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Financial and environmental costs of reusable and single-use anaesthetic equipment

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Abstract

Background. An innovative approach to choosing hospital equipment is to consider the environmental costs in addition to other costs and benefits.

Methods. We used life cycle assessment to model the environmental and financial costs of different scenarios of replacing reusable anaesthetic equipment with single-use variants. The primary environmental costs were CO_2 emissions (in CO_2 equivalents) and water use (in litres). We compared energy source mixes between Australia, the UK/Europe, and the USA.

Results. For an Australian hospital with six operating rooms, the annual financial cost of converting from single-use equipment to reusable anaesthetic equipment would be an AUD$32 033 (£19 220), 46% decrease. In Australia, converting from single-use to reusable equipment would result in an increase of CO_2 emissions from 5095 (95% CI: 4614–5658) to 5575 kg CO_2 eq (95% CI: 5542–5608), a 480 kg CO_2 eq (9%) increase. Using the UK/European power mix, converting from single-use (5575 kg CO_2 eq) to reusable anaesthetic equipment (802 kg CO_2 eq) would result in an 84% reduction (4873 kg CO_2 eq) in CO_2 emissions, whilst in the USA converting to reusables would have led to a 2427 kg CO_2 eq (48%) reduction. In Australia, converting from single-use to reusable equipment would more than double water use from 34.4 to 90.6 kilolitres.

Conclusions. For an Australian hospital with six operating rooms, converting from single-use to reusable anaesthetic equipment saved more than AUD$30 000 (£18 000) per annum, but increased the CO_2 emissions by almost 10%. The CO_2 offset is highly dependent on the power source mix, while water consumption is greater for reusable equipment.

Key words: life cycle assessment; environment; footprint; health economics; anaesthesia

Environmental sustainability is achieving increasing prominence within anaesthesia.[1–3] There are several recent studies examining the ‘environmental footprint’ of anaesthesia, including volatile anaesthetics,[4] laryngeal mask airways (LMAs),[5] drug trays,[6] and whole operations.[7 8] Such studies rely upon life cycle assessment (LCA) to measure the environmental and financial costs throughout an entire life cycle, ‘cradle to grave’.[9 10] Our previous studies[6 11] have shown that there is some complexity in the relative benefits of reusables *vs* disposables for different environmental effects [CO_2 equivalent (eq) emissions, water use etc.] and for different energy sources (e.g. coal, renewables).

Anaesthetists use anaesthetic breathing circuits, face masks, LMAs and laryngoscopes that can be reusable or single use/disposable. We considered that reusable anaesthetic equipment would be less expensive, have similar associated CO_2 emissions, and a higher water use in Australia, but in the UK/Europe and the USA the CO_2 emissions for reusables would be considerably lower as a result of different marginal (new) energy sources.

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Editor's key points

- Anaesthetists use large amounts of equipment for airway management and ventilation.
- The authors estimated the financial and environmental costs for a small hospital to switch from single-use to reusable airway equipment.
- Estimated costs halved, whereas water consumption almost trebled.
- Estimates of CO_2 emissions increase for some countries and decrease for others, depending on the national power source mix.

Australia has an electricity mix principally based upon coal, which is associated with high CO_2 emissions. New electricity generation in the UK/Europe is now principally sourced from renewables (mainly wind power), whereas in the USA, natural gas has become the most important new source. For the same amount of electricity use, brown coal produces approximately twice the CO_2 emissions compared with gas and at least six times that of wind power.[12 13]

This study was a consequential LCA; that is, we were interested in the consequences of changing from one pattern of equipment use to another, looking to whether new labour would be required or where the next kilowatt hour of electricity (the marginal supplier) would be sourced from (e.g. coal, renewables, natural gas). We sought to define the environmental and financial consequences of the following five different scenarios: Scenario 1, the current practice at Hospital 1 of using reusable anaesthetic circuits, face masks, 'Proseal'® (Teleflex, Westneath, Ireland) LMAs, and direct and videolaryngoscope blades and handles; Scenario 2, changing the practice at Hospital 1 to that occurring at Hospital 2 of using disposable anaesthetic circuits, and single-use face masks, LMAs, and direct laryngoscope blades, retaining reusable direct laryngoscope handles and reusable videolaryngoscopes; Scenario 3, replacing all reusable with single-use/disposable anaesthetic equipment; Scenario 4, from Scenario 1, replacing only reusable with single-use face masks; and Scenario 5, from Scenario 1, replacing only reusable with single-use direct laryngoscope blades.

