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Comparative Study on Environmental Impacts of Reusable and Single-Use Bronchoscopes

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Abstract: The introduction of single-use alternatives has stressed the need for environmental comparisons between reusable and single-use devises in the healthcare sector. Discarding of single-use devices intuitively causes concern among staff in hospitals, other users and people with environmental concerns as to whether the single use is environmentally friendly. This study aims to compare carbon dioxide (CO_2)-equivalent emissions and resource consumption from a single-use bronchoscope (Ambu® aScope™ 4) to a reusable flexible bronchoscope. The comparison is made using a simplified life-cycle-assessment methodology. The analysis shows that the materials used for the cleaning operations of the reusable scopes are a key factor affecting the impact factors assessed; energy consumption, emission of CO_2-equivalent and consumption of scarce resources. Initially, it is assumed that each reusable scope is cleaned using one set of personal protective equipment (PPE) per cleaning operation, but since cleaning practice may vary the consequence of cleaning more scopes with one set of PPE is also assessed. Using one set of protective wear per operation and the materials for cleaning and disinfection determine that reusable scopes have comparable or higher material and energy consumption as well as higher emissions of CO_2-equivalents and values of resource consumption. Cleaning two or more reusable scopes per set of PPE makes the impacts fairly comparable. Other aspects that may impact the results are also assessed, including energy consumption for washing and drying units, differences in use of PPE and differences in the disposal of PPE or single-use scopes. As the three assessed parameters are highly dependent on cleaning procedures and the use of protective equipment, it cannot be concluded from these results which type of bronchoscope affects the environmental factors investigated here the most.

Keywords: Flexible Bronchoscopy, Single-Use Versus Reusable, Energy, Carbon Footprint, Scarce Resources

1. Introduction

The United Nations Sustainable Development Goals [1] aim to provide a framework for the challenges that need collaborative and joint focus from governments, the private sector, civil society and people. These challenges include some important global environmental factors. One challenge is to take urgent action to combat climate change and its impacts, partly as a result of emissions of carbon dioxide (CO_2) and other greenhouse gases resulting from the use of fossil fuels [2]. Another challenge is ensuring responsible consumption and production due to the increasing scarcity of resources because of the exploitation of known reserves in the production of, for example, electronics and other commodities [3].

The consumption of miscellaneous devices causes various environmental impacts originating from the use of resources, energy use from production and the use of devices. Impacts originating from the use of devices may apply to different sectors, for example, the medical sector [4]. The consumption of scarce resources is usually related to manufacturing of devices, while CO_2 emissions usually relate to the use of fossil fuels for production, transport and use of the product [5].

Fortunately, concern for the environment has also entered the healthcare sector. Hence, there is a need to be able to understand the contributors and map the impacts, when comparing diverse ways to perform the same operation. Recent studies have compared greenhouse gas emissions calculated as CO_2-equivalent emissions for reusable and single-use ureteroscopes [6], environmental impacts of single-use versus reusable scissors [7] and single-use versus reusable anaesthetic equipment [8].

The introduction of single-use alternatives has stressed the need for such environmental comparisons [9]. Discarding of single-use devices intuitively causes concern among staff in hospitals, other users and people with environmental concerns as to whether the single use is environmentally friendly [4]. Disposable products were originally intended for exceptional circumstances or conditions where proper disinfection cannot be guaranteed, for example, during wars, disasters and epidemics [10, 11].

Furthermore, concerns over patient safety have led to the introduction of high disinfection standards and procedures replacing simple sterilisation. Specialised functions in hospitals clean and disinfect reusable devices [12-14]. Such developments have naturally led to an increase in the use of personal protective equipment (PPE) and specialised cleaning and disinfection equipment, which have increased the environmental burden [8].

Consequently, and due to increasing labour costs, capital costs, repair costs and energy requirements, single-use devices have become the preferred choice for many choices of equipment use, e. g. anaesthetic equipment [8, 10, 12-14].

