# Environmental sustainability of oral health interventions study

Submitted by

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## Declaration

I, Rawan Abed, declare that this thesis entitled “environmental sustainability of oral health interventions” submitted toward partial fulfilment of the requirements for the Degree of Clinical Doctorate in Paediatric Dentistry (DDent) has been composed solely by myself and that it has not been submitted, in whole or in part, in any previous application for a degree. This was a Doctor of Clinical dentistry research project which included research parts.

## Abstract

Environmental sustainability is responsible for maintaining natural resources and conserving the global ecosystem to protect health and wellbeing. Healthcare services are essential for maintaining and promoting human well-being; however, the current delivery of healthcare is not sustainable because of the high environmental load, rising costs, and increased demands. The profession of dentistry has high energy and intensive resources with a significant environmental impact. Healthcare professionals should incorporate environmental sustainability alongside the clinical and financial needs of the patient. This doctoral project included three studies to investigate this further.

**Study 1.** An exploratory study design, comparing the environmental footprint of eight interdental cleaning aids included dental floss and interdental brush, using life cycle analysis (LCA). This study concluded no single best environmentally friendly product; however, the bamboo interdental brush had the lowest environmental impact.

**Study 2.** A rapid scoping review of existing evidence regarding the impact of oral health interventions on the environment and a review of the methodology. Out of 5 included studies, only the environmental impact of the toothbrush has been extensively studied in the United Kingdom. Regarding the methods, Life cycle analysis dominated the protocol for measuring the environmental impact of dental products; due to the limited number of publications, further research is needed to establish a comprehensive knowledge base of current interventions to reduce carbon emissions and other environmental impacts.

**Study 3.** A cross-sectional survey was conducted as an online questionnaire to compare the dentist' perspective about the environmental impact of oral health interventions. The online survey was distributed among 33 dentists who practice in England. A modified questionnaire was used to collect information about clinical interventions' sustainability, comprising 15 questions. Microsoft Office 365 form was used to host the survey.

The majority of dentists, 70% had not considered sustainability as a factor when recommending the toothbrush as well as dental floss 91%. Most participants (n=30) ranked bamboo toothbrushes and dental floss as the most sustainable interdental cleaning aids. Lack of enough knowledge regarding the sustainability of clinical interventions was the prime factor that influenced the recommendation of sustainable products. According to the current study, participants' knowledge, and practice of sustainability of clinical interventions are not up to the mark. As a result, all dentists must contribute at their level by updating their knowledge of the topic to put it into practice during their planned recommendations and help achieve the goal of making green dentistry a global phenomenon.

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## Covid-19 pandemic impact statement

Unrelated to personal causes, the Covid-19 pandemic has seriously affected my research and study productivity. Due to sickness and quarantine during the pandemic, I spent significantly less time on research than before. During the lockdown period, I had to wait longer to deliver the sample materials needed for study one. Also, as I conducted the survey in the period immediately after the lockdown, it took much longer to get ethical approval for study three.

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## List of Abbreviations

| | |
|---|---|
| **CO2** | Carbon dioxide |
| **CO2e** | Carbon dioxide equivalent |
| **DALYs** | Disability Adjusted Life Years |
| **GWP** | Global warming potential |
| **IDBs** | Interdental brushes |
| **SO** | International Organization for Standardization |
| **LCA** | Life cycle analysis |
| **LCI** | life cycle inventory |
| **LCIA** | life cycle impact assessment |
| **NHS** | National Health service |
| **PHE** | Public Health England |
| **SDU** | Sustainable Development Unit |
| **WHO** | World Health Organization |

# 1 Introduction and Review

## 1.1 Health and Environment

Health is frequently interpreted differently by people. The World Health Organization (WHO) defined health in 1948 as " a state of complete physical, mental, and social well-being, rather than only the absence of sickness or disability” (WHO 1948). Wellbeing includes people’s feelings of worthiness in the things they do in life. This perspective allows people to have good health even during physical illness.

The environment is a significant determinant of health. A clean environment is essential for human health and well-being. People require clean air to breathe, pure water to drink, and an environment free of hazardous and toxic substances. Pollution can potentially damage people’s health throughout their lives, even before birth. Studies are revealing more about the connection between human health and environmental quality. Nowadays, the methods through which people's exposure and interaction with the natural world can affect their well-being are beginning to be identified.

The environmental difficulties we face today differ from those humanity faced in previous generations. A variety of environmental issues can impede human health. These include climate change, air pollution, chemical pollution, noise, poor water quality, microbes caused by different diseases, and lack of access to healthcare (Prüss-Üstün et al. 2016). The WHO in their report on preventing diseases through a healthy environment highlighted that those deaths caused by environmental factors are preventable. These environmental modifiable and preventable factors are estimated to be responsible for about 24% of all deaths (Prüss-Üstün et al. 2016). Therefore, improving the environment's quality, including air, water, and noise, can help to avoid disease and promote human health. Recent evidence shows that living in or near greener environments lower death rates and improve mental health. Those with good natural environment access are 22% more likely to be physically active (GOVUK. 2021). The major environmental issues that affect human health will be described briefly in the following paragraphs.

### 1.1.1 Climate change

Global warming due to carbon dioxide ($CO_2$) emissions is accelerating climate change and threatens the survival of millions of people. Climate change has a wide range of effects on human health and life. It jeopardises the foundation of human health. Clean air, safe drinking water, nutrition, and secure shelter have the potential to reverse global health progress. Climate change is the principal global health threat of the twenty-first century. It resulted in the loss of 5.5 million disability-adjusted life years worldwide. Also, it poses immediate health risks in heat waves and shifts in the patterns of infectious diseases and allergens (Goklany 2009).

Greenhouse gas emissions that result from burning fossil fuels are significantly associated with climate change and air pollution. Many policies and individual actions, such as transportation, food, and energy use decisions, have the potential to cut greenhouse gas emissions and create significant health benefits, primarily by reducing air pollution. The phase-out of polluting energy systems, for example, or the promotion of public transportation and physical mobility, for example, might reduce carbon emissions while also reducing the burden of home and ambient air pollution, which causes 7 million premature deaths each year (GOVUK. 2021).

### 1.1.2 Air pollution

Air pollution has a significant impact on public health. Poor air quality is the largest environmental health threat in the UK. Pollutants in the air are a complex mix of particles and gases of both natural sources and human origin. Particulate matter (PM) and nitrogen dioxide (NO2) are two significant components of air pollution. In addition, ammonia (NH3), ozone (O3), and carbon monoxide (CO).

Currently, there is no clear evidence of a safe level of exposure below which there is no risk of adverse health effects. As a result, further reductions in particulate matter and nitrogen dioxide levels below air quality guidelines are anticipated to result in substantial health advantages. Moreover, transportation, industrial work, farming, and energy generation, and household heating are all an example of activities that might degrade air quality (GOVUK 2018).

The cost of the health effects of air pollution, according to the Environmental Audit Committee is likely to exceed the prediction of £8.5 billion to £20.2 billion a year (GOVUK 2018). Based on the epidemiological studies, it has been estimated that long-term exposure to air pollution over the years reduces average life expectancy by several months because of chronic conditions caused mainly by respiratory conditions, cardiovascular diseases, stroke, and lung cancer. Short-term exposure over hours or days can also have various negative health consequences, including decreased lung function, asthma exacerbation, cough, wheezing, shortness of breath, increase in hospital admissions, and mortality. The United Kingdom government, in their statement on the environment, estimated that air pollution is projected to cause 5% of total mortality in England. It affects people throughout their lifetime. The elderly and children are the most vulnerable to the health effects of air pollution.

### 1.1.3 Noise

After air pollution, noise causes the second-highest pollution related to the burden of disease in Western Europe. It causes more life-years to be lost than lead, ozone, or dioxins (Prüss-Üstün et al. 2016). Road traffic is the primary cause of noise pollution in Europe. According to the National Noise Attitude Survey, 8% of the population is concerned, annoyed, or disturbed by traffic noise (GOVUK. 2021). In England, recent noise mapping data shows that the number of people exposed to road and railway traffic noise exceeding WHO guidelines are 11.5 million and 1.5 million, respectively. Excessive noise harms people's health and interferes with their daily activities at home, school, work, and leisure time.

Excessive noise can produce sleep disturbance, cardiovascular and psychophysiological consequences, decreased performance, irritation responses, social behaviour abnormalities, and metabolic outcomes such as diabetes and obesity.

### 1.1.4 Water pollution

According to the WHO, the composition of polluted water has been altered to the point where it is no longer useable. It is toxic water that can cause many diseases such as typhoid, poliomyelitis, diarrhea, cholera, and dysentery. Release of pollutants into subsurface groundwater or lakes, streams, rivers, estuaries, and oceans, causes it to reach the point when the substances obstruct beneficial water usage or ecosystem function

Pathogenic bacteria, viruses, parasites, fertilise, pesticides, plant nitrates, phosphates, plastic, radioactive substances, faecal waste, and petroleum oil can pollute water bodies. Every year, roughly 1.6 million people worldwide die due to a lack of safe water and sanitation (Prüss-Ustün et al. 2019). In England, everyone has access to a well-managed drinking water supply. The introduction of sanitation methods, including piped water and sewage management, was introduced in the 19th century, and helped prevent mortality from water-borne diseases (GOVUK. 2021).

### 1.1.5 Chemical pollution

Hazardous chemical exposure is also a significant risk. People are exposed to various synthetic chemicals daily, including in homes, workplaces, healthcare, and agriculture. Products containing synthetic chemicals include plastic, cleaning, personal care items, fire- retardant furniture and paints. In 2017, Europe, including the United Kingdom, generated 81 million tonnes of environmentally harmful chemicals (GOVUK 2021). This raises concerns about the long-term health consequences of exposure to chemical combinations, particularly during vulnerable periods, including early childhood, pregnancy, and old age. No clear evidence exists that low-level exposure to synthetic chemicals causes health problems in normal life, but additional research is needed. Acute toxic effects are easier to examine and so better known than long-term, low-level exposure effects (GOVUK. 2021).

### 1.2 Definition and the terms of sustainability

The definition of sustainability is constantly evolving in this rapidly changing world. It is an essential point of attention for the public, governments, and the healthcare systems. Previously, the term sustainability has been largely associated with environmental degradation. In recent years, the importance of sustainability has changed as it is linked to other factors, including patient health, healthcare workers, and the community. As a result, a sustainable structure should be described as one that ensures resource preservation from an ecological, social, and economic standpoint and addresses the needs of various stakeholders (Molero et al. 2021).

There have been many definitions of sustainability. In 1987, the World Commission on Environment and Development of the United Nations defined sustainability as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Molero et al. 2021).

As there is no universally agreed definition of sustainability, it is widely agreed that to obtain sustainability, we must get an equal balance of the three factors known as the three pillars of sustainability, including environmental, economic, and social aspects.

Social sustainability means achieving and maintaining the social well-being of the employees, stakeholders, and the community or country in the long term. The economic pillar of sustainability requires that a government or a business can operate its resources efficiently and sustainably and earn a profit. The environmental pillar means we must ensure that we consume our natural recourses such as materials, energy fuels, land, and water at a sustainable rate to aspire to net-zero carbon emissions (Molero et al. 2021).