The only differences between Hospital 1 (Scenario 1) and Hospital 2 (Scenario 2) that were of relevance for this study were that Hospital 1 used reusable anaesthetic equipment, whereas Hospital 2 had mainly single-use equipment. The other three scenarios were models of what was anecdotally occurring in other local hospitals.

Methods

We performed an LCA using Monte Carlo analysis[14 15] at two major hospitals in Melbourne, Victoria, Australia (ethical approval from Western Health WH/LRE-2013.165). We obtained data (including numbers used and the nature of their use) for breathing circuits, face masks, LMAs, and direct and videolaryngoscopes. Data of anaesthetic equipment use were obtained for Hospital 1 (Scenario 1, reusable variants) and for Hospital 2 (Scenario 2, mainly single use) for 2015. Scenario 3 (completely single use=Scenario 2 plus single-use direct laryngoscope blades) was anecdotally the routine approach in many USA hospitals and to a lesser extent elsewhere. We were also interested in the financial and environmental consequences of substitution of only one reusable to single-use device (purchased in high volume) for two further scenarios. Scenarios 4 (reusables except for single-use face masks) and 5 (reusables except for single-use laryngoscope blades) were chosen because they were occurring in Australian hospitals and were high-volume products.

We modelled what the financial and environmental consequences would be if reusable equipment in Scenario 1 was replaced with single-use equipment as per Scenarios 2–5). We measured the environmental and financial costs [in Australian dollars (AUD$)], including the labour, electricity, and water costs for the Central Sterile and Supply Department (CSSD).

Health economists from the University of Melbourne, Victoria, Australia, gave advice about the financial costs requiring inclusion. As we wished to know the financial consequences of substituting reusable with single-use anaesthetic equipment from the viewpoint of the hospital, we examined real changes in labour times, electricity use etc. If, for example, the substitution of single-use with reusable equipment did not increase the amount of casual/part-time/full-time hospital labour, from the perspective of hospital staff there was no financial cost increase. On the contrary, if the number of washer loads increased, these financial and environmental costs were included. We did not include washer and sterilizer maintenance and depreciation because these would be unaltered by the presence or absence of reusable anaesthetic equipment; maintenance and depreciation costs were fixed annually, regardless of the number of loads performed.

In accordance with the International Organization for Standardization (ISO) 14040 Standards, an LCA has a system boundary; that is, included and excluded items (Supplementary Fig. S1).[16] For example, all capital costs of existent infrastructure (to make single-use equipment or clean reusable equipment) are not included within the system boundary.[16] An LCA has inputs and outputs;[9] every input has a degree of uncertainty associated with it.[15 17] A final 95% confidence interval (CI) for a process is achieved based upon the random sampling thousands of times anywhere within the 95% CIs for all inputs.[14 15] We gave 95% CIs for the comparisons between Scenarios 1 and 2 because these were of most importance, and performing thousands of runs for each comparison was unlikely to provide further clinically useful information. We performed LCA modelling with SimaPro software (PRé Consultants, Amersfoort, The Netherlands). Further details of LCA methods for a medical audience can be found elsewhere.[3 5 6] Some of our data were obtained from life cycle inventories (LCIs; Ecoinvent v2.1; Swiss Centre for Life Cycle Inventories, Zurich, Switzerland).[18]