It is necessary to consider the cleaning and disinfection of reusable devices, and the impacts of disposal of single-use devices, to give a complete comparison of single-use devices and reusable devices. In this context, it seems that the application of a life-cycle-assessment (LCA) approach – sometimes called the cradle to grave approach – is gaining popularity within the healthcare sector [6, 9, 11].

In this study, the motivation to perform an environmental comparison originates from the fact that a Danish medical company Ambu A/S has developed a single-use flexible device for bronchoscopy: the Ambu® aScope™ 4 broncho. A challenge is an intuitive reaction from users that it is wrong to discard a functional device.

FORCE Technology performed during 2017 end-of-life profiles for an Ambu ® aScope™ 4 broncho depending on the different disposal procedures around the world [15]. Used bronchoscopes may be landfilled, incinerated or sent for material recycling. Countries that incinerate waste and include energy recovery have the lowest impact. The second most crucial factor to reduce impacts is the amount of recycled paper and cardboard packaging used and the option for recycling these. The present study builds on this but aims for comparison with reusable bronchoscopes (RBs).

2. Goal and Scope

The present study aims to evaluate the CO_2-equivalent emissions and resource consumption from using a single-use bronchoscope such as the Ambu® aScope™ 4 broncho compared to those for the materials used to clean flexible RBs. The assessment compares:

(1) the use and disposal of one Ambu® aScope™ 4 broncho with

(2) the cleaning and sterilisation of one conventional RB, including the miscellaneous consumables needed for personal protection.

