The life cycle analysis of a dental examination: Quantifying the environmental burden of an examination in a hypothetical dental practice

Linnea Borglin1 | Stephanie Pekarski1 | Sophie Saget2 | Brett Duane2,3

1Faculty of Odontology, Malmo University, Malmo, Sweden
2Trinity College Dublin, Dublin 2, Ireland
3Dublin Dental University Hospital, Dublin 2, Ireland

Abstract

Objectives: Global sustainability is considered the number one health concern facing our planet. Dental care is currently not provided in a sustainable way. This study aims to quantify the potential environmental burden of an examination in a hypothetical dental practice and identify major contributors to environmental harm.

Materials and Methods: A life cycle analysis was performed for the life cycle of an examination of one patient in a hypothetical dental practice. The equipment and products analysed were those available at the Faculty of Dentistry, Malmö University. The Ecoinvent version 3.5 database and the life cycle assessment software tool OpenLCA version 1.10 were chosen for this study.

Results: Normalized results indicate that the impact categories to which the modelled examination most significantly contributes are water scarcity, freshwater eutrophication and human toxicity (cancer effects). The major contributors or hotspots relating to the environmental harm of an examination procedure are soaps and detergents, disposable bibs, surface disinfection, stainless-steel instruments, clothing, water use and wastewater.

Conclusion: Normalized results indicate that the potential environmental impact of an examination compared to one individual's impact per year is minimal. Considering the potential number of dental examinations and other dental procedures performed every year puts the findings in another perspective. This paper touches on some of the ways that the environmental burden of an examination could be reduced. Small changes to everyday practice, such as always making sure the dishwasher and washing machines are full when turned on, using less environmentally damaging soaps, more sustainable clothing alternatives and using necessary instruments could significantly reduce dentistry's environmental impact. Changes in materials and practice may result in potential trade-offs. Research would need to be carried out comparing the environmental burden of any alternatives. We hope in the near future that there will be more evidence relating to products used within dental care settings, potential trade-offs and dentistry's environmental burden.
1 | INTRODUCTION

Global sustainability is considered the number one health concern facing our planet. A sustainable world ‘must meet the needs of the present, without compromising the ability of future generations to meet their own needs’.

Climate change is a significant threat to biodiversity. With the growing population, the consumption of natural resources is increasing rapidly along with the associated greenhouse gas (GHG) emissions. Climate change is responsible for adverse weather conditions, natural disasters and sea level rises, as well as an increase in cardiovascular diseases, malaria and other diseases; all of which harm the population. Many other factors beyond GHG emissions harm the environment, including resource depletion and ocean acidification. Internationally, there are a number of agreements to reduce environmental harm, including the United Nations Paris Agreement and the Sustainable Development Goals. The European Union and its member states aim to reduce GHG emissions by at least 40% by 2030 and by 60%-85% by 2050 compared to 1990 levels.

At present, healthcare is not provided in a sustainable way. In the United Kingdom, healthcare was responsible for 3.2% of the national footprint. Dentistry has a significant environmental impact, using a large amount of energy and resources. Patient and staff travel to and from the dental practice are the largest contributors, generating 60% of the total carbon dioxide emissions of dentistry. Water consumption and restorative materials potentially contribute to dentistry’s environmental harm.

The shift towards a more sustainable dental practice is becoming increasingly important as the consequences of climate change become severe. The World Dental Federation recently adopted a policy for sustainability in dentistry. Considering the environment, without compromising patient safety and the quality of care, in decisions regarding the consumption of resources and energy in addition to educating the dental team are recommended in the policy paper.

Life cycle assessment (LCA) is a modelling tool used to estimate the environmental impacts of a process/product throughout its lifetime. LCAs can model from cradle-to-grave, accounting for all the environmental inputs and outputs; including resource extraction, the production and use and disposal of a process/product. A cradle-to-gate LCA models the life cycle of a process/product up until it is ready to be transported to the consumer. The goal of an LCA is to compile the inputs and outputs of energy and materials, evaluate their potential environmental impacts, and interpret the results allowing for environmentally informed decision making. This is done in four stages, as described by the International Organization of Standardization guidelines; ISO 14040:2006. Boundary conditions and a functional unit are defined in stage one (definition of goal and scope). In stage two, Life Cycle Inventory (LCI), raw data are compiled, quantified and categorized as inputs or outputs. LCI data are converted into values corresponding to the impact categories in the third stage, the Impact Assessment. A large number of impact categories including global warming potential, human toxicity, marine eutrophication, abiotic depletion and acidification are assessed using this method. Finally, findings are interpreted and analysed for areas contributing significantly to environmental impacts within the system. Normalization and weighting are two optional steps to a LCA. Impact category results are normalized, to a reference value, to calculate their magnitude. Results may then be weighted by a freely defined factor expressing the impact factor.