Moreover, some key terms such as carbon footprint, global warming, carbon dioxide emissions, and greenhouse gases can help understand sustainability (Duane, Harford, Ramasubbu, et al. 2019). Greenhouse gases are referred to as any gas that absorbs infra-red radiation. In addition to absorbing solar and radiated heat. The increased heat is responsible for the greenhouse effect, or global warming. These included carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride. Carbon dioxide equivalent (CO2e) simply converts all greenhouse gases into amounts equivalent to carbon dioxide and can be compared. The global warming potential (GWP) measures how much heat it contributes over a specific period; carbon dioxide has an index value of one (Duane, Harford, Ramasubbu, et al. 2019).

## 1.3 Environmental sustainability

Environmental sustainability is a public health concern that affects populations all around the world. It is a significant concern for the general population, governments, and the healthcare system. As mentioned, many challenges are facing the world's population and the planet, including climate change, air and water pollution, reduction in biodiversity, and ozone depletion (Costello et al. 2009). Because of rising temperature and global warming, efforts are being made to reduce the impacts of environmental damage by considering sustainability. According to the Sustainable Development Unit, a sustainable health and care system works with existing financial, environmental, and social resources to improve and protect health for present and future generations (Duane, Harford, Ramasubbu, et al. 2019).

## 1.4 Sustainability in healthcare

Healthcare services are essential for maintaining and promoting human well-being; however, the current delivery of healthcare is not sustainable because of the high environmental load, rising costs, and increased demands (Duane, Harford, Ramasubbu, et al. 2019). They have an environmental footprint that contributes to health-related environmental risks (Tennison et al. 2021). Although the health effects of pollution and environmental change are well-known, the environmental impact of healthcare has received less attention.

The National Health Service (NHS) of the United Kingdom is the world’s largest publicfunded health system. They include more than 200 hospital trusts which provide 17 million inpatient admissions, about 7000 general practices offer more than 270 million primary care appointments, and they prescribe more than 11 billion items each year (Costello et al. 2009). The NHS in England is responsible for about 25% of the country's public sector carbon footprint (Costello et al. 2009). Similar services in the

United States accounted for 10% of the total (Joury et al. 2021). The Sustainable Development Unit (SDU) in England was designed to embed sustainable development at all levels of healthcare (Tennison et al. 2021).

Climate change is the greatest threat to healthcare. A healthcare system, which was designed to protect and promote health, contributes significantly to the climate crisis and, as a result, endangers people's health. The healthcare system internationally has a large climate footprint, accounting for about 4%-5% of global net CO2 emissions (Tennison et al. 2021). The health care sector has a critical role in climate change mitigation efforts, which can lead to improved patient care, employee satisfaction, and cost savings in addition to significant reductions in emissions.

### 1.5 Sustainability in Dentistry

There is no doubt that the profession of dentistry uses high energy and intensive resources with a significant environmental impact (Duane, Harford, Ramasubbu, et al. 2019). High energy demands of electric dental equipment, a large amount of water required, the environmental effects of biomaterials used, radiation, and the generation of hazardous waste containing mercury, lead, and other heavy metals, have all contributed to this (Mulimani 2017).

An ethical obligation bounds all healthcare professionals, including dentists (first, do no harm). Even though healthcare systems were created to eliminate disease in the world’s population, they also harming the world’s population. In England, the NHS produced 22.8 million tonnes of carbon equivalent emissions which is an estimated 3% of the carbon footprint of the whole country (846 million tonnes) (Duane et al.

2017). In comparison, equivalent services in the United States and Australia were 10% and 7%, respectively (Duane et al. 2017).

A study commissioned by Public Health England evaluated the carbon footprint of dental care by measuring carbon emissions. It was highlighted that the highest proportion of greenhouse gas emissions from dental care is caused by patient and staff travel making up over 64.5 %. This is followed by procurement in the second rank with 19%, and energy ranks third at 15.3%. Regarding the more intensive recourses, travel accounts for a lower proportion, followed by procurement by 39 to 61%, while energy for 9 to 13% (Duane et al. 2017).

Another study evaluated the carbon footprint by the individual procedure. The study evaluated 17 different dental procedures; the dental examination adds the most to the carbon footprint, accounting for 27.8% of the overall carbon footprint, followed by scale and polish with 13.5%, amalgam and composite fillings with 9.7 %, and 9.5 %, respectively. Acrylic dentures constitute 8.6%, radiographs taken 6.4%; extractions contribute 3.5%, non-precious metal crowns 3.3%, fluoride varnish 2.9% and endodontic treatment 2.1%. 6 %of the greenhouse gas emissions are associated with study models and 1.5% with glass ionomer fillings. Precious metal crowns, metal dentures, fissure sealants, and porcelain crowns contribute less than 1% to the carbon dioxide equivalents of dental procedures (Wilson, Shah, and Pugh 2020, Duane et al. 2017).

Dental travel is a significant contributor to carbon emissions and air pollution. Patients frequently need to travel many times to complete a course of treatment by using a car. Based on evidence travelling for NHS dentistry affects air quality by producing over

443 tons of nitrogen oxides and 22 tonnes of particulate matter annually (Duane, Steinbach, et al. 2019). This reduction in air quality reduces over 325 quality-adjusted life years per year. The action point is to minimise appointment times by merging family members' visits or combing operative procedures; this can help reduce the carbon emissions from dental travel (Duane, Steinbach, et al. 2019).

Although dental practices generate waste by around 0.1 % of carbon emissions, practices produce a significant amount of hazardous, recycling, offensive hygiene, domestic(non-food), and food waste. And based on (Duane, Ramasubbu, et al. 2019) study, there are three ways for dental waste management. The first is to purchase fewer procurements, such as reusable instruments, reduce nitrous oxide, reduce paper use, and reduce medication and water consumption. The second way is to ensure that waste is classified and separated appropriately to segregate clinical and non-clinical waste. Thirdly, ensure that practices are assessed by conducting an audit and considering a detailed waste survey.

The energy consumed within dentistry accounts for one-seventh of the carbon footprint (Duane, Harford, Steinbach, et al. 2019). The dental team should think about renewable energy for electricity. It suggested that using energy-efficient heating systems, lighting, and insulation, as well as limiting the use of larger equipment, can result in sustainable savings (Duane, Harford, Steinbach, et al. 2019).

Dental practitioners, like other healthcare peers, must consider the sustainability of services they provide, from clinical pathway design to care organisation and delivery.

There are three reasons for this. First, the dentist must understand where and how they use resources like carbon and money to maintain or improve service quality while reducing consumption. Second, under the Climate Change Act of 2008, the NHS is legally required to reduce greenhouse gas emissions by up to 80% by 2050 compared to 1990 levels (Duane et al. 2017). Third, the NHS has committed to decreasing its environmental consequences in the Sustainable Development Strategy for the Health and Social Care System (Duane et al. 2017).

## 1.6 Oral health

Having good oral health is an important issue. Oral health is a key indicator of general health, well-being, and quality of life. Oral disease affects about 3.5 billion people globally. Poor oral health is associated with many oral diseases and conditions, including dental caries, periodontal disease, oral cancer, dental trauma, and birth defects such as cleft lip and palate. Untreated dental caries in permanent teeth is the most common oral health condition (O'Brien et al. 2022).

Oral diseases are caused by various modifiable risk factors, including poor oral hygiene, excessive sugar intake, excessive alcohol use, tobacco use, stress, and underlying socio-economic determinants. It includes age, gender, education level, income, medical service access, race, ethnicity, and geographic location.

Poor oral health causes millions of people to suffer from pain and increases society's out-of-pocket cost. Also, oral diseases can impair an individual's performance in school and at work and generate social and personal issues. Many oral disorders have a significant psychosocial impact that lowers the quality of life. Evidence indicated that poor oral health had been linked to poor overall health (Spanemberg et al. 2019).

Oral diseases disproportionately affect poor and socially disadvantaged members of society. The prevalence and severity of oral diseases have a strong and constant relationship with socioeconomic status (income, occupation, and educational level). Addressing the social determinants of oral health is essential to reducing health inequalities and improving oral health (Spanemberg et al. 2019).

Out-of-pocket costs for oral health care can be major barriers to accessing care. Paying for critical oral health care is one of the primary causes of high health costs. They are putting people at risk of poverty and financial hardship. In most low- and middle-income nations, the demand for oral health care exceeds the capacity of healthcare systems, and many people in certain low-income countries cannot afford proper care (Peres et al. 2019).

Dental caries and periodontal disease are the most common oral conditions and are largely preventable and can be treated early. Even though they are mostly preventable, they remain a major dental issue. Based on statistics, the NHS spends roughly £3.4 billion on dental care each year, whereas the private sector is worth £ 2.3 billion (GOVUK 2018).

## 1.7 Dental caries

Dental caries is the “most common non-communicable disease worldwide” (Lee 2013). Despite continuous efforts to reduce its prevalence, it is still the most prevalent oral disease, especially in lower socioeconomic groups. It is a multifactorial disease involving the host, agent, and environment. The primary causative agent of dental caries is “Mutans streptococci” which adheres to the dental pellicle and uses glucose as energy to make lactic acid, resulting in an acidic environment around the tooth and demineralise the enamel and dentin. Three factors are involved in developing dental caries: the tooth, bacteria in the form of dental plaque, and a diet high in sugar. Caries incidence and prevalence are significantly influenced by the amount and frequency of sugar intake (Lee 2013).

Even though dental caries is largely preventable, extraction of carious teeth is the most common cause of hospital admission in children in England (Levine 2021). The prevalence of dental caries in children has decreased considerably during the last five decades; this is widely related to the introduction of fluoride-containing toothpaste, changes in social attitudes, the availability of access to dental care, advances in preventative dental materials, health promotion, and clinical procedures, which have all contributed to these shifts over time. Nonetheless, dental caries, which is entirely preventable, is common, and disparities are significant. Untreated tooth decay is a great issue in most cases ("Delivering better oral health: an evidence-based toolkit for prevention, GOVUK" 2021).

## 1.8 Periodontal disease

Periodontal disease, involving gingivitis and periodontitis is the most common chronic condition estimated to affect around 20% to 50% of the global population (Nazir 2017). It is the 6th most prevalent disease worldwide (Tonetti et al. 2017). It is “a chronic inflammatory disease of periodontium, causing loss of periodontal ligaments and destruction of surrounding alveolar bone” (Nazir 2017). It is caused by an interaction of bacterial infection and host response. Most of the periodontal infection is caused by anaerobes bacteria such as “treponema denticola” and “porphyromonas gingivalis” (Nazir 2017).

Evidence shows that the risk of periodontal disease is increased by several factors. These factors could be modifiable and non-modifiable. Modifiable risk factors include smoking, stress, poor oral hygiene, lack of proper toothbrushing, hormonal change in females, diabetes mellitus, and some medication that minimize the saliva flow and cause mouth dryness. Non-modifiable risk factors include age, and some genetic factors (Nazir 2017).

Periodontal disease is an individual's leading cause of tooth loss (Tonetti et al. 2017). This disease is complicated by a variety of signs and symptoms, including tooth migration and drifting, tooth hypermobility, tooth loss, and eventually increased degree of masticatory dysfunction. Therefore, masticatory dysfunction jeopardises nutrition and overall health. The early stages of periodontal disease are frequently symptomless, and most affected individuals do not seek professional help (Tonetti et al. 2017).

