BMJ Open

Before/after intervention study to determine impact on life-cycle carbon footprint of converting from single-use to reusable sharps containers in 40 UK NHS trusts

Terry Richard Grimmond ,[1] Anna Bright,[2] June Cadman,[3] James Dixon,[4] Sally Ludditt,[5] Clive Robinson,[6] Clare Topping[7]

To cite: Grimmond TR, Bright A, Cadman J, *et al*. Before/after intervention study to determine impact on life-cycle carbon footprint of converting from single-use to reusable sharps containers in 40 UK NHS trusts. *BMJ Open* 2021;**11**:e046200. doi:10.1136/bmjopen-2020-046200

► Prepublication history and additional supplemental material for this paper are available online. To view these files, please visit the journal online (http://dx.doi.org/10.1136/bmjopen-2020-046200).

Received 29 October 2020
Accepted 18 August 2021

Check for updates

© Author(s) (or their employer(s)) 2021. Re-use permitted under CC BY-NC. No commercial re-use. See rights and permissions. Published by BMJ.

For numbered affiliations see end of article.

Correspondence to
Terry Richard Grimmond; terry@terrygrimmond.com

ABSTRACT

Objectives To compare global warming potential (GWP) of hospitals converting from single-use sharps containers to reusable sharps containers (SSC, RSC). Does conversion to RSC result in GWP reduction?

Design Using BS PAS 2050:2011 principles, a retrospective, before/after intervention quantitative model together with a purpose-designed, attributional 'cradle-to-grave' life-cycle tool, were used to determine the annual greenhouse gas (GHG) emissions of the two sharps containment systems. Functional unit was total fill line litres (FLL) of sharps containers needed to dispose of sharps for 1-year period in 40 trusts. Scopes 1, 2 and 3 emissions were included. Results were workload-normalised using National Health Service (NHS) national hospital patient-workload indicators. A sensitivity analysis examined areas of data variability.

Setting Acute care hospital trusts in UK.

Participants 40 NHS hospital Trusts using RSC.

Intervention Conversion from SSC to RSC. SSC and RSC usage details in 17 base line trusts immediately prior to 2018 were applied to the RSC usage details of the 40 trusts using RSC in 2019.

Primary outcome measure The comparison of GWP calculated in carbon dioxide equivalents (CO_2e) generated in the manufacture, transport, service and disposal of 12 months, hospital-wide usage of both containment systems in the 40 trusts.

Results The 40 trusts converting to RSC reduced their combined annual GWP by 3267.4 tonnes CO_2e (–83.9%); eliminated incineration of 900.8 tonnes of plastic; eliminated disposal/recycling of 132.5 tonnes of cardboard and reduced container exchanges by 61.1%. GHG as kg CO_2e/1000 FLL were 313.0 and 50.7 for SSC and RSC systems, respectively. A sensitivity analysis showed substantial GHG reductions within unit processes could be achieved, however, their impact on relevant final GWP comparison varied <5% from base comparison.

Conclusions Adopting RSC is an example of a sustainable purchasing decision that can assist trusts meet NHS GHG reduction targets and can reduce GWP permanently with minimal staff behavioural change.

Strengths and limitations of this study

- Limitations: Data representativeness in location of manufacture of polymer for SSC and use of Plastics Europe values for GHG associated with polymer product ion in South Korea (RSC) Saudi Arabia (SSC); avoided emissions for UK regional electricity intensities were not stated; extrapolation of SSC usage data in 17 base line trusts to the 40 trusts using RSC; the extent to which the 40 trusts had converted all their facilities to RSC was not able to be ascertained.
- Strengths: Primary activity data for: total fill line litres used, tare weight data and distance data for single-use sharps containers (SSC) and reusable sharps containers (RSC) in 17 trusts; RSC usage, RSC fill line litres, weights and distance data for 40 trusts; vehicle size by route and injection moulding intensity.
- Reputable secondary data for polymer production, vehicle greenhouse gas (GHG) and UK region-specific data for electricity intensity.
- The trusts studied represented three-quarters of hospital trusts currently using RSC in UK.

INTRODUCTION

The climate crisis, brought about by increasing greenhouse gas (GHG) emissions, is the greatest threat to global health in the 21st century,[1–3] and the healthcare sector, being a significant GHG contributor, can play a leading role in resolving the crisis.[1 2 4] In 2008, the UK government recognised the impact of GHG on climate change and legislated a target of reducing UK's 1990 net carbon account by 80% by 2050, with a 26% reduction by 2020,[5] and increased to 34% in 2009.[6] In 2019, the Climate Change Act was amended to increase the 2050 net reduction to 100% ('Net Zero')[7] and to achieve this the UK Committee on Climate Change set a new UK target reduction of 37% by 2020.[8]

BMJ Open: first published as 10.1136/bmjopen-2020-046200 on 27 September 2021. Downloaded from http://bmjopen.bmj.com/ on April 26, 2024 by guest. Protected by copyright.

Internationally, healthcare's carbon footprint is equivalent to 4.6% of global net emissions,[2 3] with healthcare footprints in other countries ranging from 3.3% to 8.1% of their national emissions.[4] England's Health and Social Care (HSC) activities account for 4% of England's GHG emissions.[9] In 2010, to mirror UK government targets, the National Health Service England (NHS) set a 2020 target of reducing NHS 2007 GHG levels by 34%.[10] In 2020, the NHS committed to being the world's first 'net zero' NHS and, for NHS plus its supply chain ('NHS Plus'), set a new reduction target of 100% (net zero) by 2045.[9]

To achieve global and national reductions in healthcare emissions, particularly in developed countries, interventions should focus on reducing waste, including unnecessary plastics and single-use items.[11] Within England's HSC, supply chain goods and services contribute 66% of 'NHS Plus' GHG emissions.[9] To meet NHS targets, the NHS Sustainable Development Unit and others, recommend hospitals adopt sustainable purchasing strategies to reduce their GHG[10 12–14]—a position supported by the Royal College of Nurses[15] and the Royal College of Physicians.[16] Replacing disposable products with reusable alternatives and adopting circular economy principles is such an example[17–19] and marked reductions in GHG using this principle have been confirmed in many studies,[20–24] but not all.[25]

Clinical waste containers are among the top 20 medical devices prioritised for action in the UK NHS supply chain carbon footprint,[14] and replacing single-use sharps containers (SSC) with reusable sharps containers (RSC) is recommended.[26] Several non-peer-reviewed UK studies confirming GHG reduction with RSC have been conducted at single trusts,[27–32] and further quantitative studies are recommended to facilitate sustainable purchasing decisions in different scenarios.[18 33]

This study compared the annual carbon footprint of the sharps containment waste streams of 40 UK NHS hospital trusts converting from SSC to RSC.

MATERIALS AND METHODS

Study overview

Because of the infection and physical hazard posed by sharps waste, on completion of clinical procedures all sharps must be safely and immediately discarded into either SSC or RSC. Individual brands of SSC and RSC may vary in shape slightly but user requirements for design and function are identical and testing requirements are identical in standards covering both container types.[34] When sharps containers are filled to their fill line, they are closed and transported to an offsite treatment facility. With SSC, the container is used once and in UK the intact container and contents are incinerated and the residual, mainly inert ash, is landfilled. With RSC, the container (certified to a specified lifetime number of uses) is transported from the healthcare facility to the processing plant where it is automatedly decanted of its contents (which are treated and disposed to landfill), and the reusable container is robotically cleaned and decontaminated, quality checked and returned to the service pool for reuse. At end-of-life (EOL), RSC parts are reused or recycled.