Dental examinations are essential in order to identify, treat and prevent oral diseases such as caries and periodontitis. During an examination, the dentist records the patient’s medical history as well as examines the oral cavity, the teeth and supporting tissues. Dental examinations are the most frequently performed procedure by dentists. It is important that patients visit a dental practice regularly, and regularly can range anywhere between 3 months to 2 years. In the Public Health England report, ‘Carbon modelling within dentistry,’ the dental examination was the procedure that contributed the highest proportion to the dentistry’s carbon footprint. This report was undertaken using input-output hybrid methodology for carbon modelling. Due to its high contribution, it was decided a more detailed analysis of the environmental burden of a dental examination would be useful.

LCA methodology was used to analyse the environmental burden of an examination in a hypothetical dental practice. As dental examinations are frequently performed, identifying which aspects of the procedure contribute to dentistry’s environmental impact is important and was the focus of this study. From our understanding, LCA has previously been used in only one paper within dentistry. Environmental analysis of this nature attributed to dentistry is limited. Dentistry is far behind other sectors when it comes to sustainability, and there is an urgent need for more research. Dental professionals must consider the long-term environmental costs of providing dental care. This study aims to quantify the potential environmental burden of an examination in a hypothetical dental practice and identify major contributors to environmental harm.

2 | METHODOLOGY

2.1 | Scope and system boundaries

An attributional LCA was performed according to the ISO 14040:2006 guidelines for the life cycle of an examination in a hypothetical dental practice.

The functional unit was defined as the examination of one patient in a hypothetical dental practice. The scope of this study is from cradle-to-grave. The manufacturing, transportation, use and
waste management of both disposable and reusable products were included. Components such as energy use, disinfection, laundry and waste disposal were also included. The system boundaries are illustrated in Figure 1. The construction of the faculty building, the manufacturing and transport of large machines and any servicing (e.g., dental units), as well as staff and patient travel, were excluded from the system boundary.

A number of assumptions were made to clearly define the scope of the study and are summarized below (Table 1).

2.2 | Life cycle inventory

Primary data collection was completed at the Faculty of Dentistry, Malmö University. An examination kit was inventoried (see Appendix 1), and the average weight of each product was used. To calculate the average, 10 of each product were weighed using a scale accurate to ±0.02 g. The lifetime of each reusable product was based on conservative estimates provided by the Dental Faculty staff at both Malmö University and Dublin Dental University Hospital. For most products, there was an agreement on the lifetime. In the case of disagreement, the more conservative lifetime was chosen. Most instruments were assumed to have a lifespan of 500 uses. Weight was adjusted according to lifespan.

Several operating parameters were defined in the list of assumptions above after directly observing examinations, waste disposal and the laundry and dishwashing procedures. Energy and water consumption associated with the dental unit and compressor, dishwasher, washing machine and dryer were accounted for and acquired from the manufacturer. Transportation distances were based on manufacturing locations and the location of the distributors in Malmö, Sweden. The distance between the local distributor and the Faculty is minor and would likely result in negligible differences in environmental burden and was, therefore, excluded. Transport distances were estimated using Searates.21 All waste was disposed in a container and transported to a recycling area in Malmö where 99% of household waste is incinerated, and the energy released used for district heating.22 Transport to the recycling area was excluded. See Appendix 2 for more detailed information.

The data used to construct the life cycle inventory of a dental examination and its components is displayed in Table 2.

2.3 | Life cycle impact assessment (LCIA)

OpenLCA23 version 1.10 is a free, life cycle assessment software tool and was the chosen software for this study. The Ecoinvent version 3.524 database was chosen for this paper. It includes an extensive collection of processes; some being country-specific. All data were classified and entered into openLCA, see Table 2. The procedure was assessed across the sixteen environmental impact categories (Appendix 3) as recommended by the European Product Environmental Footprint (PEF) harmonization initiative. PEF is a harmonization initiative for LCAs by the European Union. Its methods package presents an extensive range of impact categories to assess the environmental impact of goods and services.25

The results were normalized, relative to the PEF per capita global equivalents, to identify the most significant impact categories.25

FIGURE 1 System boundaries
The main results of this LCA are summarized in Table 3. The modelled examination produces 0.73 kg CO₂, equivalent emissions, equivalent to driving 4.55 km in a small car. Normalized results indicate that the impact categories to which the modelled examination most significantly contributes are water scarcity, freshwater eutrophication, and human toxicity (cancer effects).

The main product categories and the percentage they contribute to the total burden of an examination within each impact category are displayed in Figure 2. The most significant categories are those which together contribute to at least 80% of the total impact. Soaps and detergents are a significant contributor to all impact categories except ionizing radiation photochemical ozone formation. Disposable bibs contribute significantly to 11 of 16 impact categories. Surface disinfectant contributes to more than 90% of the potential photochemical ozone formation. Surface disinfectant is also one of the most significant contributors to the potential environmental burden in 9 of the 16 impact categories. Sanitary paper has a significant burden on acidification, human toxicity (noncancer effects) and land use. Stainless-steel instruments are the largest contributor to human toxicity (cancer effects) and are also significant to resource use (minerals and metals), freshwater eutrophication, human toxicity (noncancer effects) and respiratory diseases. The only significant contributor to ionizing radiation is electricity use. Clothing has a large impact on potential ozone depletion than its burden on other impact categories. Cardboard packaging, transport and hand disinfectant are not significant to any impact category.

