Life Cycle Assessment of Disposable and Reusable Laryngeal Mask Airway in Skånevård Sund

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Abstract

Single use medical devices have been the widespread practice for clinical work for many years. However, the negative environmental impacts of using disposable products have also attracted attention worldwide. To choose a disposable or reusable medical device should not only encompass economic and clinical safety aspects but also environmental impact.

This study has compared environmental impact between disposable laryngeal mask airway (LMA) and reusable LMA during their life cycles. The life cycle assessment was performed and focused on the “cradle to grave” approach including material extraction, manufacturing, transport, use phase and end-of-life handling. The Ecoinvent database v 3.3 was applied for assumptions and modelling of the major inventory data and SimaPro software was then used for analysis based on the ReCiPe endpoint method.

Results show that the PVC made product, disposable LMA has greater environmental impacts than the reusable LMA within all selected impact categories except one, category agricultural land occupation. This is due to the use of washing detergent for the reusable LMA. Moreover, a list of alternative assumption parameters such as energy sources, reuse circles and different types of washing detergent were investigated. The results present a significant deviation when the energy source was analysed. The optimized options that are benefit for reducing the reusable product’s environmental impacts are using renewable energy such as hydro power from run-of-river or wind power. This study gives a strong evidence of that the reusable LMA is more environmentally friendly than the disposable LMA.

Keywords: life cycle assessment; laryngeal mask airway

Populärvetenskaplig sammanfattning

“Miljövänlig eller kostnadseffektiv?” - livscykelanalys av två typer av larynxmasker inom sjukvården

Den övergripande uppgiften i hälso- och sjukvård är att behandla och förebygga sjukdomar hos människor. I stor utsträckning står hälso- och sjukvården för en stor del av den totala BNP (bruttonationalprodukter), runt 10,9 % i Sverige. Samtidigt bidrar hälso- och sjukvården till en betydande del av belastningen på miljön. Den negativa miljöpåverkan som uppstår från hälso- och sjukvården är främst i form av vattenanvändning, energiförbrukning, transporter, materialförbrukning och avfallshantering. Förutom detta omfattar hälso- och sjukvården områden där miljöpåverkan är särskilt stor och specifik som läkemedel, olika former av desinfektion och sterilisering, labbkemikalier, miljöfarliga produkter, PVC/ftalater utrustningar och strålning. Begreppet ”hållbarhet ” blir därför ett kärnvärde inför utvecklingen av hälso- och sjukvård.

När det gäller miljöpåverkan inom sjukvården blir det debattämne för engångs- och flergångsmedicinsk utrustning. I praktiken behöver många olika faktorer vägas mot varandra, exempelvis tillförlitlighet, säkerhet, bräcklighet, sterilitet, kostnad för att välja mellan flergångs- och engångsmedicinska utrustningar. Det andra som också ska vägas in i praktisk användning av engångs- och flergångsmaterial inom sjukvården är miljöpåverkan. Miljövinsten med flergångsalternativen kan vara stor: återanvändbara medicinska utrustningar kan minska det medicinska avfallet samt minska kostnaderna för avfallshantering.

Larynxmasker (The laryngeal mask airway, LMA) används för att skapa fria luftvägar inom ambulanssjukvården och under operation. Det finns olika typer av LMA på marknaden som enligt antalet användningar och tillverkningsmaterial kan delas in i engångs- och flergångsLMA. Livscykelanalys (LCA) är en bra metod för att undersöka hur miljöbelastningen ser ut för de två funktionellt liknande produkter och vidare kan hjälpa att bestämma vilken produkt som är mer miljövänlig. I en LCA redovisas den totala miljöpåverkan som uppstår från produkters tillverkning, via användnings fasen till den slutliga avfallshanteringen.

Det här examensarbetet fokuserar på att utvärdera de miljöbelastningar som medförs vid användningar av engångs- och flergångsLMA i Skånevård Sund, Helsingborg sjukhuset. Med hjälp av metodik från LCA analyseras och jämförs de två produkterna med avseende på deras miljöpåverkan inom olika kategorier bland annat klimatförändring, övergödning, försurning, toxicitet, markanvändning och energianvändning. Framförallt har studien till syfte att utreda vilken av de två produkter som är lämpligast att använda sig av ur ett hållbarhet perspektiv med hänsyn till framtida upphandlingar av medicinsk utrustning.

Resultatet påvisar att flergångs LMA generellt har mindre miljöbelastning i jämförelse med engångsLMA. Det är för att plastmaterialet PVC som används för tillverkningen av engångsLMA bidrar till stor del för miljöpåverkan. Vid användning av flergångsLMA är det viktigt att vara noggrann att välja tvättmedel för att rengöra LMA efter varje användning. Det är för att den stora bidragande delen av miljöbelastning för flergångsLMA är från rengöringsprocessen enligt LCA-beräkningarna. Dessutom är förnybar energi som vattenkraft eller vindkraft till nytta för att minska den total miljöpåverkan för flergångsLMA.

List of Acronyms

BEES	Building for Environmental and Economic Sustainability
CFC	Chlorofluorocarbons
HCFCs	Halons chlorofluorocarbons
ELCD	the European Reference Life Cycle Database
EPLCA	the European Platform of Life Cycle Assessment
FU	Functional Unit
GDP	Gross Domestic Product
GWP	Global Warming Potential
HAIs	Healthcare Associated Infections
HDPE	High-density polyethylene
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impacts Assessment
LDPE	Low-density polyethylene
LMA	Laryngeal Mask Airway
MSW	Municipal Solid Waste
NOx	Nitrogen Oxides
NH3	Ammonia
PCTG	Polycyclohexylene dimethylene terephthalate glycol
PE	Polyethylene
PET	Polyethylene terephthalate
PP	Polypropylene
PVC	Polyvinyl chloride
SO2	Sulphur Dioxide

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Introduction

The main task of the healthcare is to treat patients and prevent diseases. The healthcare sector accounts for a large part of the gross domestic product (GDP), around 10.9 % in Sweden. (SCB 2018). However, at the same time the healthcare sector also contributes to a significant part of the burden on the environment. The negative environmental impacts that arise from the healthcare are primarily in the form of water usage, energy consumption, transportation, material consumption and waste management (Eckelman & Sherman 2016). In addition, health and medical services is characterised by those fields that environmental impacts might be significant such as pharmaceuticals, radiation treatment, disinfection or sterilization, chemicals used in different labs, environmentally hazardous products and disposable devices made of PVC plastics. This is the reason that an environmentally sustainable health system is put forth around the world to minimize the environmental impacts from healthcare service and in long term to increase benefit of the health and well-being of current and future generations.

Taking the environmental impacts into consideration with the aim of optimization of healthcare system makes the selection and purchase of disposable medical devices to be a debate topic. To choose a disposable or reusable medical device is complicated and encompasses many areas, including economic, ecologic and environmental impact. In practice, many different factors need to be weighed against each other, such as patient's safety, reliability, sterility, fragility and fiscal responsibility. Usually disposable products are more cost-effective than reusable products. However, disposable devices can also be cost-driven from an environmental perspective. Hence, the environmental impacts should be considered at the same time when disposable devices are chosen. A study of the medical waste which was produced in the operating rooms shows that using reusable products can cause decreasing of regulated medical waste by an average of 65 % at the same time can reduce the cost of waste disposal (Conrardy et al. 2010).

To compare the environmental impacts between two products which are made of different materials is a complicated process and needs to consider all processes that have interactions with the environment throughout products' life cycles. Therefore, a life cycle assessment (LCA) will be a comprehensive and available method for the comparison of environmental impacts of these two products.

In this study the medical device laryngeal mask airway (LMA) is chosen as the target product. LMA is a supraglottic airway device which was developed by British Anaesthesiologist Archi Brain and has been in use since 1988 (Chmielewski & Snyder-Clickett 2004). It is designed to sit in the patient's hypopharynx and cover the supraglottic structure. In this way LMA is often used to keep patient's airway open during anaesthesia or unconsciousness. (Sung et al. 2007)

A literature review identified a comparative life cycle analysis of environmental impact of disposable and reusable LMA performed for the U.S. context (Eckelman et al. 2012). The software package SimaPro was used to analyse both environmental concerns (climate change, acid rain and smog formation, water use, and ozone depletion) and human-health-related impacts (cancer and noncancer ailments and emission of criteria air pollution). Results showed that reusable LMAs were found to have fewer negative environmental effects in nearly all categories, about 50 % of the impacts of disposable LMAs. The largest difference in environmental effects was on the carcinogenesis, in which reusable LMAs contributed only 5 % of the impacts of disposable LMAs. For climate change impacts, the largest source of greenhouse gas emissions for the disposable LMAs (23 %) was the production and polymerization of PVC which was the main material of the products. However, most of the life cycle CO_2e emission for the reusable LMAs (77 %) was from natural gas production and combustion to produce steam for the autoclave machine.

The LCA study based on the U.S. data showed that disposable products such as LMA can cause more negative environmental impacts than reusable devices (Eckelman 2012). Since product's environmental performance is context-specific, it is relevant to explore how the same medical devices perform under different conditions. This study evaluates the environmental performance of LMA in a Swedish context taking the case of Skånevård Sund. It provides significant differences from the American hospital in term of products' material composition, packaging, transports distance, devices used for cleaning and sterilization, energy and water consumption and waste management. Currently, only disposable LMAs are used in Skånevård Sund while reusable LMAs are on the desired procurement list. In this project, two functionally equivalent products from the same producer but made of different materials are compared under the same context of Skånevård Sund. The disposable LMA, Ambu® AuraStraight, is currently used in the operation department and the reusable LMA, Ambu® Aura40, is considered to be used in the near future. To compare the two products is therefore also important to create database of environmental impacts that is based on the infrastructure and the workstream of Skånevård Sund in future procurement.

Purpose

The purpose of this study is to evaluate and compare the environmental impacts of disposable and reusable LMAs in a life cycle perspective under the circumstance of the Skånevård Sund. This study is also aiming to identify which environmental effects are of great importance during the respective product's life cycle stages. The results of study can provide decision support to take environmental impacts into account in future procurement of reusable LMAs. The following questions will be answered during the study:

- What are the differences between disposable LMAs and reusable LMAs when used in Skånevård Sund regarding life cycle processes in relation to the environmental burdens?
- Which product has lower environmental influence in terms of climate change, toxicity, ozone depletion, eutrophication, acidification, photochemical oxidant formation, land use and resources scarcity, and why?
- Which impact category is the most affected for each of the products?

Material and Method

The target products compared in this study are the disposable LMA, Ambu® AuraStraight, and the reusable LMA, Ambu® Aura40. Both products come from the same manufacturer Ambu A/S but are made of different materials which make their service lifetimes different. Figure 1 shows the disposable Ambu® AuraStraight, and the reusable LMA, Ambu® Aura40. The disposable LMA is acquired from the department of operation of the Helsingborg Hospital and the reusable LMA is a generous gift from the Ambu A/S company.

Ambu® AuraStraight Ambu® Aura40

Figure 1. The disposable LMA Ambu® AuraStraight and the reusable LMA Ambu® Aura40.

Table 1 shows the materials used for manufacturing each part of both products and their weight. The inflation valve part is synthesized of different materials and is difficult to gain the percentage of each materials from the company because of the trade secret. In this study this part of materials is therefore not included in modelling the production phase.

Table 1. Description of the components of products and packaging. The weight of each component is obtained by weighting in a gram scale.