The scope of this real-life before/after intervention study was to compare the life-cycle carbon footprint (LCCF) of 12 months usage of SSC with 12 months usage of RSC in a large group of UK NHS hospital trusts who had converted to RSC. Previous LCCF comparisons of sharps container systems conducted in USA have shown transport distances can be a major GHG contributor in the life-cycle of RSC and can affect comparisons significantly.[33 35] To remove distance bias in this, the first multitrust UK study, we examined a large number of geographically widespread hospitals to remove hospital, city and region bias as far as practical.

With the cessation of Healthcare Environmental Services in 2018,[36] there are currently two suppliers of RSC in UK-Stericycle UK, Leeds offering Biosystems RSC,[37] and Sharpsmart UK, Spennymoor offering Sharpsmart RSC.[38] In terms of LCCF, there are only small differences between both companies' operational models as they use similar-sized vehicles, travel similar distances between hospitals and processing facility, and both ship their RSC from overseas manufacturing facilities. As Sharpsmart UK has processing facilities throughout UK and services approximately three-quarters of UK NHS hospitals currently using RSC, it was approached and agreed to supply detailed LCCF data on RSC, and SSC usage data supplied to them from trusts, for this study. This study applies to 40 hospital trusts which converted from SSC to the Sharpsmart RSC, hereafter termed 'RSC' in this paper.

The study used a previously published calculation attribution product-system GHG assessment tool constructed in Excel (Microsoft) containing some 840 data cells and developed specifically for sharps container comparisons.[33 35] Using established principles for assessment of life-cycle GHG emissions of goods and services,[39] a cradle-to-grave life-cycle inventory (LCI) was completed. The global warming potentials (GWPs) used by secondary databases for carbon dioxide equivalents (CO_2e) calculations (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFC), perfluorocarbons (PFC), sulphur hexaflouride (SF_6), nitrogen trifluoride (NF_3)) are based on the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report.[40–43] Three (CO_2, CH_4 and N_2O) represent more than 99.5% of CO_2e generated during GHG-emitting activities in the life-cycle of sharps containers.[44 45]

GHGs, other than CO_2, are converted to their CO_2e on the basis of their per unit radiative forcing using 100-year GWP defined by the IPCC.[39] The annual GHG emissions for SSC and RSC systems were expressed in metric tonnes of CO_2e.

The LCI itemised all energy-using processes in each containment system's cradle-to-grave life-cycle from fossil fuel oil/gas extraction (for polymer manufacture) to final disposal of the sharps containers.

Scope

Although not stipulated by PAS 2050,[39] in accord with international healthcare and NHS GHG assessments,[29] the

BMJ Open: first published as 10.1136/bmjopen-2020-046200 on 27 September 2021. Downloaded from http://bmjopen.bmj.com/ on April 26, 2024 by guest. Protected by copyright.

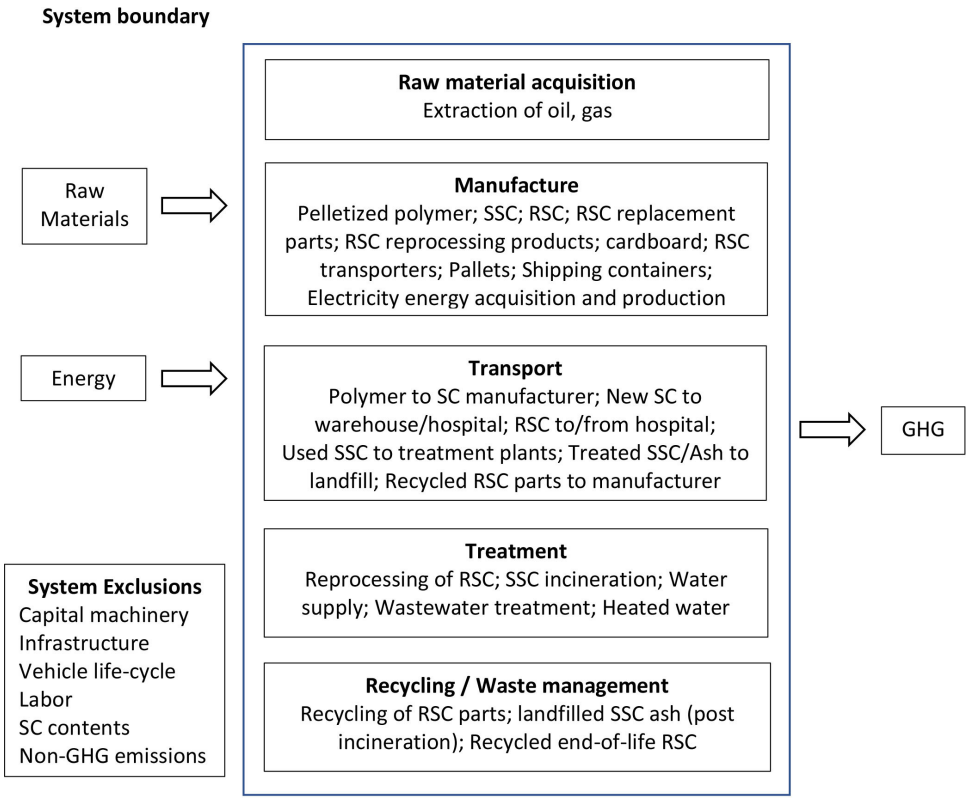

Figure 1 System boundary of life-cycle carbon footprint of sharps containers. GHG, greenhouse gases; RSC, reusable sharps containers; SC, sharps containers; SSC, single-use sharps containers.

following GHG emissions were included in both containment systems: scope 1 (company's GHG emissions related to own manufacturing/processing); scope 2 (from external energy used) and scope 3 processes (from relevant supply chain sources) including waste management and disposal in both systems. In accord with PAS 2050 requirement that product life-cycle stages encompass raw materials, distribution, use and final disposal and that GHG emissions be scoped appropriately and be applicable to the specific stakeholder base,[39] unit process GHG for SSC and RSC were collated into the following life-cycle stages:

- Manufacture (of polymer and containers).
- Transport (throughout life-cycle).
- Decanting and decontamination (RSC).
- Treatment and disposal of containers.

GHG emissions were collated from all energy sources used in these processes and in the manufacture and life-cycle of ancillary products (shipping containers, pallets, transport cabinets, cardboard boxes, wash products). The system boundary, together with inputs, outputs and exclusions, is shown in figure 1.

Patient and public involvement

No patient involvement.