Furthermore, evidence has indicated an association between periodontal disease and some medical conditions, including cardiovascular disease, metabolic disease, rheumatoid arthritis, respiratory disease, chronic kidney disorder, cancer, and cognitive impairment. The global cost of lost productivity due to severe periodontitis is projected to be 54 billion USD annually (Tonetti et al. 2017). Even though periodontal disease is a common chronic condition, it can be prevented. Effectively controlling gingivitis and promoting healthy lifestyles in both individuals and population-levels can prevent the periodontal condition. This can be achieved by instructing self-care oral hygiene advice such as toothbrushing and the use of interdental cleaning aids (Worthington et al. 2019; Tonetti et al. 2017).

## 1.9 Oral Hygiene and interdental cleaning aids

Maintaining good oral hygiene reduces the risk of dental caries and periodontal disease. The main etiological factor in periodontal diseases is the bacterial plaque that develops on all hard and soft oral tissue. Poor oral hygiene maintenance encourages plaque accumulation, which makes gingivitis more likely to grow and cause periodontal disease. It is widely known that bacterial plaque is an etiological element in the emergence of chronic inflammatory periodontal disease (Tarannum et al. 2012). The most extensively used preventive strategy for periodontal disease is mechanical plaque reduction. It is now well accepted that bacterial plaque can be removed manually, chemically, or both to reduce the severity of chronic inflammatory periodontal disease.

Strong evidence supports the hypothesis that better dental hygiene will lower the incidence and severity of gingival inflammation.

Furthermore, it has also been proven that interproximal regions are where periodontal disease is most prevalent and severe. Likewise, periodontal disease is known to spread more quickly between teeth. Therefore, it is crucial to have effective plaque control in these locations.

Oral hygiene practice, including regular and effective toothbrushing with fluoride toothpaste, is essential to protect oral health. The physical action of toothbrushing removes the plaque and prevents gingivitis and periodontitis, while dental caries is effectively prevented by fluoride in toothpaste. Moreover, maximising plaque removal by using interdental cleaning aids is an effective way to prevent caries and periodontal diseases (Langa et al. 2022).

Interdental cleaning aids prevent oral disease and optimize gingival health (Langa et al. 2022). Different types of interdental cleaning aids developed to clean interdentally include dental floss, interdental brushes, wood stick, and water pressure devices known as oral irrigators (Ng and Lim 2019).

### 1.9.1 Dental floss

Even though much evidence suggests flossing is ineffective at removing plaque, there may still be benefits (Ng and Lim 2019). Some evidence in the literature showed that interproximal caries risk had been reduced with professional flossing; however, this beneficial effect was lost with self-performed flossing (Hujoel et al. 2006; Langa et al. 2022).

The percentage of adults who regularly use dental floss ranges from 10% to 30%; this is because adults may not floss as often as they found flossing is technically tricky. The patients struggle to properly floss, especially in tight contact areas between teeth (Ng and Lim 2019). Several different types of dental floss are available in the markets, including waxed with plant-derived candelilla wax and unwaxed dental tape, floss picks, newly advertised eco-friendly floss, and silk floss, In addition to an electric water flosser (Tarannum et al. 2012).

### 1.9.2 Interdental Brushes (IDBs)

It was found that interdental brushes are effective in removing plaque upto 2-2.5mm below the gingival margin and they are available in different widths and small bristled heads to suit the sizes of the gaps (Langa et al. 2022). Evidence shows no association between gingival damage or hard tissue damage after using interdental brushes (Ng and Lim 2019). They are made up of soft nylon filaments twisted around a central metal wire core. Interdental brushes are available in different materials, widths, and small bristled heads to suit the sizes of the gaps.

Their effectiveness is well documented. According to the European Federation of Periodontology 2015 workshop “cleaning with interdental brushes is the most effective method for interproximal plaque removal, consistently associated with more plaque removal than flossing or wood sticks” (Chapple et al. 2015). When selecting an interdental brush, there are several factors to consider that could affect its efficacy.

The first is the size, the interdental brush’s size should fit tightly into the interdental space with less interdental bleeding.

The geometry of the interdental brush is another factor to consider. Interproximal plaque removal with straight interdental brushes may be more effective than with an angled interdental brush.

The material of the interdental brush is also another factor to consider. It has been noted that metal wire can be more sensitive in patients with exposed root services. Rubber interdental brushes/ picks could be used as an alternative with further benefits of greater patient compliance and acceptance in terms of comfort (Ng and Lim 2019).

### 1.9.3 Wooden Interdental Aids

Woodsticks or toothpicks are designed for mechanical plaque removal from the proximal area by friction against proximal tooth surfaces. Similarly, it can remove plaque up to 2-3mm subgingival. Woodsticks do not have a significant advantage for proximal plaque reduction compared to toothbrushing alone (Ng and Lim 2019).

### 1.9.4 Oral irrigators

There are many available products for oral irrigators such as "Waterpik, Philips, and Sonicare Air floss". They provide a mechanical action of compression and decompression of gingival tissue to flush out subgingival and supragingival bacteria and debris (Ng and Lim 2019). Most of the research showed that oral irrigators might be more effective at reducing bleeding, plaque, or probing depth than dental floss or interdental brushes (Barnes et al. 2005; Ng and Lim 2019).

Using interdental cleaning aids at home, dental floss, interdental brushes, oral irrigators, and wooden interdental aids help remove all plaque and food particles in gaps between the teeth as a regular toothbrush cannot reach them. Based on the available research, interdental brushes may be more effective in plaque removal than dental floss regardless of the patient's periodontal condition (gingival index, reduction in bleeding, reduction in probing depth). This is probably because the bristles of an interdental brush can better fill embrasures and contact root surface irregularities (Ng and Lim 2019). However, The Cochrane oral health information has shown that using interdental cleaning device at home including dental floss or interdental brushes in addition to toothbrushing may reduce gingivitis or plaque, or both, more than toothbrushing alone (Worthington et al. 2019). The available evidence on oral irrigators and tooth cleaning sticks is limited.

A wide range of commercially available interdental cleaning aids makes various promises about how they might reduce plaque scores and gingival irritation. Many oral hygiene products have recently hit the market, each claiming to be better than the others. One such newly introduced items are bamboo products.

### 1.9.5 Alternative bamboo products

Several types of dental floss and interdental brush are available on the market. All traditional products are made of different kinds of plastic (nylon or Teflon). The best alternative and the trendiest is bamboo products. Bamboo floss and bamboo interdental brushes are eco-friendly choice products, typically made from bamboo fibers that don’t spend years in landfills and decompose after 60 to 90 days. Also, they are made in a sustainable package to reduce plastic use. Most of the benefits of bamboo products are related to their environmental impact. Bamboo products use less water and less energy than making plastic products. They have been developed to allow access to all interdental spaces.

Many bamboo floss products use organic wax such as candelilla wax and are flavoured with organic peppermint and tea tree oil instead of toxic chimlas, which are found in traditional floss. And others are infused with charcoal. An interdental brush with bamboo handles is made from biodegradable, naturally antibacterial, and sustainable bamboo plus BPA -free bristles. The smooth, natural bamboo handle is lightweight and easy to grip to catch gaps below the gum lines.

## 1.10 Measuring environmental sustainability within dentistry

Environmental sustainability can be measured in dentistry in various ways, including carbon footprint and life cycle analysis. Carbon footprint calculation is a standard method of evaluating and reporting the environmental impact of a building, land, structure, or retail site. Reduced energy consumption is one way to reduce carbon emissions while simultaneously lowering costs. Carbon footprint is defined as “the total amount of greenhouse gas emissions created during the delivery of a certain activity or the production of a product". Carbon dioxide ($CO_2$) accounts for 82% of all greenhouse gas emissions. Usually represented in equivalent tonnes of carbon dioxide ($CO_2e$) and is calculated for a year (Duane, Harford, Ramasubbu, et al. 2019). The consumption of resources, changes in air quality, change in waste output, and biodiversity are all alternative ways to consider sustainability.

To understand how sustainable specific practice is, researchers should look at the carbon footprint as a proxy measure of climate change impact to see how sustainable it is. This allows us to see which aspects of our current practice are not sustainable. Natural resources and carbon emissions are increasingly being assessed to obtain a more comprehensive estimate of overall sustainability. However, because of isolation, the usage of carbon footprint can be problematic. Fluoride varnish applications, for example, have a carbon impact but, in the long run, will enhance dental health and lower dentistry's long-term carbon footprint (Duane, Harford, Ramasubbu, et al. 2019).

The other method used to consider sustainability is the life cycle analysis (LCA) also called cradle-to-grave. It is essential for the government to support and shape environmental policy. It is a methodological tool used to quantify all stages of the life cycle of commercial products, processes, or services within the context of environmental impact. LCA will consider all the product's lifetime, for example, raw material extraction of material and processing (cradle), via production, distribution, and use phases, to the waste management and recycling(grave) (Finnveden et al. 2009).

Tools for specific calculations are being used for these aims. A LCA involves an inventory of the product’s energy and tools for precise calculation are being used for these aims. Thus, LCA assesses cumulative potential environmental impacts. The aim is to improve the overall environmental profile of the product.

LCA is a systematic approach that consists of several steps. The first is the definition and scope of a LCA. The second is known as the life cycle inventory (LCI) which involves gathering data on the use of resources, including emissions, energy requirements, and materials flow for each life cycle involved. This is where most of the LCA's complexity is involved because it involves dozens of processes and hundreds of tracked substances. The third step is the life cycle impact assessment (LCIA), where the impact of the life cycle inventory is calculated and evaluated. A picture of the environmental effects brought on by the product or activity is built using the LCIA. The last step is the analysis and interpretation of the results. The LCA is broadly concerned with impact factors regarding global warming potential, air, water and soil pollution, ecotoxicity, human health, resource depletion, ecosystem quality, and resources.

LCAs are included in the 14000 series of environmental management standards of the International Organization for Standardization (ISO). In particular, ISO 14040 and ISO 14044. ISO 14040 provides the 'principles and framework' of the Standard, while ISO 14044 outlines the 'requirements and guidelines. Therefore, the findings assist decision-makers in selecting products or processes with the most negligible environmental impact by considering the total product system and avoiding suboptimization that could occur if only one process was used.

As with every scientific method, there is always some limitation; the methodology focuses entirely on the ecological components of sustainability rather than the economic or social aspects (Finnveden et al. 2009). In England, the Coalition for Sustainable Pharmaceuticals and Medical Devices (CSPM), founded by the NHS and other healthcare industries, proposes LCA to compare services and enable policymakers to make educated recommendations (Kløverpris 2018).

### 1.11 Environmental impact of oral hygiene

Healthcare professionals should consider the environmental impact when recommending any healthcare device or product to their patients. A previous study has carried out LCA methodology on toothbrushes to explore the environmental impact, finding variations between different types of toothbrushes. It compared four types of toothbrushes: plastic, bamboo, plastic with replaceable head, and an electric toothbrush. It highlighted that manual bamboo and plastic replaceable-head toothbrushes had the lowest environmental impact when compared to the electric toothbrush's poor sustainability (Lyne et al. 2020).

There is currently limited information on the long-term impact of interdental cleaning aids including dental floss and interdental brushes to explore the impact of this preventative device on the environment. Thus, we found it is essential to examine floss and interdental brushes, which come in multiple forms.

This study is divided into three sections; in the first section, the LCA methodology was used to quantify the environmental impact of perhaps the most used interdental aids.

The aim was to compare the sustainability of different interdental cleaning aids and identify which aspects of the life cycle have the most significant environmental impact. In the second section, a rapid scoping review was done to compare the existing evidence regarding the impact of oral health interventions on the environment and review the methodology. In the third section, a cross-sectional survey was conducted as an online questionnaire; the aim was to compare the dentist's perspective on the environmental impact of oral health interventions.