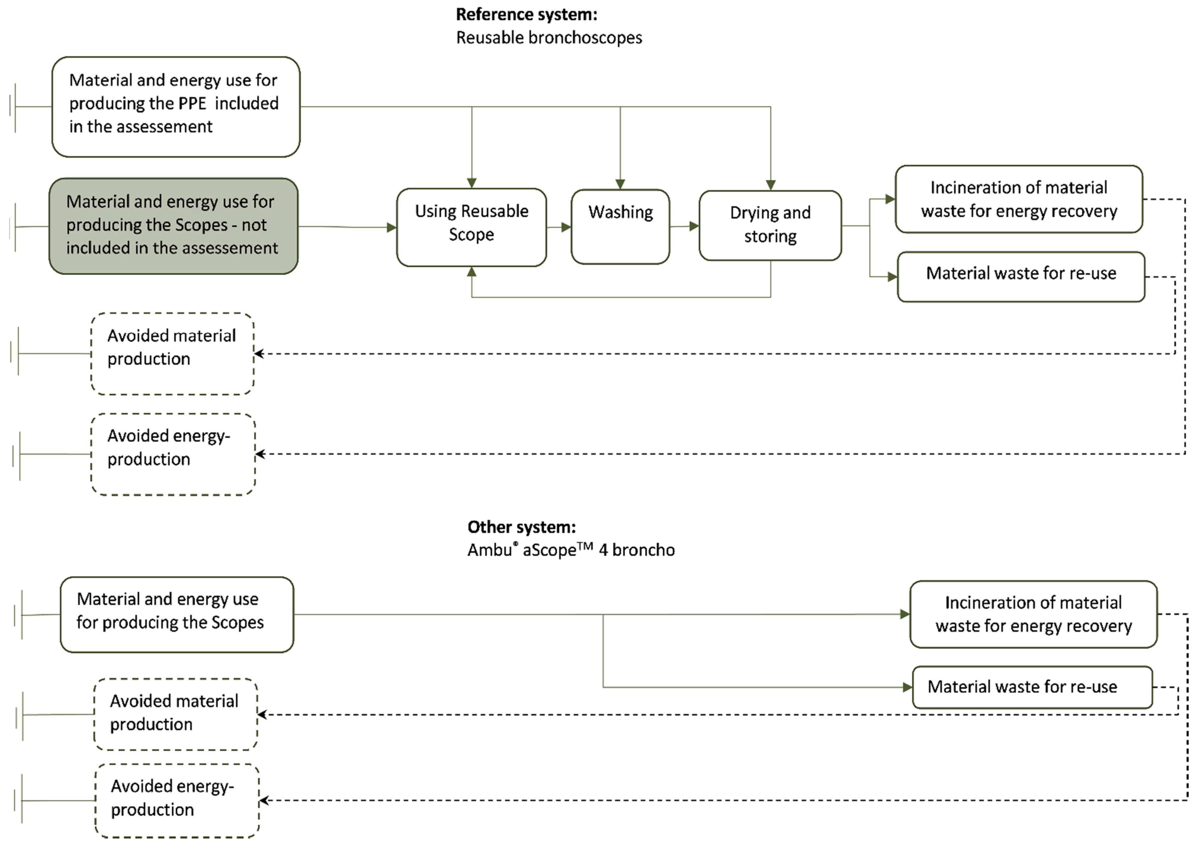


Figure 1. *The reference system for RBs compared to the system for the Ambu ® aScopeTM 4 broncho.*

Figure 1 illustrates the compared systems. The reference system includes the use of RBs until discarding them. After cleaning, an RB must be brought from a washer to a dryer/storage cabinet [16] in a clean environment with the operator wearing one set of protective equipment such as an apron, protective shoes, gloves, etc. (see table 1). After using the RBs many times (number of times unknown) they are discarded. The materials contributions and their end-of life fate is not considered in this assessment.

Single-use bronchoscopes are assumed to be used similarly to the RBs, then discarded afterwards. The analysis does not include manufacturing of the screen needed to use the Ambu® aScope™ 4 broncho, nor the materials and manufacturing of the RB.

The approach here is similar to that using the ISO 14040/44 standards for LCA. It is, however, not fully compliant with the standards as the LCA technique has been used to produce information on only part of the lifecycle for the RBs. It is outside the scope of this study to conduct a full analysis, the scope here is to compare the use and end of life for possible learnings.

3. Methods

The comparison has been made using the simplified LCA methodology prepared for the Danish Ministry of Environment [17]. This methodology assesses the 'embodied energy' of the materials included in a product or cleaning operation, and the additional energy used to manufacture and use the product. Additionally, the methodology assesses the potential embodied energy recovered by recycling of the materials at end-of-life or the energy recovered by incineration of the product at end-of-life.

Analogously, the methodology assesses the emission of greenhouse gases as CO_2-equivalents and the number of scarce resources expressed as the commercial value of the scarce resources (expressed in DKK ~ 0.15$). A resource is scarce when the supply horizon is less than 100 years [18].

The assessment approach is simplified, compared to 'conventional' LCA, in the sense that the results are limited to focus on only two impact categories. Here, we only include greenhouse gas emissions (as CO_2-equivalents) and the loss of scarce resources.

The described setup corresponds to the European market scenarios described by [15]. The end-of-life fate included in this analysis assumes recycling of all recyclable materials and incineration with energy recovery of auxiliary materials. In section 6.4 the consequence of handling the end-of-life materials in a system without incineration.

4. Data

Ambu A/S collected the data used for the analysis of cleaning and disinfection of RBs. The monitoring of materials included in the analysis for cleaning a RB was based on current practice at Rigshospitalet, the University Hospital of Copenhagen, Denmark. The procedure here is comparable to that of the American National Standards ST91: 2015 Flexible and semirigid endoscope processing in health care facilities prepared by the Association for the Advancement of Medical Instrumentation [16].

Rigshospitalet collected samples of the materials used for protective wear. We tracked the reprocessing procedure of a RB and materials collected versus the above-mentioned standard. The procedure, as well as the material used for the process, complied with [16] and current practice at Rigshospitalet. Weighing of the materials was done on a Mettler Toledo PG5002-S Delta Range with a resolution of 10 mg.

Section 4.6.1 of [16] describes the requirements related to attire when minimising the risk of cross-contamination between RBs and contamination from the environment. Section 4.6.2 describes the PPE intended to protect personnel from pathogens and detergents. Attire and PPE are assumed changed between each reprocessing cycle and when moving from the decontaminated area to the clean area, thus implying one change of attire and PPE per RB complies with current practice at Rigshospitalet.

Sections 5.5 and 5.6 of [16] describe the equipment utilised during manual cleaning and manual rinsing, respectively.