Data sources

Primary activity data of high accuracy and specificity (direct from manufacturer/user/supplier) were used wherever possible. Primary energy usage data for injection moulding was obtained from the injection moulder of sharps containers; primary data for vehicle size and transport distances, RSC processing inputs of electricity, water and wash products, and material inputs for RSC transporter cabinets were obtained from the RSC manufacture; primary data on usage of SSC and RSC was obtained from NHS trusts and RSC service provider. Secondary databases were chosen for their representativeness: temporally (ie, data published within last 5 years); geographically (ie, sourced from same region/country in which the process was carried out) and applicability (ie, the process was identical or as close as possible to the process in the SSC and RSC life-cycles. In gathering data, relevance, completeness, consistency, accuracy and transparency were paramount.[39]

For SSC and RSC polymer production, reputable secondary ecoprofiles constructed by Plastic Europe were used and these utilised foreground GHG data from several PP and acrylonitrile butadiene styrene (ABS) processors and background GHG from the Gabi database.[42 43] For transport impacts, secondary 2018/2019 UK Department for Environment, Food and Rural Affairs well-to-wheel GHG values for vehicles (scopes 1 and 3) were used.[40] The GHG associated with manufacture of ancillary reusable equipment in either system (transport cabinets, pallets, shipping containers) were calculated on a per use/trip basis using their expected life span, lifespan uses and the GHG emitted in their construction. Regional intensity values for supply of UK electricity were

BMJ Open: first published as 10.1136/bmjopen-2020-046200 on 27 September 2021. Downloaded from http://bmjopen.bmj.com/ on April 26, 2024 by guest. Protected by copyright.

from regional generators and collated by electricity information.[46] The same databases and values were applied to the relevant unit processes in SSC and RSC systems.

Baseline activity data

Detailed data on RSC container size, model numbers, fill line capacities and annual usage required to service the 40 RSC hospital trusts during the study-year 1 August 2018 to 31 July 2019 were obtained from the RSC manufacturer. Trusts trialling RSC and private hospitals using RSC were excluded from the study. Detailed data on SSC container size, model numbers, fill line capacities and annual usage numbers for 12 months of SSC usage ('SSC study-year') were supplied by 17 UK NHS trusts converting to RSC in the 2 years prior to 1 July 2018 and obtained via the RSC manufacturer. The SSC usage details from the 17 base line trusts were used to calculate the mean SSC fill litre size and an SSC-to-RSC fill litres ratio which were then applied to the total RSC fill litres processed by the manufacturer in the RSC study-year so as to calculate the annual usage of SSC replaced by RSC in the 40 RSC trusts.

Total polymer weight required for manufacture of SSC and RSC was ascertained by multiplying the weight of each model of container (obtained from SSC/RSC manufacturer or manufacturer's website) by the total number of containers used in their respective 12-month periods.

Patient workloads impact sharps volumes and the LCCF of each system's study-year in the 40 trusts was workload-normalised by applying changes in the three major NHS hospital patient-workload indicators (finished admission episodes (FAE), total A&E attendances (AEA), total outpatient attendances (OPA)) for the respective years in the 40 trusts.[47–49] Average time taken in minutes for containers to be replaced when full ('container exchanges') was obtained from service personnel at trusts.

System function

The supply of sharps containers for the disposal of sharps waste (biological, chemotherapeutic, pharmaceutical) within the 40 hospital trusts that had adopted RSC before December 2018 and were being serviced by the RSC supplier for the full duration of the 12-month RSC period, 1 January 2019 to 31 December 2019.

Functional unit

The total fill line litres (FLL) of sharps containers needed to dispose of sharps over the respective study years across the 40 trusts.

System boundary

See figure 1. Excluded from the system boundary were treatment of container contents (identical in both SSC and RSC), infrastructure and assets, and any inputs and outputs that comprised less than 1% of mass or energy,[39] or were not relevant to a carbon footprint analysis.

ALL polypropylene (PP) polymer for SSC was assumed sourced from Jeddah, Saudi Arabia and shipped to UK ports in bulk sacks on pallets within 40ft shipping containers to two UK SSC manufacturers (representing 99.3% of SSC used in the 17 base line trusts examined). Once manufactured, the SSC are nested in cardboard containers, transported to NHS Supply Chain (NHSSC) distribution centres on wooden pallets, from whence they are supplied in cardboard boxes by NHSSC to individual trusts. The ABS polymer used for RSC was sourced from South Korea, shipped to Vancouver and rail freighted to the RSC manufacturer in Greenville MI. Once manufactured, the RSCs are shipped on pallets in 40 ft shipping containers to the UK service contractor and transported to/from trusts at least weekly in purpose-built transport cabinets. Annual emissions for 'RSC manufacturing' were determined by dividing total manufacturing GHG by the years of life-expectancy.[39]

GHG attribution

The production of polymer from oil or gas is a multifunction process and emissions were attributed on a mass (metric ton) basis.[42 43] Transport emissions were attributed on a mass-distance (ton.km) basis.[40] In the life-cycles of reusable pallets, RSC transporters, and shipping containers, attribution was averaged using cut-off and per trip GHG. Recycling of products or use of recycled product, if conducted, was credited to the manufacturing process of the product.[38 40] All cardboard was assumed collected and recycled in a closed loop system.[40] The injection moulding of SSC/RSC and the processing (cleaning and decontamination) of RSC are single-function processes and no allocation to coproducts was necessary. Incineration of SSC in UK is carried out in energy-from-waste incinerators that coproduce heat or electricity and the avoided utility emissions subtracted to give net GHG emissions per ton of polymer incinerated, however, UK Government GHG conversion factors do not differentiate between materials combusted[40] and US Waste Reduction Model (WARM) values were used for incineration of polypropylene.[50]

Impact category

GWP due to GHG emissions was the single impact assessment category to which all inventory data were classified. GWP was chosen as it is well known, commonly used and understood by healthcare facilities, and is the impact category used in NHS 'Net zero' reports.[9]

Sensitivity analysis

A sensitivity analysis was conducted on unit processes where emission variabilities and energy intensities would have the greatest impact on inputs with large GWP contributions to life-cycle, namely larger vehicle size, transport distances, polymer and container-manufacturing geographies, larger SSC container size,[33] and changing the lifespan of RSC from a base of 18 years, to 1 year, theoretical maximum of 66 years and the 'break-point at which lifespan RSC GWP matches SSC GWP.

Expression of results

Results were expressed as total annual tonnes of CO_2e of both containment systems; kg CO_2e/1000 FLL of each

BMJ Open: first published as 10.1136/bmjopen-2020-046200 on 27 September 2021. Downloaded from http://bmjopen.bmj.com/ on April 26, 2024 by guest. Protected by copyright.

containment system and kg CO_2e/1000 patient activity episodes (FAE+AEA+OPA). The mean tonnes CO_2e saved/1000 activity episodes in the 40 study trusts, with 95% CIs, together with NHS national activity episodes in 2019/2020, were used to calculate tonnes CO_2e that could potentially be saved if all UK NHS trusts adopted RSC.

RESULTS

Using the baseline SSC usage data from the 17 base line trusts, it was determined that to service the 40 trusts with SSC for 12 months in the base line period, 1 601 466 SSC would need be manufactured from 850.4 tonnes of PP polymer, and 125.1 tonnes of corrugated cardboard would be needed for transport packaging of SSC. The SSC used did not contain recycled polymer.

To service the 40 trusts in the RSC year, 84 786 RSCs were manufactured. During the RSC year, 3% (52 466) of the previous year's SSC quantity were retained for special purposes (crash carts, home-patient use, biosafety cabinets, suspected prion cases, phlebotomy trays and sharps used for radionucleotide injections) and their associated GHG were included in 'RSC' GHG allocations. During the RSC study-year, any damaged RSC that required repair had 80% by weight of parts recycled and 20% by weight of parts reused. Of the new RSC parts needing to be manufactured, with recycling credit,[50] and divided by years of life expectancy,[39] an equivalent of 273 RSC were manufactured, resulting in an 'RSC manufactured' total of 85 059 RSC for year 1 (requiring 223.6 tonnes of ABS polymer (table 1).

