e, carbon dioxide equivalent

SAFETY

There was no study reported on the safety issue or adverse events of rigid sterilisation container.

However, one study evaluated the steam quality from 2016 to 2022 at Brazil. The findings suggested that, regular monitoring and maintenance of sterilisation processes, including the quality of steam, are essential to ensure the effectiveness of sterilisation and the condition of the containers. In addition, implementing proper sterilisation protocols and handling procedures is vital to maintain the safety and effectiveness of rigid sterilisation containers.[29]

According to the United States Food and Drug Administration, evidence has shown that rigid sterilisation containers are classified as Class II medical devices (subject to general and special controls). The data indicated no concerns regarding their safety or effectiveness, allowing these devices to be marketed.[30] To date, nine different brands of rigid sterilisation containers have been registered with the Malaysia Medical Device Authority.[31]

ECONOMIC IMPLICATION

Two studies have reported on the economic impact of using instrument sets within rigid sterilisation containers to reduce carbon emissions.

The carbon footprint and financial costs associated with the decontamination and packaging of reusable surgical instruments were assessed at the Royal Sussex County Hospital, United Kingdom, a publicly funded National Health Service regional hospital that handles both elective and emergency surgeries across various specialties **(Rizan C et al., 2022)**. The hospital's Sterilisation Services Department also supports a network of local public hospitals, alongside a smaller department at another location. During 2018 to 2019, approximately 62,000 procedures or interventions were conducted annually across these hospitals. From April 2017 to March 2018, about two-thirds of the sterilised items were instrument sets, while one-third were individually wrapped. Of the instrument sets, 85.0% were placed in reusable containers and the remaining 15.0% used single-use tray wraps. The total carbon footprint and cost of decontaminating and packaging instruments (based on the baseline model and assumptions) were calculated as follows: for instruments housed in aluminium containers, the footprint was 77 g CO_2e (€1.05) per instrument, totalling 2,252 g CO_2e (€30.41) for the entire set; for instruments in tray wrap, it was 66 g CO_2e (€1.07) per instrument, amounting to 1,918 g CO_2e (€30.98) for the full set; and for individually wrapped instruments, it was significantly higher at 189 g CO_2e (€7.35) per instrument. In summary, individually wrapped instruments had the highest carbon footprint and financial cost compared to instruments in sets. Instruments packaged in rigid aluminium containers had a higher carbon footprint per use than those in tray wraps, though both had similar financial costs.[27]

Furthermore, removing items from a set led to a proportional increase in the carbon footprint and cost associated with decontaminating and packaging reusable instruments **(Figure 5)**. In cases where the removed instruments were still needed as individually wrapped items (20.0% of procedures), this added 189 g CO_2e and incurred an extra cost of €7.35 per item. On average, the carbon footprint rose by 38 g CO_2e, with an additional cost of €1.47, for each item removed across all operations using the streamlined set. If extra instruments were needed during surgery (within 10 tools), decontamination and packaging them caused less environmental impact when each tool was wrapped separately. Financial costs were also lower when four or fewer items were needed. However, when these thresholds were exceeded, both the carbon footprint and costs were reduced by opening an additional instrument set instead.[27]

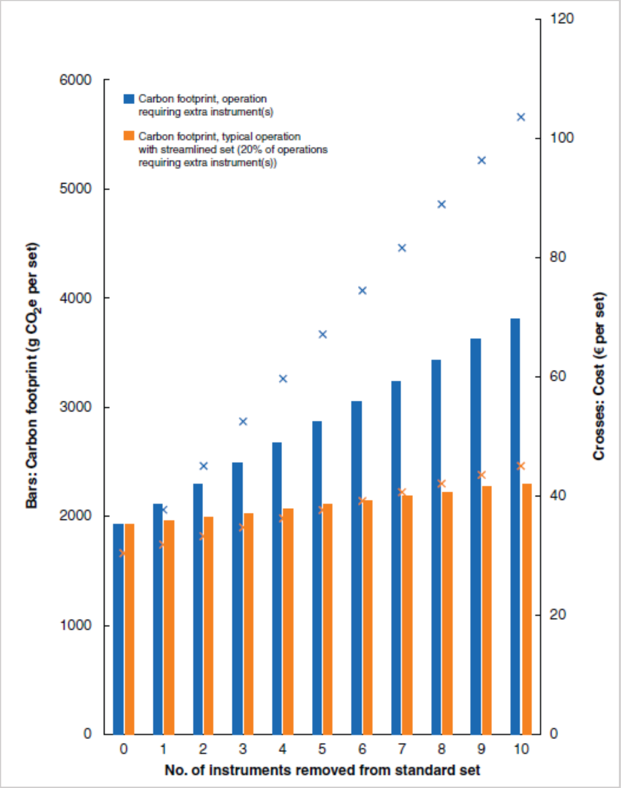


Figure 5: Impact of streamlining instrument sets on the carbon footprint and cost of decontamination and packaging of reusable instruments.[27]