In this analysis, the use of three disinfectant wipes was included, in agreement with current practices at Rigshospitalet and those of [19].

The selection of detergents depends on the manufacturer instructions for use; included here is 40 ml of Sekusept for pre-cleaning and as an intercept detergent (Rapicide A and B) for use in the automated bronchoscope reprocessor.

The use of isopropyl alcohol 70% is included in current practice at Rigshospitalet for disinfection and is recommended by the Standards of Infection Control in Reprocessing of Flexible Gastrointestinal Endoscopes [19].

The materials used and the composition of the protective gear used for reprocessing the RB are shown in table 1. SDU Life Cycle Engineering determined the material composition of the brushes used for cleaning. The metal compounds were determined using X-ray fluorescence, and the polymers were measured using Fourier transform infrared/attenuated total reflectance spectroscopy.

Table 1. *Material composition and amounts of protective gear and washing agents for RBs. The main components giving the basis of the simplified calculation of impacts are shown in bold.*

	Material	Amount	Weight per unit(g)	Total weight (g)	The fate of materials after end-of-life
PPE:					
Bouffant hair covers	Polypropylene, latex-free elastic	2	2.99	5.98	Incinerated – heat value credited

	Material	Amount	Weight per unit(g)	Total weight (g)	The fate of materials after end-of-life
Pop-up face shields	Polypropylene, cellulosic fibre, polyester	2	7.98	15.96	Incinerated – heat value credited
Gown, long sleeves	Polypropylene non-woven, laminated with polyethylene, Nylon	2	70.74	141.48	Incinerated – heat value credited
Examination gloves	Latex	3	10.95	32.85	Incinerated – heat value credited
Shoe covers	LDPE	2	7.74	15.48	Incinerated – heat value credited
Materials for cleaning:					
Lint-free cloth	Polyether	2	6. 27	12.54	Incinerated – heat value credited
Disinfectant wipes	Low-Density Polyethylen, Polyethylene, fluff, non-woven	3	4.23	12.69	Same
Transport container liner	Polypropylene, polyethylene, cellulose	1	58.14	58.14	Same
Port/valve brush**	Stainless steel	1	0.3	0.3	Incinerated – lost as ash
	Polypropylene	1	2.71	2.71	Incinerated – heat value credited
Channel brush**	Stainless steel	1	3	3	Incinerated – lost as ash
	Polypropylene	1	3	3	Incinerated – heat value credited
Syringe	Polyethylene, polypropylene	2	16.64	33.28	Same
Isopropyl alcohol 70%				10*	Discharged to wastewater treatment – only impacts of production considered
Sekusept		40 ml		40*	Same

*) Estimated by SDU Life Cycle Engineering. **) Composition measured by SDU Life Cycle Engineering.

Date for consumptions for washing and drying of RBs originates from data sheets for the cleaning systems from three different suppliers [20-22]. The resulting average consumptions used can be found in table 2.

Table 2. *Average energy consumption for washing and drying of RB.*

	Duration of operation (min)	Energy use of equipment (W)	Total energy consumption per operation (kWh)
Washing	20	400	0.13
Drying	120	130	0.26

Ambu A/s provided the data on material composition and amounts for the Ambu ® aScope™ 4 broncho [15] summarised in table 3. Around 96% of the product is plastic. The remainder comprises different metals. The packaging consists of plastic, paper and cardboard.

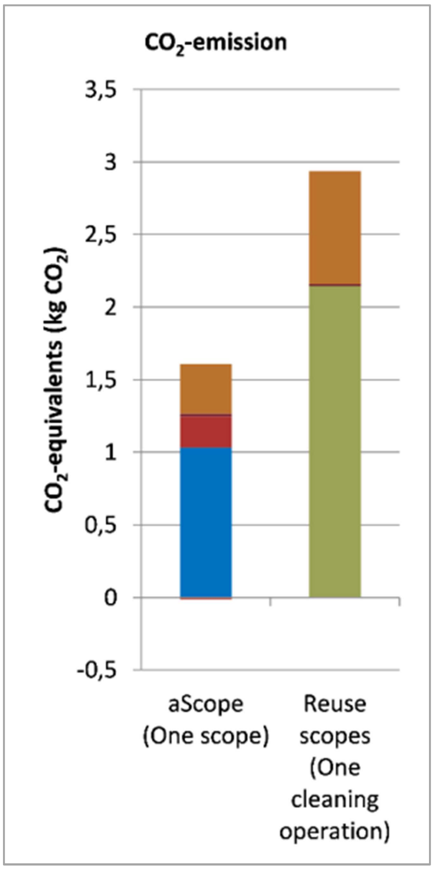
Table 3. *The overall composition of an Ambu ® aScope™ 4 broncho.*