In 1991, the Society for Environmental Toxicology and Chemistry (SETAC) defined the components of an LCA of an item to be analysed as follows: (i) raw material acquisition; (ii) processing and manufacturing; (iii) distribution and transportation; (iv) use, reuse, and maintenance; (v) recycling; and (vi) waste management.[10] Further evolution saw the development of the impact assessment (environmental effects) method using ReCiPe LCIA (life cycle impact assessment).[19] In accordance with ISO 14040 standards for LCAs,[16] researchers decide *a priori* what will be the environmental impacts likely to be of greatest interest. For this study of anaesthetic equipment, the following impact categories (and their units) were calculated and results given: climate change (in grams of CO_2 equivalent; g CO_2 eq), water use (in kilolitres), eutrophication (as phosphorus deposition), and human, terrestrial, and marine ecotoxicity (in kilograms of 1,4-dichlorobenzene equivalents; DCB eq). Eutrophication is the deposition of chemicals (particularly nitrogen and phosphorus from human land-based activities) in water bodies, leading to excessive algal growth. Although we did examine the following environmental impacts, these were considered to be less relevant to our study: ozone depletion, ionizing radiation, urban and natural land transformation, mineral depletion as kilogram iron equivalents, fossil fuel depletion, photochemical oxidant (smog) formation, and air particulate matter. Further details of the large body of evidence regarding environmental impacts are available elsewhere.[10 19]

Normalization indicates the relative importance and provides a context of an environmental effect or impact. We 'normalized' the results for each environmental effect (divided our results by an average Australian's per capita total annual environmental effects, i.e. all travel, food, electricity, etc.).[16] Normalization takes into account potential effects from national electricity and fuel mixes. Per capita, Australia is a high emitter of CO_2 eq, which may appear to reduce the environmental impacts of processing anaesthetic equipment. Nevertheless, anaesthetic items processed in the UK/Europe, for example, would have a lesser climate change impact (CO_2 eq) than anaesthetic items processed in Australia because of the different electricity mix. A lesser environmental impact being compared with a lesser per capita emission may be comparable to the normalization percentage of Australia.

This study was a consequential LCA, which studied how environmental and financial flows changed according to the decisions made;[16] if a hospital required more electricity because single-use equipment had been replaced with reusable equipment, one would examine the source of each new kilowatt hour of electricity. Consequential LCAs highlight real changes occurring in the broader economy. For example, the CO_2 eq emissions stemming from electricity used to process more reusable anaesthetic equipment were not an average of CO_2 eq emissions for electricity generation in Australia, but rather the CO_2 eq emissions arising from the marginal supplier of electricity generation. Each new kilowatt hour of electricity during the next 5–10 yr in Australia will most probably be sourced from coal, whereas in the UK/Europe renewables (particularly wind) now dominate, and in the USA natural gas predominates. By examining recent trends in electricity use and generation, one can predict the likely new electricity sources. A consequential LCA models the real changes ('new' effects) that occur as a result of decisions not 'averages'.

Senior CSSD staff considered (estimated) the financial consequences (i.e. amount of labour time and thus money saved) that would accrue throughout 1 yr of changing from reusable to single-use equipment. To corroborate these estimates, we performed real 'time-and-motion' studies (intermittently, during a period of months) of labour costs attributable to processing anaesthetic equipment, including washing, drying, packaging, sterilizing, and tracking.

Single use, as defined by the Australian and New Zealand (ANZ) Standards, indicated that an item could be used on one patient only, whereas a disposable item could be used on one or more patients but not re-cleaned, and reusable items could be re-cleaned.[20] The only item we studied that came as disposable or reusable was the anaesthetic breathing circuit, whereas all other items came as either single-use or reusable variants. No reprocessing (making single-use medical items patient ready again) occurred in this study. Although such reprocessing of single-use items is a multi-billion dollar industry in the USA,[21] reprocessing does not currently occur in Australia.

In Australia (and elsewhere),[22] each patient undergoing general anaesthesia received a new airway filter, but disposable anaesthetic breathing circuits were changed weekly. In the USA, each patient is required to have a new anaesthetic circuit.[23] Face masks were either reusable (thermally disinfected or 'washed') or single use. The large majority of standard LMAs were single use, which we did not study. Only less commonly used LMAs came as reusable ('Proseal'®), which were washed then sterilized, or single-use variants ('Supreme'®; Teleflex, Westneath, Ireland). Routinely, direct laryngoscopes (for direct laryngoscopy) were reusable; the blades were washed then steam sterilized, whilst the handles were washed. The reusable videolaryngoscopes were sterilized in hydrogen peroxide (H_2O_2) at 50 °C to avoid steam damage.