# 2 An environmental impact study of interdental cleaning aids

## 2.1 Abstract


**Aim**

The aim of this study was to compare the environmental footprint of eight interdental cleaning aids using life cycle analysis (LCA).

**Materials and methods**

A comparative LCA was conducted based on an individual person using interdental cleaning aids every day for 5 years. The primary outcome was a life cycle impact assessment, consisting of 16 environmental impact categories, including a carbon footprint. Secondary outcomes included normalised data, disability adjusted life years (DALYs) and a contribution analysis.

**Results**

Interdental cleaning using floss picks had the largest environmental footprint in 13 out of 16 impact categories. Depending on the environmental impact category measured, the smallest environmental footprint came from daily interdental cleaning with either bamboo interdental brushes (5 impact categories, including carbon footprint), replaceable-head interdental brushes (4 impact categories), regular floss (3 impact categories), sponge floss (3 impact categories) and bamboo floss (1 impact category).

## Conclusion

Daily cleaning with interdental cleaning aids has an environmental footprint that varies depending on the product used. Clinicians should consider environmental impact alongside clinical need and cost when recommending interdental cleaning aids to patients.

## 2.2 Introduction

There are many environmental challenges facing our planet, including climate change and global warming, pollution, and ozone depletion. These challenges impact not only the health of the planet, but also the health of the planet's human population. Environmental damage, therefore, is a public health issue (Costello et al. 2009).

Healthcare itself has a significant carbon footprint and dentistry is no exception (Duane et al. 2017). Services and products designed to improve oral health come with an associated environmental cost that will ultimately impact global human health. It is important, therefore, to consider ways to make oral health care more environmentally sustainable.

Periodontal disease is a common global oral disease, with studies suggesting the prevalence of mild periodontitis is as high as 50%, and severe periodontitis 7.4% (Sanz et al. 2020; Kassebaum et al. 2017). It has a wide range of health consequences, including tooth loss, masticatory dysfunction, and reduced quality of life (Sanz et al. 2020). In addition, the burden of periodontal disease has a huge socioeconomic cost, with the global cost of lost productivity due to severe periodontitis projected at 54 billion USD per year (Tonetti et al. 2017). Preventing periodontal disease, therefore, is of utmost importance, and supported by the European Federation for Periodontology (Sanz et al. 2020).

Daily mechanical plaque removal is the cornerstone of preventing periodontal disease and controlling periodontal health. Using dental floss and interdental brushes helps to remove plaque and food particles in areas between the teeth where a regular toothbrush cannot reach. A recent systematic review (Worthington et al. 2019) found that using interdental cleaning aids (in addition to toothbrushing) may reduce gingivitis compared to toothbrushing alone (Sanz et al. 2020).

There are a range of interdental cleaning aids available in the European and UK market. Traditionally, floss and interdental brushes were made from plastic. However, new products with ‘eco-friendly’ branding have come to market recently, for example using bamboo or replaceable brush heads. Previous studies of different types of toothbrushes (Duane et al. 2020; Lyne et al. 2020) suggest that there is variation in the environmental footprint of different oral healthcare products, with bamboo and replaceable head brushes performing better than traditional plastic and electric toothbrushes. The environmental impact of different types of floss and interdental brushes, however, has not previously been quantified.

Environmental sustainability can be measured in different ways. Carbon footprinting is the most common measure and relates to climate change potential from the collective greenhouse gases of a product or service. Life cycle analysis (LCA) is a more comprehensive assessment of a product’s environmental footprint that encompasses not only climate change, but a range of measures relating to global human health (for example: ionizing radiation, ozone depletion, and respiratory disease from particulate matter), ecosystem quality (for example: freshwater ecotoxicity, marine eutrophication, and terrestrial acidification), and planetary resource use (for example: land use, fossil fuel use, and water use). LCA methodology is recommended by the European Union (European Commission, 2018), and considers the entire life of a product, including raw materials, manufacture and packaging, transport, use, and disposal.

This aim of this study was to use LCA methodology to quantify and compare the environmental impact of eight different types of interdental cleaning aids and identify which aspects of the life cycle have the most significant environmental impact.

### 2.3 Materials and Methods

A comparative attributional life cycle analysis of eight interdental cleaning aids including four dental floss and four interdental brushes was undertaken at the Eastman Dental Hospital, London, in partnership with the Dublin Dental University Hospital (Trinity College Dublin, Ireland).

The software OpenLCA v1.8 was used for the LCA, alongside the reference database Ecoinvent v3.7. The LCA methodology was used under international organisation for standardization (ISO), and product environmental footprint (PEF) recommendations ('European Commission Joint Research Centre, Product Environmental Footprint Category Rules Guidance, Version 6.3. ‘ 2018; 'Sustainable Development Unit,Coalition for Sustainable Pharmaceuticals and Medical Devices' 2019.).

#### 2.3.1 Sample selection

A review of interdental cleaning aids on the Amazon UK website was used to identify varieties of floss and interdental brush (IDB) products available on the UK market ('Amazon UK'). A sample product was chosen to represent each type of interdental cleaning aids. All products, brands and manufacturers have been anonymised. An attributional life cycle analysis from cradle to grave was undertaken utilising physical allocation by mass.

The 4 types of dental floss examined in this study where:

1. Floss tape or regular floss _ a roll of nylon floss in plastic dispenser.

2. Bamboo floss _ a roll bamboo floss in glass jar.

3. Floss picks_ a length of nylon floss fixed to plastic handle, packaged in packs of 30.
4. Sponge floss_ 50 pre-cut lengths of spongy or expanded floss designed to use around appliances and prosthetics, packaged in printed cardboard box.

The 4 types of interdental brush (IDBs) examined in this study where:

1. Weekly plastic interdental brush – brush with plastic handle and plastic lid, packaged in packs of 8, brush changed every week
2. Daily plastic interdental brush or toothpick– plastic handle and brush head, packaged in packs of 36, brush changed daily. This is sometimes referred to as a toothpick.
3. Plastic interdental brush with replaceable heads – plastic handle with replaceable brush heads and plastic lid, the reusable handle is packaged with 5 replaceable heads, and the 'refill' heads are packaged in packs of 12, with the brush head changed every week
4. Bamboo interdental brush – brush with bamboo handle, packaged in packs of 6, brush changed every week.

### 2.3.2 Functional unit

In order to compare the different products, a baseline scenario was used; an individual person using interdental cleaning aids every day over 5 years. This is called the functional unit and allows for equal comparison between products with different usage.

The 5-year period was chosen as the functional unit to aid the comparison of results with a previous LCA of toothbrushes. Five years was chosen in the previous study as the duration corresponds to the life span of an electric toothbrush (Lyne et al. 2020).

### 2.3.3 System boundaries

The entire product life cycle was mapped using a system boundaries diagram. Appendix 7.1 shows the system boundaries for all products. The entire product system was considered, including the geographic location of the manufacture.

For each type of dental floss and interdental brush, a life cycle inventory was produced, see appendix 7.2. A detailed list of assumptions for each product is available in table 2.1, and outlined below:

1. Raw materials. To identify and weigh the component materials, a sample of each product (and it's packaging) was dismantled and weighed to the nearest 0.01g. Components that were less than 0.01g were excluded. The quantity of products required for daily use over 5 years was calculated (for example, an individual using a IDB that comes in packets of 6, where each brush lasts for 1 week, would need 43.3 products over 5 years).
2. Manufacture. Individual manufacturers were contacted to obtain information about manufacturing and packaging processes. All products were confirmed as manufactured and packaged in the same factory location. For manufacturing machinery, the machine's energy consumption (kilowatt/per hour/kWh) was used, assuming the machine was being used at maximum

capacity. Machinery maintenance and servicing was excluded. Any waste materials from the manufacturing and packaging were assumed to be recycled back into the process.

3. Transport. Transport of the product from the factory to the UK was allocated based on weight of the products (kg), distance travelled (km), and method of travel (lorry for land transport, freight ship for sea transport). Six out of eight products were manufactured in Europe, and two were manufactured in China. The transport was modelled from the factory location to the manufacturer's UK headquarters. Transport from the European locations was assumed to be via lorry from the factory to Calais; then via ferry to Dover; and then again via lorry to the UK headquarters for that manufacturer. Transport from the Chinese location was assumed to be via lorry from the factory to Shanghai port; then via ship to Southampton port; and then again via lorry to the UK headquarters/ storage facility for that company. All distances were estimated using Google Maps (2021) in km and the shortest route chosen. The exact locations have been concealed to anonymise the individual manufacturers.
4. Retail. The retail processes (e.g., shopping travel distances, supermarket resources) were excluded as this was assumed to be the same for all products.
5. Consumer use. It was assumed that the individual person would use the product as directed by the manufacturer every day for 5 years. It was assumed this individual was located in the UK and used unheated tap water to clean the products where needed (e.g., for the weekly IDBs).

6. Disposal. It was assumed that the individual would dispose of the product in the UK as per manufacturer's recommendations, and place materials in recycling where possible. The final life cycle inventory for each product is available in Appendix 7.2.

**Table 2.1 Detailed assumptions and exclusions of each type of interdental cleaning aids.**

| Product | Assumptions and exclusions |
|---|---|
| All products | Colouring pigments were excluded from the materials and packaging. |
| | Materials were taken from a teardown of a sample product combined with information from the manufacturer and weighed to the nearest 0.01g. Components weighing less than 0.01g were excluded. |
| | All products were manufactured and packaged in the same location. |

| | |
|---|---|
| | All products were transported from the location of manufacture to the UK (manufacturer's UK company headquarters). Transport of the product from the factory to the UK was allocated based on weight of the products (kg), distance travelled (km), and method of travel (lorry for land transport, freight ship for sea transport). Six out of eight products were manufactured in Europe, and two were manufactured in China. The transport was modelled from the factory location to the manufacturer's UK headquarters. Transport from the European locations was assumed to be via lorry from the factory to Calais; then via ferry to Dover; and then again via lorry to the UK headquarters for that manufacturer. Transport from the Chinese location was assumed to be via lorry from the factory to Shanghai port; then via ship to Southampton port; and then again via lorry to the UK headquarters/ storage facility for that company. |

| | |
|---|---|
| | All distances were estimated using Google Maps (2021) in km and the shortest route chosen. |
| | Retail processes were excluded as they were assumed to be negligible and similar for all products. |

| | |
|---|---|
| | No water was used for the single-use products (all floss products and the daily IDB). For products requiring cleaning between use with tap water (all IDBs excluding the daily IDB), it was assumed 3 seconds worth of tap water (0.25L) was used daily (except for the 7$^{th}$ day when the product was disposed of) based on the authors measuring their household tap water use to thoroughly clean a sample product. |
| | The product itself was disposed of in UK household waste. All cases and packaging were disposed of in glass, metal, plastic or paper recycling where possible. All non-recyclable plastics were disposed of in UK household waste. |
| Regular floss | The product comes in packs containing 25 meters of floss. It was assumed that 18 inches were used per day, therefore 35 products were needed for 5 years' worth of daily use. |
| | Materials and manufacture:<br><br>1. Floss tape: polyethylene was made in tape through plastic extrusion. A winding machine was used to wind the floss tape into a roll. The wax used on the tape was excluded as could not be quantified and was assumed as negligible. |