Based on a standard set containing 29 instruments, housed in single-use tray wrap, with loading of decontamination machine at mean values. Bar graph shows carbon footprint and crosses indicate financial cost. CO_2e, carbon dioxide equivalents.

To reduce the carbon footprint and cost of instrument decontamination and packaging, four strategies were implemented **(see Figure 6)**. These included processing instruments in sets, fully loading the decontamination machine with 30 instruments per slot, increasing the use of low-carbon energy and recycling the sterile barrier. Using a reusable rigid container for housing the set resulted in a reduced financial cost (marginally cheaper than using single-use tray wrap), although single-use tray wrap had the lowest carbon footprint. The optimal financial expenses while using reusable rigid containers were €30.41 per set and €1.01 each instrument. In the United Kingdom, the optimum carbon footprint (using single-use tray wrap) was 1,348 g CO_2e per set and 45 g CO_2e per instrument. When Icelandic electricity was simulated, the carbon footprint was lowered to 633 g (electricity) or 1,141 g (natural gas-fuelled steam generation) CO_2e per set, resulting in 21 g (electricity) or 38 g (natural gas-fuelled steam generation) CO_2e per instrument.[27]

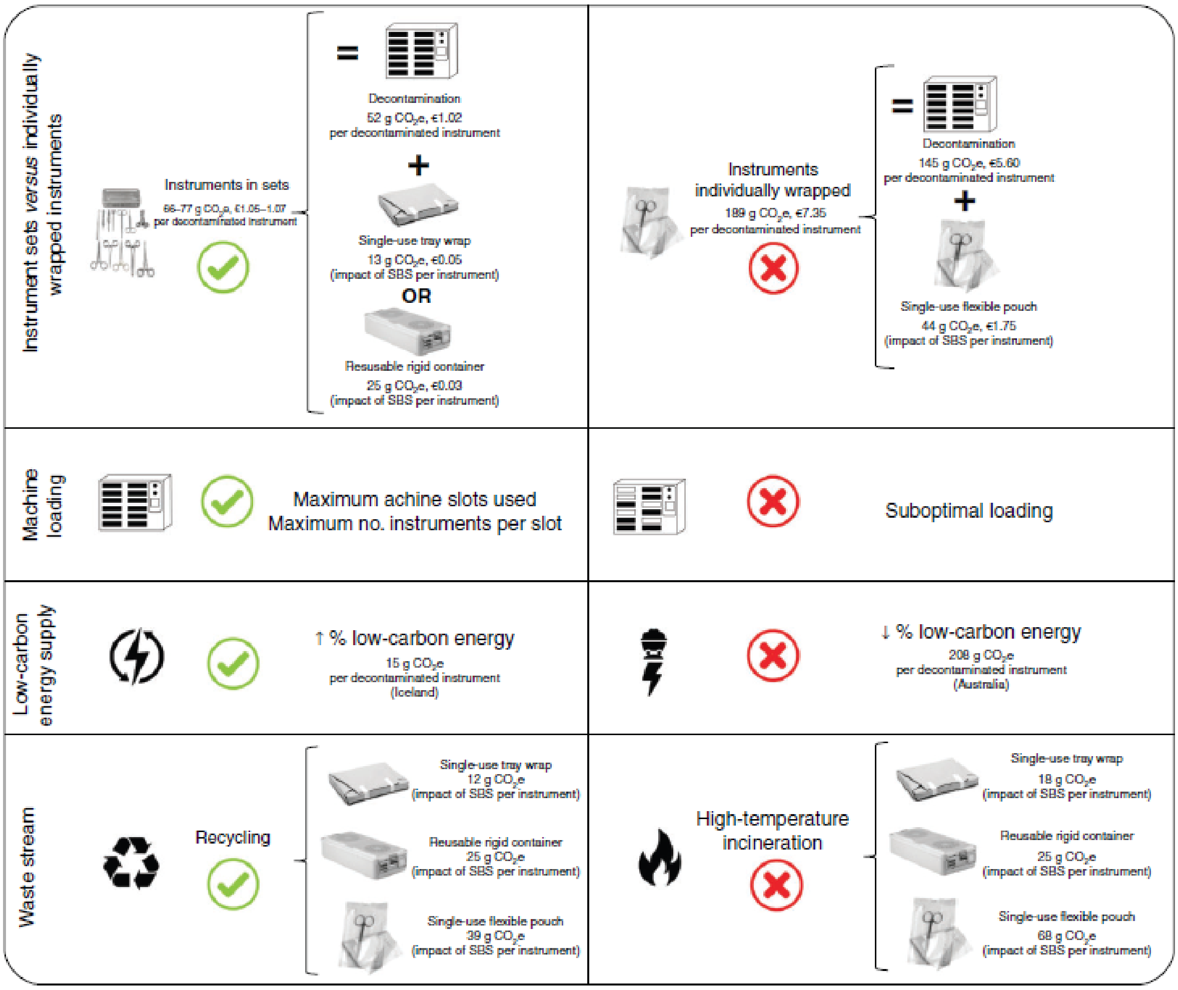


Figure 6: Optimising carbon footprint and financial cost of decontaminating and packaging reusable instruments.[27]

Low-carbon energy supply models assume electricity-powered steam generation. CO2e, carbon dioxide equivalents; SBS, sterile barrier system.