4 | DISCUSSION

The aim of this study was to calculate the potential environmental burden of an examination in a hypothetical dental practice. With growing awareness around climate change and an increased interest in sustainability, identifying major contributors (hotspots) to environmental harm within dentistry is essential.

Previous studies on sustainability within dentistry have focused on aspects concerning travel, procurement and building energy. These papers only considered GHG emissions and concluded travel for both work and commuting purposes were the most significant contributing factors. By performing a detailed life cycle analysis, our study identified other significant contributors within several additional impact categories (see Table 3).

4.1 | Limitations of the LCA

The assumptions and exclusions made to clearly define the system boundary were based on the frameworks set by the University and hospital staff. Bias from the origin and quantity of products used, the operating parameters and lifespan, for example, must be taken into consideration and will affect the accuracy of the findings.

The quantity of products, such as paper towels and surface disinfection, will differ between individuals and procedures. Surface disinfection is a significant contributor to a number of categories and sanitary paper to three categories. Large discrepancies will have a significant impact on the potential environmental burden.

The defined lifespan of stainless-steel instruments and other re- usables was conservative. In a study by Campion et al, the lifespan of all stainless-steel products was defined as 3650 uses. Assuming this figure is closer to the actual lifespan, the potential burden on resource use and human toxicity, among others, could be considerably reduced.

The LCIA, data used were generic. When country-specific data were unavailable, European or global averages were used. Some findings were based on manufacturing averages from countries different from the actual manufacturing locations. Regulations differ between countries, and factories differ in technological advances resulting in
potential burdens that may differ significantly between factories. Health risks, such as lung cancer, due to exposure to carcinogens vary depending on manufacturing locations, with developing countries bearing a much higher risk. A large proportion of stainless-steel instruments was manufactured in European countries. The LCIA for stainless steel was performed using Rest-of-World inventory data. Human toxicity may, therefore, be much lower than calculated. In this model, waste was assumed to be incinerated. The energy released from waste incineration is used for district heating and electricity, which is increasingly common in European countries. Waste incineration is much better than landfills in terms of waste management, however, results in high CO₂ eq emissions. The energy produced is more carbon intense compared to renewable energy sources such as wind and solar power. Reducing the amount of waste produced by recycling, composting and preventing waste (avoided production) will significantly reduce the potential environmental impact of waste incineration.

4.2 Analysis of the findings

This is the first study that has looked at the potential environmental burden of a dental procedure within several impact categories, not just GHG emissions. Normalized results indicate that the potential environmental impact of an examination compared to an individual’s impact per year is minimal. However, considering the potential

| Material/process | Product examples | Amount | LCI database | Database process name |
|------------------|------------------|--------|--------------|-----------------------|
| Steel            | Dental explorer, pocket probe, carver, tray, | 0.798 g | ecoinvent v3.5 casting, steel, lost-wax | Cut-off, U - RoW |
| Isopropanol      | Surface disinfection | 45 mL | isopropanol production | Cut-off, U - RER |
| Tissue paper     | Paper towels, disposable bib, face mask | 27.14 g | market for tissue paper | Cut-off, U - GLO |
| Cotton           | Clothing         | 1.40 g | market for textile, woven cotton | Cut-off, U - GLO |
| Electricity      | Unit use, laundry, dishwasher | 1.79 kWh | electricity production, nuclear, pressure water reactor | Cut-off, U - SE |
| Water            | Handwashing, laundry, dishwashing | 7.10 L | water/surface water |
| Soap             | Hand soap, detergents | 21.34 mL | market for soap | Cut-off, U - GLO |
| Corrugated board box | Cardboard packaging | 6.42 g | corrugated board box production | Cut-off, U - RER |
| Nitrile          | Protective gloves | 14.20 g | market for acrylonitrile | Cut-off, U - GLO |
| Ethanol          | Hand disinfection | 10 mL | ethylene hydration | Cut-off, U - RER |
| Polypropylene    | Plastic cup      | 2.46 g | polypropylene production, granulate | Cut-off, U - RER |
| Plastic film     | Disposable bib   | 13.17 g | market for packaging film, low density polyethylene | Cut-off, U - GLO |
| Polyethylene     | Evacuation tip, evacuation tip adaptor | 8.19 g | market for polyethylene terephthalate, granulate, bottle grade | Cut-off, U - GLO |
| Emissions to air | Surface disinfection, hand disinfection | 55 g | Emission to air/high population density |
| Waste incineration | All waste       | 73.78 g | market for municipal solid waste | Cut-off, U - SE |
| Wastewater       | All wastewater   | 7.12 L | market for wastewater, from residence | Cut-off, U - RoW |
| Transport        | Small lorry      | 0.046 km | market for transport, freight, lorry | Cut-off, U - RER |
|                  | Large lorry      | 31.65 km | market for transport, freight, lorry | Cut-off, U - RER |
|                  | Sea freight      | 74.48 km | market for transport, freight, sea, transoceanic ship | Cut-off, U - GLO |
number of dental examinations performed every year magnifies the overall findings. The impact categories to which the modelled examination most significantly contributes are water scarcity, freshwater eutrophication and human toxicity (cancer effects). Being a significant contributor to the three impact categories mentioned above, and to all but two others, makes soaps and detergents one of the most environmentally harming aspects of dentistry. Nevertheless, essential for proper infection control. Handwashing with soap and water, which is not always taken as seriously as it should, and the importance of preventing the transmission of diseases has been brought to attention with the recent COVID-19 pandemic. With a potential change to health care practices following the pandemic, the environmental consequences should not be neglected. Decontaminating reusable instruments to remove, inactivate and/or destroy pathogens requires heat and detergents. According to a study by Golsteijn et al, it is the use phase and the ingredients of both laundry and dishwashing detergents that majorly contribute to environmental harm. The use phase includes the temperature of the water, a factor that can not be changed without compromising antimicrobial efficiency. The use of products containing biosurfactants instead of synthetic surfactants can be more an eco-friendly alternative. Using alternative detergents with less environmentally harmful ingredients, as well as always making sure the dishwasher and washing machines are full when turned on could significantly reduce dentistry’s environmental burden, including the impact on water scarcity, one of the three main impact categories.