	Ambu® AuraStraight		**Ambu® Aura 40**	
Components		Weight (g)		Weight (g)
Airway connector	PCTG	3.06	Polysulfone	3.60
Inflations valve	PVC/Silicone	0.69	Polyester/PP/Nitrile/Stainless steel	0.68
Cuff	PVC	63.31	Silicone	71.40
Pilot balloon	PVC		Silicone	
Pilot tube	PVC		Silicone	
Packaging				
Cuff protection	HDPE	10.09	-	
Pouch	Tyvek/PET/PE	11.28	Tyvek/PET/PE	13.73
Total weight		88.43		89.41

PVC: Polyvinyl chloride; PET: Polyethylene Terephthalate; PE: Polyethylene; PP: Polypropylene; PCTG: Polycyclohexylene dimethylene terephthalate glycol; HDPE: high density polyethylene

In this study a life cycle assessment was used to compare the environmental impacts between two different laryngeal mask airway – the disposable Ambu® AuraStraight, and the reusable LMA, Ambu® Aura40. Comparison was performed in the context of Skånevård Sund, the Helsingborg Hospital. All information and data related to the two products and required in the analysis were collected by consulting corresponding departments in the hospital and relevant companies. These relevant departments and facilities included the operation department for using and cleaning products, sterilization central for packaging and sterilisation of reusable products, Getingen AB for information of consumption of electricity and inputs of water for cleaning and autoclave sterilizing machine, Skåneteknik for electricity consumption, Ambu company for basic information of products and materials. Besides that, there were numbers of information related to the production processes for both products were based on the praxis experience and other scientific researches. Some of the information were assumed on the ground of literature searching via Google Scholar and the Web of Science.

A field trip to related departments in the hospital was performed on the 14th February 2019 with aim of collecting information along the tract of products from getting them into the department to sending waste out of the hospital. Following questions were raised on the checklist to collect as much information as possible that were related to this analysis:

- How are products transported to the department?
- How are products used during the operation?
- How is the packaging sorted?
- Is there any washing process after product was used and, if so, by which way?
- What type of machine is used for sterilization of reusable LMAs? Which program is used to autoclave the reusable product? How much LMAs can be put in the machine at one cycle?
- How are the discarded products handled?
- What is the origin of electricity supplied to the hospital?

To perform the life cycle assessment, the LCA software package SimaPro version 9 was used. All data concerning materials, manufacturing processes of the products and waste management were drawn from the LCA inventory database, Ecoinvent v 3.3 and ELCD. The life cycle impact assessment (LCIA) method, ReCiPe endpoint (H) was chosen to analyse the environmental impacts that was related to these two products.

Life Cycle Assessment methodology

This section will describe the theoretical framework for life cycle assessment which was used for the empirical application in this study.

Life cycle assessment, as known as its abbreviation LCA, is a technical method for investigating the environmental impacts of a product, service or system. A comprehensive LCA encompasses all the inputs and outputs of a product's entire life cycle, from raw material acquisition via production and use phase to waste management, to assess total environmental impacts of the given product. To execute the LCA, the international organization for standardization (ISO) is needed to standardize the method of analysis and presentation of the environmental impacts of the products. Among those defined standards, ISO 14040 is the standard that contains principles and frameworks for an LCA while ISO 14044 consists of the requirements and guidelines that are needed to perform an LCA (Rydh et al. 2010).

According to the ISO 14040, a standardized LCA which is used internationally includes four stages:

- Goal and scope
- Inventory analysis
- Impact assessments
- Interpretation

Figure 2 illustrates these four phases of the life cycle assessment of a product and their relationships. This illustration is based on the standard ISO 140040.

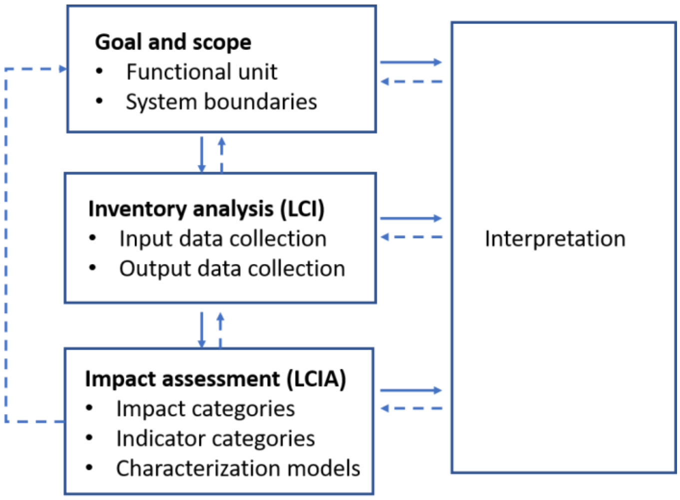

Figure 2. Illustration of LCA phases.

Goal and scope

According to the ISO 14040, the goal document of the study is to describe the intentional aim of the study and explain the reason for executing the study: what is the intended application, how to use the results and to whom the results are to be reported. On the other hand, the scope of the study "*should be sufficiently well defined to ensure that the breadth, depth and detail of the study are compatible and sufficient to address the stated goal*" (ISO 14949, 2012). The goal and scope definition include therefore detailed recommendations for functional units, system boundaries and data quality requirement.

Functional unit is of vital importance for the accuracy of the study because of its quantitative characterization, especially in the study which is aimed to compare the environmental impacts of different products. The functional unit provides a vital basis to an equivalent level of function of different products and based on that can provide a reference flow to which the inputs and outputs data can be related. Reference flow is an amount product needed to perform the function described by the functional unit. Reference flows of investigated products are subject to LCA evaluation (Weidema et al. 2004).

An LCA covering entire supply chains from the extraction of the raw materials from nature to the end-of-the-life of a product is referred to a cradle-to-grave LCA. To collect all the data needed for an LCA requires significant efforts and time and sometimes it is not possible to find all data needed. There are two ways to solve this problem: scoping system boundaries and using well-documented databases. More information of the defined database is described in the LCI section. The selection of system boundaries determines which unit processes will be included in the study and therefore can significantly reduce workload. However, although partially a subjective process, selecting system boundaries should be adequate to the goal and scope of the study. There are some boundaries that should be always considered (Tillman et al. 1993):

- boundaries between technological system and nature
- geographical area
- time horizon
- production of capital goods
- boundaries between the life cycle of the target product and associated life cycles of other products.

Life Cycle Inventory (LCI)

In this inventory step, the main task is to identify and quantify material flows within the product system and their interactions with the environment. Energy, water, and material of products which are associated with the target product are defined as input flows and on the opposite, emissions from the product system to the nature are defined as output flows.

To collect data of different parts of the processes or system from diverse types of sources is time-consuming and may involve a lot of individual unit processes in a supply chain. It should be also noted that the functional unit must be related in process of data acquisition. On many occasions, it is difficult to acquire all the information that are required for executing LCA. Under these circumstances, to use well- documented process data is a sound approach to save the time and labour. These kinds of databases include public national or regional databases, industry databases, and data from consultant. (Finnveden et al. 2009)

To perform the Inventory Analysis, input and output data are documented and used to construct a flow model of the technical system according to the system boundaries defined in the goal and scope phase.

This can be simplified by using a flow diagram which is aimed to give a clear picture of the essential inputs and outputs to the process or system.

Life Cycle Impact Assessment (LCIA)

The third step of LCA addresses the assessment of the potential environmental impacts of analysed product(s). In this phase, the results from the Inventory Analysis are interpreted and transformed into understandable indicators, these are so called category indicators. A list of impact category indicators can be used as the quantifiable representation of an impact category. The LCIA makes it more environmentally relevant and easier to understand the results from LCI by grouping the indicators into different impact categories. In this way it can be easier to investigate which flow in the life cycle of a given product affects environment the most and what is the nature of the effect (Rydh et al. 2010). According to the ISO 14044, the LCIA consists of three mandatory elements:

- Selection of impact categories, category indicators and characterization models. In this step, the impact categories that represent the types of environmental impacts which are relevant to the study are selected. Category indicators and characterization models are also selected to quantify these impacts.
- Classification. In this step the inventory results from LCI are assigned (grouped) to the selected impact categories according to their contributions to the environmental problems.
- Characterization. In this step the results of category indicators are calculated and expressed as impact scores in terms of the common unit to the contribution of different environmental interventions within each impact category.

The optional elements included in a LCIA are normalization and weighting. Whether to conduct these optional steps depends on the goal and scope of the study that are defined in the first phase of the LCA. In normalisation the results are related to some reference value to give a perspective on their scale. In weighting (also called valuation), the impacts of different impact categories could be compared to each other and added into one dimensionless environmental score. Valuation is a highly subjective exercise exploiting different, mostly subjective, weighting techniques. For this reason, many LCA studies do not attempt weighting and aggregating the results of impact assessment and instead provide the results in form of environmental impact scores for each selected impact category (Ahlroth et al. 2011) (Brilhuis-Meijer n.d.).

Based on the characterisation indicators, the LCIA can be assessed on the so-called midpoint level and/or on the endpoint level. The difference between midpoint and endpoint approaches lies in the way in which the environmental related category indicators is considered. In the midpoint level models, also known as the problem-oriented approach, indicators are located between the emission and the endpoint categories. While at the endpoint level with another name damage-oriented approach, indicators are used to indicate the damage of each environmental impact and its effects to human health, ecosystem quality and resources (Fokaides & Christoforou 2016).

Several LCIA methodologies are developed and these include, for instance, CML, ReCiPe or Impact midpoint 2011+ methods. In addition to the different environmental modelling approaches, midpoint and endpoint, these methodologies are also designed on base of different impact categories, different environmental models and equivalence factors. To execute the LCIA methodologies needs specific software tools such as e.g. SimaPro, OpenLCA or Gabi. The availability of the ready-to-use methodologies of LCIA makes the practitioners to avoid the step for classification and characterization, which are very laborious and knowledge-intensive.

Interpretation

In this phase, the results of the LCI and the LCIA are summarized and compiled. In accordance with the ISO 14044 standard, the interpretation phase usually involves several analytical aspects (Almemark et al. 2000), such as:

- identification of the significant issues based on the results of the LCI and LCIA phases of an LCA,
- evaluation of the study that consideration of completeness, sensitivity and consistency checks, and
- conclusions, limitations and recommendations.

The ultimate purpose to perform the life cycle interpretation is to derive conclusions and provide recommendations based on the accuracy of the results and a clear understanding of the previous stages of goal and scope definition.

The case of LCA of disposable and reusable LMA

This part describes the application of the LCA methodology on the selected case of disposable and reusable LMA.

Goal of the study

The goal of the assessment is to identify and evaluate potential environmental impacts of the disposable and reusable LMA under the context of Skånevård Sund. Furthermore, from a life cycle perspective, this study is aimed to determine which LMA has less environmental impact in terms of climate change, ozone layer depletion, eutrophication, acidification, land use, human health and toxicity and resources depletion. It is also important for the study to identify which processes of each product's life cycle have the greatest distribution to the significant environmental impacts. The choice of environmental impact categories used in this study are explained in impact assessment section below.

The reason for performing this comparative life cycle assessment lies in the gradually increased public consideration of the large amount of waste generated by single-use medical devices. The application of the results will be useful to support future procurement decisions. Besides, the results of LCA study will be published and available to the external use for those that are interested in environmental impacts when it is about selection of reusable medical devices. However, the comparative results of the two products are not aimed to have any effect on the marketing strategy of the products and investigation of the producer.

Defining the Scope

Functional unit and reference flow

In this study two different products, the disposable LMA, Ambu® AuraStraight, and the reusable LMA, Ambu® Aura40 are compared for the total environmental burdens throughout their life cycles. The majority of the disposable LMA is made of polyvinyl chloride (PVC) while the reusable LMA is made of silicone. The lifetime of the reusable product alternative recommended by manufacturer is 40 uses. The functional unit in this comparative study is therefore set as 40 uses. This implies reference flows of 40 disposable LMAs and 1 reusable LMA.