| | |
|---|---|
| | 2. Dispenser: the floss tape is placed inside a dispenser, made from a polypropylene lidded box (injection moulded) with a steel cutter (milled).<br>3. Packaging: Injection moulded recycled polyethylene terephthalate (PET) and printed cardboard (offset printing) forms the package in a blister pack. |
| Sponge floss | Sponge floss comes in packs of 50, therefore 36.5 products were needed for daily use for 5 years. |
| | Materials and manufacture:<br>1. The sponge floss is created from extrusion of low-density polyethylene. The wax used to stiffen the ends of the floss was excluded as the amount of wax could not be quantified and was assumed as negligible.<br>2. It is packaged as cut lengths in a printed cardboard sleeve and polyethylene film. |
| Floss picks | Floss picks come in packets of 30. Therefore 60.8 products were needed for daily use over 5 years. |
| | Materials and manufacture:<br>1. Floss tape is made in the same way as the regular floss product.<br>2. The floss tape is then fixed into a polyethylene handle (Injection moulded). |

| | |
|---|---|
| Bamboo floss | The product comes in packs containing 30 meters of floss. It was assumed that 18 inches were used per day, therefore 27.8 products were needed for 5 years' worth of use. |

| | |
|---|---|
| | Materials and manufacture:<br>1. Raw bamboo was formed using the same cultivation and processes as described in Lyne et al, 2020.<br>2. The raw bamboo was then made into chips (chipping machine), then pulp (thermochemical pulp machine), and then spun into thread in a similar way to cotton (spinning and then winding machine).<br>3. The wax used on the tape was excluded as could not be quantified and was assumed as negligible.<br>4. The product was packaged in a glass tube with a steel lid (milling) and a printed cardboard box (offset printing). |
| Regular IDB | Each brush is used for 7 days before disposal. The product comes in packs of 8 brushes; therefore 32.5 products were needed for 5 years' worth of use. |

| | |
|---|---|
| | Materials and manufacture:<br>1. The IDB handle and protective cover is made from polypropylene (injection moulded).<br>2. The IDB brush head is made from nylon and a steel wire, made with a brush twisting machine.<br>3. Brushes and the protective cover is packaged in recycled PET and printed cardboard. |
| IDB picks | Each brush pick is used daily, and the product comes in packs of 36, therefore 50.69 products were needed for 5 years' worth of use. |
| | Materials and manufacture: |

| | |
|---|---|
| | • The IDB pick is made from injection moulded polypropylene and synthetic rubber.<br>• A storage box made from injection moulding polypropylene<br>• The IDBs are packaged in a combination of injection moulded recycled polyethylene terephthalate (rPET) and printed cardboard. |

| | |
|---|---|
| Replaceable head IDB | The replaceable brush heads are each used for 7 days before disposal, and the reusable handle is kept for 5 years before disposal. Therefore, 1 original product (containing 1 handle and 5 heads) and 21.25 refill products (containing 12 replaceable heads) were needed for 5 years' worth of use. |
| | Materials and manufacture:<br>1. The handle and plastic component of the heads were formed from injection-moulded polypropylene.<br>2. The brush is made from nylon and a steel wire, made with a brush twisting machine.<br>3. The product is packaged in injection moulded recycled PET and printed paper insert. |
| Bamboo IDB | Each brush is used for 7 days before disposal. The product comes in packs of 6 brushes; therefore 43.3 products were needed for 5 years' worth of use. |
| | Materials and manufacture:<br>1. The bamboo handle was grown and shaped using the same processes as described in Lyne et al, 2020 for a bamboo toothbrush handle. |

| | |
|---|---|
| | 2. Soybean wax was used to treat the handle.<br>3. The Arabic gum used to glue the brush head into the bamboo handle was excluded as it was less than 0.01g and therefore could not be quantified.<br>4. The brush is made from nylon and a steel wire, made with a brush twisting machine. |
| | It was assumed that the consumer would not separate the brush heads from the handles in order to recycle the handles, therefore the entire IDB was assumed to be disposed of via household waste, and the packaging disposed of via recycling. |

### 2.4 Data analysis

An attributional LCA was undertaken utilising physical allocation by mass. The software OpenLCA v1.8 was used for the LCA, alongside the reference database Ecoinvent v3.7. The LCA methodology following International Standard Office and EU Product Environmental Footprint recommendations ('European Commission Joint Research Centre , Product Environmental Footprint Category Rules Guidance, Version 6.3. ' 2018).

The primary outcome was a life cycle impact assessment (LCIA) with 16 environmental impact categories. A description of each impact category and the LCIA method and units are described below and in table 2.2.

1- Climate change (Kg CO2-Eq): indicator of potential global warming because of greenhouse gas emissions into the atmosphere. based on the source of the emissions, they are divided into three subcategories: (1) fossil resources, (2) bio-based resources, and (3) land use change.

2- Ecosystem quality – freshwater and terrestrial acidification (mol H+ - Eq): indicator of soil and water acidification because of the emission of pollutants like nitrogen oxides and sulphur oxides.

3- Ecosystem quality - Freshwater eutrophication (kg $PO_4$-Eq): indicator of the nutrient enrichment of the freshwater ecosystem caused by the release of molecules containing nitrogen or phosphorus compounds.

4- Ecosystem quality marine eutrophication (Kg N-Eq): indicator of the marine ecosystem's nutrient enrichment because of the emission of molecules containing nitrogen compounds.

5- Ecosystem quality- terrestrial eutrophication (mol N-Eq): indicator of the nutrient enrichment of the terrestrial ecosystem brought about by the emission of molecules containing nitrogen

6- Ecosystem quality – freshwater ecotoxicity (CTU): impact of toxic compounds released into the environment and their effects on freshwater life.

7- Human health - photochemical ozone formation (kg NMVOC-Eq): indicator of gas emissions that have an impact on smog, which is the result of sunlight catalyzed photochemical ozone formation in the lower atmosphere.

8- Human health – cancer, non-cancer effect (CTUh): hazardous compounds released into the environment and its effects on people. divided into cancer and non-cancer toxic substance.

9- Human health -Ionising radiation (kg U235-Eq): impact of emissions of radionuclides.

10- Human Health – ozone layer depletion (kg CFC-11-Eq)

11- Human health – respiratory effect, inorganics

12- Eco-toxicity (freshwater): impact of toxic compounds released into the environment and their effects on freshwater life.

13- Resources - water use:  Indicator of the relative amount of water used, based on regionalized water scarcity factors.

14- Resources - land use: Measure of soil quality changes (Biotic production,

Erosion resistance, Mechanical filtration).

15- Depletion of abiotic resources – minerals and metals (kg Sb-Eq): indicator of depletion of non-fossil natural resources (kg Sb- Eq)

16- Depletion of abiotic resources – fossil fuels: indicator of the depletion of natural non-fossil resources.

**Table 2.2 Impact categories and LCIA methods used in this study.**

| Impact category(abbreviation) | LCIA methods(units) | Description |
|---|---|---|
| Acidification (A) | ILCD 2011 Midpoint+ (Mol H+ eq) | Acidification of soils and freshwater due to gas release |
| Climate change (CC) | IPCC 2013 GWP 100a (kg $CO_2$ eq) | Potential for global warming from greenhouse gas emissions |
| Ecotoxicity freshwater (ECF) | ILCD 2011 Midpoint+ (CTUe) | Harmful effects of toxic substances on freshwater organisms |
| Eutrophication freshwater (EUF) | ILCD 2011 Midpoint+ (kg P eq) | Changes in freshwater organisms and ecosystems caused by excess nutrients |
| Eutrophication marine (EUM) | ILCD 2011 Midpoint+ (kg N eq) | Changes in marine organisms and ecosystems caused by excess nutrients |
| Eutrophication terrestrial (EUT) | ILCD 2011 Midpoint+ (mol N eq) | Changes in land organisms from excess nutrients in soil and air |
| Human health: cancer effects (CE) | ILCD 2011 Midpoint+ (CTUh) | Harm to human health that causes or increases cancer risk |
| Human health: ionising radiation (IR) | ILCD 2011 Midpoint+ (kBq $U^{235}$ eq) | Potential damage to human DNA from ionising radiation |
| Human health: non-cancer effects (NCE) | ILCD 2011 Midpoint+ (CTUh) | Harm to human health that is not related to cancer or ionising radiation |
| Human health: particulate matter formation (PMF) | PM method (disease incidence) | Harm to human health caused by particulate matter emissions (respiratory inorganics) |

| | | |
|---|---|---|
| Human health: photochemical ozone formation (POF) | ILCD 2011 Midpoint+ (kg NMVOC eq) | Harm to human health from gas emissions that contribute to smog in the lower atmosphere |
| Land use (LU) | Soil quality index based on LANCA (pt) | Depletion of natural resources, change in soil quality and reduction in biodiversity |
| Ozone depletion (OD) | ILCD 2011 Midpoint+ (kg CFC11 eq) | Air emissions causing stratospheric ozone layer destruction |
| Resource use: energy carriers (REC) | CML-IA baseline (MJ) | Depletion of natural fossil fuels |
| Resource use: minerals and metals (RMM) | CML-IA baseline (kg Sb eq) | Depletion of natural non-fossil fuel resources |
| Water scarcity (WS) | AWARE ($m^3$ deprivation) | Potential for water deprivation to humans and ecosystems globally |

Secondary outcomes included:

- Normalised LCIA results. Normalisation of the LCIA results against an average person's annual environmental footprint allows for comparison between impact categories. As per PEF guidelines, the toxicity categories were excluded from normalisation while the LCIA methods are under review. Impact categories with the higher normalised values are more significant within the overall environmental footprint compared to categories with smaller normalised values.
- The burden of human health can be measured in DALYs. It is the number of years of life lost in human population because of morbidity (disease and disability) and mortality (death). LCA modelling can be used to calculate DALYs

lost across the global population based on the human health related impact categories. DALYs were calculated using ReCiPe 2016 Endpoint and presented in minutes rather than years ('The Netherlands National Institute for Public Health and the EnvironmentLCIA: the ReCiPe model.'  2018).

- A contribution analysis was reported to assess which aspect of each product life cycle contributed the most to the environmental impacts.

## 2.5 Result

### 2.5.1 Life cycle impact assessment (LCIA)

The results of the life cycle impact assessment (LCIA) for each type of the dental floss and the interdental brush are shown in table 2.3 and 2.4. Interdental cleaning using floss picks had the largest environmental footprint in 13 out of 16 impact categories. Interdental cleaning with bamboo IDBs had the lowest environmental impact in 5 categories (climate change, freshwater eutrophication, ionising radiation, fossil use, and mineral/metal use), followed by replaceable head IDBs in 4 categories (acidification, marine eutrophication, terrestrial eutrophication, and photochemical ozone creation), regular floss in 3 categories (noncarcinogenic effects, respiratory inorganics, and land use), sponge floss in 3 categories (freshwater ecotoxicity, carcinogenic effects, and ozone layer depletion), and bamboo floss in 1 category (water use).