Disposable bibs contribute significantly to environmental harm, including freshwater eutrophication and human toxicity (cancer effects). Previous studies on disposable and reusable surgical gowns showed that reusable surgical gowns have less environmental impacts. Using alternative products in place of disposable bibs could result in a reduction in the overall environmental burden of an examination. Surface disinfection (propanol) contributes significantly to half of the impact categories. Surfaces such as light handles must be disinfected between patients as they may be contaminated, serving as reservoirs to pathogens. Within dentistry, electrochemically activated pH-neutral hypochlorous acid solutions have been shown to be successful disinfectants on dental prostheses. Further research is needed before proposing this or other chemical alternatives to the conventional surface disinfectants used to wipe down surfaces after a procedure. Research would need to be carried out comparing the environmental burden of any such alternatives.

The use and production of dental clothing made from cotton have a significant impact on ozone depletion potential, water scarcity and freshwater eutrophication. With cotton production being water consuming and resource intensive, finding more environmentally friendly alternatives should be a priority. Bamboo fibres or recycled plastic from the ocean for clothing have been suggested as more environmentally friendly (less water consuming and GHG emitting) alternatives. There may, however, be trade-offs by using such alternatives. A comparative LCA should be conducted to compare the environmental burden of dental clothing made of alternative materials.

Stainless-steel instruments are the largest contributor to human toxicity (cancer effects), one of the most significant impacts of an examination. All items in the examination kit assessed may not be necessary for an examination. Having fewer stainless-steel items in each kit, alongside increasing the lifetime of instruments, would reduce the potential impacts.

The majority of ionizing radiation derived from an examination procedure is due to electricity use. According to the Swedish Energy Agency, nuclear power constitutes a large proportion of the energy generated. Using electricity from a renewable energy source could notably reduce ionizing radiation.

Examinations are performed frequently. Many of the aspects identified are used throughout several different dental procedures making them significant to dentistry’s total environmental burden.

### 5 | CONCLUSION

The impact categories to which the modelled examination most significantly contributes are water scarcity, freshwater eutrophication and human toxicity (cancer effects). The major contributors or hotspots relating to the environmental harm of an examination procedure are soaps and detergents, disposable bibs, surface disinfection, stainless-steel

### Table 3

| Impact category       | Unit       | Total potential impact | Normalized results |
|-----------------------|------------|------------------------|--------------------|
| Resource use, energy carriers | MJ         | 12.04                  | 8.13E-06           |
| Resource use, minerals and metals | kg Sb eq | 1.46E-06               | 3.11E-09           |
| Acidification         | molc H + eq| 0.01                   | 3.64E-07           |
| Freshwater ecotoxicity | CTUe       | 1.69                   | 1.15E-05           |
| Freshwater eutrophication | kg P eq    | 1.71E-04               | 9.10E-05           |
| Human toxicity, cancer effects | CTUh   | 1.19E-08               | 1.63E-05           |
| Human toxicity, noncancer effects | CTUh   | 1.27E-07               | 2.65E-06           |
| Ionizing radiation    | kBq U235 eq| 0.18                   | 7.61E-07           |
| Climate Change        | kg CO2 eq  | 0.73                   | 4.74E-07           |
| Marine eutrophication | kg N eq    | 2.03E-03               | 7.51E-06           |
| Ozone depletion       | kg CFC-11 eq| 9.39E-08              | 8.00E-09           |
| Photochemical ozone formation | kg NMVOC eq | 0.02           | 2.87E-07           |
| Terrestrial eutrophication | molc N eq | 9.44E-03               | 2.15E-06           |
| Land use              | Pt         | 43.94                  | 2.01E-06           |
| Respiratory inorganics | disease inc.| 4.41E-08            | 1.81E-06           |
| Water scarcity        | m3 depriv. | 0.47                   | 9.69E-05           |

Note: The total potential impacts were normalized to what an average person would use in 1 year globally. One person’s global average usage would represent a value of 1.