System boundaries

In order to determine which processes should be included in the study and at which level to limit tracking input energy and materials in upstream processes, a cradle-to-grave approach is used to assess the two products' life cycles. A cradle-to-grave approach is starting with the raw material extraction, then the manufacturing process, use phase and ending with the disposal of used products as municipal solid waste (waste management). In this study, system boundaries include the products' materials, manufacturing process, transport from manufacturing plant to Helsingborg Hospital, use phase (washing and sterilisation) and the final step that products are disposed as municipal solid waste to incineration.

The information from the production processes regarding sterilization process of the disposable products are excluded in this study. The reason is mainly because of the difficulty of achieving all the detailed information of sterilization of disposable LMA from the manufacturer. During the usage phase in the hospital, the environmental burdens of the machines for cleaning and sterilization are not either included in boundaries of the study. They are considered capital goods, (similar to buildings, roads and other infrastructure), which, according to literature, are frequently excluded from system boundaries (Finnveden et al. 2009; Tillman et al. 1993). A description of the system boundaries and the flow of processes for both disposable and reusable LMA is shown in figure 3.

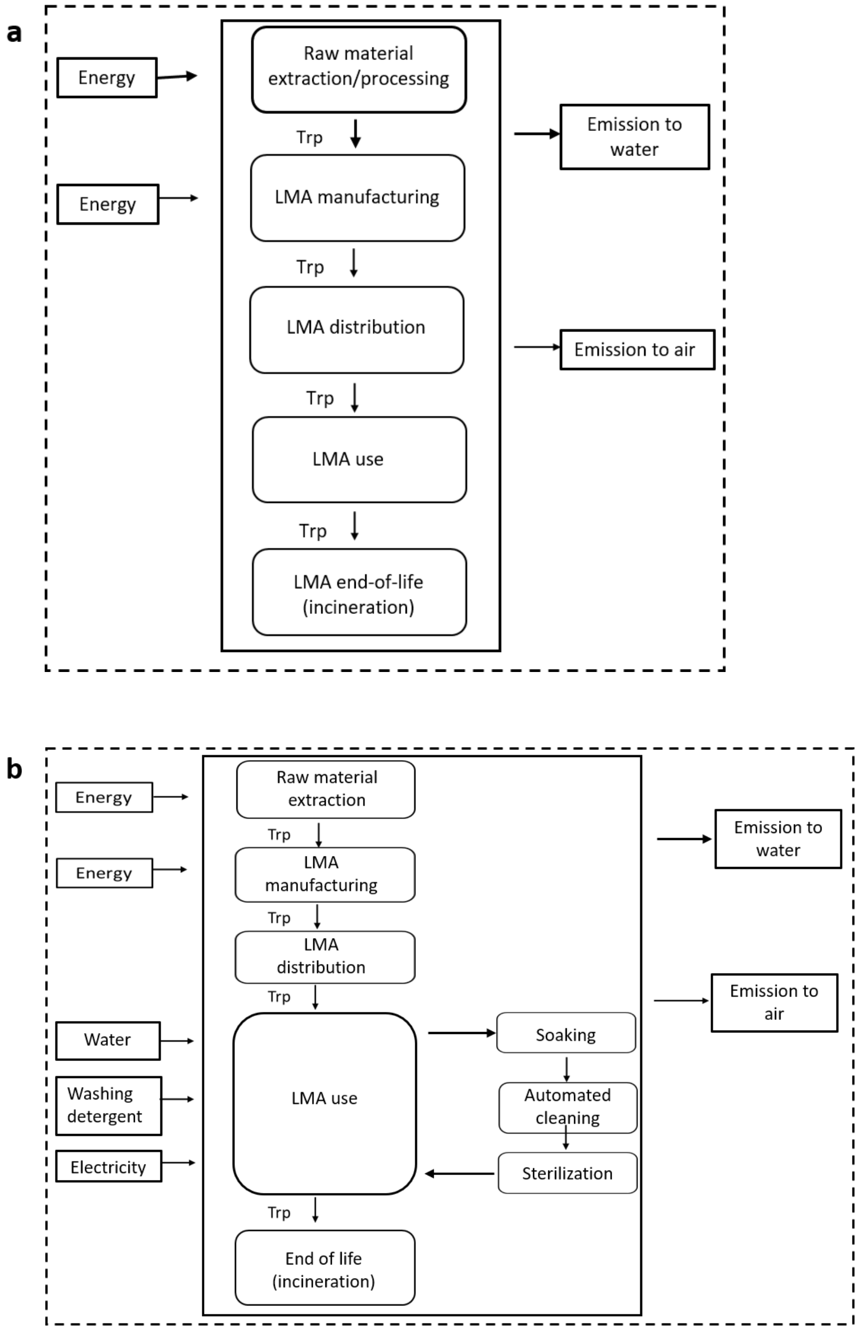

Figure 3. System boundaries and system flow diagram of the disposable and reusable LMA. The dashed lines represent the system boundaries. a. Diagram for the disposable LMA. b. Diagram for the reusable LMA.

Life Cycle Inventory (LCI)

Choice of database

In the phase of LCI, data collection is the most time and resource demanding task. Under many circumstances it is not possible to collect all the information that is needed to perform life cycle assessment. To use the well-documented process data is therefore a good choice to solve the problem with the missing data.

In this study Ecoinvent v 3.3 database and ELCD database are chosen to cover the unavailable processes and materials. Ecoinvent database is the compilation of several LCI databases by different Swiss organizations. It is considered one of the most comprehensive LCI databases in the world and is very often used by LCA practitioners. This database provides a wide range of relevant, reliable and transparent LCI data. Ecoinvent database version 3.3 contains LCI data on several sectors including energy systems, transport systems, waste management systems, chemical production, building materials, metal production and many others. The database covers over 10,000 datasets, each of which contains detailed description of life cycle inventory at a unit process level (Weidema et al. 2013).

ELCD, the European Reference Life Cycle Database, is developed by the EPLCA (the European Platform of Life Cycle Assessment) with the ambition to provide and improve high quality datasets. The ELCD contains more than 500 datasets and provides data on energy production, transport systems and waste management systems (Garrain et al. 2015).

Creating the LCI model of the LMA

To create a model of the product system in the LCA software is a way to describe the life cycle of both LMAs. After collection of data and transferring the data into models, eventually three life cycle processes were identified for the disposable LMA – production, transport and waste management, while four life cycle processes were determined for the reusable LMA – production of LMA, transport, use phase and waste management. The use phase of the reusable LMA was further divided into three phases – soaking, automated cleaning and sterilisation in accordance with the product's cleaning instruction provided by the manufacturer.

Modelling disposable LMA

The disposable LMA had a relatively simple life cycle compared with the reusable LMA. The product contained several components which were grouped into three major parts: the body of the product that was made of PVC, the airway connector with PCTG material and the cuff protection made of HDPE. Here only those parts that weighted more than 2 % of the total weight of the whole product were taken into account. The inflation valve had the minimum proportion of weight, less than 1 gram. However, the component of this part was complicated due to different synthetic materials. In the model of the production system, this part of components was accounted to have negligible impact and therefore was not included in the model. In addition, it should be noted that there was no matching material for the airway connector PCTG in the inventoried data. A similar material PET was then chosen for modelling the airway connector material.

To conduct the model of manufacturing process, an injection moulding was chosen in accordance with a scientific paper (Petersen & Hofmann 2006). The airway connector was modelled by an extrusion moulding and cuff protection was assumed to be produced with thermoforming moulding according to the praxis knowledge.

The packaging of the product was also of importance for assessment of environmental impact for the disposable LMA. The package pouches produced of Tyvek and PET/PE were replaced by the materials HDPE and PET which were available in the inventoried database and were assumed manufactured with extrusion moulding. The components of the products were modelled with the end-of-life stage as municipal solid waste as unspecified plastic fraction which were then sent to incineration. Packaging pouches were modelled as mixed plastic undergoing material recycling based on the information provided by the operation department in the Helsingborg Hospital. All these assumptions and modelling are presented in table 2.

Table 2. Modelling processes and materials of the disposable LMA

	Materials	Weight (kg)	Modelling	Processing	Waste management scenario
Production					
Body of the product	PVC	0.06021	Polyvinylchloride, suspension polymerised	Injection moulding (GLO)	Waste incineration of plastics (unspecified) fraction in municipal solid waste (MSW) EU-27
Airway connector	PCTG	0.00306	Polyethylene terephthalate, granulate, amorphous	Extrusion, plastic pipes (GLO)	Waste incineration of plastics (unspecified) fraction in municipal solid waste (MSW) EU-27
Cuff protection	HDPE	0.01009	Polyethylene, high density, granulate (GLO)	Thermoforming of plastic sheets (GLO)	Waste incineration of plastics (unspecified) fraction in municipal solid waste (MSW) EU-27
Packaging					
Package pouches	Tyvek	0.00763	Polyethylene, high density, granulate (GLO)	Extrusion, plastic film (GLO)	Recycling of mixed plastics (waste treatment) (GLO)
	PET/PE	0.00365	Polyethylene, terephthalate, granulate, amorphous (GLO)	Extrusion, plastic film (GLO)	Recycling of mixed plastics (waste treatment) (GLO)
Total product	Solid waste	0.08464			Municipal solid waste (waste scenario) (SE), treatment of municipal solid waste, incineration

GLO: global dataset; SE: dataset from Sweden.

Modelling reusable LMA

The same assumptions were applied to model the life cycle of the reusable LMA regarding the materials, production processes and packaging pouches. Most of the product was synthesized of silicone and manufactured with injection moulding (Petersen & Hofmann 2005). Material for airway connector was polysulfone and product was produced through extrusion manufacturing process. The complete packaging product did not include any cuff protection. The same reason as the disposable LMA, the inflation valve was excluded in modelling the production process of the reusable LMA. Production, package pouches and their waste treatment modelled with the help of default databases are summarized in table 3.

Table 3. Modelling of materials and production processes as well as waste management for reusable LMA

	Materials	Weight (kg)	Modelling	Processing	Waste management scenario
Production					
The body of the product	Silicone	0.06780	Silicone product (GLO)	Injection moulding (GLO)	Waste incineration of plastics (unspecified) fraction in municipal solid waste (MSW) EU-27
Airway connector	Polysulfone	0.00360	Polysulfone (GLO)	Extrusion, plastic pipes (GLO)	Waste incineration of plastics (unspecified) fraction in municipal solid waste (MSW) EU-27
Packaging					
Package pouches	Tyvek	0.00745	Polyethylene, high density, granulate (GLO)	Extrusion, plastic film (GLO)	Recycling of mixed plastics (waste treatment) (GLO)
	PET/PE	0.00628	Polyethylene terephthalate, granulate, amorphous (GLO)	Extrusion, plastic film (GLO)	Recycling of mixed plastics (waste treatment) (GLO)
Total product	Solid waste	0.08513			Municipal solid waste (waste secanio) (SE), treatment of municipal solid waste, incineration

GLO: global dataset; SE: dataset from Sweden.