Previously, we had measured the washer and steam sterilizer utility usage.[6 24] Here, we measured the electricity consumption of the Sterrad S-100 H_2O_2 sterilizer (Sterrad, Irvine, CA, USA) throughout several days in Hospital 1 (this H_2O_2 sterilizer is representative of a standard H_2O_2 sterilizer). Steam sterilizer idle periods would occur regardless of whether there were any reusable anaesthetic items as the sterilizer was required for the much larger number of surgical items. Furthermore, a steam sterilizer cycle was never performed solely for anaesthetic items, as surgical equipment routinely formed the majority of sterilizer loads.

The consequential effects of adding anaesthetic equipment to a steam sterilizer load were 0.15 kWh kg^{-1} and 40 litres of water kg^{-1}.[24] All reusable anaesthetic items were washed as an 'anaesthetic load' for 10 min at 80 °C. Surgical equipment decontamination at 90 °C for 1 min damaged the plastic breathing circuits and face masks, although LMAs (stronger plastic) and laryngoscopes (steel) could be so washed. Sterilization records defined all items sterilized, but disinfection loads gave only type ('surgical', 'anaesthetic'). 'Anaesthetic' washer loads included anaesthetic and respiratory or sleep medicine equipment (washed separately). The CSSD staff observed the proportion of 'anaesthetic' loads for anaesthetic equipment. We obtained anaesthetic equipment information for 2015, weighing the equipment with an electronic balance (accurate within 0.1 g; Satrue KA, Taichung, Taiwan).

Results

In all five scenarios, the financial cost to process single-use anaesthetic equipment was more than for reusable anaesthetic equipment. In contrast, comparisons between the environmental effects of reusables and single-use equipment were more complex, and depended particularly upon the source of energy to manufacture or clean the equipment. Most yearly environmental impacts were at least 100-fold lower compared with an Australian person's yearly total environmental impacts (a per capita average of everything that occurs in the Australian economy); only CO_2 emissions and water use were relatively important (see Table 1). In our Australian hospital, conversion from single-use to reusable equipment increased the CO_2 emissions. Single-use and reusable equipment, in combination rather than alone, had greater environmental effects because washer or sterilizer loads were still required.

Supplementary Tables S1–S3 give background information for anaesthetic equipment purchasing and non-labour and labour financial costs. Purchasing reusable handles and video monitors for videolaryngoscopes was expensive, occurring regardless of reusable or single-use blade choice, whilst

Table 1 Annual environmental impacts of processing anaesthetic equipment for the five scenarios. *This column gives the average Australian's per capita annual environmental impacts for comparison with the annual environmental impacts of processing anaesthetic equipment. †Water use includes all embodied water use per capita, such as industrial and agricultural use, which is much greater than direct individual water use alone. kg CO_2 eq, kilogram carbon dioxide equivalent; kilolitres water, volume of water used in kilolitres; kg P eq, kilogram phosphorus equivalent; kg 1,4-DB, kilogram dichlorobenzene equivalent

Impact (effect) category	Units	Average Australian's total activities*	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Climate change	kg CO_2 eq	22 727	5575	5095	5775	6556	6763
Water depletion	kilolitres	920†	82.2	30.6	30.9	78.9	69.7
Eutrophication	kg P eq	20.88	0.00	0.12	0.12	0.04	0.07
Solid waste	kg	1389	250	1222	1542	375	917
Human toxicity	kg 1,4-DB eq	6330	12	713	1,023	195	491
Terrestrial ecotoxicity	kg 1,4-DB eq	41 846 391	0.011	0.4	0.405	0.118	0.2
Freshwater ecotoxicity	kg 1,4-DB eq	10 582 311	0.7	91.0	93.4	3.1	88.0
Marine ecotoxicity	kg 1,4-DB eq	11 532	0.7	94.5	97.2	2.8	92.3

reusable direct laryngoscope handles and blades were expensive but rarely purchased (Supplementary Table S1). Supplementary Table S2 indicates that H_2O_2 sterilization (AUD$24 per cycle) was much more expensive than washing loads (AUD$2.90 per cycle) or steam sterilization (AUD$0.15 kg^{-1}). The total labour cost to process reusable anaesthetic equipment was AUD$13 720 (Supplementary Table S3). All anaesthetic items were simple, so cleaning time was brief. We corroborated these results with CSSD staff estimations of the labour consequences of converting from single-use to reusable equipment. Replacing the 4490 single-use direct laryngoscope blades with reusable variants was estimated to increase the labour costs by 156 h p.a. (0.1 EFT). Changing from entirely single-use items to reusable variants was estimated to increase labour costs by 0.2 EFT or AUD$14 560 p.a. (within 10% of the AUD$13 720 from the time-and-motion studies).