Sherman JD et al. (2018) conducted life-cycle assessment and life-cycle costing assessments to evaluate reusable stainless steel and rigid single-use disposable laryngoscope handles and blades made of steel and plastic, respectively. The study examined several cleaning and waste management scenarios and conducted sensitivity analysis to account for device attrition and labour needs, making the findings applicable to a variety of operating settings. The stainless steel laryngoscope handle was reusable and rated for 4,000 uses, whereas the single-use disposable options were only rated for one use. The cost analysis covered purchase, reprocessing, refurbishing and waste removal costs. **Figure 7** shows the life-cycle cost findings for reuse and single-use disposable laryngoscope handle and blade options. Reprocessing labor was the most expensive feature of employing reusable components. Meanwhile for single-use disposables, procurement expenses outweighed per-use costs.[26]

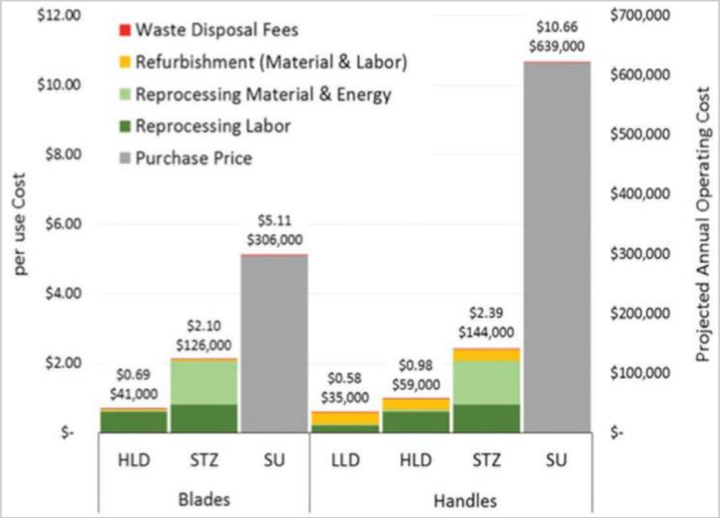


Figure 7: Life-cycle costs for each component per use and projected annual operating costs and contribution by reprocessing phase at Yale-New Haven Hospital (60,000 intubations).[26]

(1) Only the plastic single-use device costs were included here, as discounted prices for the single-use steel alternatives were unavailable at YNHH; (2) refurbishment included battery replacement; (3) this assumed each intubation required 1 tongue blade and 1 handle; however, in reality, more than 1 of either might be required or video laryngoscopy might be performed. HLD, high-level disinfection; LLD, low-level disinfection; MU, multiuse (reusable); STZ, sterilization; SU, single-use disposable.