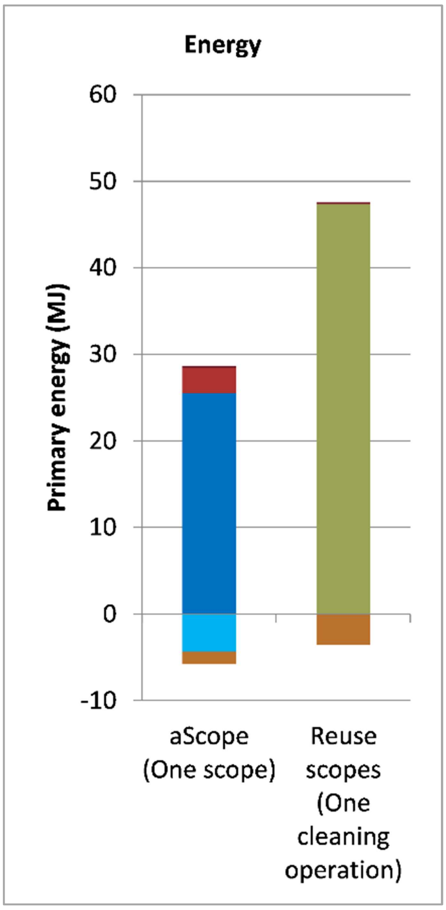
Materials	Weight (g)	Fate of materials at end-of-life
Plastic in product	146.0	Incinerated – heat value credited
Metal in product	5.6	Incinerated – lost as ash
Plastic in the inner packaging	43.8	Incinerated – heat value credited
Paper and cardboard in inner packaging	0.1	Incinerated – heat value credited
Plastic in the outer packaging	2.4	Recycled – credited as such
Paper and cardboard in outer packaging	148.7	Recycled – credited as such
Total	346.6	

The current assessment assumes that the typical disposal pattern for disposal of the single-use bronchoscopes is incineration together with the inner packaging due to hygiene requirements. The consequence is that the heat value of the plastic and paper/cardboard will be credited in the assessment. The metals will be lost in the ash.

5. Results

Figure 2 presents the results for the two options assessed. The results for RBs base on only one bronchoscope being cleaned per cleaning operation and thereby using one set of PPE per RB.