Table 2 summarizes the five scenarios and the consequences of washing and sterilization changes. In 2015, there were 1150 anaesthetic washer loads (550 loads for anaesthetic equipment and 600 loads for respiratory and sleep medicine equipment), 4490 reusable direct laryngoscope blades and 630 LMAs were steam sterilized, and there were 180 H_2O_2 sterilizer cycles (Scenario 1).

Table 3 compares annual financial costs, indicating that the cost to process reusable anaesthetic equipment (Scenario 1) was AUD$32 033 (£19 220).[25] The annual cost to process mainly single-use equipment (Scenario 2) was AUD $69 018 (£41 411), an increase of 46% [AUD$36 985 (£22 191)] compared with processing reusable equipment. Labour contributed almost 40% (AUD$14 560/$36 985) to costs to process reusable equipment, whilst purchasing reusable LMAs (AUD$8500 because of frequent losses) and H_2O_2 sterilization cycles (AUD$4356) were also expensive. Single-use face masks (AUD$19 800), direct laryngoscope blades (AUD$19 350), and videolaryngoscope blades (AUD$11 500) contributed considerably to single-use costs. Scenario 3 (=Scenario 2 and single-use direct laryngoscope handles) cost a further AUD$57 130 (£34 280). Replacing only reusable with single-use face masks (Scenario 4) would have cost an extra AUD$16 506. Replacing only reusable direct laryngoscope blades with single use would cost an extra AUD$9690 (Scenario 5).

Table 1 shows that all environmental impact categories to reuse/dispose of anaesthetic equipment for an Australian hospital with six operating rooms were less than an average Australian person's total annual activities (travel, food, clothing etc.), excluding solid waste for Scenario 3 (all single use). The CO_2 emissions from reusing or disposing of anaesthetic equipment were important and are detailed later, whereas water use for such equipment processing was minor as a proportion of an Australian's entire water use (including all industrial and agricultural use).

Solid waste has a variable environmental effect, here being mainly plastic, which has a low environmental effect as landfill (plastic degrades slowly).

All other environmental effects of the reusing or disposing of anaesthetic equipment were minor compared with other daily human activities. It is important to consider not only the calculated magnitude of these impacts but also the likely potential risk of such environmental impacts in the LCA study. For example, eutrophication (excessive nutrient runoff leading to aquatic plant growth) was unlikely to be important because the waste treatment of hospital water is thorough in Melbourne, Victoria, Australia, and unlikely to lead to algal blooms. Likewise, human toxicity was considered unlikely to lead to real toxicity because hospital waste disposal practices would minimize this. All ecotoxicities were minor, as were environmental impacts not tabled (metal depletion, ionizing radiation etc).

For CO_2 emissions (Fig. 1), using reusables (Scenario 1) had a 9% higher [5575 kg CO_2 eq (95% CI 5542–5608)] impact compared with using mainly single use [Scenario 2; 5095 kg CO_2 eq (95% CI 4614–5658)]. For the reusable approach 4807 kg CO_2 eq (86%) was for washer electricity and 387 kg CO_2 eq (7%) for H_2O_2 sterilizer electricity, with all other processes contributing 381 kg CO_2 eq (7%). For Scenario 2 (mainly single use), the majority of the CO_2 emissions (2695 kg CO_2 eq, 52%) was for purchasing the 9900 single-use face masks and 1396 kg CO_2 eq (27%) for the 4500 single-use direct laryngoscope blades, with all other items contributing 1052 kg CO_2 eq (21%). Scenarios 4 (single-use face masks) and 5 (single-use direct laryngoscope blades) led to 6556 and 6763 kg CO_2 eq emissions respectively, because 365 and 550 washer loads, respectively, remained. The substitution of one reusable with a single-use item (Scenarios 4 and 5) led to higher CO_2 emissions than either completely reusable or single-use equipment (Scenarios 1–3).