Furthermore, the life-cycle cost analysis found that the reusable handle cleaned with low-level disinfection was the most cost-effective option at $0.58 per use. Upgrading to high-level disinfection raised costs by 68.0% to $0.98 per use, while using sterilisation increased costs by 300.0% to $2.39 per use. Despite these increases, all reusable handle cleaning methods were significantly cheaper than using a single-use disposable handle, which cost $10.66 per use (over 18 times more than low-level disinfection). Over a year at Yale-New Haven Hospital (with 60,000 intubations), using single-use disposable handles would raise costs by $495,000 to $604,000, depending on the cleaning scenario.[26]

For the reusable tongue blade, sterilisation cost $2.10 per use, more than double the $0.69 for high-level disinfection. The single-use disposable blade cost $5.11 per use, making it two to seven times more expensive than reusable options. Annual single-use disposable blade use would add $180,000 to $265,000 to costs. The largest cost factor for reusable options was labor time. Observed reprocessing times (0.5 to 2.0 minutes) were well below these thresholds, confirming that single-use disposables are consistently more expensive than reusable alternatives.[26]

Baseline data collection for assessing rigid sterilisation container feasibility

Although no local economic evaluation was conducted, several baseline data collection methods were recommended to assess the feasibility of rigid sterilisation containers. The following suggestions outline a range of parameters that hospitals are encouraged to collect before any detailed cost or feasibility analysis of rigid sterilisation containers can be conducted. The availability of these data (financial, labour, operational, maintenance, waste and carbon footprint factors) will enable a more informed decision regarding long-term viability, operational impact, cost implication and environmental impact associated with the use of rigid sterilisation containers in Central Sterile Supply Departments of selected Ministry of Health hospitals in comparison to disposable wraps.[8,11,33 and 34, level I]

a. Financial and procurement parameters

Parameter	Items to Collect		Reason for Collection
	Rigid Containers	Disposable Wraps	
Lease or Purchase Costs	1. Monthly or annual leasing fees (if applicable) 2. One-time capital expenditure (if purchasing) 3. Financing terms and conditions (including interest rates) 4. Warranty or service contract details i.e., coverage and duration	1. **Unit price** for wraps (per box or pack) 2. Order volume (weekly, monthly, or as needed- including any seasonal variations) 3. Historical spending totals	Establishes baseline investment for rigid containers versus ongoing cost of single-use wraps Enables direct cost comparison over a set period
Accessory Costs	1. **Per-unit prices** of filters, seals, gaskets (**each** item) 2. Expected usage frequency and total monthly or annual spending for **each** item 3. Any applicable bulk purchase discounts	1. **Unit cost** and quantity of tape, corner guards, indicator strips (**each** item) 2. **Unit cost** and quantity of any specialised wraps (e.g., large sizes) 3. Average monthly usage (including any seasonal variations) for **each** item	Contributes to the total cost of ownership, since even reusable containers incur regular consumable expenses (ongoing purchase of accessories)
Order Frequency	1. How often new wraps and accessory supplies are procured (weekly, monthly, quarterly) 2. Typical lead times for delivery 3. Storage capacity and stock requirements	1. Frequency of ordering wraps and related supplies 2. Typical lead times for receiving new stock 3. Bulk ordering versus "just in time" approach	Identifies procurement patterns and inefficiencies, such as frequent small orders versus bulk ordering, which may influence costs

b. Labour and staffing parameters

Parameter	Items to Collect		Reason for Collection
	Rigid Containers	Disposable Wraps	
Preparation Time	1. Average time to load, lock, and seal rigid containers 2. Any extra inspection steps (e.g., checking gasket integrity) 3. Sampling at different shifts (morning, evening)	1. Average time required to wrap trays in disposable sheets 2. Average time to apply tape, indicators, or corner protectors 3. Observations across multiple staff (workload levels) or different shifts	Directly influences labour expenditures; significant differences may indicate areas of efficiency or inefficiency

Staffing Requirements	1. Number of personnel needed for container assembly 2. Changes in staffing levels or roles required by container usage 3. Skill sets needed (for example, specialised maintenance)	1. Number and role of personnel currently involved in wrapping and packaging instruments 2. Any specialisd training or skill level needed for proper wrapping technique	Affects overall labour costs if additional or fewer staff are necessary
Training Hours	1. Frequency and duration of training sessions 2. Number of staff attending each session 3. Follow-up or refresher sessions required	1. Wrapping technique orientations (if staff are new) 2. Ongoing training on updated wrap protocols or best practices	Training is an initial cost driver that can also affect how smoothly staff adapt to new equipment
Overtime or Additional Shifts	1. Number of instances where container usage causes extended hours 2. Reasons for overtime or extra shifts (e.g., slower handling, unexpected repairs) 3. Overtime costs incurred	1. Number of instances where large numbers of wraps or complicated sets lead to extended hours 2. Number of overtime or weekend shifts needed to keep up with demand	Extra labour demands may offset potential savings from using rigid containers Indicates workflow disruptions or transitional issues