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instruments, clothing, water use and wastewater. Normalized results indicate that the potential environmental impact of an examination compared to one individual's impact per year is minimal. Considering the potential number of dental examinations and other dental procedures performed every year puts the findings in another perspective. This paper touches on some of the ways that the environmental burden of an examination could be reduced. Small changes to everyday practice, such as always making sure the dishwasher and washing machines are full when turned on, using less environmentally damaging soaps, more sustainable clothing alternatives and using only necessary instruments could significantly reduce dentistry's environmental impact. Changes in materials and practice may result in potential trade-offs. Research would need to be carried out comparing the environmental burden of any alternatives. We hope in the near future that there will be more evidence relating to products used within dental care settings, potential trade-offs and dentistry's environmental burden.

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FIGURE 2 Life cycle environmental effects of an examination procedure in a hypothetical dental practice. Impacts are displayed as a proportion of the total potential impact of each impact category. See Appendix 4 for numerical information.

AUTHOR CONTRIBUTIONS

L. Borglin contributed to the conception, design, data acquisition, analysis and interpretation drafted and critically revised the manuscript. S. Pekarski contributed to conception, design and data acquisition. S. Saget contributed to data analysis and interpretation and critically revised the manuscript. B. Duane contributed to conception, design, data analysis and interpretation and critically revised the manuscript. All authors gave final approval and agree to be accountable for all aspects of the work.

DATA AVAILABILITY STATEMENT

Data available in article supplementary material.

ORCID

Linnea Borglin [1] https://orcid.org/0000-0001-7014-6791
Sophie Saget [2] https://orcid.org/0000-0002-6941-4055
Brett Duane [3] https://orcid.org/0000-0001-9670-0594

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APPENDIX 1

COMPOSITION ASSUMPTIONS FOR AN EXAMINATION KIT

Disposable products

| Item                  | Quantity | Material               | Total weight (g) | Origin        |
|-----------------------|----------|------------------------|------------------|---------------|
| Face mask             | 2        | Nonwoven fabric        | 5.92             | Malaysia      |
| Gloves                | 4        | Nitrile                | 14.2             | Wimpassing, Austria |
| Patient bib           | 1        | Plastic film/tissue    | 7.58             | Aneby, Sweden |
| Syringe tip           | 1        | Virgin plastic         | 0.83             | Irvine, CA, USA |
| Paper towel           | 7        | Virgin pulp            | 8.05             | Mannheim, Germany |
| Hygoformic            | 1        | Polyethylene           | 4.50             | Råå, Sweden   |
| Evacuation tip        | 1        | Polyethylene           | 2.86             | Klagstorp, Sweden |
| Plastic cup           | 1        | Polypropylene          | 2.46             | Sweden*       |
| Examiner bib          | 2        | PE/tissue              | 18.76            | Aneby, Sweden |
| Surface disinfection  | 100 mL   | Propan-2-ol            | 1.00             | Borlänge, Sweden |
| Hand soap             | 20 mL    | Aqua, sodium laureth sulphate, sodium chloride, glycerine | 2.00 | Gothenburg, Sweden |
| Hand disinfection     | 10 mL    | 45% ethanol            | 1.00             | Borlänge, Sweden |
| Washing detergent     | 0.27 mL  | Sodium hydroxide, phosphonates, alcohol ethoxylates | 0.03 | Älvsjö, Sweden |
| Dishwashing liquid    | 1.08 mL  | Potassium carbonate   | 1.08             | Utrecht, Netherlands |

Reusable products

| Item                  | Quantity | Material               | Assumed lifespan | Total weight (g) | Weight adjusted for lifespan (g) | Origin        |
|-----------------------|----------|------------------------|------------------|------------------|----------------------------------|---------------|
| Mirror handle         | 2        | Stainless steel/silicone | 500              | 29.8             | 0.06                             | Parainen, Finland |
| Mirror head           | 2        | Stainless steel and glass | 50               | 8.84             | 0.18                             | Parainen, Finland |
| Dental explorer       | 1        | Stainless steel/silicone | 500              | 14.78            | 0.03                             | Parainen, Finland |
| Pocket probe          | 1        | Stainless steel        | 500              | 17.47            | 0.04                             | Chicago, IL, USA |
| Straight probe        | 1        | Stainless steel        | 500              | 18.41            | 0.04                             | Chicago, IL, USA |
| Forceps               | 1        | Stainless steel        | 500              | 23.67            | 0.05                             | Germany*       |
| Spoon excavator       | 1        | Stainless steel        | 500              | 17.94            | 0.04                             | Ballaigues, Switzerland |
| Carver                | 1        | Stainless steel        | 500              | 21.73            | 0.04                             | Germany*       |
| Carver (small)        | 1        | Stainless steel        | 500              | 21.17            | 0.04                             | Germany*       |
| Evacuation tip adaptor| 1        | Polypropylene          | 500              | 3.31             | 0.01                             | Råå, Sweden    |
| Small rectangular dish| 1        | Stainless steel        | 500              | 12.04            | 0.02                             | Stockholm, Sweden* |
| Tray                  | 1        | Stainless steel        | 2000             | 658.12           | 0.33                             | Uppsland Väsby, Sweden |
| Shirt                 | 2        | 50% cotton, 50% polyester | 50               | 847.50           | 16.95\(^1\)                      | Lithuania     |
| Pants                 | 2        | 35% cotton, 65% polyester | 50               | 601.86           | 12.04\(^1\)                     | China         |
| Coat                  | 2        | 35% cotton, 65% polyester | 50               | 653.50           | 13.07\(^1\)                     | Lithuania     |

\(^{1}\) Clothing was assumed to be used for 30 patients a day. The weight adjusted for lifespan was divided by 30, before being entered into OpenLCA.