The 5.5 tonnes of CO_2 emissions for processing all reusable anaesthetic equipment at our six-operating room hospital for 1 yr was 24% of the 22.7 tonnes of CO_2 emissions stemming from all activities of one average Australian per year. If our hospital had been in the UK/Europe and converted from processing single-use

Table 2 Five scenarios giving the consequences when changing from reusable to single-use/disposable anaesthetic equipment (for 2015)*. *All data relating to the number of washer loads and sterilizer cycles for Scenarios 1 and 2 took place and were measured. Scenario 3 had no reusable equipment requiring loading. The numbers of loads and cycles for Scenarios 4 and 5 were modelled estimates (by the Central Sterile and Supply Department staff) of the numbers of loads and cycles for these scenarios. †In 2015, the H_2O_2 sterilizer was used at 90% capacity, so 500 videolaryngoscopes would require 180 cycles. ‡Scenarios 2 and 3 differ only in that Scenario 2 has reusable direct videolaryngoscope handles. The scenarios have identical effects on washer and sterilizer use because reusable direct laryngoscope handles (metal) can be washed as additions to 'surgical'-type washer loads; see Results. ¶If any reusable (plastic) face masks or circuits were present then a minimum of one 'anaesthetic' (80°C) washer load per day was required to ensure security of supply. §Given that reusable direct laryngoscope blades could be washed with surgical equipment in surgical-type washer loads, the consequences of replacing them with single-use variants would not lead to any measureable reduction in the number of washer loads required. LMAs, laryngeal mask airways

Scenarios for replacing reusable anaesthetic equipment with disposable/single-use items	Washer and dryer loads p.a.	Steam sterilizer use p.a.	Hydrogen peroxide (H_2O_2) sterilizer use p.a.
Scenario 1. All reusable anaesthetic equipment (current practice at Hospital 1)	550 loads	4490 reusable direct laryngoscope blades and 630 LMAs	Reusable videolaryngoscopes 180 cycles†
Scenario 2. All disposable anaesthetic equipment except for reusable handles for direct laryngoscopes (current practice at Hospital 2)‡	0 loads	0 cycles	0 cycles
Scenario 3. All disposable/single-use anaesthetic equipment (including single-use direct laryngoscope handles; modelled practice)	0 loads	0 cycles	0 cycles
Scenario 4. Replace only reusable face masks with single-use face masks¶ (modelled practice)	365 loads	4490 reusable direct laryngoscope blades and 630 LMAs	1. cycles
Scenario 5. Replace only direct laryngoscope reusable blades with single-use blades§ (modelled practice)	550 loads	630 LMAs	180 cycles

Table 3 Summed financial costs (in AUD$) for anaesthetic equipment for Scenario 1 (reusables) and Scenario 2 (mainly single use) in 2015. CSSD, Central Sterile and Supply Department; LMAs, laryngeal mask airways

Process/device	All reusable equipment (Scenario 1)	All disposable or single-use equipment except for reusable direct laryngoscope handles and videolaryngoscopes (Scenario 2)
Labour in CSSD	$14 560	$0
Washer loads	$1595	$290
Steam sterilization	$815	$0
H_2O_2 sterilization cycles	$4356	$0
Circuits and bags	$2292	$3850
Face masks	$2482	$19 800
LMAs	$8500	$13 230
Direct laryngoscope blades	$1460	$19 350
Direct laryngoscope blades' wrappings	$180	$0
Direct laryngoscope handles	$470	$470
Videolaryngoscope blades	$0	$11 500
Videolaryngoscope handles	$0	$0
Videolaryngoscope blades' packaging	$250	$250
Waste costs (general waste at $0.25 kg^{-1})	$25	$278
Total	$36 985	$69 018