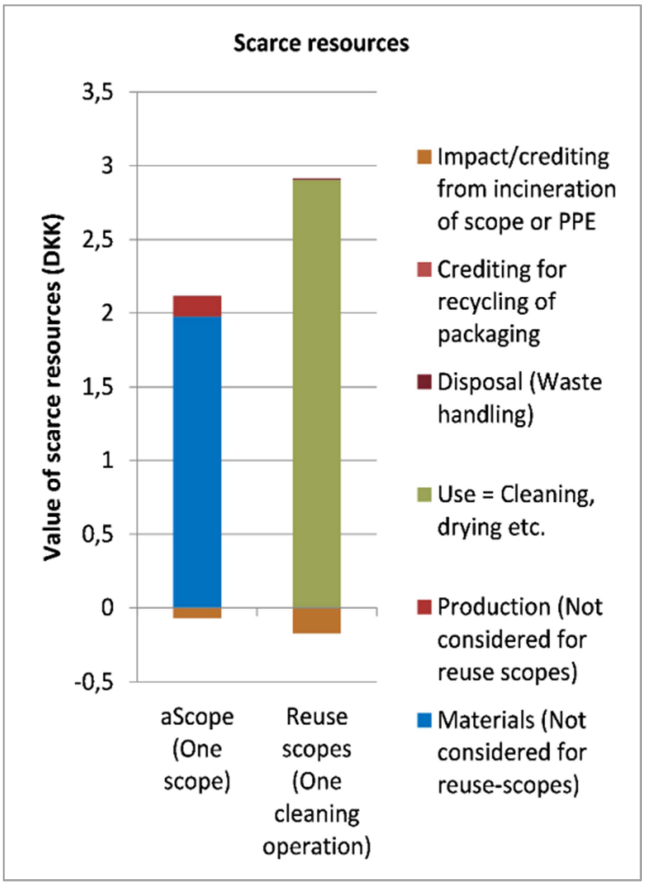


Figure 2. *Contributions from the different life-cycle-stages to the three impact categories. Please note that the graphs compare one single-use scope with one cleaning operation. See text for further explanation.*

6. Discussion

Several assumptions and specific factors may affect the results and comparisons presented in figures 3, 4 and 5. Below the most important factors are discussed.

It is important to note that the boundary conditions stated limit the focus of the assessment to the use and disposal stages. The exclusion of the manufacturing and disposal of the RBs means that the assessment of this option is fairly conservative.

6.1. Different Standards for Cleaning and Disinfection

There are several standards for cleaning and disinfection of RBs. The basic assumption in this study is that the staff doing the cleaning and disinfection follow the procedure strictly stated in [16].

There might also be several practical adaptations and modifications of the recommended procedures. An obvious modification may be not to change the PPE for each RB cleaned but keep it on for a small number of RBs. Using a different approach to that described by the standard and used as a basic assumption in this assessment will affect the net consumption/emission/loss, as illustrated in figures 3 and 4.

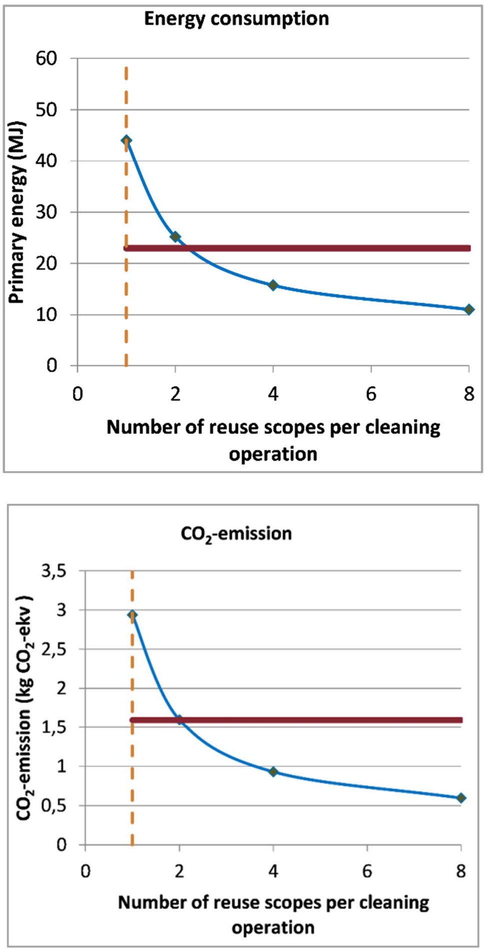


Figure 3. *Results for the number of RBs handled per cleaning operation. Ambu ® aScope™ 4 broncho red line and cleaning of scopes blue curve, orange dotted line corresponds to [23].*

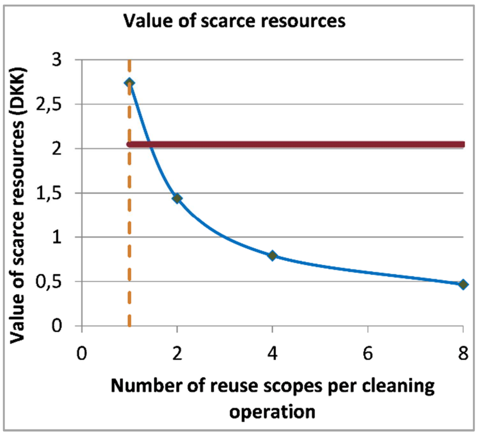


Figure 4. *Scarce resources in DKK related to the number of RBs handled per cleaning operation. Ambu ® aScope™ 4 broncho red line and RB and cleaning blue curve, orange dotted line corresponds to [23].*