**Table 2.3 LCIA results for dental floss used in the study**

| Impact category | Floss tape | Floss picks | Sponge floss | Bamboo floss |
|---|---|---|---|---|
| Climate change (KG CO2 EQ) | 3.06620 | 11.41851 | 2.29005 | 2.11247 |
| Acidification (MOL H+ EQ) | 0.00875 | 0.04284 | 0.00831 | 0.01583 |
| Ecotoxicity freshwater (CTU E) | 2.94673 | 10.47154 | 1.63381 | 4.60173 |
| Eutrophication freshwater (KG P EQ) | 0.00110 | 0.00314 | 0.00048 | 0.00059 |
| Eutrophication marine (KG N EQ) | 0.00208 | 0.01062 | 0.00223 | 0.00427 |
| Eutrophication terrestrial (MOL N EQ) | 0.01849 | 0.09024 | 0.01841 | 0.04278 |
| human health: carcer effects (CTU H) | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| human health: ionising radiation (KG U235 EQ) | 0.30514 | 1.12993 | 0.12559 | 0.14186 |
| human health: non cancer effects (CTUH) | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| Ozone depletion (KG CFCII EQ) | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| human health: photochemical ozone creation (KG NMVOC EQ) | 0.00674 | 0.03344 | 0.00731 | 0.01069 |
| human health: particulate matter formation (DISEASE INC.) | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| Water scarcity (M3 DEPRIV) | 0.93845 | 4.90694 | 0.92533 | 0.53934 |
| Resource use: energy carriers (MJ) | 58.62235 | 277.52988 | 52.45484 | 26.85346 |
| Land use (PT) | 15.88605 | 170.62410 | 40.20217 | 63.96853 |
| Resource use: minerals and metals (KG SB EQ) | 0.00001 | 0.00005 | 0.00001 | 0.00002 |

**Table 2.4 LCIA results for IDBs used in the study**.

| Impact category | Plastic IDB | Toothpick IDB | Plastic IDB with replaceable heads | Bamboo IDB |
|---|---|---|---|---|
| Climate change (KG CO2 EQ) | 2.10923 | 6.52787 | 1.37564 | 1.30526 |
| Acidification (MOL H+ EQ) | 0.00845 | 0.02155 | 0.00546 | 0.00792 |
| Ecotoxicity freshwater (CTU E) | 2.77375 | 8.59329 | 2.85597 | 2.61815 |
| Eutrophication freshwater (KG P EQ) | 0.00068 | 0.00155 | 0.00044 | 0.00043 |
| Eutrophication marine (KG N EQ) | 0.00205 | 0.00512 | 0.00142 | 0.00308 |
| Eutrophication terrestrial (MOL N EQ) | 0.01782 | 0.04365 | 0.01225 | 0.02122 |
| human health: carcer effects (CTU H) | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| human health: ionising radiation (KG U235 EQ) | 0.25709 | 0.62332 | 0.15582 | 0.10724 |
| human health: non cancer effects (CTUH) | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| Ozone depletion (KG CFCII EQ) | 0.00000 | 0.00001 | 0.00000 | 0.00000 |
| human health: photochemical ozone creation (KG NMVOC EQ) | 0.00637 | 0.01608 | 0.00404 | 0.00600 |
| human health: particulate matter formation (DISEASE INC.) | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| Water scarcity (M3 DEPRIV) | 3.38397 | 2.32207 | 3.07590 | 5.77255 |
| Resource use: energy carriers (MJ) | 47.41064 | 132.93535 | 22.34250 | 13.00912 |
| Land use (PT) | 36.41511 | 46.89337 | 34.61679 | 109.97917 |
| Resource use: minerals and metals (KG SB EQ) | 0.00001 | 0.00004 | 0.00001 | 0.00001 |
| | | | | |

### 2.5.2 Normalised results

The normalised results are shown in figure 2.1 and 2.2. The most important impact categories for each product were:

- Regular floss and sponge floss: freshwater eutrophication, climate change, and mineral/metal use.
- Bamboo floss: mineral/metal use, acidification, and climate change.
- Plastic IDB and Bamboo IDB: water use, climate change, and freshwater eutrophication.
- IDB picks: ozone layer depletion, climate change, and mineral/metal use.
- Replaceable head IDB: ozone layer depletion, water use, and climate change.

**Figure 2.1 Normalised LCIA results for interdental cleaning aids used in this study for 7 impact categories: Ozon layer depletion, climate change, freshwater eutrophication, mineral, freshwater terrestrial, and water use.**

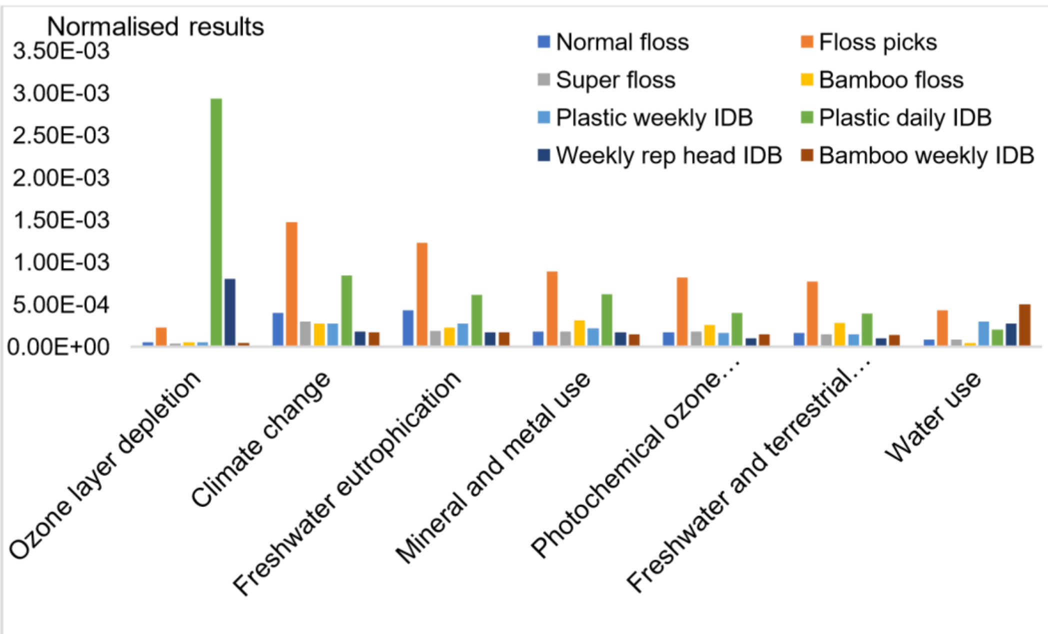
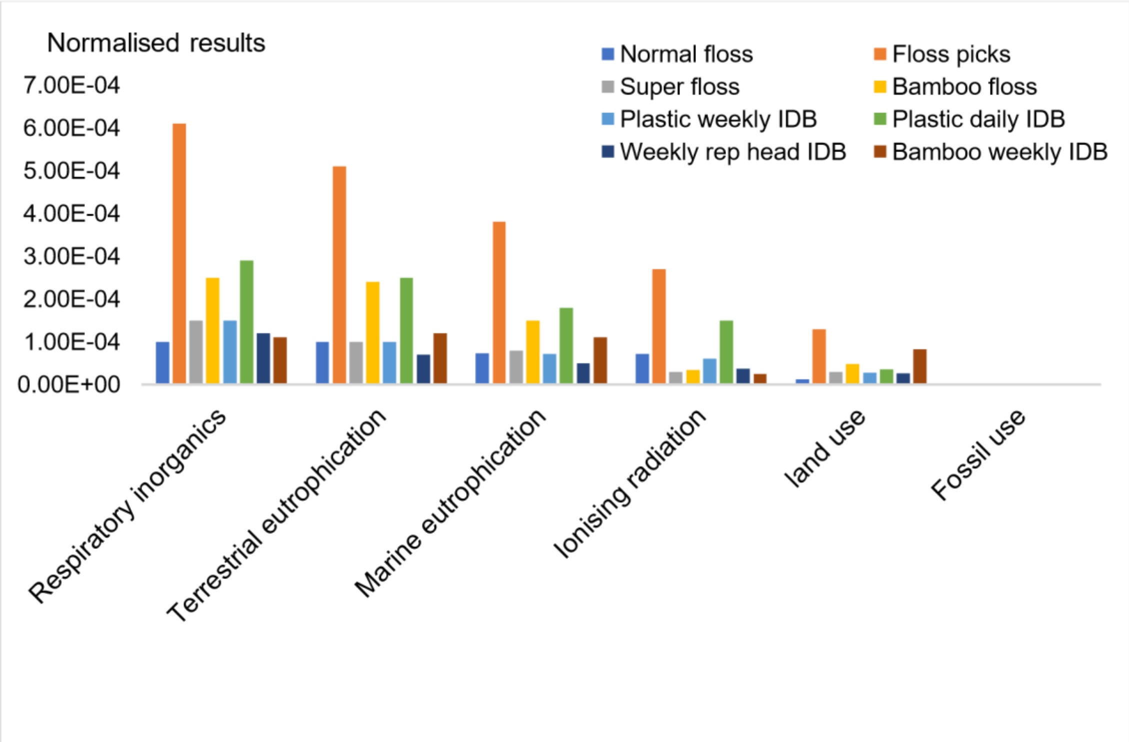


**Figure 2.2 Normalised LCIA results for interdental cleaning aids used in this study for 6 impact categories: respiratory inorganics, terrestrial eutrophication, marine eutrophication, ionizing radiation, land use, and fossil use.**



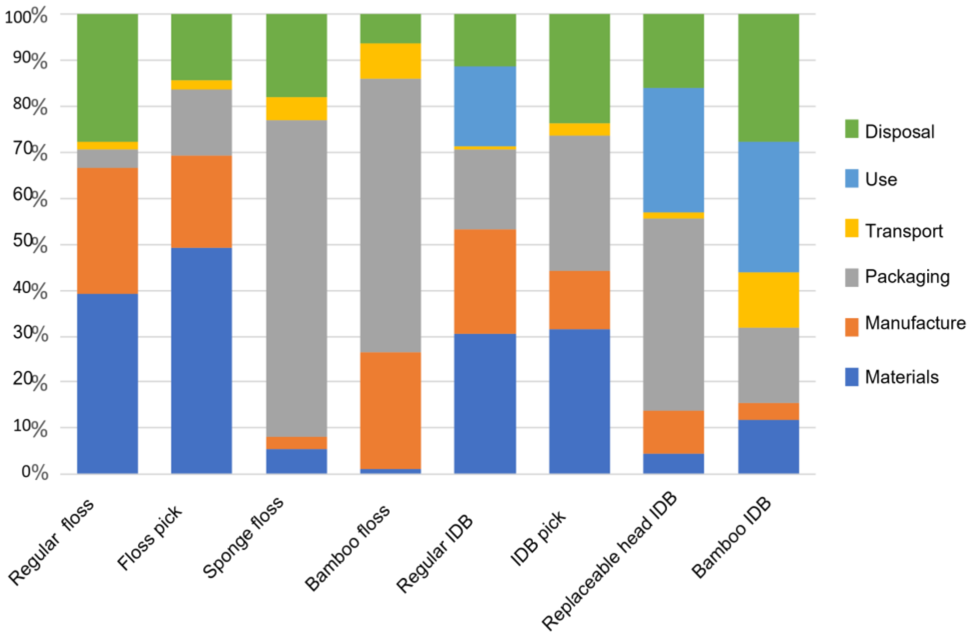

### 2.5.3 Contribution analysis

A contribution analysis was carried out for each impact category. The figure 2.3 below shows the contributions for all type of interdental cleaning aids to each impact category. Appendix 7.2 showed all the results, for floss pick and floss tape, the polypropylene material had the greatest contribution. the polypropylene, used to make the handle in the floss pick and the dispenser in the floss tape with an average (39.83% for floss pick and 32.45%, for floss tape). For super floss, the biggest contributing factor was the cardboard used in the packaging with around 22.63%.  For the bamboo floss the biggest contributing factor was steel lid used with glass bottle in the packaging making up 32.51%.