\(^{*}\) Assumed location of origin.

APPENDIX 2

LIFE CYCLE INVENTORY

The production, use, disinfection, sterilization and disposal of all disposable and reusable instruments used was included. The production, washing and drying and disposal of dental clothing was also included. Water and energy use associated with the disinfection and sterilization of instruments, the washing and drying of clothing and even the use of the dental unit were included (eg lighting). The disinfection of the
dental unit and the handwashing of the dentist was also included. For the purpose of this study, the construction of the faculty building and the production of large machines such as the dishwashers, the dental unit and other electrical appliances (eg computers) were excluded. Staff and patient travel were also excluded.

Transport
Transportation distances were based on the manufacturing locations of each product and the location of the distributors in Malmö, Sweden. For some products, such as the carver, manufacturing locations could not be found. These were assumed to originate from the locations of other similar products (see Appendix 1). The distance between the local distributor and the Faculty is minor and would likely result in negligible differences in environmental burden and was, therefore, excluded. Transport distances were estimated using Searates.20

Use
Disposable products were discarded after a single use. All reusable stainless-steel products were disinfected in the dishwasher after use. Data on the laundry and dishwashing procedures were obtained by direct observation. All reusable products are washed in the KEN IWD 2311 dishwasher. Twelve examination kits can be loaded during each cycle.

Average procedure times
The estimated time for an examination is fifteen minutes. The unit light was used throughout the full examination and no water is used. The other instruments were used for different periods of time, see below.

A summary of the average time, energy and water usage of an examination and the estimated usage time of instruments during each procedure.

| Dental unit use during an examination |
|--------------------------------------|
| Duration (min) | 15 |
| Water usage (mL) | 0 |

| Machines used and rating | Equipment usage (min) | kWh exam |
|--------------------------|-----------------------|----------|
| Dental unit motor (400 W) | 1 | 0.4 |
| Dental light (30-40 W) | 15 | 0.6 |
| Unit screen (20-30 W) | 0 | 0 |
| Instrument light (2.5 W) | 0 | 0 |
| Suction (9 kW) | 0.5 | 0.075 |
| Machines operated by compressor (9kW) | 0.5 | 0.075 |
| **Total power consumed (kWh)** | | **1.15** |

Energy and water consumption
The energy consumption (kWh) for electrical appliances included in the scope of the study was estimated by using the total running time for each standard program of the dishwasher, washing machine and dryer, or the average procedure time for the dental unit. Other programmes were not taken into consideration and excluded from the study. The amount of water consumed was obtained directly from the manufacturers of each appliance (see below). Relevant Faculty staff provided information on the type of electricity at the Faculty.

Energy and water consumption values for the machines used according to the manufacturers.

| Machine       | Brand         | Power (kW) | Time (mins) | Energy consumption (kWh) | Water consumption (litres) |
|---------------|---------------|------------|-------------|--------------------------|---------------------------|
| Dishwasher    | KEN IWD 2314  | 1.00       | 50.00       | 0.83                     | 55                        |
| Central compressor | Kaeser SM15T | 9.00       | see Table 3 | see Table 3              | see Table 3               |
| Washing machine | Electrolux   | -          | 50.00       | 0.4-1.0                  | 197                       |
| Dryer         | Electrolux    | 24.00      | 15.00       | 6.00                     | 0                         |

Disposal/end of life
In this model, waste was assumed to be disposed of in a container and transported to a recycling area in Malmö where it is incinerated. The energy released from waste incineration is used for district heating. Transport to the recycling area was excluded from this study.
## Appendix 3