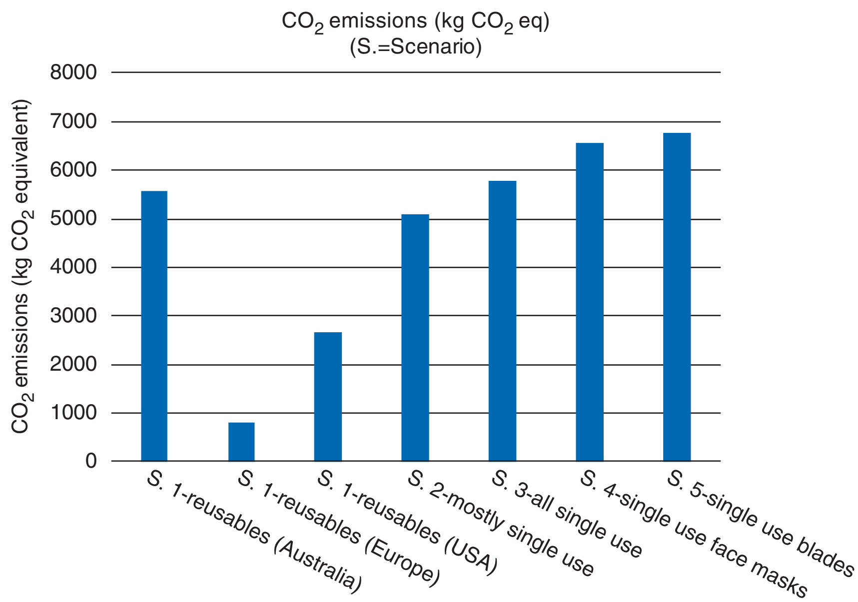

Fig 1 CO_2 emissions from different scenarios. S., Scenario (S.1 = Scenario 1 etc.). S.1 represents CO_2 emissions from processing reusable anaesthetic equipment. S.1 (Europe) and S.1 (USA) are estimations of what the CO_2 emissions would be if our Australian hospital had been based in Europe or the USA and processing reusable anaesthetic equipment. S.2 represents mainly single use (reusable direct laryngoscope handles). S.3 represents completely single use. S.4 and S.5 are variants of S.1 with replacement of reusable with single-use face masks and laryngoscope blades, respectively.

(5095 kg CO_2 eq) to reusable anaesthetic equipment, this would have resulted in only 802 kg CO_2 eq (reduction of 4293 kg CO_2 eq, 84%) owing to the majority of the next kilowatt hour of UK/European electricity generation arising from renewables (primarily wind). In the USA, processing reusables would have resulted in 2668 kg CO_2 eq (reduction of 2427 kg CO_2 eq, 48%) because natural gas now provides most new electricity generation.

Single-use equipment would be unlikely to be made in the UK/Europe or USA rather than Asia because of prohibitively high financial costs. Nevertheless, we calculated the CO_2 emissions to process single-use equipment made in the UK/Europe (Scenario 2) to be 4330 kg CO_2 eq (*vs* 5095 kg CO_2 eq for Asia). The reduction in CO_2 emissions for single-use equipment in Europe (765 kg CO_2 eq) is not as great as the reduction for processing reusables (4293 kg CO_2 eq) because two essential processes to make single-use equipment require non-renewable sources of energy (coking coal for steel manufacture, and oil and gas for plastic manufacture).

Water use for processing reusables (90 kilolitres) was greater than for single-use equipment (31 kilolitres), attributable particularly to washer water use (55 kilolitres, 69%) and steam sterilization (23 kilolitres, 28%). For the single-use approach, the majority of water use was for the manufacture of the single-use face masks (15 kilolitres, 50%) and single-use direct laryngoscope metal blades (12 kilolitres, 38%). An entire year's washing of reusable anaesthetic equipment (82 kilolitres) was equivalent to 9% (82/920) of one average Australian's water use (which includes all agriculture and industrial use in addition to direct water use).[26]

Discussion

For an Australian hospital with six operating rooms, we examined the financial and environmental effects of five different scenarios of processing combinations of reusable and single-use anaesthetic equipment. For all scenarios, using single-use anaesthetic equipment always cost more than using reusable equipment, from approximately AUD$10 000 (£6000) p.a. more for single-use laryngoscope blades alone to almost AUD$90 000 (£54 000) for completely single-use anaesthetic equipment. Labour costs to process all reusable equipment were modest. Most environmental impacts to process anaesthetic equipment were small, with only CO_2 emissions and water use being relatively important. In an Australian hospital, conversion from single-use equipment to reusable variants increased the resultant CO_2 emissions by almost 10%, whereas in Europe/UK and the USA converting to reusables would reduce CO_2 emissions by 85 and 50%, respectively. A combination of single-use and reusable equipment led to greater CO_2 emissions than use of either reusables or single-use equipment alone. Water use was greater for reusable *vs* single-use equipment for all scenarios.