The biggest contributing factor for the bamboo interdental brush was consumer use (the tap water used during brushing) making up 19%. For the plastic daily and weekly interdental brush with replaceable head the polyethylene material used in packaging case had the greatest impact. The polypropylene handle was the single biggest contributing factor in plastic weekly interdental brush by 20.62 %. The greatest contributor to its overall environmental impact was the material followed closely by the packaging. The disposal had the smallest contribution to the environmental impact for all products.

## Figure 2.3 Contribution analysis for all types of interdental cleaning aids

**Figure 2.** Contributions analysis for all type of interdental cleaning aids.




60

### 2.5.4 Disability-Adjusted Life years (DALYs)

Table 2.5 and 2.6 shown the findings of the DALYs impact calculations and figure 2.4 shows the DALY results (presented in minutes). The highest DALY impact was the floss pick (7.5 minutes) followed by IDB picks (4.1 minutes). The lowest DALY impact came from bamboo floss (1.2 minutes). The DALY result for all products came from the same 2 human health impact categories: climate change (44-99%) and carcinogenic effects (0-64%). All other human health impact categories (ozone depletion, ionising radiation, respiratory inorganics, noncarcinogenic effects, water use, and photochemical ozone formation) formed less than 1% of the DALY result combined.

**Figure 2.4 DALYS results presented in minutes**

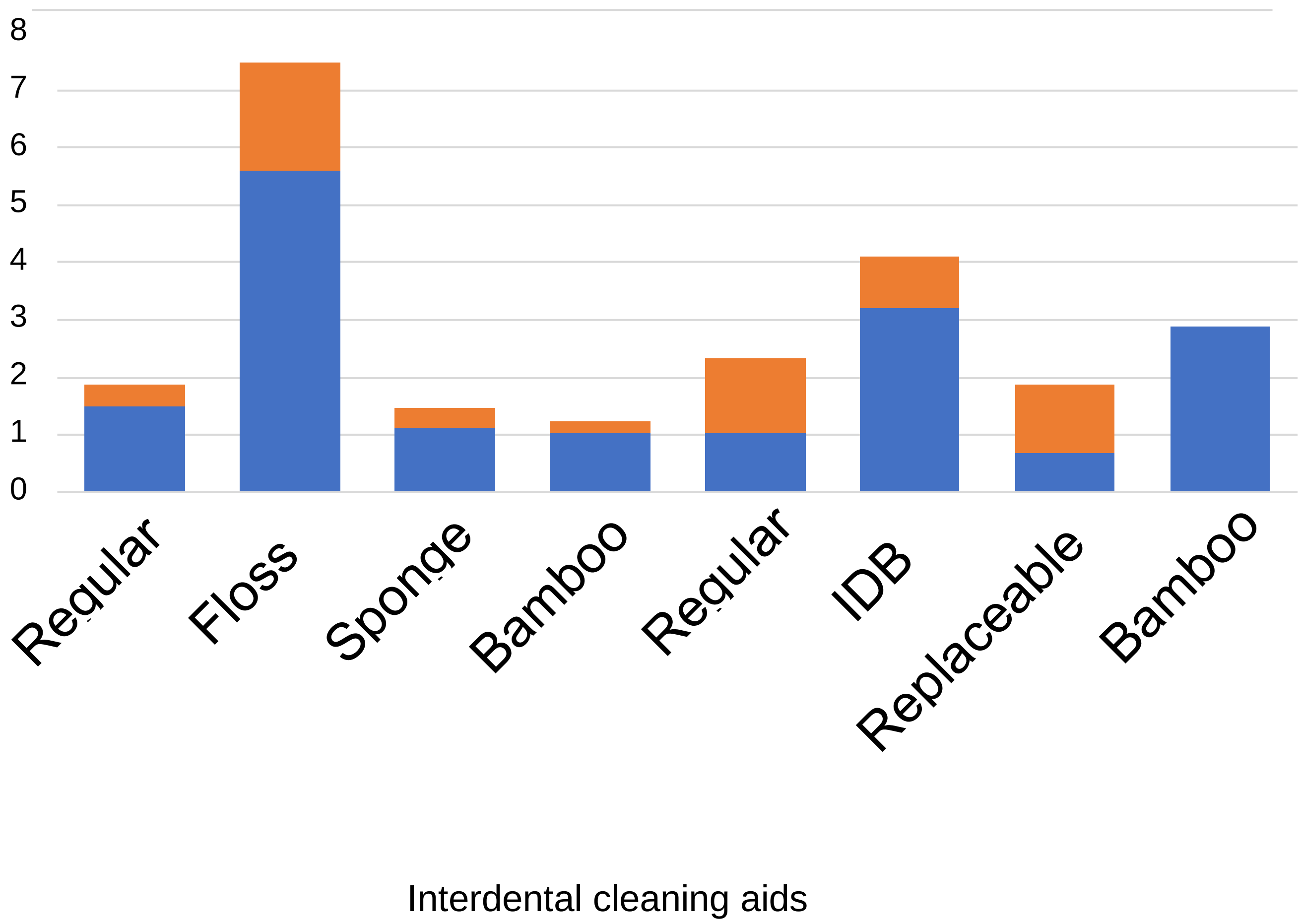


**Table 2.5 DALYs lost due to one individual using a dental floss over five years.**

| Impact categories | Floss tape | Floss picks | Sponge floss | Bamboo floss |
|---|---|---|---|---|
| **Global warming, Human health** | 2.85E-06 | 1.06E-05 | 2.13E-06 | 1.96E-06 |
| **Stratospheric ozone depletion** | 6.18E-11 | 2.84E-10 | 4.58E-11 | 6.70E-11 |
| **Ionizing radiation** | 2.59E-09 | 9.60E-09 | 1.07E-09 | 1.21E-09 |
| **Fine particulate matter formation** | 4.01E-11 | 2.44E-10 | 5.82E-11 | 1.01E-10 |
| **Human non-carcinogenic toxicity** | 5.91E-09 | 2.93E-08 | 6.41E-09 | 9.37E-09 |
| **Water consumption, Human health** | 1.32E-13 | 6.29E-13 | 1.14E-13 | 1.04E-12 |
| **Ozone formation, Human health** | 1.09E-15 | 5.37E-15 | 1.09E-15 | 2.25E-15 |
| **Human carcinogenic toxicity** | 6.90E-07 | 3.61E-06 | 6.80E-07 | 3.97E-07 |
| **Total DALYs (years)** | 3.544E-06 | 1.4243E-05 | 2.813E-06 | 2.3676E-06 |
| **Total DALYs (days)** | 0.00129355 | 0.0051988 | 0.00102676 | 0.00086418 |
| **Total DALYs (hours)** | 0.03104513 | 0.12477128 | 0.02464212 | 0.02074041 |
| **Total DALYs (mins)** | 1.86270807 | 7.48627695 | 1.47852741 | 1.24442431 |
| | **Floss tape** | **Floss picks** | **Super floss** | **Bamboo floss** |
| **Total DALYs lost over 5 years** | 111.762484 | 449.176617 | 88.7116448 | 74.6654585 |

**Table 2.6 DALYs lost due to one individual using an interdental brush over five years.**

| Impact categories | Plastic weekly | Plastic daily | Weekly rep head | Bamboo weekly |
|---|---|---|---|---|
| **Global warming, Human health** | 1.96E-06 | 6.06E-06 | 1.28E-06 | 1.21E-06 |
| **Stratospheric ozone depletion** | 6.61E-11 | 3.63E-09 | 9.89E-10 | 5.06E-11 |
| **Ionizing radiation** | 2.19E-09 | 5.30E-09 | 1.32E-09 | 9.12E-10 |
| **Fine particulate matter formation** | 6.11E-11 | 1.17E-10 | 4.85E-11 | 4.59E-11 |
| **Human non-carcinogenic toxicity** | 5.58E-09 | 1.41E-08 | 3.54E-09 | 5.26E-09 |
| **Water consumption, Human health** | 3.88E-13 | 3.50E-13 | 3.52E-13 | 3.74E-13 |
| **Ozone formation, Human health** | 1.61E-15 | 2.77E-15 | 1.34E-15 | 1.69E-15 |
| **Human carcinogenic toxicity** | 2.49E-06 | 1.71E-06 | 2.26E-06 | 4.24E-06 |
| **Total DALYs (years)** | 4.4531E-06 | 7.7881E-06 | 3.5438E-06 | 5.4614E-06 |
| **Total DALYs (days)** | 0.00162538 | 0.00284267 | 0.0012935 | 0.00199341 |
| **Total DALYs (hours)** | 0.03900905 | 0.06822411 | 0.03104401 | 0.04784196 |
| **Total DALYs (mins)** | 2.34054275 | 4.09344667 | 1.86264069 | 2.87051757 |
| | **Plastic weekly** | **Plastic daily** | **Weekly rep head** | **Bamboo weekly** |
| **Total DALYs lost over 5 years** | 140.432565 | 245.6068 | 111.758442 | 172.231054 |

## 2.6 Discussion

This study found variation in the environmental footprint between eight interdental cleaning aids available on the UK market. Overall, the worst environmental footprint came from the floss picks which had the highest environmental impact in 13 out of 16 categories, followed by the interdental brush picks. No single product had the 'best' environmental footprint, although perhaps the bamboo interdental brush preformed the best overall, with the lowest impact in 5 out of the 16 categories.

This study highlights the fact that carbon foot printing alone is not a comprehensive measure of environmental sustainability. The normalisation of the results (allowing for comparison between different impact categories) found that, overall, the most significant impact categories were ozone layer depletion, climate change, and freshwater eutrophication. Sponge floss performed the best for ozone layer depletion, producing the equivalent of 26% less CFCs than regular floss. The bamboo interdental brush performed the best for climate change and freshwater eutrophication, producing the equivalent of 48% less CO2 than a regular interdental brush, and 37% less phosphorus (the measure of water eutrophication).

This trend continues with the Disability Adjusted Life Years (DALYs), presented in this paper as minutes. DALYs combine the human health impact categories to provide the global human quality of life loss of a product. Using the floss picks as an example, one individual using floss picks for 5 years means that the global human population will lose the equivalent of 7.4 minutes of life. The DALY impact of regular floss was 75%

less than floss picks; and the DALY impact of regular interdental brushes was 57% less than that of interdental brush picks.

The contribution analysis shows which aspects of the product's life cycle contributed the most to the environmental impact. For floss picks, it was the polypropylene plastic handle that contributed the most to the environmental impact (for example, the handle formed 49% of the carbon footprint). This is due to the sheer weight of plastic needed to use these floss picks every day for 5 years. In comparison, the bamboo handle of the bamboo interdental brush contributed just 5% to the product's carbon footprint.

To our knowledge, this is the first study to quantify the environmental impact of different types of interdental cleaning aids, such as floss and interdental brushes. Data collection and analysis was performed in line with European Union Product Environmental Footprint guidance (PEF) European Commission, 2018 and offers a holistic view of environmental sustainability over carbon footprinting alone.

However, the main limitation of this study was in data collection and analysis. we relied on manufacturers information to form the basis of the life cycle inventory model, and where this information was not available, a reasonable assumption was made, and this may have impacted on the results. These assumptions are listed in table 2.1. Ideally, it would be the responsibility of any product manufacturer to report their environmental footprint, however there is currently no legal obligation for this, even for products using labels such as 'eco-friendly' or 'sustainable'.