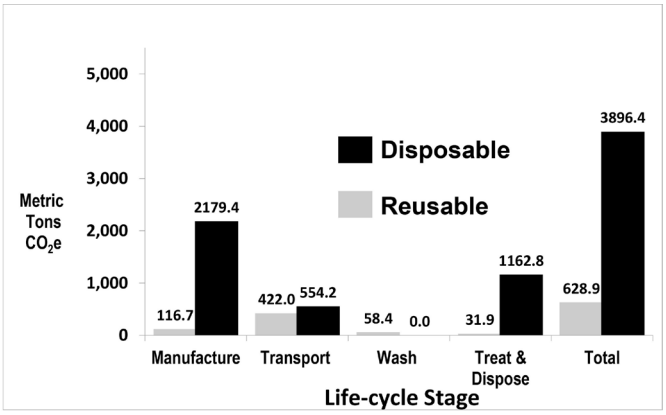

Figure 2 Annual carbon footprint, by life-cycle stage, of single-use and reusable sharps containers at 40 NHS trusts. CO_2e, carbon dioxide equivalent; NHS, National Health Service.

Nationally across the NHS, the sum of the three NHS patient activity episodes rose 3.6% from 2017/2018 to 2019 calendar-year,[47–49] however, the activity episodes in the 40 study trusts increased from 28.8 million to 31.4 million episodes (+9.2%) in the same period. Normalising this workload increase to SSC usage in 2019, table 1 shows sharps management in 2019 would require 1 748 851 SSC (928.7 tonnes plastic; 136.6 tonnes cardboard) generating 3896.4 tonnes CO_2e (table 1). With RSC use, GWP decreased to 628.79 tonnes CO_2e, a 3267.4 tonnes reduction in CO_2e (–83.9%).

Manufacturing (of polymer and containers) gave the largest differential between the two systems (see figure 2)

Table 1 Comparison of SSC and RSC 12-month GHG-related data in 40 trusts (SSC adjusted for 9.2% workload increase over the study period)

	SSC	RSC
Containers manufactured	1 748 851	85 059 (+52 466 SSC)*
Weight polymer required (tonnes)	928.7	223.6
Containers incinerated	1 748 851†	52 466‡ (–97.0%)
Weight plastic incinerated (tonnes)	928.7	27.9§ (–97.0%)
Weight cardboard boxes (tonnes)	136.6	4.1¶ (–97.0%)
Container exchanges	1 748 851	681 037†† (–61.1%)
MTCO_2e GWP**	3896.4	628.9 (–83.9%)
kg CO_2e/1000 fill line litres	313.0	50.7 (–83.8%)
kg CO_2e/1000 patient activity episodes	124.0	20.0 (–83.9%)

Container exchanges indicates replacement of full SSC with new SSC or replacement of full RSC with processed clean RSC.
*84 786 RSC manufactured in year 1 only, +273 replacement RSC (allowing for recycling credits), plus 52 466 SSC retained.
†All SSC incinerated.
‡Only SSC incinerated. No RSC incinerated—all parts either reused or recycled.
§Tonnes of SSC incinerated (52 466 SSC used during RSC year)
¶SSC packaging used in RSC study-year.
**Emissions of GHG expressed in terms of GWPs, defined as the radiative forcing impact of one mass-based unit (kg) of a given GHG relative to an equivalent unit of carbon dioxide over a given period of time (100 years).[30]
††RSCs were larger in fill line capacity than SSC (19.1 L vs 7.1 L) and were exchanged less often than SSC.
GHG, greenhouse gas; GWP, global warming potential; MTCO_2e, metric tonnes carbon dioxide equivalent; NHS, National health Service; RSC, reusable sharps container; SSC, single-use sharps container.

BMJ Open: first published as 10.1136/bmjopen-2020-046200 on 27 September 2021. Downloaded from http://bmjopen.bmj.com/ on April 26, 2024 by guest. Protected by copyright.

and is predominantly a function of the energy required for the higher tonnage of polymer needed to be manufactured and moulded for the larger number of SSC required in the 12-month period. Although RSCs are regularly transported to and from the processing plant and trusts, the larger number of SSC resulted in their transportation GHG being higher over the year than that for RSC (see figure 2).

The RSCs in this study, certified for 500 uses, were reused an average of 7.4 times/year, giving a theoretical EoL lifespan of 68.5 years. Each individual RSC is barcoded, and its uses automatically monitored to determine when each RSC's maximum 500 uses has been achieved, and when reached they can be either discarded to landfill, recycled or class recertified for further years of use. However, breakages and scuffing results in the need for 1.5% of RSC to be dismantled per year, and with 80% of parts being reused, the average predicted lifespan of RSC is 28.2 years. For this study a conservative 'worst-case' lifespan scenario of 18 years was adopted as this is the average age of RSC currently in service in UK. Total GHG emissions and GHG differences between the four life-cycle stages of SSC and RSC are shown in figure 2. The contribution of RSC wash stage to RSC GWP is low (figure 2) as RSC are required to be thoroughly cleaning/disinfected before reuse (not sterilised).

The average time taken for container exchanges was 2.5 min per container and, when applied to the 61.1% reduction in container exchanges (table 1), equates to 44 492 hours reduction in labour in the study year across the 40 trusts using RSC.

In terms of 'GWP efficiency', each 1000 FLL of sharps removed with SSC was associated with 313.0 kg CO_2e vs 50.7 kg $C0_2$e with RSC. Using the combined NHS patient workload indicators (FAE, AEA, OPA), each 1000 activity episodes was associated with 124.0 kg CO_2e using SSC and with 20.0 kg CO_2e using RSC. The mean tonnes CO_2e/1000 activity episodes of the study trusts was 104.9 with 95% confidence the population mean is between 84.7 and 125.0.

Sensitivity analysis

Polymer manufacture

It is of note that, in this study, the country in which SSC polymer is manufactured has the highest fossil-fuel derived (100%) energy production of G20 countries.[51] We examined changing to polymer production in North-West (NW) England and found the impact of shorter distances and lesser energy intensity brought system GWP reductions of up to 16%, however, the life-cycle GWP comparison was less than 1% different from base result (table 2).