The major difference between the reusable and disposable LMA lay in the use phase. The disposable LMA could be used direct for the routine and emergency anaesthetic procedures. After use it was disposed of as normal municipal solid waste. In contrast to the disposable LMA, the reusable LMA was packaged as non-sterile and must be sterilised before the first use. After each use, the LMA must be washed and disinfected according to the recommended procedures to guarantee the subsequent use. It was recommended that the reusable LMA could be reused maximum 40 times only if it was cleaned in strict accordance with the recommended washing and sterilisation procedures. As stated in the instruction from the producer, the LMA should be immersed in a mild detergent for 30 minutes after use. Concentration of the solution was 30 ml detergent per litre water. Following soaking process, the LMA should be placed in an automated washer, a 46-4-203 washer-disinfector manufactured by Getinge AB. According to the recommended automated cleaning program, the pre-wash step was about 2 minutes and then followed the enzyme wash for 2 minutes in which the concentration of the detergent was about 32 ml per 5 litre water. After that followed another washing step for 2 minutes with the same concentration of detergent as the enzyme wash. The last step of the cleaning program was to rinse the product for 0:15 minutes. The washing machine used about 4,2 kWh electricity and around 18 litres water one washing program.

The recommended detergent for cleaning the product was Neodisher® MediClean forte, manufactured by Dr. Weigert or Endozime® (manufactured by Ruhof Corporation). It was difficult to find any information of ingredients for both cleaning detergents, but the products' data sheets stated that the ingredients contain non-ionic and anionic surfactants. This could be modelled by a generic washing agent that was available in the Ecoinvent database. In this study it was assumed that the soap production (in Ecoinvent this selection was based on the dataset representing production in Europe) which contained surfactants had the similar function as a washing detergent to clean the used LMA.

After the automated cleaning process the sterilisation was performed. The LMA was packaged in a steam autoclave-proof pouch (here it was assumed that the same Tyvek pouches were used for all the subsequent packaging) and later placed in a steam autoclave sterilizing machine, Ångautoklaver HS 6617-ER2, manufactured also by Getinge AB. The machine could accommodate 72 pieces LMAs per cycle and consume 20,4 kWh electricity and 400 litre water. Over its life cycle a reusable LMA undergone 40 such washing cycles. In the end of life, the reusable LMA was discarded as the regular municipal solid waste and ends up in incineration. This scenario was modelled as municipal solid waste (waste scenario) (this scenario was based on the dataset with the geographic location in Sweden) treatment of municipal solid waste, incineration in Ecoinvent database. Packaging pouches was modelled as mixed plastic for recycling.

Transports

Based on the vague information of transportation of the products acquired from the Ambus company, it was assumed that both LMAs were manufactured in Xiamen, China and transported from Xiamen harbour first to Amsterdam harbour in Netherland via container ship over ocean. Then products were transported further to the warehouse in Münster by trucks. Finally, the products were delivered to the customer (the Helsingborg hospital) by car or truck. Transport from the hospital to the waste incineration plant (here it was assumed that waste was send to the Filbornateverket in Helsingborg) was also included in the calculation of the transport distance.

To estimate the distance, the web distance calculator sea-distances.org and Google Maps were used. The result of the transport distance from Xiamen harbour to Amsterdam Harbour was displayed by nautical miles which needed to convert to kilometres with the help of Google converter. The inventory data for the transports of both LMAs are summarized in table 4. It should be emphasized that to model transport with the Ecoinvent database, the unit should be tkm (ton kilometre) which means that the distance should be converted from km to tkm by followed formulation: ton cargo per transport × km per transport = ton kilometre (tkm) (Naturskyddsföreningen 2005). It means that if one ton of goods is moved one kilometre, the vehicle has produced one tkm transport work. Based on this data transport related environmental loadings were calculated in the model.

Table 4. Modelling the transport of the disposable and reusable LMA

Transport	Distance (km)	Means of transport	Calculating method	Modelled with the Ecoinvent database
From Xiamen, China to Amsterdam	18642	Oversea container ship	Sea-distances.org	Freight, sea, transoceanic ship
From Amsterdam to Münster	223	Trucks via land road	Google map	Freight, lorry 16-32 metric ton, EURO 4
From Münster to Helsingborg	702	Trucks via land road	Google map	Freight, lorry 16-32 metric ton, EURO 4
From Helsingborg hospital to Filbonateverket	1.8	Trucks via land road	Google map	Freight, lorry 16-32 metric ton, EURO 4

Life Cycle Impact Assessment and interpretation

Selection of the LCIA methodology

As mentioned earlier in the part of introduction of the LCA, there are several LCIA methodologies for the practitioner to choose. Selection of methods is based on the goal of the study and the relevant environmental impacts for the comparative products. In this study the ReCiPe methodology was chosen for assessment of environmental impact of both products' entire life cycles. ReCiPe is a robust and versatile impact assessment methodology which enables to calculate both the midpoint indicators and endpoint indicators. ReCiPe also offers three versions of environmental assessment:

- Individualist (I) – is based on the short-term interests and technical optimism. It focuses only on undisputed types of impacts.
- Hierarchist (H) – is based on the most common policy principles with medium time frame. This is often used to be the default model for LCIA.
- Egalitarian (E) – is based on precautionary principle considering, the long-term perspective. For example, 1000-year timeframe for global warming (GWP1000).

ReCiPe contains three endpoint indicators (damage to human health, ecosystem quality and resource availability) and eighteen midpoint indicators. In this study, the impact assessment method is the ReCiPe endpoint (H) version 1.13 with the normalisation values of Europe. The choice of ReCiPe is because of the goal of the study which is aimed to address what the potential environmental impacts actually are of the two products and further to compare environmental impacts of two products. To choose a method that includes as much relevant indicators as the study needed is therefore rationalised. Table 5 shows the endpoint indicators and midpoint indicators and relationships between these parameters on ground of the report of ReCiPe by Goedkoop et al. (2009).

Table 5. The relations between the midpoint indicators and endpoint indicators in ReCiPe method.

Endpoint indicators	Damage pathways	Midpoint impact category
Damage to human health	Increased risk for respiratory diseases	Particulate matter
		Photochemical oxidant formation
	Increased risk for cancer	Ionizing radiation
		Ozone depletion
		Human toxicity (cancer effect)
	Increased risk for other diseases	Ionizing radiation
		Ozone depletion
		Human toxicity (non-cancer effect)
		Global climate change
Damage to ecosystem	Damage to freshwater species	Global climate change
		Freshwater ecotoxicity
		Freshwater eutrophication
		Water use
	Damage to marine species	Marine ecotoxicity
	Damage to terrestrial species	Global climate change
		Water use
		Terrestrial acidification
		Terrestrial ecotoxicity
		Agricultural land occupation
		Urban land occupation
		Natural land transformation
Damage to resource available	Oil/gas/coal energy cost	Fossil resources
	Increase extraction costs	Mineral resources
		Metal depletion

Selection of the impact categories related to the study

A list of environmental impacts related to the studied products should be made within the goal and scope definition. However, to make things clear, the list of impact categories is displayed here to correspond to the LCIA methodology. The choice is based on the consideration of the most broadly accepted environmental problems such as climate change, ozone depletion, eutrophication, acidification, lack of resources, land occupation and some other impact categories that may be potential in close relation with the production, transport, energy generation and waste management.

In combination with the impact categories available in the ReCiPe method, following environmental indicators were chosen for the impact assessment in this study:

Climate change – also known as global warming, is the most recognised environmental problem in the whole world. Climate change occurs on the base of the increased emissions of the greenhouse gases such as carbon dioxide, methane and nitrous oxide. In the ReCiPe method, the climate change category is divided into two different affects: upon human health and ecosystem.

Ozone depletion – ozone depletion occurs when emissions of the certain chemicals such as chlorofluorocarbons (CFC) and halons chlorofluorocarbons (HCFCs) increase. The consequences are potential damage to human health, such as cancer, and damage to ecosystem at global scale.

Eutrophication – refers to the increased emissions of nutrients to air, water and soil which can cause excessive growth of plants and algae in aquatic and marine systems. In this study the most potential process that could be directly related to this impact category is the use of detergent solution.

Acidification – enrichment of certain nutrients can cause acidification in both marine and terrestrial system. The acidifying substances refer to nitrogen oxides (NOx), ammonia (NH_3) and sulfur dioxide (SO_2) which have their original sources from human activities. Deposition of these substances causes decreased pH value in the water or soil which as a result may suffer biodiversity of both marine and terrestrial system. Here in consistent with the midpoint indicators in the ReCiPe method, the terrestrial acidification is chosen.

Toxicity – many chemical substances can be harmful when they are emitted to the environment or are taken up by both animals and human. In ReCiPe the characterization indicators for human toxicity is calculated with the environmental persistence (fate) and accumulation in the human food chain (exposure) as well as the toxicity (effect) of a certain chemical (Huijbregts et al. 2016)

Land use – land use is defined as impact on the land that is caused by agriculture, anthropogenic settlement and land resources application. It has two types of use on land – land occupation and land transformation (Mattila et al. 2011). In this study agricultural land occupation is chosen to describe the potential environmental impact of the products.

Fossil resource scarcity – this impact category refers to the consumption of fossil resources such as natural gas, crude oil and coal. It is defined as an end-point indicator because depletion of fossil resource can result in damage to natural resources and ecosystem.

Photochemical oxidant formation – also called “summer smog”. Photochemical oxidants are mixture of primary and secondary air pollutions such as ozone, nitrogen dioxide and some small particles. These secondary air pollutants refer to the compounds formed by the reaction of sunlight on certain organic compounds such as nitrogen oxides. The negative consequence of photochemical smog includes possible asthmatic attacks or impaired pulmonary function in sensitive population.

Normalization

Normalization is an optional process according to the standard ISO 14044 or 14040. It is a method for “*calculating the magnitude of category indicator results relative to reference information*” (ISO 14044, 2006). The normalised effect score is obtained by calculating the results in each impact category indicator (so called characterized results) in relation to some reference information. By this way, the situation that each impact category has its own unit which makes the results difficult to understand turns out to be that the results of each impact category have the same consistent unit which makes it possible to compare with each other. The results of LCIA are therefore simplified and easy to interpret. The normalisation can be formulated as followed equation (Aymard & Botta-Genoulaz 2016):

$$\text{Normalized impact category results} = \frac{\text{Characterized impact of the impact category of the studied system}}{\text{Characterized impact of the impact category of the reference system}}$$

The reference systems that can be used in calculation include functional unit, reference flow or total input and output for a given geographical area over a reference year (for example, environmental impact of 25 European Union countries in 2000) (Aymard & Botta-Genoulaz 2016). In this study, the ReCiPe method contains two reference systems which are the normalisation data for Europe in year 2000 and the normalisation data for the World in year 2000 (Ponsioen 2014).

Sensitivity analysis

This LCA study includes many input parameters that are based on the model assumptions and therefore will increase uncertainty of the results. The uncertainty can be due to the data quality, system boundaries, transport, life span of the products or electricity mix (Budavari et al. 2011). A sensitivity analysis is then helpful to evaluate the influence of the assumptions on the results regarding methods and data. To perform sensitivity analysis, it simply needs to use alternative assumptions and recalculate the LCA. In this study, the important assumptions that may affect the results include modelling energy for the source of electricity, ingredients of detergent solution and the reuse cycles of the reusable LMA. It should be noted that the recommended reuse times of the reusable LMA is 40 according to the manufacturer. However, there are several reports showed that it can be reused more than the recommended 40 uses if it is handled properly after use (Lal & Hooda 2008) (Goodman et al. 2008). Therefore, the alternative lifespans of the reusable LMA was simulated for 20, 40, 60 and 80 rounds while the 40 rounds is the regular lifespan that used for the assessment of life cycle and comparative analysis.

Another assumption that can be of importance for uncertainty of the results lies in the production of electricity. According to the Region Skåne which was responsible for the electricity consumption of the Helsingborg Hospital, all electricity used in the area was labelled according to the Swedish Society for Nature Conservation “Bra Miljöval” and generated from renewable sources. It was difficult to get further information on which renewable sources were used. Assumptions of electricity sources may therefore cause uncertainty of the result. Considering the geographic localization, wind power as the source of electricity was reasonable to use for modelling the consumption of electricity. At the same time, hydro power and average national electricity mix were also chosen as alternative assumptions.