6.2. Different Uses of PPE

Different adaptations of the standard might also mean a different use of PPE during the cleaning and disinfection procedures and thereby use of different amounts of PPE. Table 4 compares the consumption of PPE in this study with the findings of Ofstead [24].

Table 4. *Comparison of the consumption of PPE for cleaning and sterilisation of one RB.*

PPE	This study	Ofstead (2017) [24]	
		Min.	Max.
Bouffant hair covers	2	2	2
Pop-up face shields	2	2	
Drop down face shield			2
Surgical mask			2
Examination gloves (pairs)	3	4	7
Extended-cuff gloves (pairs)		1	1
Gown, long sleeves	2	2	2
Shoe covers	2	2	2

The table clearly illustrates that some variations in the types and amount of PPE is to be expected. The amount of PPE used as the basis for this study is less than [24] and hence is expected to be a conservative assumption.

According to [16] one change in attire and PPE is likely to be conservative as pre-cleaning is carried out by cleaning staff at the site, where the bronchoscopy procedure is conducted, suggesting an additional change of attire and PPE.

6.3. Different Equipment for Cleaning and Disinfection

Another factor relates to the different equipment applied for cleaning and disinfection of RBs. Hence the consumption of energy for performing operations may differ between different equipment manufacturers.

The detailed calculations show the consumption of energy for washing and drying of the RBs is relatively low (3.5 MJ) compared to the total reprocessing operation (47 MJ).

Energy used for washing and drying RBs may also be affected by the fact that the RBs are often kept in the dryers for longer than the two hours assumed here, and sometimes rewashing is required when the RBs have been stored longer than accepted by the standard.

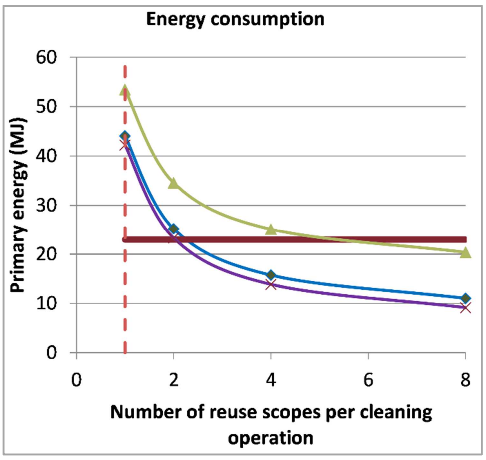


Figure 5. *Energy consumption related to the number of RBs handled per cleaning operation. Ambu ® aScope™ 4 broncho red line and cleaning of bronchoscopes blue curve, orange dotted line corresponds to [23]. The purple line corresponds to low energy consumption for washing and drying, and the green line shows high energy consumption for washing and drying of RBs.*

The impact of the energy used for washing and drying is further assessed as illustrated in figure 5. Figure 5 shows the energy consumptions for two more extra scenarios. They have been calculated based on either five times lower energy consumption for washing and drying, or five times higher energy consumption than the typical situation.

The high energy consumption might happen if the drying cupboard runs at maximum capacity for 10 hours per scope instead of two hours as assumed in the typical situation. If so the total energy consumption increases to 56 MJ for RBs. Similarly, assuming a potential saving of energy used for drying of the scopes, the total energy consumption decreases to 42 MJ (figure 5).

If the RBs have been stored for more than 72 hours, washing and drying need to be repeated. If so, it will result in a higher energy consumption per bronchoscope. The ratio of rewashing per procedure may be between 1 and 2. The extra energy used for rewashing and drying a RB can, therefore, be understood as already included in the interval shown in figure 5.