Table 2 Quantitative sensitivity analysis of alternative configurations for processes with large contribution to system GWP

Unit process/stage altered	System	Process GWP (MT CO_2e) Base (% of system GWP)	Process GWP (MT CO_2e) Effect (% of system GWP)	% impact on system GWP	Outcome GWP comparison (Base: RSC 83.9% less than SSC)
Polymer manufacture North-West (NW) England; Container manufacture in UK company site	SSC	2103.8—Saudi Arabia (59.0)	1757.4 (NW Eng) (59.0)	−13.9	RSC 84.3% less than SSC
	RSC	120.2—Sth Korea (+UK SSC) (19.1)	94.8 (NW Eng) (18.0)	−16.0	
Manufacture containers in NW England	SSC	522.2—Eng. 2 sites (13.4)	115.4 (NW Eng) (3.3)	−11.4	RSC 82.4% less than SSC
	RSC	30.7—USA (+UK SSC) (4.9)	5.4 (NW Eng) (0.9)	−3.4	
SSC FLL (7.1 L) matches RSC (19.1 L)	SSC	3896.4 (100)	3262.4 (100)	−16.3	RSC 81.3% less than SSC
	RSC	628.9 (100)	611.5 (100)	−2.8	
Transport in UK (use of large vehicle)	SSC	152.8 (3.9)	78.2 (2.3)	−3.8	RSC 87.5% less than SSC
	RSC	304.6 (48.4)	144.6 (23.0)	−25.8	
RSC polymer and container manufacture					
If lifespan 66 years/500 uses		120.2 (19.1)	78.7 (13.4)	−6.6	RSC 84.9% less than SSC
If lifespan 1 year/7.4 uses		120.2 (19.1)	1147.5 (69.0)	164.2	RSC 57.3% less than SSC

FLL, fill line litres; GWP, global warming potential; MTCO_2e, metric tonnes carbon dioxide equivalent; RSC, reusable sharps containers; SSC, single-use sharps containers.

BMJ Open: first published as 10.1136/bmjopen-2020-046200 on 27 September 2021. Downloaded from http://bmjopen.bmj.com/ on April 26, 2024 by guest. Protected by copyright.

Container manufacture

Injection moulding is an energy-intense process (accounting for 13.4% of SSC life-cycle GWP) and siting the moulding facility in NW England (where electricity intensity can be as low as 25% of national intensity average)[46] enabled system GWP reductions of up to 11.4% but the end comparison, again was less than 2% different from base result (table 2).

Sharps container size

In a US study where RSC FLL capacity was 65% greater than SCC, when SCC GWP was recalculated with the SCC having identical size RSC, the reduction in GWP with RSC was 3% less than the base reduction.[33] In the current UK study, SSCs were smaller again and to test the impact of container size on GWP we re-examined the GWP using SSC of identical size and exchanges to RSC, that is, SSCs were 169% larger with some 60% less SSC being manufactured in the study year. With fewer containers being manufactured and less polymer being used, SSC GWP was reduced by 16.3%, however, the end comparison was 3.9% less than the base result (table 2).

UK vehicle size

Transport of sharps containers from local manufacturing or to and from trusts, either for use, reprocessing or disposal, contributed between 3.9% (SSC) and 48.4% (RSC) of system GWP. When the largest vehicle (3.5–33 tons articulated; 100% load utilisation; 0.096 kgCO_2e/ton.km) was alternatively tested, it reduced system GWP by 3.8% (SSC) and 25.8% (RSC) and GWP comparison outcome was 3.4% higher than base result (table 2).

RSC lifespan

Changing RSC lifespan from 18 years (conservative base age) to a theoretical 66 years (ie, 7.4 uses/year; certified for 500 uses) decreased RSC manufacturing GWP by 5.7% and the end comparison was 1% greater than base result (table 2). Changing RSC lifespan to 1 year (7.4 uses) increased RSC GWP by 161.0% and the end comparison was 26.6% less than base result (table 2). The RSC 'break-even' lifespan (RSC and SSC GWP equal) was three uses (approximately 4–5 months lifespan).

DISCUSSION

The study found that, within the study parameters, the 40 hospital trusts converting from SSC to RSC reduced the carbon footprint of their sharps waste streams by a combined 3267.4 tonnes CO_2e—a reduction of 83.9%. In addition to the GWP reduction, the 40 trusts: annually eliminated incineration of 900.8 tonnes of plastic SSC; annually eliminated 132.5 tonnes of cardboard from their sharps disposal waste stream; and reduced the labour required for sharps container exchanges by 61.6% (larger size of RSC resulted in fewer container exchanges). The impact of repeated SSC manufacture and one-off RSC manufacture is best illustrated over multiple years. If a 10-year period were examined for the 40 trusts, using this study's results and excluding further workload increases), 17.5 million SSC would need be manufactured compared with 87 022 RSC, and adoption of RSC would eliminate 32 674.3 tonnes of GHG emissions, 9008.2 tonnes of fossil-fuel derived plastic and 1325.3 tonnes cardboard, from the sharps waste stream.

Sensitivity analysis

The results of the quantitative sensitivity analysis (table 2), revealed that, because of the large disparity in life-cycle GWP of the two systems in the base comparison, the changes achieved by changing processes/geography within life stages, were not mirrored in the final GWP comparisons, which in all but one alternative scenarios did not achieve changes of more than 5%. The one exception was examining an RSC lifespan of 1 year which achieved an end-comparison reduction of 57.3%, some 26.6% less than the base comparison but this was an academic exercise as no RSC in use in the UK is currently less than 18 years old and minimum RSC lifespan is expected to be 20–25 years. Likewise, using larger vehicles in the UK is not feasible due to the narrow streets and tight corners in most UK cities. Optimisation of reprocessing of medical devices is recommended to lower GHG emissions,[18] however, in this study, RSC reprocessing accounted for only 9.3% of total RSC life-cycle GWP (figure 2) and examining alternative processing scenarios was unlikely to achieve meaningful reductions in the GWP comparison.

Limitations and strengths

Limitations of the study included geographical representativeness in the location of manufacture of polymer for SSC; Plastics Europe values for polymer production GHG used for South Korea (RSC) and Saudi Arabia (SSC); apart from USWARM GHG emissions for incineration,[50] avoided emissions were not stated by other secondary databases used;[40 42 43 46] the extrapolation of detailed SSC usage data in 17 trusts to the 40 trusts using RSC; and, in extrapolating the GHG savings nationally, the fact that not all trusts may have converted 100% of their facilities to RSC will impact the mean and range used for projections. It is possible that not all RSC had 80% of their components recycled at EoL as a small percentage may have been discarded to landfill—with little impact to GWP outcome. Study strengths included the high proportion of primary-sourced activity data and reputable secondary data; availability of detailed usage, size and weight data for SSC by brand in the 17 base line trusts; the detailed usage, size and weight data on RSC in 40 trusts using RSC; the use of 2018/2019 UK-specific data on energy intensity for freight vehicle transport and UK region-specific electricity generation; use of NHS-published activity episodes to obtain trust and national patient workload denominators. A further study strength is in the inclusion of 40 trusts as previous studies on sharps container carbon footprints were limited to single-hospital studies.[33 35]

BMJ Open: first published as 10.1136/bmjopen-2020-046200 on 27 September 2021. Downloaded from http://bmjopen.bmj.com/ on April 26, 2024 by guest. Protected by copyright.