Result

Impact assessment of disposable LMA

The results of the impact assessment for the disposable LMA on each impact category are shown in figure 4. Each impact category is set equal, 100 %, to the sum for the life cycle of the product. The life cycle processes of the disposable LMA include the LMA production, transport and waste management. It shows that the LMA production process is the most dominated contributor in the life cycle in all the selected categories. The highest score for production process lies in category agricultural land use, 97 % and lowest is within category human toxicity, about 56 %. In addition, transport contributes a mild effect with less than 40 % of the whole impact within categories ozone depletion and terrestrial acidification. Upon these nine impact categories, waste management is not the most significant contributor to the product's environmental burden.

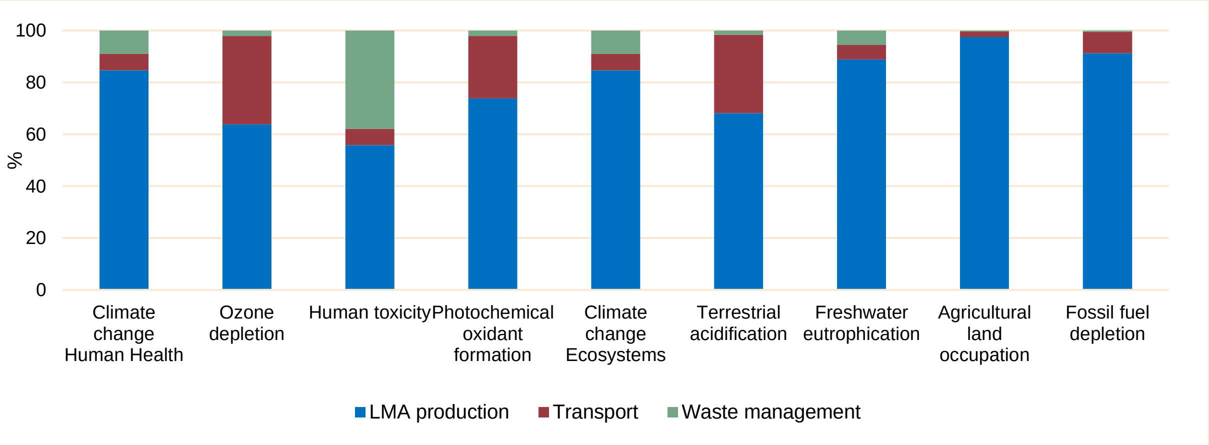

Figure 4. Impact assessment results of the disposable LMA. Each impact category is modified to 100% and divided into different colours for the direct contribution of production, transport and waste management.

The LCIA results after normalization are shown in figure 5. The highest score of potential environmental impact lies in the category fossil fuel depletion, followed by category climate change upon human health as second biggest environmental burden. Climate change upon ecosystem is on the third place. It also shows that the production process contributes the overwhelming proportion of these three categories.

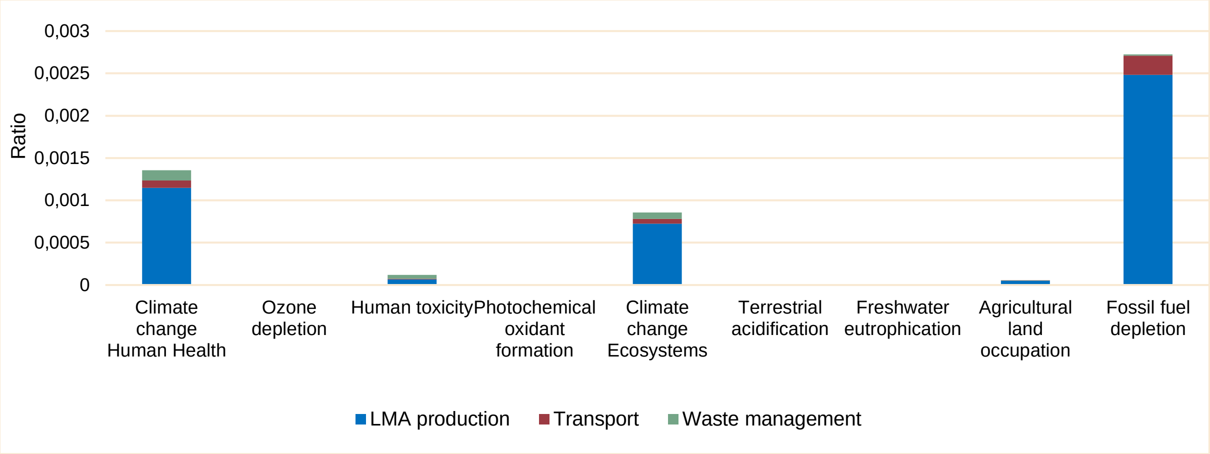

Figure 5. Normalisation of the environmental impact of the disposable LMA. The impact category indicator results are normalised by the reference sets of impact of Europa in 2000 and impact of the World in 2000.

To present more details of environmental burdens from the complete life cycle processes of the disposable LMA, a network diagram is used and shown in figure 6. On the top of the diagram is the product – disposable LMA, and below is the contribution of important contributed input processes. The cut-off is set to 5 %. The thickness of the red line displays how heavy the environmental burden is for the process flow. The red colour lines represent environmental burdens while the green colour lines indicate environmental benefits. The network presents that the major environmental load comes from the processes for production of material PVC.

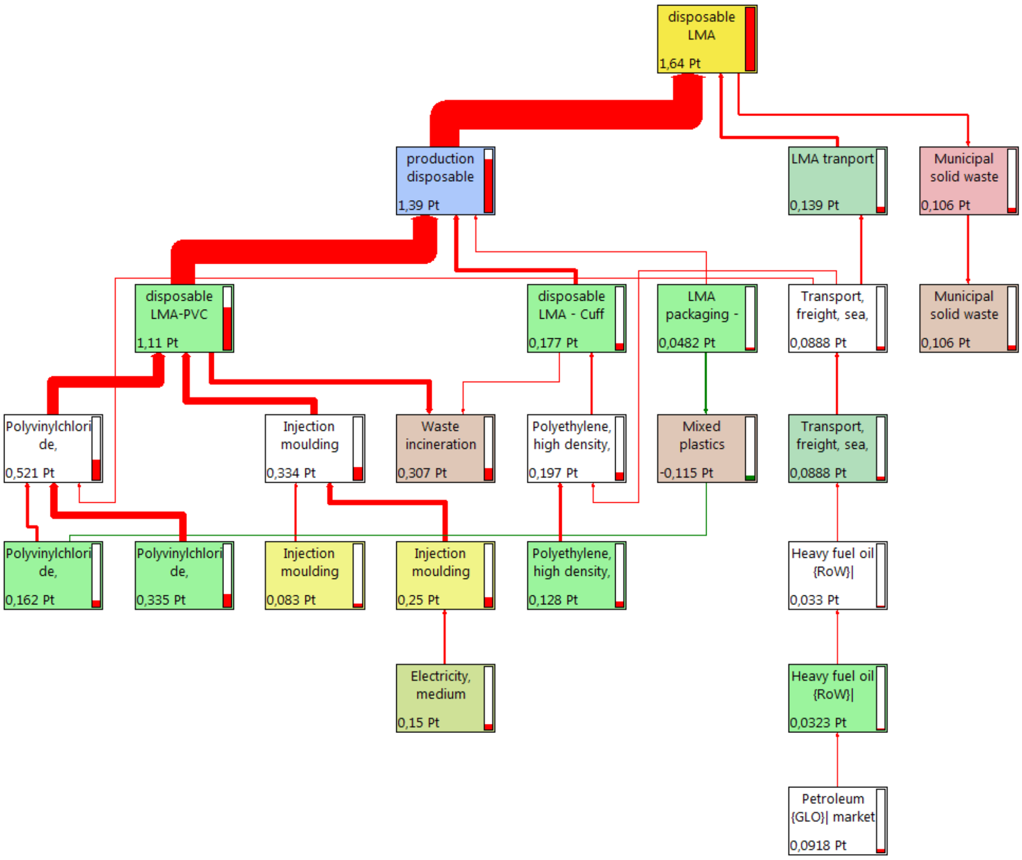

Figure 6. Network diagram of the life cycle of the disposable LMA contributing to total environmental impact with application of cut-off of 5 %. The red colour lines represent environmental burdens while the green colour lines indicate environmental benefits. Pt: point, unit for the total environmental load that expressed as a single score.

Impact assessment of reusable LMA

The life cycle of the reusable LMA was divided into six major processes: production, transport, soaking, automated cleaning, sterilisation and waste management. The soaking, automated cleaning and sterilisation processes were essential processes to guarantee that the reusable LMA can be reused for 40 occasions and were grouped as one process – the use phase. The impact assessment results are shown in figure 7. All impact scores are set equal to the sum as 100 % for the entire life cycle. It is presented that the production of LMA contributes over 50% within categories ozone depletion (62 %) and fossil fuel depletion (54 %). It also shows that effects of the use phase on impact categories human toxicity, photochemical oxidant formation, terrestrial acidification and freshwater eutrophication are over 50 %. The greatest effect of use phase is within category agricultural land occupation, around 80 %. While the waste management has not such effect as production and use phase, the highest is only 16% within the Human toxicity. Transport shows relatively less importance regarding contribution to the environmental burdens in the product’s life cycle.

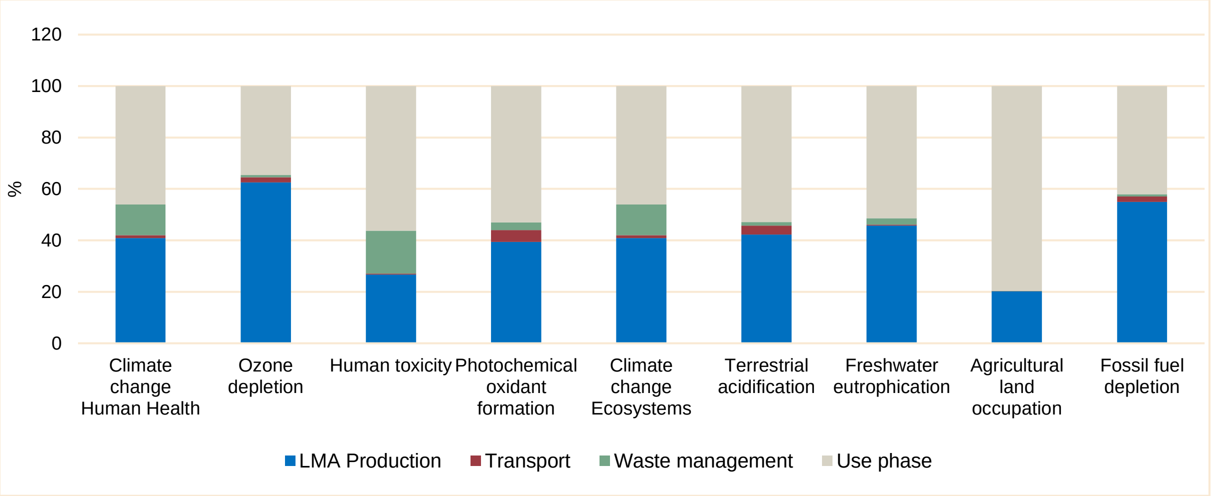

Figure 7. Impact assessment results for each impact category by calculating with the LCIA method ReCiPe endpoint H/A. Each impact category is modified to 100% and divided into different colours for the direct contribution of production, transport, use phase and waste management.