### Life Cycle Impact Assessment Methods Employed in This Study

| Impact category                  | Indicator                                                                 | Unit          | Recommended default LCIA model | Source of characterization factors | Robustness | Selected method in OpenLCA |
|----------------------------------|---------------------------------------------------------------------------|---------------|--------------------------------|-----------------------------------|------------|---------------------------|
| Resource use, fossils            | Abiotic resource depletion – fossil fuels (ADP-fossil)                    | MJ            | CML Guinée et al (2002) and van Oers et al (2002). | EC-JRC, 2017 II/interim            | III        | CML IA Baseline           |
| Resource use, minerals and metals| Abiotic resource depletion (ADP ultimate reserves)                        | kg Sb eq      | CML Guinée et al (2002) and van Oers et al (2002). | EC-JRC, 2017 II/interim            | III        | CML IA Baseline           |
| Acidification                    | Accumulated Exceedance (AE)                                               | molc H + eq   | Accumulated Exceedance (Seppälä et al 2006, Posch et al, 2008) | EC-JRC, 2017 II/interim            | II         | ILCD+                     |
| Freshwater ecotoxicity           | Comparative Toxic Unit for ecosystems (CTUe)                              | CTUe          | USEtox model (Rosenbaum et al, 2008) | EC-JRC, 2017 II/interim            | III/interim| ILCD+                     |
| Freshwater eutrophication        | Fraction of nutrients reaching freshwater end compartment (P)             | kg P eq       | EUTREND model (Struijs et al, 2009) as implemented in ReCiPe | EC-JRC, 2017 II/interim            | II         | ILCD+                     |
| Human toxicity cancer effects    | Comparative Toxic Unit for humans (CTUh)                                 | CTUh          | USEtox model (Rosenbaum et al, 2008) | EC-JRC, 2017 II/interim            | III/interim| ILCD+                     |
| Human toxicity non-cancer effects| Comparative Toxic Unit for humans (CTUh)                                 | CTUh          | USEtox model (Rosenbaum et al, 2008) | EC-JRC, 2017 II/interim            | III/interim| ILCD+                     |
| Ionizing radiation               | Human exposure efficiency relative to U235                                | kBq U235 eq   | Human health effect model as developed by Dreicer et al 1995 (Frischknecht et al, 2000) | EC-JRC, 2017 II/interim            | II         | ILCD+                     |
| Climate change                   | Radiative forcing as Global Warming Potential (GWP100)                    | kg CO₂ eq     | Baseline model of 100 years of the IPCC (based on IPCC 2013) | EC-JRC, 2017 II/interim            | I          | IPCC 2013                 |
| Marine eutrophication            | Fraction of nutrients reaching marine end compartment (N)                | kg N eq       | EUTREND model (Struijs et al, 2009) as implemented in ReCiPe | EC-JRC, 2017 II/interim            | II         | ILCD+                     |
| Ozone depletion                  | Ozone Depletion Potential (ODP)                                          | kg CFC-11 eq  | Steady-state ODPs as in (WMO 1999) | EC-JRC, 2017 II/interim            | I          | ILCD+                     |
| Photochemical ozone formation    | Tropospheric ozone concentration increase                                  | kg NMVOC eq   | LOTOS-EUROS (Van Zelm et al, 2008) as applied in ReCiPe 2008 | EC-JRC, 2017 II/interim            | II         | ILCD+                     |
| Terrestrial eutrophication       | Accumulated Exceedance (AE)                                               | molc N eq     | Accumulated Exceedance (Seppälä et al 2006, Posch et al, 2008) | EC-JRC, 2017 II/interim            | II         | ILCD+                     |
| Land use                         | Soil quality index                                                        | Pt            | PM method recommended by UNEP (UNEP 2016) | EC-JRC, 2017 II/interim            | III        | ILCD+                     |
| Respiratory inorganics           | Impact on human health                                                    | Disease incidence | Soil quality index based on LANCA (Beck et al 2010 and Bos et al 2016) | EC-JRC, 2017 II/interim            | I          | ILCD+                     |
| Water scarcity                   | User deprivation potential (deprivation-weighted water consumption)        | m³ depri      | Available WATER REMaining (Aware) as recommended by UNEP, 2016 | EC-JRC, 2017 II/interim            | III        | ILCD+                     |
### APPENDIX 4