Commercial RSC, first used in the USA and Australia in 1986, now represent the majority of sharps containers used in hospitals in the two countries. Since 1999, RSCs have been increasingly used in Canada, UK, Ireland, New Zealand, South Africa and South America. In the UK, RSCs has been used by hospital trusts since 2001 and, at the time of this study, the two RSC manufacturers supply and service 25% of NHS hospital trusts.[38]

In terms of sharps container safety, sharps container standards governing design and performance requirements have been developed by many countries and, as design and performance requirements need be identical for both SSC and RSC, both can be covered in the one standard.[34] The International Organization for Standardization (ISO) Standard 23 907-1 (SSC) was published in 2019,[52] and the ISO RSC standard 23 907-2 (identical in design and testing to part 1) was also published in 2019.[53] To ensure the UK has a high standard of sharps container safety, the British Standards Institute adopted both ISO standards in 2019 (BS EN ISO 23907-1:2019;[54] BS EN ISO 23907-1:2019.[55] and UK hospitals must use sharps containers conforming to these standards.[56]

While early sharps containers were regarded as 'waste bins' (often resembling paint pails with a base, lid and flap), current UK sharps container standards require they meet up to 31 safety requirements in their design and must pass up to 9 performance tests. While not as intricate in design as many medical devices used on patients for example, arthroscopes, many sharps containers are engineered safety devices. Although reuse may appear to be a simple task of emptying and decontaminating, and perhaps even performed onsite by trusts (as with some other medical devices), this is not the case for several reasons: both SSC and RSC are purpose designed and SSC can only be used once;[54 55] they contain sharps contaminated with blood and body fluids and because of the serious risk to staff, manual opening is prohibited; both SSC and RSC are required to be designed such that once closed, they are not able be opened manually; RSCs require dedicated processors that can robotically open, decant and decontaminate the container to a specified level (at a factory licensed to process clinical wastes). Such robotic machinery is large, expensive and proprietary and not available (or feasible) to conduct onsite.

Two previous SSC/RSC life-cycle studies in USA confirmed that transport distances play a key part in GHG of the two systems and, depending on distance, the reduction in GHG with RSC varied from 65.3% to 83.5%, with transport accounting for up to 90% of the total RSC GHG.[33 35] The 83.9% GWP reduction achieved in this study was due to UK transport distances being relatively short, with the RSC transport stage accounting for 67.1% of life-cycle GWP (figure 2).

The reduction in sharps waste management carbon footprint with RSC use, while only a small component of the total supply chain emissions of NHS, has been a positive step in assisting the RSC trusts to meet NHS sustainability targets. Unlike GHG reduction strategies dependent on changes in staff behaviour (waste segregation, turning off lights, car-pooling, etc), this study confirms that purchasing strategies can enable immediate, permanent and institution-wide GHG reductions to be achieved.

This study examined the GWP of sharps containers, however, healthcare facilities may choose to adopt RSC for one or more of several other reasons including sharps injury reduction,[27 29 45 57] cost[27–31 33] and labour.[29 33] In this study, the reduced number of container exchanges with the larger RSC (with associated labour reduction) was noteworthy (table 1).

In terms of environmental impact categories, this study considered only one, GWP, however, other impact categories such as ozone depletion, ecotoxicity, acidification, particulate matter, eutrophication and human toxicity, may enable additional conclusions to be drawn.[58]

To meet the UK's 2050 target of 100% net carbon account reduction,[7] the NHS recommends trusts should: reduce the quantities of products purchased; seek low carbon alternatives; and incentivise product manufacturers to investigate and report the environmental footprints of their products.[14]

This study found that hospitals converting from SSC to RSC met all these requirements in that, within their sharps waste stream, they:

- Markedly reduced the quantities of single-use plastic containers purchased.
- Used low carbon footprint alternatives.
- Purchased RSC with a published carbon footprint.
- Markedly reduced the carbon footprint of their sharps waste stream.
- Markedly reduced the volume of clinical plastics incinerated.
- Markedly reduced the mass of cardboard generated.

The 2020 NHS Report on Delivering a Net Zero NHS states 'Despite the progress, there is a significant challenge ahead.'[9] The Report goes on to state, one of the greatest areas of opportunity—or challenge—for change is in the supply chain and that '…before the end of the decade, the NHS will no longer purchase from suppliers that do not meet or exceed our commitment to net zero.'[9]

Notwithstanding that NHS England trusts vary greatly in size and function, this study, if extrapolated nationally, indicates that if all 227 NHS trusts[59] were to adopt RSC, NHS England could achieve an annual national reduction in GHG of some 16 424 tonnes (range 13 291–19 615 tonnes) of CO_2e. While this is only 3.4% of the annual reduction rate of 488 000 tonnes needed to achieve the NHS 2028–2032 target,[9] it is an achievable, worthwhile and permanent contribution to the challenges required to meet NHS reduction goals—and can be achieved with little change in financial cost to trusts or behavioural change on the part of staff.

BMJ Open: first published as 10.1136/bmjopen-2020-046200 on 27 September 2021. Downloaded from http://bmjopen.bmj.com/ on April 26, 2024 by guest. Protected by copyright.

CONCLUSIONS

- Under the parameters of this study, RSC achieved significant GHG reductions over SSC.
- In SSC LCCF, container manufacture was largest GHG contributor; for RSC it was transport.
- RSC lifespans can be substantially reduced and achieve marked GWP reductions over SSC.
- Sustainable purchasing decisions can assist trusts meet NHS GHG reduction targets.
- Adoption of reusable over SSC can reduce GHG emissions permanently with minimal staff behavioural change.

Author affiliations
[1]Grimmond and Associates, Hamilton, New Zealand
[2]Sustainability West Midlands, Birmingham, UK
[3]Waste Management & Environmental Services, Rotherham NHS Foundation Trust, Rotherham, UK
[4]Sustainability, Newcastle Upon Tyne Hospitals NHS Foundation Trust, Newcastle Upon Tyne, UK
[5]Health, Safety and Environmental, Derbyshire Support and Facilities Services Limited, Chesterfield Royal Hospital NHS Foundation Trust, Chesterfield, UK
[6]Sustainable Development, University Hospitals Coventry and Warwickshire NHS Trust, Coventry, UK
[7]Energy and Sustainability, Northampton General Hospital NHS Trust, Northampton, UK

Twitter Terry Richard Grimmond @terrygrimmond

Contributors TRG contributed to concept and design (C&D), planning (P), data acquisition (DA), analysis and interpretation (A&I), literature review (LR), original manuscript (OM) drafting, post-review manuscript (PRM); final manuscript approval (FMA); AB contributed to C&D, P, A&I, LR, OM, FMA; JC contributed to C&D, DA, A&I, LR, OM, FMA; JD contributed to C&D, P, DA, A&I, LR, OM, PRM, FMA; SL contributed to C&D, P, A&I, LR, OM, FMA; CR contributed to C&D, A&I, LR, OM, FMA; CT contributed to C&D, A&I, LR, OM, FMA.

Funding Sharpsmart UK granted £5000 to the project which covered approximately 20% of the hours required for completion and publication.

Disclaimer The funder had no role in study initiation, design, data analysis, journal selection, or content of the manuscript. No other grant or funding was received from any funding agency in the public, commercial, or not-for-profit sectors.

Competing interests TRG is an international consultant on sharps injury prevention and sharps containment to healthcare facilities, professional associations and contractors in the healthcare sector, and from time to time, Sharpsmart UK (the manufacturer of the RSC studied in this paper) use his services. All other authors are employed by, or associated with, trusts using Sharpsmart reusable sharps containers and declare no conflicts of interest.

Patient consent for publication Not required.