The normalised results of each impact category for the reusable LMA is presented in figure 8. The biggest environmental burden of entire products life cycle lies in the category fossil depletion. The next is climate change upon human health. It is also presented that the production of LMA and the use phase have almost evenly proportion within these three categories. Within categories human toxicity and agricultural land occupation, the use phase is the dominated contributor.

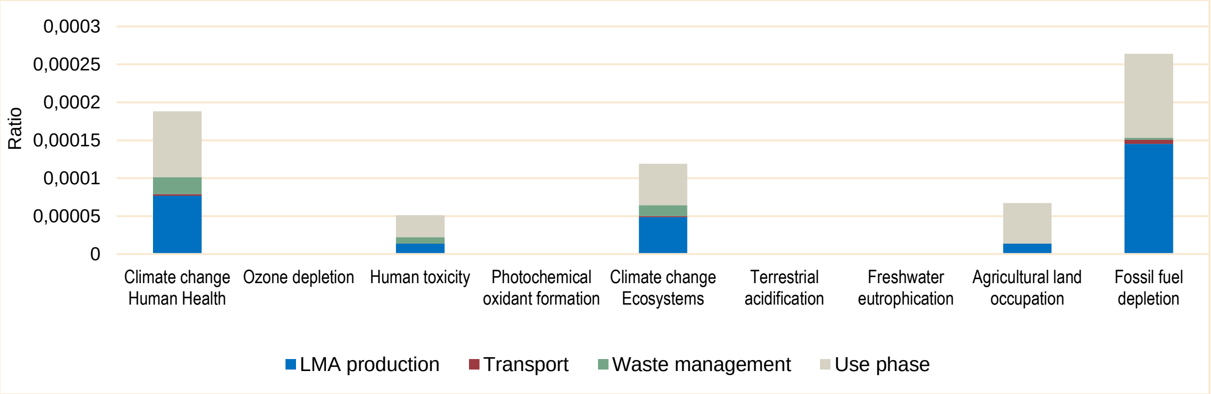

Figure 8. Normalised results of each impact category for the entire life cycle of the reusable LMA. The impact category indicator results are normalised by the reference sets of impact of Europa in 2000 and impact of the World in 2000.

A network diagram is quite helpful to understand the details of the contribution of all the input flows. It is displayed in figure 9 with a cut-off of 9 % (to set cut-off to 9% is to show contributions of all five major processes). The major contribution to the environmental burdens of the product’s complete life cycle comes from the soaking process. The thickness of the red line displays how heavy the environmental burden is for the process flow. The process for materials of packaging pouches have certain grade contribution to environmental burdens, almost the same as the automated cleaning process. It should be noted that sterilization pouches include the original package pouch and subsequent sterilization pouches that are needed to prepare the reusable LMA for reuse. An interesting observation is that recycling of these type materials generates some environmental benefits as shown in the figure with thick green lines.

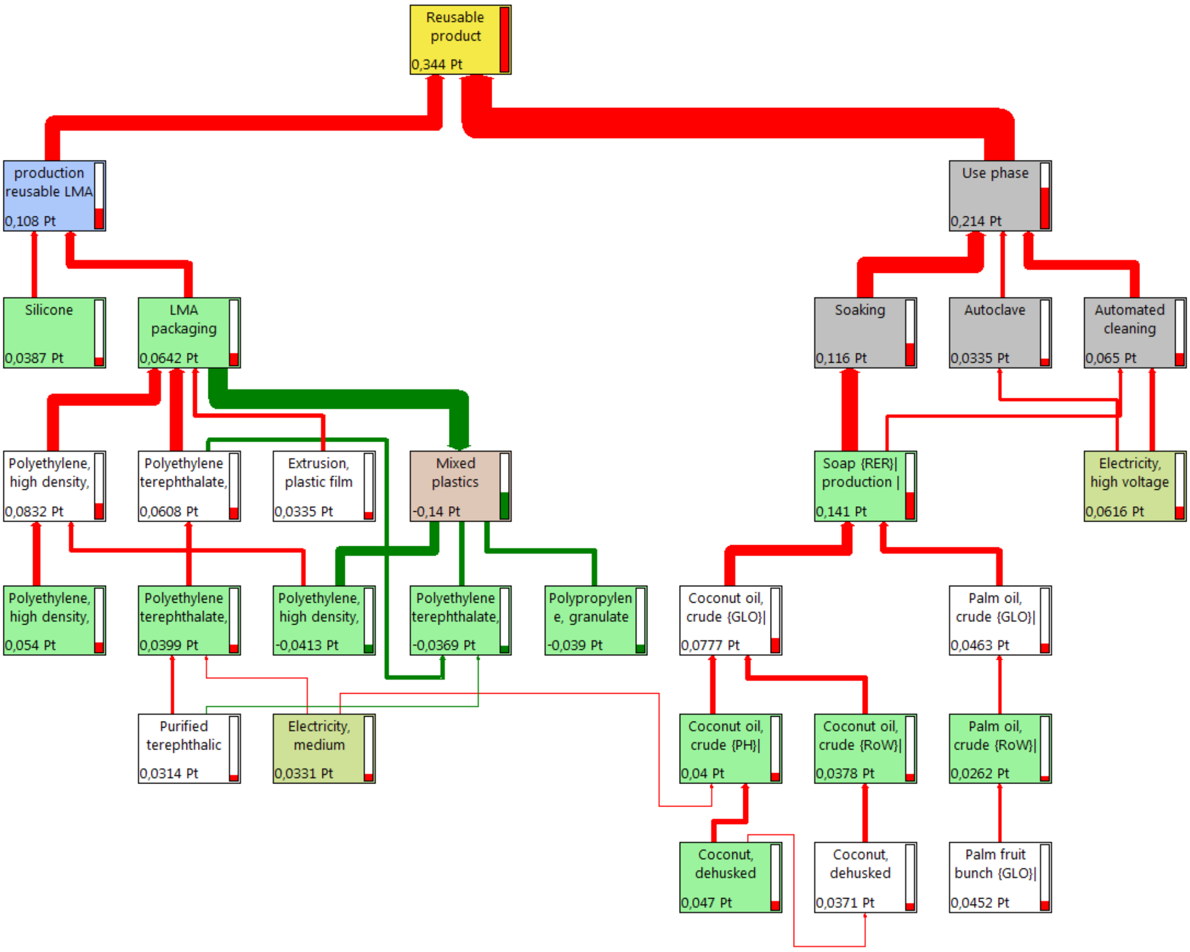

Figure 9. Process network of the entire life cycle of the reusable LMA regarding total environmental impact (cut-off = 9 %). The red colour lines represent environmental burdens while the green colour lines indicate environmental benefits. Pt: point, unit for the total environmental load that expressed as a single score.

Results of comparative life cycle assessment of disposable and reusable LMA

The LCIA results for the disposable and reusable LMA in comparison in terms of all the selected impact categories are shown in figure 10. The largest effect score for each impact pair is scaled to 100 % while the lower one is therefore a relative proportion. The result shows that the disposable LMA has the higher potential environmental impact in almost all the impact categories in relation with the reusable LMA except category agricultural land occupation. With the exception of this category, the reusable LMA has the greater impact. Within the category fossil depletion, these two products have the biggest difference in which the reusable LMA causes only about 9 % of the impacts of the disposable LMA.

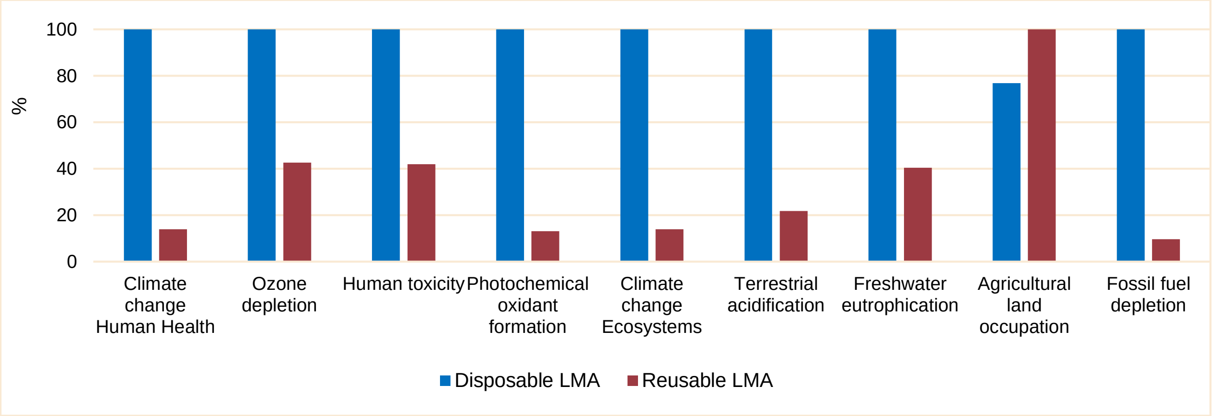

Figure 10. Results of comparative LCA of the disposable and reusable LMA in terms of all the selected impact categories. The higher score is set to 100% while the lower one is then a relative percent.

In the normalised result of impact assessment, it shows that the most significant difference between these two products lies in categories fossil depletion and climate change (upon human health and ecosystem) (figure 11). However, the effects on the agricultural land occupation for both products are insignificant in comparison with those three categories.

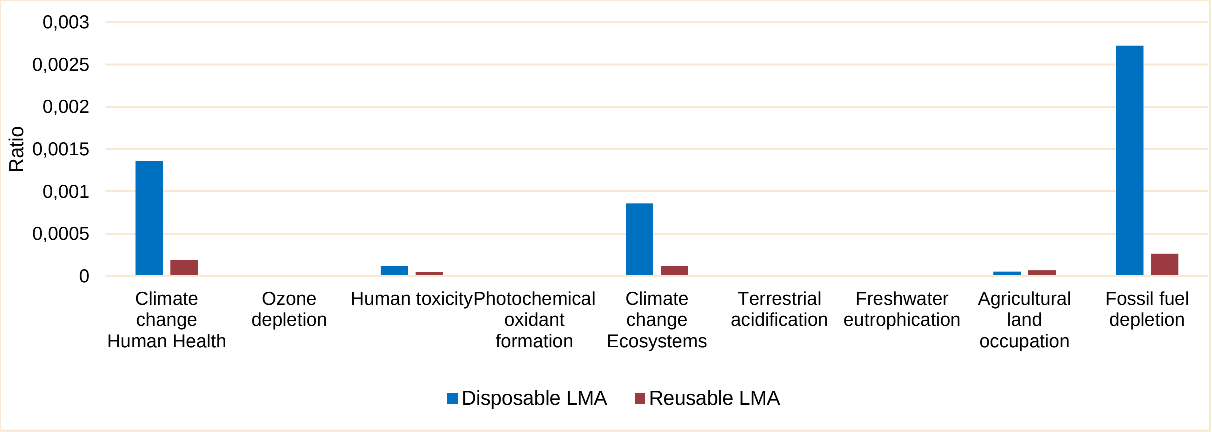

Figure 11. Comparative LCA of disposable and reusable LMA in terms of each impact categories after normalization. The impact category indicator results are normalised by the reference sets of impact of Europa in 2000 and impact of the World in 2000.

To investigate the cause of reusable LMA having a higher score within category agricultural land occupation, an overview of the contribution of all input flows on the level of the individual impact categories is executed and shown in figure 12. A cut-off of 0.2 % is applied. It shows that the biggest contribution of the reusable LMA is from the production of dehusked coconut and palm fruit bunch. Referring to figure 9 which shows the process network of the entire life cycle of the reusable LMA, these processes locate in the upstream supply chain for producing soaking detergent which is consumed in the use phase for washing the used LMA. This means that the major contributor for environmental impact in category agricultural land occupation is the production of washing detergent. The unit “species.yr” refers to the loss of species diversity that is caused by the production of a certain product by occupying agricultural land during the period of occupation (year).