6.4. Different Waste Treatment Scenarios

The end-of-life impact assessment performed by FORCE Technology [15] for the Ambu ® aScope™ 4 broncho considers different scenarios for the fate of materials from the bronchoscopes depending on where in the world the products are used and discarded. The same segregation will be relevant for the materials and protective wear from cleaning and disinfection of the RBs.

The tables 1 and 3 describe the fate of the materials. The fates described in this study correspond to the European market scenarios described by FORCE Technology 2017 [15], and the results of this study are comparable to their results. Other studies have found optional incineration with energy recovery and recycling to be significant, when assessing the options for waste treatment, for example, recycling [8].

The main differences between the end-of-life scenarios relate to whether incineration with energy recovery is available in the different regions. Table 5 highlights the crediting from incineration and recycling.

Table 5. *Data for crediting from incineration and recycling.*

	Net impacts	Crediting from incineration		Crediting from recycling	
			%		%
Ambu ® aScope™ 4 broncho					
Energy (MJ)	23	1.4	6%	4.3	19%
CO_2-equivalent emissions	1.6	-0.34	-21%	0.014	1%
Scarce resources	2.1	0.07	3%	0.000008	~0%
Reusable bronchoscope					
Energy (MJ)	43.8	3.54	8%	0	0%
CO_2-equivalent emissions	2.9	-0.76	-26%	0	0%
Scarce resources	2.7	0.17	6%	0	0%

The table shows that the Ambu® aScope™ 4 broncho, gives a credit of 6% energy when incinerated but adds an extra 21% emission of CO_2-equivalents. Because the incineration substitutes other fossil fuels, it also gives a credit of 3% scarce resources. The numbers are similar for the RB. The consequence for regions where incineration with energy recovery is not available is that the energy consumption will be 6% higher, the CO_2-equivalent emissions will be 21% lower, and the consumption of scarce resources will be 3% higher for the aScope. In the same way, the numbers can be interpreted for RBs.

Recycling of the packaging materials from the Ambu ® aScope™ 4 broncho gives nearly 20% crediting of energy and 1% crediting for CO_2-equivalent emissions. Because the materials come from renewable resources, the crediting of scarce resources are insignificant. Due to the assumption, that none of the PPE or auxiliary materials used for the cleaning of RBs is recycled, there will be no crediting to consider.

7. Conclusion

From the above discussion, environmental assessment of the reuse option is far more complex than an assessment of the single-use option; furthermore, production of the multiple-use system is not included in this study. The challenge of defining the typical or average procedure for cleaning and sterilisation is obvious. Furthermore, the use of diverse types of PPE may vary significantly, and the various PPE used may have significantly different environmental impacts due to the varying material composition. Investigation of these hidden environmental impacts – and costs – is an important challenge for the future, as also pointed out by [24], if the comparison of upcoming single-use devices to existing complex multiple-use options is to be carried out.

The end-of-life scheme will have a significant impact on the results, but as single-use devices and single-use PPE will follow the same disposal route, it will have a limited impact on the comparison.

Presented here is a case of how such a comparison between a single-use device and multiple-use systems may look. It will hopefully contribute to the continuous development of such assessments.

The analysis shows that the materials used for the cleaning operation are substantial when comparing the two types of bronchoscopes. It is clear from this simple and limited analysis, on embodied energy, CO_2-equivalent emissions and value of scarce resources, that if RBs are cleaned using one set of PPE per cleaning operation per bronchoscope, the material consumptions are significant. The use of cleaning materials and PPE determines that RBs have comparable or higher material and energy consumption as well as emissions of CO_2-equivalents and value of resource consumption to Ambu® aScope™ 4 bronchoscopes. It must be emphasised that the result of the assessment highly depends on the use of PPE and the cleaning procedures applied for the RBs.

Hopefully, this study can contribute to establishing a more neutral approach to the assessment and comparison of single-use versus multiple-use options in the healthcare sector. Even though it does not intuitively seem right to discard a fully functional device, although, it may make sense if cleaning and disinfection are sufficiently complex and resource consuming.

Competing Interests

This study has been funded and by Ambu a/s. The authors have no competing interests.

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