Ethics approval This study did not involve humans nor human data or specimens, nor did it involve animals and as such ethical approval was not required by author institutions.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available in a public, open access repository. To supplement the methodology in this paper, a raw data table detailing all data sources, flow units, GHG conversion factors, unit process GHG emissions, and representativeness of data, is available on the Dryad Repository at https://doi.org/10.5061/dryad.nvx0k6dsr *as "Grimmond, Terry et al. (2021), A before/after intervention study to determine impact on life cycle carbon footprint of converting from single-use to reusable sharps containers in 40 United Kingdom NHS Trusts, Dryad, Dataset -v3 Aug 27, 2021" (published Sep 6, 2021).* No other data are available

Supplemental material This content has been supplied by the author(s). It has not been vetted by BMJ Publishing Group Limited (BMJ) and may not have been peer-reviewed. Any opinions or recommendations discussed are solely those of the author(s) and are not endorsed by BMJ. BMJ disclaims all liability and responsibility arising from any reliance placed on the content. Where the content includes any translated material, BMJ does not warrant the accuracy and reliability of the translations (including but not limited to local regulations, clinical guidelines, terminology, drug names and drug dosages), and is not responsible for any error and/or omissions arising from translation and adaptation or otherwise.

Open access This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited, appropriate credit is given, any changes made indicated, and the use is non-commercial. See: http://creativecommons.org/licenses/by-nc/4.0/.

ORCID iD
Terry Richard Grimmond http://orcid.org/0000-0001-6130-4305

REFERENCES

1 World Health Organization, Geneva Switzerland. Climate change and human health. Available: https://www.who.int/globalchange/global-campaign/cop21/en/ [Accessed 10 Jun 2021].
2 Health Care's Climate Footprint. How the health sector contributes to the global climate crisis and opportunities for action. Health care without harm and ARUP, 2019. Available: https://noharm-global.org/sites/default/files/documents-files/5961/HealthCaresClimateFootprint_092319.pdf [Accessed 10 Jun 2021].
3 Watts N, Amann M, Arnell N, *et al*. The 2020 report of the *Lancet* countdown on health and climate change: responding to converging crises. *Lancet* 2021;397:129–70.
4 Pichler P-P, Jaccard IS, Weisz U, *et al*. International comparison of health care carbon footprints. *Environ Res Lett* 2019;14:064004.
5 The Stationery Office Limited. Climate change act 2008. Original (as enacted) 2008. UK Government. Available: http://www.legislation.gov.uk/ukpga/2008/27/enacted/data.pdf [Accessed 10 Jun 2021].
6 The climate change act 2008 (2020 target, credit limit and definitions), 2009. Available: https://www.legislation.gov.uk/uksi/2009/1258/made [Accessed 10 Jun 2021].
7 Climate change act 2008. Amendment 2019. UK government. The Stationery office limited. Available: http://www.legislation.gov.uk/ukpga/2008/27/data.pdf [Accessed 10 Jun 2021].
8 Committee on Climate Change. Advice on reducing the UK's emissions, United Kingdom. Available: https://www.theccc.org.uk/our-expertise/advice-on-reducing-the-uks-emissions/ [Accessed 10 Jun 2021].
9 Delivering a 'Net Zero' National Health Service. NHS England and NHS improvement, United Kingdom, 2020. Available: https://www.england.nhs.uk/greenernhs/wp-content/uploads/sites/51/2020/10/delivering-a-net-zero-national-health-service.pdf [Accessed 10 Jun 2021].
10 National Health service England. Saving carbon, improving health update. sustainable development unit, 2010. Available: https://www.sduhealth.org.uk/documents/publications/1264693931_kxQz_update_-_nhs_carbon_reduction_strategy.pdf [Accessed 10 Jun 2021].
11 Lenzen M, Malik A, Li M, *et al*. The environmental footprint of health care: a global assessment. *Lancet Planet Health* 2020;4:e271–9.
12 NHS England. NHS England carbon footprint: GHG emissions 1990-2020 baseline emissions update. sustainable development unit, 2010. Available: https://www.sduhealth.org.uk/documents/publications/Carbon_Footprint_2010.pdf [Accessed 10 Jun 2021].
13 NHS England. Sustainable, resilient, health people and places. A sustainable development strategy for the NHS, public health and social care system. sustainable development unit, 2014. Available: https://www.sduhealth.org.uk/documents/publications/2014%20strategy%20and%20modulesNewFolder/Strategy_FINAL_Jan2014.pdf [Accessed 10 Jun 2021].
14 National Health Service. Identifying high greenhouse gas intensity Procured items for the NHS in England. sustainable development unit, 2017. Available: https://www.sduhealth.org.uk/documents/publications/2017/Identifying_High_Greenhouse_Gas_Intensity_Procured_Items_for_the_NHS_in_England_FINAL.pdf [Accessed 10 Jun 2021].
15 The Royal College of Nurses. Sustainability. Why it matters in health and care, and what the RCN is doing about it? Available: https://www.rcn.org.uk/about-us/sustainability-and-greening-the-workplace [Accessed 10 Jun 2021].
16 Royal College of Physicians. Less waste, more health: A health professional's guide to reducing waste. Available: https://www.

BMJ Open: first published as 10.1136/bmjopen-2020-046200 on 27 September 2021. Downloaded from http://bmjopen.bmj.com/ on April 26, 2024 by guest. Protected by copyright.