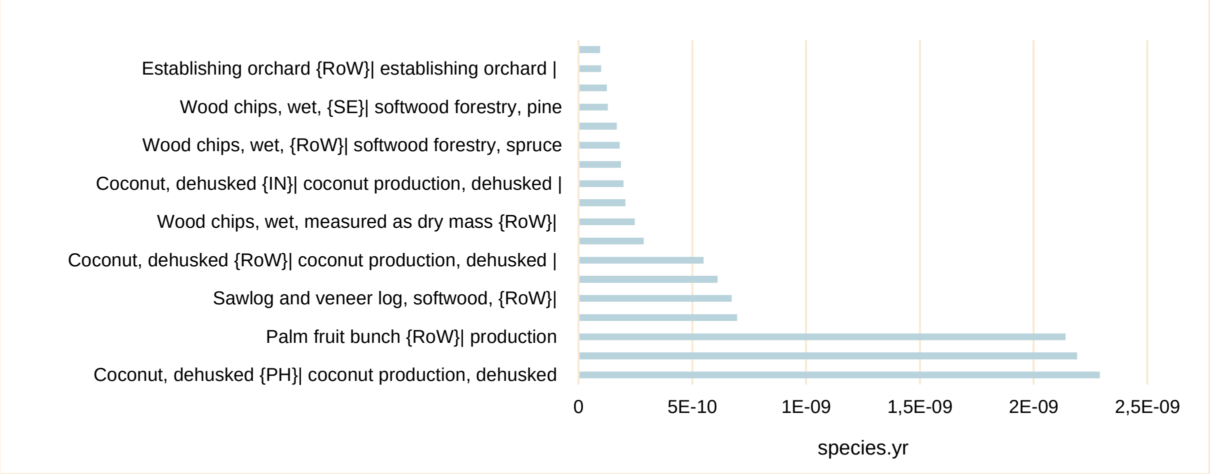

Figure 12. Process contribution of the life cycle of the reusable LMA to impact category agricultural land occupation. Result should be interpreted by referring to figure 9. Species.yr is the unit used for calculating potential disappeared fraction of species by occupying agricultural land during occupation time.

When the result of comparative LCA of both products is shown in terms of damage category indicators and overall impact, the disposable LMA causes higher impact scores than the reusable LMA on all three endpoint category indicators: damage to human health, ecosystem and resources (figure 13 a). The reusable LMA has less than 40 % impact burdens compared with the disposable LMA. Normalisation of the results is shown in figure 13 b. It presents that the biggest difference between the disposable and the reusable LMA lies in damage to resources.

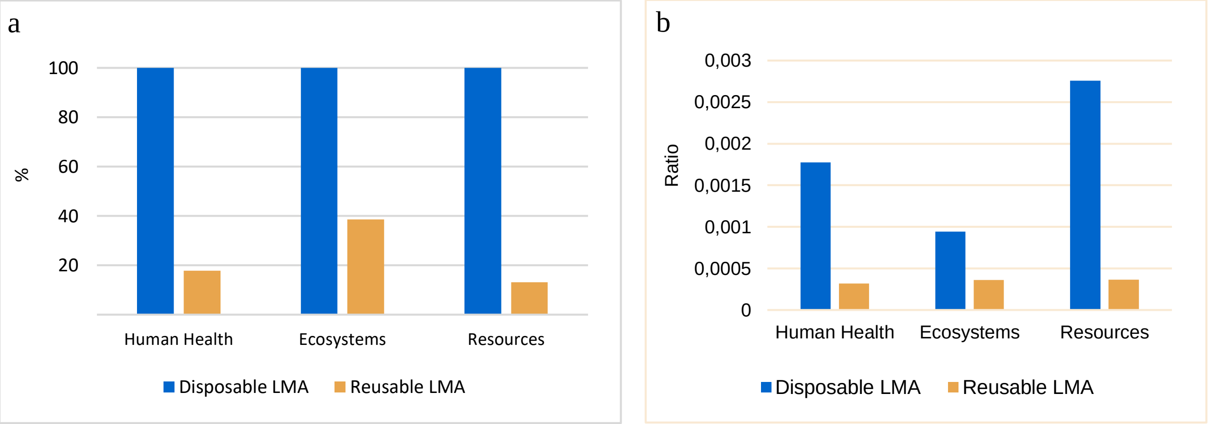

Figure 13. Comparative analysis of the disposable and reusable LMA for each of three endpoint damage category indicators. a. Impact results for three endpoint categories. The maximum impact is set to 100 percent. b. Normalised impact assessment results for three damage categories.

Sensitivity analysis

Number of reuse cycles

The number of reusing the reusable LMA is an uncertain assumption that can influence the result of comparative LCA. In this study, alternative reuse times was set for 20, 40, 60 and 80 times. The recommended 40 times was set as standard. Results are shown in figure 14. Here effect from disposable LMA is set to 100 %, the others are relative proportions to this effect. It presents that as the reuse cycle of the reusable LMA increases the environmental burdens decrease in all the selected impact categories. However, no matter how many times it reused, the environmental impacts caused by the reusable LMA is consistently lower than that of the disposable LMA. One exception is within category agricultural land use. Even though the trend of decreasing impact with the increasing reuse cycle remains, the reusable LMA always has higher impact than the disposable LMA. In general, the reuse cycle of the reusable LMA would not affect the conclusion of the impact assessment which is that the reusable LMA has fewer environmental burdens in relation with the disposable LMA.

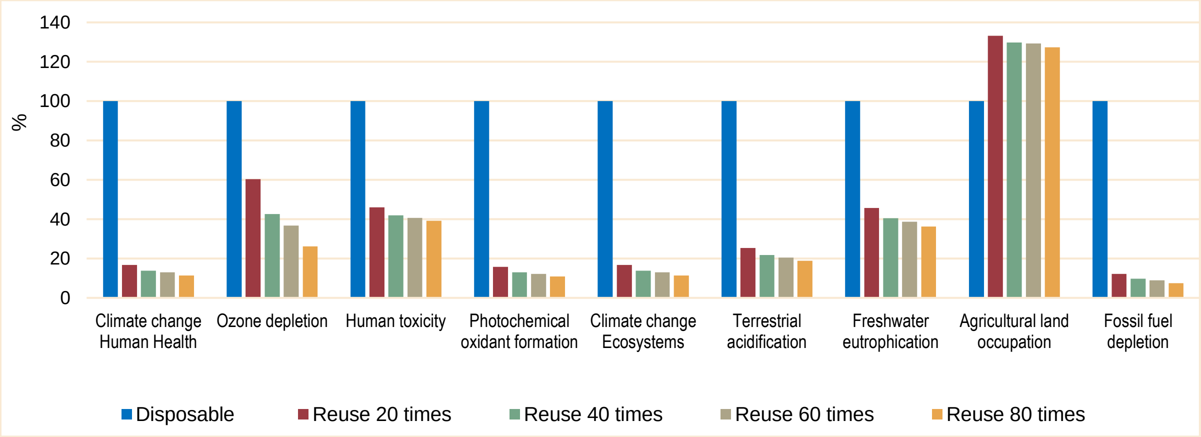

Figure 14. Comparison of the disposable and reusable LMA per selected impact categories with varied reusing occasions.

Alternative electricity sources

The alternative assumptions selected from Ecoinvent database for modelling energy sources for electricity were used to evaluate the uncertainty of the results. Two types of sources counted as renewable energy to generate electricity were assumed to be useful in this analysis – wind power and hydro power. In Ecoinvent database, the wind power had different types among which the wind power with 1-3 MW onshore turbines and 1-3 MW offshore turbines were chosen. Among them the wind power with 1-3 MW offshore turbines was chosen as the regular energy source for electricity supplied to the Helsingborg Hospital. For hydro power, three types of generating methods were chosen as alternative selections: hydro power from run-of-river, reservoir and pumped storage. Another type of power that was available in the database was also applied to investigate if alternative modelling approaches can affect the impact assessment results – the country mixes of low voltage electricity. The results of several simulations are shown in figure 15.

It appears that the different assumptions of energy sources for electricity indeed affect the impact assessment results within several categories. This is especially significant with the selection of country mixes of low voltage electricity. This selection has greater effects within categories ozone depletion, human toxicity and freshwater eutrophication compared with other renewable energy sources. Selection of hydro power from pumped storage as energy sources significantly affects the comparative result within category ozone depletion. Within agricultural land occupation, the result of impact assessment does not fluctuate greatly. On the other hand, selections of other renewable energies including wind power with 1-3 MW onshore turbines and 1-3 MW offshore turbines as well as hydro power from run-of-river and reservoir would not have significant influence on environmental burdens within all the impact categories.

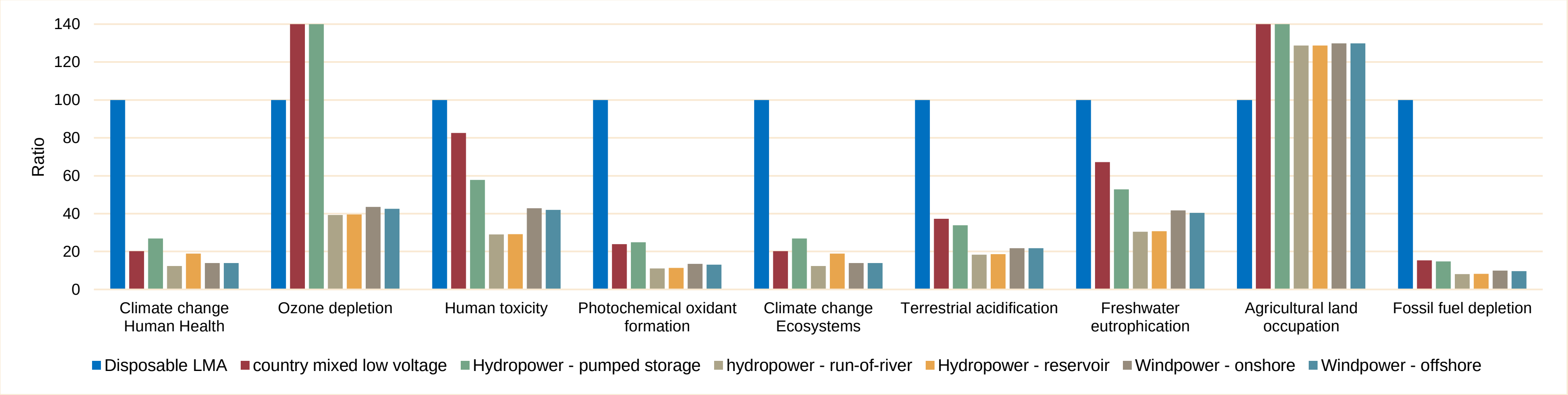

Figure 15. Alternative assumptions of energy sources for electricity affect the comparative LCA result. This diagram presents a characterisation result of LCIA. The scores over 140 % within categories ozone depletion and agricultural land occupation are presented as the maximum score.

Assumptions about detergent

Another analysis was performed to clarify if assumptions of ingredient for washing detergent can affect the result of impact assessment. When changing the detergent from soap to fatty alcohol sulphate, a significant variation occurs only in category agricultural land occupation (figure 16). The percentage value of environmental effect for the reusable LMA is dropped from higher than the value of impact for the disposable LMA by using soap, about 130 % to around 73 %. This result can also be used as confirmation of process contribution results displayed in figure 11.