The number of general anaesthetics performed in 2015 was ~1.5 million in Australia[27] and 4.5 million in the UK.[28] If extrapolated nationally from our study, and assuming that 50% of hospitals used single-use anaesthetic equipment, the financial savings of converting from single-use to reusable anaesthetic equipment throughout Australia could be approximately AUD$2.3 million and thrice that in the UK. We caution that our results may not be repeatable, but our methods are, and the savings are potentially large.

For perspective, we compare our data with car transport CO_2 emissions. The average Australian and UK cars have CO_2 emissions of 200[29] and 136 g CO_2 km^{-1},[30] and yearly distances travelled of 13 800[31] and 12 640 km,[32] respectively. Converting from single-use to reusable anaesthetic equipment for all Australian hospitals would approximate yearly to adding 25 cars to

Australian roads, whereas if all UK hospitals had single-use anaesthetic equipment and converted to reusables this would be the equivalent of taking >1000 cars off UK roads.

Each new kilowatt hour of electricity in Australia will most probably be sourced from coal with high-CO_2 emissions, whereas in the UK and Europe renewables now dominate to lower the carbon footprint of processing reusable equipment.

We considered the purchasing data for 1 yr adequate. For uncommonly purchased equipment, we averaged the annual purchase costs from historical procurement data. Both the reusable videolaryngoscopes and the reusable handles associated with the single-use videolaryngoscope blades were very expensive, although none had recently been purchased and were considered standard of care. We did not include washer and sterilizer maintenance and depreciation as these are fixed annual costs. These costs would be unaltered by the presence or absence of reusable anaesthetic equipment, owing to the much larger number of surgical items that would require cleaning regardless. We probably overestimated the number of face masks required, because patients might have received regional or local anaesthesia (uncommon at our hospital), although some patients required multiple masks. We sampled the majority of CSSD staff's processing times of reusable equipment, which approximated the labour time estimates. If no staff member had decreased work hours, there were no labour savings. At AUD$35 (£21) per hour, it is likely that our hospital CSSD staff were paid relatively well compared with other countries.

Although we knew the number of anaesthetic washer loads per annum, we asked CSSD staff to exclude the respiratory medicine loads. Likewise, for the models of replacing different equipment we relied upon estimates from CSSD staff. Country-specific variations occur in the use of anaesthetic items (e.g. single-use breathing circuits in the USA),[23] adding considerably to the financial and environmental burdens. All single-use anaesthetic items were manufactured in Asian countries with lower manufacturing staff pay. It is unlikely that single-use anaesthetic equipment would be produced in the UK/Europe etc.

Infection control concerns vary between countries, leading to differences in anaesthetic equipment use; for example, the Association of Anaesthetists of Great Britain and Ireland states: 'The use of such (single-use) equipment is to be encouraged. However, there are problems of cost, storage and disposal of single patient use devices.'[33] We would add the problem of environmental costs, recognizing that effective CSSD quality assurance is an integral part of hospital infection control and can be environmentally sustainable.

Reprocessing reusable *vs* single-use anaesthetic equipment clearly saved money, which if extrapolated elsewhere in Australia could be difficult to ignore. Our methods could be applied to processing anaesthetic equipment elsewhere to enable informed financial and environmental assessments. Although processing reusable *vs* single-use anaesthetic equipment was found to have similar CO_2 footprints in Australia, this was overwhelmingly attributable to our coal-fired electricity. In the UK/Europe and the USA, why would one not 'return to reusables', achieving financial and environmental benefits?

Authors' contributions

Conceived the study: F.M.
Study design: D.A., T.L.
Developed the methods: F.M., S.M.
Obtained funding: F.M., D.A.
Obtained the results: F.M., T.L., S.M.
Statistical analyses: F.M., S.M.
Wrote the manuscript: F.M., T.L.
Edited the manuscript: D.A., S.M.

All authors drafted the manuscript and approved the final version to be published, and agree to be accountable for all aspects of the work.

Supplementary material

Supplementary material is available at *British Journal of Anaesthesia* online.

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Declaration of interest

None declared.

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