## TABLE SHOWING THE FIGURES OF THE CONTRIBUTION OF EACH PROCESS FOR ALL IMPACT CATEGORIES

|                                | Cardboard packaging | Clothing | Disposable bibs | Disposable plastic instruments | Electricity use | Hand disinfectant |
|--------------------------------|---------------------|----------|-----------------|--------------------------------|-----------------|-------------------|
| Resource use, energy carriers  | MJ                  | 0.08 766 | 0.39 526        | 2.89 299                        | 0.79 594        | 2.10 824          | 0.31 967          |
| Resource use, minerals and metals | kg Sb eq          | 1.2E-08  | 5.12E-08        | 1.33E-07                        | 9.5E-08         | 5.66E-08          | 3.41E-08          |
| Acidification                  | molc H + eq        | 0.00 021 | 0.00 062        | 0.00 315                        | 0.00 341        | 0.00 206          | 0.00 013          |
| Freshwater ecotoxicity         | CTUeq               | 0.00 837 | 0.06 861        | 0.14 626                        | 0.01 949        | 0.01 315          | 0.00 351          |
| Freshwater eutrophication      | kg P eq            | 2.99E-06 | 1.65E-05        | 4.31E-05                        | 6.57E-06        | 7.57E-06          | 3.91E-06          |
| Human toxicity, cancer effects | CTUh                | 6.23E-11 | 5.42E-10        | 1.74E-09                        | 3.85E-10        | 4.97E-10          | 7.69E-11          |
| Human toxicity, non-cancer effects | CTUh             | 1.71E-09 | 3.81E-09        | 2.07E-09                        | 1.84E-09        | 4.89E-09          | 4.4E-10           |
| Ionizing radiation             | kBq U235 eq        | 0.00 074 | 0.00 409        | 0.00 998                        | 0.001 362       | 0.15 074          | 0.0002            |
| Climate Change                 | kg CO2 eq          | 0.00 616 | 0.03 391        | 0.1545                          | 0.03 163        | 0.01 614          | 0.00 948          |
| Marine eutrophication          | kg N eq            | 1.29E-05 | 5.01E-05        | 0.00 169                        | 2.52E-05        | 2.15E-05          | 6.25E-06          |
| Ozone depletion                | kg CFC-11 eq       | 7.83E-10 | 5.18E-08        | 7.33E-09                        | 1.21E-09        | 8.67E-09          | 2.8E-10           |
| Photochemical ozone formation  | kg NMVOC eq        | 2.24E-05 | 8.97E-05        | 0.00 545                        | 0.00 104        | 4.26E-05          | 4.42E-05          |
| Terrestrial eutrophication     | molc N eq          | 9.51E-05 | 0.00 049        | 0.00 162                        | 0.00 027        | 0.000 205         | 6.71E-05          |
| Land use                       | Pt                  | 0.63 711 | 1.85 364        | 0.5064                          | 0.11 051        | 1.71 644          | 0.03 878          |
| Respiratory inorganics         | disease inc.       | 5.2E-10  | 1.54E-09        | 9.5E-09                         | 1.36E-09        | 1.07E-09          | 3.32E-10          |
| Water scarcity                 | m3 depriv.         | 0.00 141 | 0.12 273        | 0.07 358                        | 0.01 261        | 0.02 628          | 0.00 325          |

Note: See Figure 2 for the relative graph of these results.
| Nitrile gloves | Sanitary paper | Soaps and detergents | Stainless steel instruments | Surface disinfectant | Transport | Waste management | Wastewater | Water |
|----------------|----------------|----------------------|-----------------------------|---------------------|-----------|------------------|------------|-------|
| 1.07 881       | 0.19 901       | 0.9196               | 0.35 583                    | 2.6794              | 0.10 025  | 0.06 267         | 0.04 054   | 0.0403|
| 1.04E-07       | 2.25E-07       | 4.84E-07             | 1.97E-07                    | 2.33E-07            | 1.75E-08  | 8.47E-09         | 1.26E-08   | 6.85E-09|
| 0.00 041       | 0.00 054       | 0.00 198             | 0.00 044                    | 0.00 137            | 5.97E-05  | 6.75E-05         | 6.29E-05   | 0.000 246|
| 0.02 088       | 0.02 44        | 0.95 149             | 0.06 009                    | 0.03 303            | 0.014 402 | 0.298 122        | 0.02 922   | 0.00 349|
| 4.54E-06       | 6.93E-06       | 3.97E-05             | 1.15E-05                    | 1.4E-05             | 5.9E-07   | 5.02E-06         | 7.81E-06   | 1.82E-06|
| 2.41E-10       | 2.39E-10       | 1.96E-09             | 3.72E-09                    | 5.79E-10            | 4.61E-11  | 1.11E-09         | 6.75E-10   | 2.54E-10|
| 1.75E-09       | 7.23E-08       | 8.04E-09             | 6.11E-09                    | 5.54E-09            | 8.93E-10  | 6.75E-09         | 1.11E-08   | 1.08E-09|
| 0.00111        | 0.00 167       | 0.00 557             | 0.00 267                    | 0.00 428            | 0.000 505 | 0.00 277         | 0.00 268   | 0.00 084|
| 0.04 397       | 0.01 672       | 0.21 938             | 0.02 842                    | 0.09 416            | 0.006 626 | 0.068 142        | 0.0039     | 0.00 236|
| 0.00 018       | 2.24E-05       | 0.00 129             | 2.85E-05                    | 5.55E-05            | 7.8E-06   | 2.48E-05         | 0.00 014   | 2.69E-06|
| 2.69E-09       | 1.28E-09       | 1.13E-08             | 1.62E-09                    | 4.44E-09            | 1.49E-09  | 8.44E-10         | 2.34E-10   | 2.02E-10|
| 0.0001         | 5.25E-05       | 0.00 068             | 7.74E-05                    | 0.01 974            | 2.7E-05   | 4.93E-05         | 1.76E-05   | 8.01E-06|
| 0.0009         | 0.00 195       | 0.00 444             | 0.00 027                    | 0.00 061            | 8.65E-05  | 9.65E-05         | 9.34E-05   | 3.13E-05|
| 0.0795         | 10.91 459      | 27.59 603            | 0.12 352                    | 0.19 844            | 0.08 862  | 0.059 334        | 0.02 202   | 0.02 008|
| 2.47E-09       | 1.21E-09       | 1.96E-08             | 1.7E-09                     | 3.53E-09            | 3.95E-10  | 4.46E-10         | 4.46E-10   | 1.59E-10|
| 0.0281         | 0.00 701       | 0.40 915             | 0.00 858                    | 0.0312              | 0.000 695 | 0.008 398        | 0.26 104   | 0.28 384|

Note: See Figure 2 for the relative graph of these results.