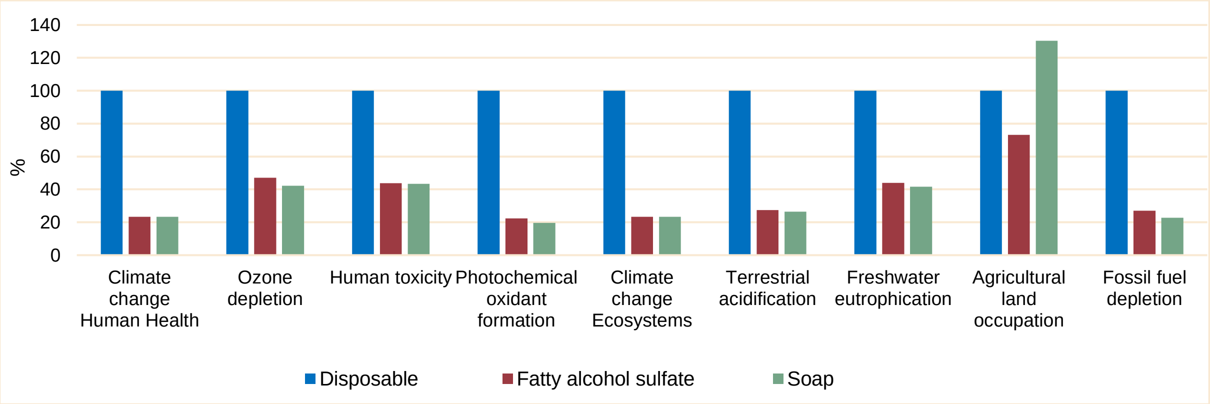

Figure 16. Relative results for the disposable and reusable LMA with alternative assumptions of washing detergent.

Summary of results

Results of impact assessment show that the production of the disposable LMA contributes to most of environmental impacts. For the reusable LMA the use phase is the major contributor to the environmental burdens and the production process have relatively mild effect to the environment compared with the use phase. In addition, the normalized results show that the most significant effects lie in categories fossil depletion, climate change upon human health and ecosystem. The major contribution of the life cycle of the reusable LMA to the environmental impact comes from the soaking process.

The comparison of results for the two products show that the reusable LMA is more environmentally friendly during its lifespan than the disposable LMA in selected environmental impact categories. An exception is category agricultural land occupation, in which the reusable LMA has greater environmental impact. Analysis of process contribution indicates that the usage of the washing detergent for the reusable LMA is inseparably connected with the higher environmental burden within category agricultural land occupation. Results of normalisation analysis present that the greatest environmental burden related to the life cycle of the reusable product is attributed to the category fossil depletion. The impact to category agricultural land occupation is negligible in comparison with categories fossil depletion and climate change.

Sensitivity analysis investigate influences of different modelling approaches on the LCIA results. It shows that different modelling approach of the energy sources for electricity indeed obtained varying results within several impact categories.

Discussion

This study is aimed to find out the difference between the disposable and reusable LMA under the conditions of the Skånevård Sund regarding environmental impacts throughout the products' life cycles. Results show that the disposable LMA in general has greater environmental burdens than the reusable LMA.

The LCIA results are in good agreement with the findings of previous study in the context of the Yale New Haven Hospital in USA (Eckelman et al. 2012). In brief, both results point out that the disposable LMA has more environmental burdens than the reusable one. The PVC material used for the disposable LMA is the dominant contributor to the selected environmental impacts. This conclusion should not cause much controversy on the ground that PVC is described as a well-known chemical compound that can cause damage to ecosystem quality and human health (Klar et al. 2014). Even though the manufacturer states that toxic plasticizers such as phthalate is not applied in the disposable product, the environmental burdens arising from PVC are still remarkable according to the LCIA result of this study.

On the other hand, it is relatively complicated to explore the aspects contributing to the environmental burden of the reusable LMA. In the U.S. study, major process contributing to the environmental impact of the reusable LMA is due to the use of the autoclave sterilizing machine (Eckelman et al. 2012). Differing from Eckelman's results, this study shows that the main cause of environmental burden for the reusable LMA is the soaking process before the automated cleaning. This difference can be explained by differences in the application of the autoclave machines and washing procedures. The autoclave machine in the U.S. hospital is only available to run 5 LMAs compared to 72 LMAs in Helsingborg Hospital. Furthermore, what needs to be stated here is that in practice, it is impossible to sterilize 72 units of LMA at once. More often than not, a mixed load with different types of products is performed to increase the efficiency of the autoclave machine. In addition, there is no description of any washing detergent in Eckeman's report, which may imply that the environmental impacts from washing detergent is not included in the U.S. study.

It should be noted that material for packaging pouches used for subsequent sterilization has association with certain grade of contribution to environmental burdens of the reusable LMA. The choice of material of package pouches is based on the modelling assumptions drawn from the Ecoinvent database. It is assumed that porous packaging pouches for subsequent sterilisation of the reusable LMA are made of Tyvek and PET/PE. There are many other pouches on the market made of different materials including e.g. medical grade paper. Quality differences between Tyvek material and medical-grade paper have been discussed in several reports. Experimental results of these reports support the superiority of Tyvek compared to medical-grade paper in terms of microbial penetration resistance which otherwise can cause serious consequences such as healthcare associated infections (HAIs) (Kaller 2014; Blocher 2009; Dupont n.d.). In light of the above considerations, Tyvek material is selected as the standard material, and medical-grade paper is not considered in this study.

The other aspect differed from Eckelman's study is the LCIA methodology. While this study applies the ReCiPe methodology, Eckelman's report the Building for Environmental and Economic Sustainability (BEES) v4.02 impact assessment method is used. The BEES is designed to measure the environmental performance of build products so that help to select environmentally friendly, cost-effective building product (Lippiatt 2007). The differences in LCA methodologies may have also contributed to some discrepancies between the two studies. Exploring the differences would require a re-run of LMA models, which is outside the scope of this study.

The reason why some of the categories are excluded is that the major process contributors to these categories located in the supply chain within the product's life cycle are not included in the system boundaries defined in the goal and scope episode. Nevertheless, this study is only aimed to compare the difference in environmental burdens between these two products within a limited boundary. Further investigations and a more comprehensive LCA are required to clarify which and what environmental burdens are actually associated with the product under its whole life cycle. In consideration with the possibility of expanding the goal and scope of the study, an overview of impact assessment within all default impact categories provided in ReCiPe method is advantageous. Results of comparative impact assessment of the life cycle of these two products regarding all categories supplied in ReCiPe method are shown in Appendix. An interesting part of the assessment result with all defaulted impact categories is that the reusable LMA has more environmental burdens than the disposable LMA within impact categories terrestrial ecotoxicity and metal depletion. This may be due to the production of washing detergent and generating electricity as parts of the supply chains for the life cycle of the product. In order to explain, a further investigation and a more comprehensive LCA is needed.

Sensitivity analysis is performed by using the one-at-a-time approach (OAT), which means that an input parameter is changed at a time and the related impact assessment is then investigated (Groen et al. 2014). It should be noted that the upstream contribution of production and downstream application of the products is modelled and approximated by datasets from the Ecoinvent database. The different modelling approaches allow us to analyse the influence of life cycle-based modelling assumptions on the impact assessment results. In this study, the sensitive parameters include reuse cycles of the reusable LMA, the energy for the source of electricity and the composition of washing detergent. According to the results of the sensitivity analysis, assumptions regarding energy sources are important and should be done with care. Datasets on country electricity mix are drown from Ecoinvent and modelled based on the available statistical data on present and future electricity mixes. The average current electricity mix in Sweden consists of hydropower (as main energy source, 43 %), nuclear power (38 %) and power imported from other countries (8 %) (Itten et al. 2014). Explanation of deviation for country's mixed electricity is that nuclear power has a relatively large proportion which can cause more environmental burdens compared with single energy sources. Since the Ecoinvent database does not provide any available process data for solar energy and to create a new one requires amount of time and efforts; this type renewable energy was not applied as sensitive parameter.

Another factor that would influence the outcome of the assessment results is the modelling of the washing detergent since the soaking process gives an important contribution to the environmental burdens of the reusable LMA. Uncertainty of the results arises when modelling approach of ingredient of washing detergent varies significantly. The best way to solve this problem is to create a new database that includes more detailed information. This is beyond the capacities of this study as a new database is highly time- and effort intensive.

Conclusion

Life cycle assessment is a comprehensive and wildly used method to assess the environmental impacts of products. It is very practical for comparing two products with similar functions. This study with help of SimaPro software has compared environmental impact between disposable LMAs and reusable LMAs. The results of impact assessment provide a compelling evidence for supporting the priority of reusable LMA as environmentally friendly. This is due to that the PVC material of the disposable LMA dominates the contribution to most of the environmental burdens during product's life cycle. However, the negative environmental impacts of the reusable LMA are mainly because of the use of washing detergent.

It is very clear that the use phase of the reusable LMA is the major contributor to environmental impacts which means that optimization of washing and sterilization processes will make product more sustainable. Different types of energy used as sources for electricity have certain influence for environmental loads for the reusable product. These include the renewable energy sources such as hydro power and wind power. It can also be a good reason for selection of the reusable LMA when it is used in a hospital such as Skånevånd Sund, where the renewable energy are the only sources available for generating electricity. Another factor that may influence the impacts is the washing detergent. However, it needs further investigation to make decision of which is the best suitable detergent both for patient safety and environmental benefit.

It should be emphasized that this study is only performed in regards of the environmental burdens derived during both products' life cycles under the circumstance of Skånevård Sund. Other aspects such as social and economic values of the products should be also taken into account when it is time to decide the most suitable products for procurement. To achieve this, a more comprehensive LCA should be considered.

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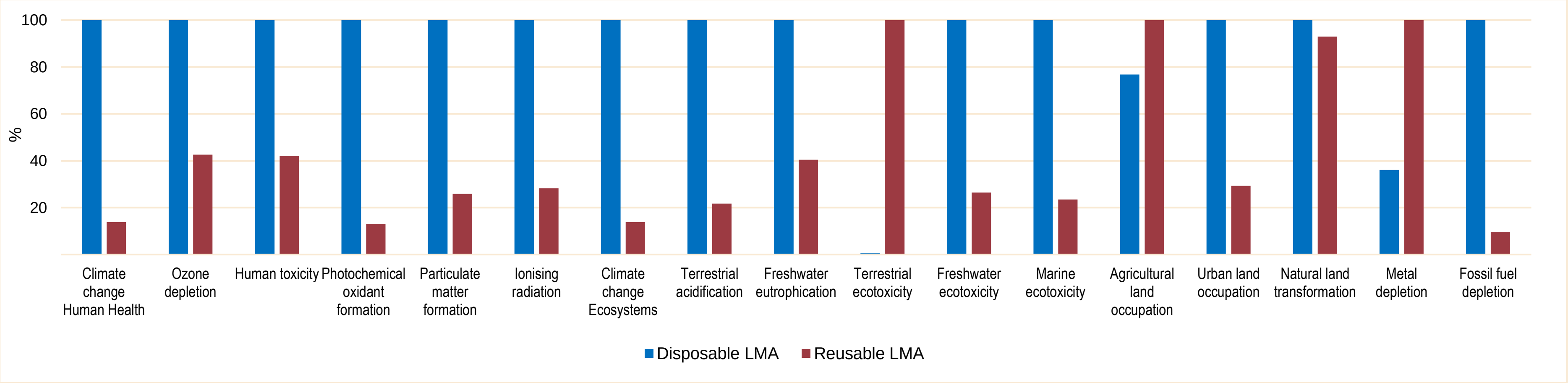
Appendix

Comparative result of LCIA for the disposable and reusable LMA with all defaulted impact categories. Method: ReCiPe Endpoint (H) V1.13 / Europe ReCiPe H/A / characterisation



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