c. Operational workflow and incident data

Parameter	**Items to Collect**		**Reason for Collection**
	Rigid Containers	**Disposable Wraps**	
Number and Type of Sterilisers	1. Total count of machines (steam sterilisers, low-temperature sterilisers, etc.) 2. Model and manufacturer 3. Age or expected lifespan of each unit 4. Number of slots in a machine available to place rigid containers		Different machines have varying throughput, cycle times, and energy consumption
Cycle Capacity (Load Size)	1. Typical load of containerised sets per cycle (e.g., minimum and maximum of rigid containers per cycle – according to their sizes, if several sizes are available) 2. Sizes of rigid containers used and average number of instruments can be fitted/ packed into them (count of instruments for each different size of the containers)	1. Typical number of wrapped instruments sets per load (e.g., minimum and maximum number of instrument sets per cycle) 2. Typical number of individually wrapped instruments per load (e.g., minimum and maximum number of individually wrapped	Helps in comparing throughput between two packaging types (which may require more or fewer trays to fill a cycle)

	3. Average number of slots filled with rigid containers per load 4. Number of large containers that can fit in one load 5. Any height or stacking constraints for containerised sets	instruments per cycle) 3. Whether wraps can be stacked without compromising airflow 4. List and count of instruments individually wraps for sterilisation 5. List and count of instrument sets 6. Average number of slots filled per load 7. Any size limitations that reduce usable chamber space	
Reprocessing and Turnaround Time	1. Time from decontamination to availability for use 2. Any special steps for container loading/ unloading 3. Timing variations by special procedures, shifts or busy days 4. Number of cycles run per day or week 5. Duration of drying or pre-vacuum steps required for containers if any	1. Time from decontamination to availability for use 2. Duration of each sterilisation cycle 3. Timing variations by special procedures, shifts or busy days 4. Number of cycles run per day or week 5. Average duration of drying phase for typical instruments 6. Duration of extended drying phases for dense or bulky wrapped sets	Longer turnaround times may necessitate additional instruments and influence staffing and operating room scheduling
Compromised Packaging	1. Frequency of issues with rigid container seals, such as improper locking or gasket failure, wet interior or misaligned latches 2. Number of incidences in handling errors leading to compromised sterility 3. Number of additional reworks required	1. Frequency of torn wraps, wet packs, or incorrectly sealed edges 2. Frequency of any wrap integrity failure that requires re-wrapping or re-sterilisation	Failures lead to rework (labour, materials) and potential delays to scheduled procedures
Re-sterilisation Events	1. Frequency of trays requiring a second sterilisation cycle 2. Reasons for reprocessing (compromised sterility, contamination) 3. Additional labour or consumables used (water, energy, staff time)	1. Count of times a tray wrapped in disposable material is re-sterilised 2. Reasons (torn wrap, contamination) 3. Cost impact (new wrap, repeated sterilisation)	Identifies hidden expenses Repeated events could signal process or product issues

Storage and Inventory	1. Space needed to store rigid containers 2. Shelf layout adjustments, new racks or labelling 3. Frequency of lost or misplaced container incidents	1. Space needed to stack or store wrapped trays 2. Typical method for labelling wrap sets 3. Extra supplies for wrap storage (e.g., protective bins)	Storage changes may incur new expenses or require modifications to existing setups

d. Maintenance and repair parameters

Parameter	**Items to Collect**		**Reason for Collection**
	Rigid Containers	**Disposable Wraps**	
Maintenance Frequency (for rigid containers)	1. Scheduled inspection intervals (monthly, quarterly, etc.) 2. Unplanned or emergency repairs 3. Vendor-recommended versus actual service schedules	Not applicable	Helps assess container durability in real-world conditions Frequent repairs may erode potential cost benefits
Nature of Maintenance	1. Types of specific issues encountered (broken latch, seal failure) 2. Root causes (mishandling, normal wear) 3. Parts replaced or repaired	Not applicable	Identifies recurring problems and potential training gaps
Maintenance Costs	1. Price of spare parts (seals, latches) 2. Labour charges for repairs (in-house or vendor) 3. Inclusion or exclusion under warranty or lease agreement	Not applicable	Ensures all ongoing expenses are accounted for when comparing total costs
Downtime	1. Number of containers out of rotation at any time 2. Duration for which containers are unavailable (hours/days) 3. Impact on scheduling in the sterile processing department or operating rooms 4. Alternative packaging used during repairs – using older containers or disposable wraps	Count of times staff run out of wraps due to low inventory	Extended downtime can disrupt workflow (availability in operating room) and may result in additional disposable wrap usage