rcplondon.ac.uk/projects/outputs/less-waste-more-health-health-professionals-guide-reducing-waste [Accessed 10 Jun 2021].
17 World Health Organisation and Health Care Without Harm. Healthy hospitals healthy planet healthy people, 2009. addressing climate change in health care settings. Available: https://www.who.int/globalchange/publications/climatefootprint_report.pdf?ua=1 [Accessed 10 Jun 2021].
18 Unger SR, Campion N, Bilec MM, *et al*. Evaluating quantifiable metrics for hospital green checklists. *J Clean Prod* 2016;127:134–42.
19 Karlsson M, Pigretti Öhman D. Material consumption in the healthcare sector: strategies to reduce its impact on climate change—The case of region Scania in South Sweden. *J Clean Prod* 2005;13:1071–81.
20 Ibbotson S, Dettmer T, Kara S, *et al*. Eco-efficiency of disposable and reusable surgical instruments—a scissors case. *Int J Life Cycle Assess* 2013;18:1137–48.
21 Overcash M. A comparison of reusable and disposable perioperative textiles: sustainability state-of-the-art 2012. *Anesth Analg* 2012;114:1055–66.
22 McGain F, McAlister S, McGavin A, *et al*. The financial and environmental costs of reusable and single-use plastic anaesthetic drug trays. *Anaesth Intensive Care* 2010;38:538–44.
23 Eckelman M, Mosher M, Gonzalez A, *et al*. Comparative life cycle assessment of disposable and reusable laryngeal mask airways. *Anesth Analg* 2012;114:1067–72.
24 Sherman JD, Raibley LA, Eckelman MJ. Life cycle assessment and costing methods for device procurement: comparing reusable and single-use disposable laryngoscopes. *Anesth Analg* 2018;127:434–43.
25 Davis NF, McGrath S, Quinlan M, *et al*. Carbon footprint in flexible ureteroscopy: a comparative study on the environmental impact of reusable and single-use ureteroscopes. *J Endourol* 2018;32:214–7.
26 Regulated Medical Waste (RMW) Minimization Strategies. Step 7. review specialty RMW streams: sharps management, Practice Greenhealth, VA USA. Available: https://practicegreenhealth.org/sites/default/files/2019-03/How%20to%20reduce%20regulated%20medical%20waste.pdf [Accessed 10 Jun 2021].
27 Reusable Sharps Containers at University Hospitals Coventry & Warwickshire NHS Trust. Case-Study – sustainable development Unit National Health Services England. Available: https://www.sustainabilitywestmidlands.org.uk/wp-content/uploads/2018_Sharpsmart_SWM_Cov_Warwick-1.pdf [Accessed 10 Jun 2021].
28 The Rotherham NHS Foundation Trust. Sharp practice: green apple environment award. inside hospitals 2011.
29 Dailly S, Davis-Blues K. You can have it all: prevent sharps injuries, save money and reduce CO2! paper presented at the infection prevention Society annual conference, Sep 20-22, 2010, Bournemouth UK.
30 Reusable sharps containers help Chesterfield Royal cut related CO2 emissions by 90%. Hospital Bulletin Sept 2010.
31 University Hospital North Staffordshire Trust. The introduction to a whole lifecycle improvement approach to the safe disposal of healthcare generated sharps. CS-UHNH -20-3-2010/1.
32 Topping C, Robinson N, Martyn B. Detailed life cycle assessment report of kg CO_2e for Northampton General Hospital. Northampton UK: Northampton General Hospital NHS Trust.
33 Grimmond T, Reiner S. Impact on carbon footprint: a life cycle assessment of disposable versus reusable sharps containers in a large US Hospital. *Waste Manag Res* 2012;30:639–42.
34 CAN/CSA-Z316.6:2014(R2019); Sharps injury protection - Requirements and test methods - Sharps containers. Canadian Standards Association, Mississauga ON L4W 5N6 Canada.
35 McPherson B, Sharip M, Grimmond T. The impact on life cycle carbon footprint of converting from disposable to reusable sharps containers in a large US hospital geographically distant from manufacturing and processing facilities. *PeerJ* 2019;7:e6204.
36 Healthcare environmental Services closes down. Let's recycle, 2018. Available: https://www.letsrecycle.com/news/latest-news/healthcare-environmental-services-closes-down/ [Accessed 10 Jun 2021].
37 Stericycle UK. Available: https://www.stericycle.co.uk/ [Accessed 10 Jun 2021].
38 Sharpsmart UK. Available: https://www.sharpsmart.co.uk/ [Accessed 10 Jun 2021].
39 British Standards Institute,. *BSI PAS 2050:2011. Specification for the assessment of the life cycle greenhouse gas emissions of goods and services*. London, United Kingdom: British Standards Institution, 2011. https://shop.bsigroup.com/upload/shop/download/pas/pas2050.pdf
40 Department for Business, Energy & Industrial Strategy and Department for Environment Food & Rural Affairs. UK government GHG conversion factors for company reporting 2019. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/806027/Conversion-Factors-2019-Full-set-for-advanced-users.xls [Accessed 10 Jun 2021].
41 Parry ML, Canziani OP, Palutikof JP, *et al*. *IPCC, 2007: climate change 2007: impacts, adaptation and vulnerability. contribution of working group II to the fourth assessment report of the Intergovernmental panel on climate change*. Cambridge, UK: Cambridge University Press, 2007.
42 Plastics Europe: eco-profiles & environmental product declarations of the European Plastics Manufacturers, Polypropylene (PP), 2016. Available: https://www.plasticseurope.org/en/resources/eco-profiles [Accessed 10 Jun 2021].
43 Plastics Europe: Eco-profiles & Environmental Product Declarations of the European Plastics Manufacturers, Styrene Acrylonitrile (SAN) and Acrylonitrile Butadiene Styrene (ABS), 2015. Available: https://www.plasticseurope.org/en/resources/eco-profiles [Accessed 10 Jun 2021].
44 American Chemistry Council,. Cradle-to-gate life cycle inventory of nine plastics resins and four polyurethane precursors. prepared by Franklin associates for the plastic division of the American chemistry Council, 2010. Available: https://plastics.americanchemistry.com/LifeCycle-Inventory-of-9-Plastics-Resins-and-4-Polyurethane-Precursors-Rpt-Only/ [Accessed 10 Jun 2021].
45 United States Environmental Protection Agency. Greenhouse gas inventory guidance: direct emissions from mobile combustion sources, 2020. Available: https://www.epa.gov/sites/production/files/2020-12/documents/mobileemissions.pdf [Accessed 10 Jun 2021].
46 Electricity Info. Carbon intensity by region: reginal data archive. Available: https://electricityinfo.org/region-archive/ [Accessed 10 Jun 2021].
47 NHS Digital. Hospital admitted patient care activity. Available: https://digital.nhs.uk/data-and-information/publications/statistical/hospital-admitted-patient-care-activity [Accessed 10 Jun 2021].
48 NHS Digital. Hospital accident & emergency activity. Available: https://digital.nhs.uk/data-and-information/publications/statistical/hospital-accident-emergency-activity [Accessed 10 Jun 2021].
49 UK National Health Service. Hospital outpatient activity 2017/18. Available: https://digital.nhs.uk/data-and-information/publications/statistical/hospital-outpatient-activity/2017-18 [Accessed 20 Jul 2021].
50 Documentation for greenhouse gas emission and energy factors used in the waste reduction model (warm): management practice Chapters. United States environmental protection agency, may 2019. Available: https://www.epa.gov/sites/production/files/2019-10/documents/warm_v15_management_practices_updated_10-08-2019.pdf [Accessed 10 Jun 2021].
51 Climate Transparency. Brown to green: the G20 transition to a low-carbon economy, 2018. Available: https://www.climate-transparency.org/wp-content/uploads/2019/01/2018-BROWN-TO-GREEN-REPORT-FINAL.pdf [Accessed 10 Jun 2021].
52 International Organization for Standardization. ISO 23907-1:2019 sharps injury protection – requirements and test methods – Part 1: single-use sharps containers. Geneva SW.
53 International Organization for Standardization. ISO 23907-2:2019 sharps injury protection – requirements and test methods – Part 2: reusable sharps containers. Geneva SW.
54 British Standards Institute. BS EN ISO 23907-1:2019. Sharps injury protection. requirements and test methods. Single-use sharps containers.
55 British Standards Institute. BS EN ISO 23907-2:2019. Sharps injury protection. requirements and test methods. Reusable sharps containers.
56 National Institute for Health and Clinical Excellence (NICE). Healthcare-associated infections: prevention and control in primary and community care. Updated Feb 2017, 2012. Available: https://www.nice.org.uk/guidance/cg139/resources/healthcareassociated-infections-prevention-and-control-in-primary-and-community-care-pdf-35109518767045 [Accessed 10 Jun 2021].
57 Grimmond T, Bylund S, Anglea C, *et al*. Sharps injury reduction using a sharps container with enhanced engineering: a 28 hospital nonrandomized intervention and cohort study. *Am J Infect Control* 2010;38:799–805.
58 Eckelman MJ, Sherman J. Environmental impacts of the U.S. health care system and effects on public health. *PLoS One* 2016;11:e0157014.
59 NHS Trusts. National Health Service England. Available: https://www.nhs.uk/servicedirectories/pages/nhstrustlisting.aspx [Accessed 23 Jul 2021].

BMJ Open: first published as 10.1136/bmjopen-2020-046200 on 27 September 2021. Downloaded from http://bmjopen.bmj.com/ on April 26, 2024 by guest. Protected by copyright.