e. Waste and disposal data

Parameter	Items to Collect		Reason for Collection
	Rigid Containers	**Disposable Wraps**	
Packaging Waste (Weight or Volume)	1. Number of used filters, seals, broken container parts (if irreparable) over a set period (week/month/year) 2. Frequency or volume of discarded accessories 3. Frequency of part replacements	1. Volume or weight of discarded wraps per week or month 2. Volume or weight of discarded accessories (e.g., tape, corner protectors)	Rigid containers are not 100% waste-free Single-use wraps can be a large source of waste
Disposal Method and Fees	1. Type of disposal for broken parts (landfill or recycling) 2. Cost incurred for disposing container accessories (if regulated versus general waste) 3. Any specialised recycling contracts or fees	1. Disposal route for wraps (incineration, landfill) 2. Cost of regulated medical waste versus general waste 3. Any extra fees (incineration charges, landfill tipping fees)	Disposal costs can be substantial, and reductions may indicate potential savings
Recycling or Diversion Rates	1. Identification of recyclable components (for instance, metal lids) 2. Weight or volume of materials diverted from landfill 3. Potential revenue or reduced fees from recycling programs	1. Any program allowing wrap recycling or reuse (if feasible) 2. Proportion of wrap materials that are diverted from landfill	Demonstrates potential environmental benefits and possible additional savings from reduced waste disposal

f. Carbon footprint parameters

Parameter	Items to Collect		Reason for Collection
	Rigid Containers	**Disposable Wraps**	
Energy Usage for Sterilisation	1. Electricity consumption **per cycle** (amount of kilowatt-hour for each sterilisation run) 2. Steam and water usage - whether metered and amount used **per cycle** 3. Standard time and temperature (cycle settings) for sterilisation 4. Variation in times for special instruments or large sets	1. Electricity consumption **per cycle** (amount of kilowatt-hour for each sterilisation run) 2. Steam and water usage - whether metered and amount used **per cycle** 3. Standard time and temperature (cycle settings) for sterilisation 4. Variation in times for special instruments or large sets	Energy consumption is a major factor in both environmental impact and utility bills; to record any differences in the settings between different types of packaging

Maintenance and Transport	1. Distance travelled and frequency of deliveries for **each** accessory (e.g., filters, seals) 2. Distance travelled or fuel used for in-hospital movement of containers using motorised vehicle (e.g., electric cart, diesel van) 3. Type of vehicles used for deliveries – diesel or petrol, and their manufacturer names	1. Frequency of wrap deliveries from suppliers 2. Fuel usage or distances for distributing wrap supplies within hospital (if applicable) 3. Type of vehicles used for deliveries – diesel or petrol, and their manufacturer names	Transport and logistics can be a hidden but significant source of emissions
Waste Treatment Emissions	1. Types of disposal routes - incineration or landfill, for used container parts (e.g., filters, broken container parts) 2. Recycling or recovery efforts (e.g., if parts of the container can be recycled)	1. Disposal route for wrap waste (incineration versus landfill) 2. Disposal route for associated items (e.g., tape, corner protectors) waste 3. Any recycling possibility (rare for certain plastics)	Reduced waste typically lowers greenhouse gas emissions, thus measuring potential environmental benefits Recycling can reduce net emissions

CONCLUSION

Comparative studies on medical instrument packaging and usage reveal that reusable systems generally have lower environmental impacts and financial costs than single-use alternatives. Reusable rigid sterilisation containers significantly reduce carbon footprints, eco-costs and environmental damages compared to single-use blue wraps. However, maintaining their sterility over time remains a challenge, as older containers show higher contamination risks.

In terms of surgical instruments and medical devices, reusable options, such as laryngoscopes, ureteroscopes and central venous catheter kits, consistently offer lower life-cycle costs despite higher initial investments and labor-intensive reprocessing. Studies highlight that human labor is the most significant cost factor for reusable instruments, but even with reprocessing, they remain cheaper and more sustainable than single-use disposables. Optimising decontamination processes, improving machine loading efficiencies and integrating renewable energy sources (e.g., solar power) further enhance the sustainability of reusable systems. While single-use devices occasionally offer comparable environmental impacts (as seen with ureteroscopes), they generally result in higher carbon footprints and financial costs, especially in large-scale operations.

Overall, adopting reusable systems where feasible, coupled with proper maintenance and efficient sterilisation protocols, presents a more cost-effective and environmentally sustainable approach in healthcare settings.

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17 March 2025