This study used eight sample products, selected as best-selling products on the Amazon UK website. However, this may not be representative of the range of products available in the UK and other countries. Also, this study did not include any electronic forms of interdental cleaning, such as water or air flossing products, because it was assumed, they would have a greater environmental impact than manual products, based on a previous study of manual and electric toothbrushes. This study was based in the UK; therefore, the impact of transport may vary for these same products in other countries. Transport by land and sea to the UK accounted for between 1.3% and 10.2% of the carbon footprint of the products.

LCA methodology, although more comprehensive than carbon footprinting, is limited when it comes to interpretation in a healthcare setting. Currently, LCA methodology does not allow for data analysis or results including p values and confidence intervals, and so data needs to be interpreted based on descriptive statistics alone, making it difficult for clinicians and the public to easily interpret. Furthermore, PEF guidance itself points out that the data analysis methods for the 3 toxicity impact categories are currently under review, meaning that results in these categories need to be interpreted with caution (freshwater ecotoxicity, carcinogenic effects, and noncarcinogenic effects)('European Commission Joint Research Centre , Product Environmental Footprint Category Rules Guidance, Version 6.3. ' 2018).

The results of this LCA highlight the difficulty in naming the 'best' eco-friendly product. Although the bamboo interdental brush performed the best in climate change, bamboo is not an ideal sustainable material – it requires water and fertilizers to grow, and the land used for the crop will result in a reduction in biodiversity. Previous studies on toothbrushes found that although bamboo toothbrushes have a lower climate change impact compared to plastic toothbrushes, recycled plastic toothbrushes are even better (Duane et al, 2020). As the popularity of bamboo products increases, the environmental impact of producing bamboo may worsen, feed global demand for this material.

Comparing these LCIA results to a previous LCA study of toothbrushes, we find that the environmental impact of all the interdental cleaning aids in this study is less than that of a plastic toothbrush (for example, using a plastic toothbrush over 5 years produces 25.6kg $CO_2e$, compared to 11.4kg $CO_2e$ using floss picks over 5 years) (Lyne et al. 2020).

The results of this study could be used by both individuals (when choosing an interdental cleaning aid) and dental healthcare professionals. Dental healthcare professionals who are recommending interdental cleaning aids should consider clinical, cost, and environmental effectiveness of different products.

Interdental cleaning aids are recommended in clinical guidelines. The European Association of Periodontology recommend inter-dental cleaning, preferably with interdental brushes, is professionally taught to patients with gingival inflammation (Sanz et al. 2020). All interdental cleaning aids, such as those included in this study, will reduce certain periodontal parameters such as bleeding and gingival health indices (Hujoel, Hujoel, and Kotsakis 2018). Admittedly, the quality of evidence to recommend one product over another is poor, perhaps with some preference for interdental brushes over traditional floss (Worthington et al. 2019). Interdental brushes have been shown to remove plaque up to 2mm below the gingival margin (Sälzer et al. 2020) and are favoured over floss by European experts (Chapple et al. 2015). For individual patient oral health, it is best to form a tailored solution based on their oral health status and risk profile.

Where floss is clinically recommended; regular, sponge or bamboo floss products are preferable for the environment over floss picks. Where interdental brushes are clinically recommended; weekly brushes are preferable over daily 'single use' brush picks, and those with a bamboo handle or a plastic reusable handle are preferable over plastic handles. The bamboo interdental brush was overall the most environmentally effective interdental cleaning aid in this study.

## 2.7 Conclusion

Interdental cleaning is part of periodontal disease prevention and management and can have a positive impact on the oral health of patients. However, this study demonstrated that all floss and interdental brush products have an environmental footprint that negatively impacts planetary health. Floss picks (a short piece of floss fixed to a plastic handle) had the worst environmental footprint of the eight products included in this study. There was no single best environmentally friendly product, however the bamboo interdental brush had the lowest environmental impact in 5 out of 16 categories, including climate change. Healthcare professionals could use the results of this study when making product recommendations to patients, incorporating environmental sustainability alongside the clinical and financial needs of the patient.

This paper was approved for publication (see appendix 7.3).

# 3 Environmental sustainability of oral health interventions, a scoping review

## 3.1 Abstract


**Aim**

Oral health is essential to people's general health and wellbeing. Oral health interventions such as toothbrushing, interdental cleaning aids, and fluoride varnish play a crucial role in preventing oral disease. Oral healthcare has concentrated only on providing the best possible patient care, with no regard for the environmental impact, showing that it is essential to think about the entire product life cycle. Dentists should try to transform the practice of dentistry from a hazardous to a sustainable one by implementing environmental-friendly measures to help in decision-making and oral healthcare. This study aims to examine the literature on the impact of existing oral health interventions on environmental sustainability and review the methodology.

**Material and Methods**

Three key electronic databases were searched "(MEDLINE-Ovid, EMBASE-Ovid, and the Cochrane Library)" and the titles and abstracts were screened. Those that met inclusion criteria were retrieved, and key findings were extracted.

**Results**

Five papers met the inclusion criteria for the review. Data regarding the oral interventions and methods used to measure the environmental impacts were extracted in tables. The first three studies looked at specific oral health interventions, toothbrush,

and dental floss. The last two were considered public health interventions including, fluoride varnish, fissure sealants, and supervised toothbrushing. The environmental impact was carried out using either LCA methodology or carbon footprinting.

The environmental impact of toothbrushes and dental floss was mainly measured using LCA, while other public health interventions such as fluoride varnish and fissure sealant were measured with the carbon footprint.

## Conclusion

Due to the limited number of publications specifically related to the environmental sustainability of oral health interventions, further research is needed to establish a comprehensive knowledge basis of current interventions to reduce carbon emissions and other environmental impacts. Life cycle analysis is beneficial for measuring the environmental impact of dental products and provides a more comprehensive assessment than carbon foot printing alone.

## 3.2 Introduction

Measuring environmental impact of health interventions is important to deliver maximum health gain with minimum financial cost and harmful effect. Within dentistry, many oral interventions have been studied to improve individuals' oral health. The intervention can be located at various levels of stakeholders or involved in the care process on the dentist, organizational, and patient levels. For instance, initiatives have been created in Scotland to promote oral health at the population and clinical levels. "The Scottish Dental Clinical Effectiveness Programme (SDCEP) and Scottish Intercollegiate Guidelines Network" have released national recommendations on oral health evaluation in adults and caries prevention and management in children ("Prevention and management of dental caries in children: dental clinical guidance" 2018).

Also, in England the prevention toolkit "Delivering Better Oral Health" was created by Public Health England to provide practical, evidence-based advice for improving oral health and reducing diseases ("Delivering better oral health: an evidence-based toolkit for prevention " 2014).

Currently, there are a lot of evidence-based oral interventions recommended either in hospitals or dental offices or within a home setting. Home dental care products play an essential role in preventing and treating oral illness (Pitts et al. 2012). The most commonly prescribed oral intervention is toothbrushing. It is considered a fundamental self-care practice for the maintenance of oral health. Based on the Public Health

England toolkit for prevention, the toothbrush’s effectiveness as a preventative measure is well established. It is recommended to brush the teeth twice daily based on the caries risk assessment ("Delivering better oral health: an evidence-based toolkit for prevention " 2014). The Cochrane study of electric versus manual toothbrushes reported that despite electric toothbrushes showing 21% better plaque reduction over three months, there is no evidence that any form of toothbrush is preferable for caries reduction (Yaacob et al. 2014).

Moreover, many studies recommended using interdental cleaning aids to clean the interproximal area between the teeth and eliminate plaque accumulation, and it has been reported that an interdental brush is more effective than other alternative oral hygiene products including floss, toothpicks, and oral irrigators (Amarasena, Gnanamanickam, and Miller 2019; Worthington et al. 2019). Oral irrigators and cleaning sticks have few and inconsistent studies.

Many works of literature reported the effectiveness of oral interventions in hospitals or dental offices. For example, fluoride varnish effectively prevents dental caries and improves oral health in both primary and permanent dentitions (Sudhanthar et al. 2019; Medjedovic et al. 2015; Marinho et al. 2013). The Scottish government has established a national programme known as the child smile which aims to improve children’s oral health, reduce inequalities in dental health, and increase access to dental services. It is strongly helping to improve children’s teeth by distributing free dental packs and supervised toothbrushing programmes in all nurseries and schools (Macpherson et al. 2015).

Likewise, studies on the efficacy of pit and fissure sealants have shown that resinbased sealants reduce dental caries by between 11% and 51% (Ahovuo-Saloranta et al. 2017). Therefore, oral health care professionals should recommend prevention measures based on the patient and dentist levels to improve people's oral health and prevent dental caries and periodontal diseases.

There is no doubt that, as I have discussed previously in this study, environmental sustainability is considered a public health problem facing our planet (Duane, Harford, Ramasubbu, et al. 2019). The environment within healthcare services is obtaining greater attention across all clinical specialties, including dentistry (Grose et al. 2018). Health care delivery is not environmentally sustainable because of the significant waste production and high level of high carbon dioxide equivalent (CO2e) which harms the environment (Martin et al. 2021).

Based on the previous evidence, dentistry has a significant environmental impact because of the use of high energy and intensive resources (Mulimani 2017; Duane, Harford, Ramasubbu, et al. 2019). The profession of dentistry should develop sustainable guidelines for daily practices and promote the transition to green dentistry.

Currently, there are no definitive criteria or guidelines for sustainable dentistry. However, according to recent studies, dental teams are becoming more interested in how to become more sustainable; there is a series of 7 papers focusing on environmental sustainability within dentistry (Duane, Harford, Ramasubbu, et al.

2019). Oral health practitioners are becoming increasingly aware of the need to provide care sustainably, limiting the impact on natural resources while promoting and safely delivering excellent oral health.

The current increased single-use plastics emphasize the difficulty of establishing sustainable health care practices. The cost, individual attitudes, difficulty implementing remedial procedures, and the necessity to operate within statutory frameworks are all obstacles to sustainable health care practices. Therefore, it is necessary to create a framework for oral health care delivery that advocates optimal patient care while promoting environmental sustainability.

Evidence based intervention either at the dental office or at home such as toothbrushing with fluoride toothpaste, interdental cleaning aids to clean interproximal areas, community fluoride varnish programme, and fissure sealants in addition to water fluoridation are all examples of oral cost-effective interventions which clinical specialists can recommend promoting the prevention and decrease of dental diseases.

Prevention has a significant economic benefit for the individual and society. Prevention of dental caries and periodontal disease is more cost-effective than treating them. The sustainability agenda of public health activity has implications for oral disease prevention. It is rapidly impacting the nature of new items that hit the market, some of which have minimal research to back them up. For example, the study on the sustainability of toothbrushes has suggested that switching from traditional plastic toothbrushes to bamboo toothbrushes or a plastic one with a replaceable head is more environmentally sustainable. On the other hand, all other different options of the toothbrush have trade-offs that should be carefully considered (Lyne et al. 2020).

While many oral interventions have been recommended for use, evidence for their environmental impact is unclear. Many oral interventions have been studied. We were interested in what had been done before and how the interventions were measured. Many studies reported the environmental impact of the material, procurement, energy, and waste by assessing the life cycle and some by using carbon footprint. To our knowledge, no one focused on the sustainability of oral health intervention. Oral healthcare has concentrated only on providing the best possible patient care, with no regard for the environment, showing that it is essential to think about the entire product life cycle. Dentists should work to change dentistry to be more sustainable by implementing environmentally friendly products to help in decision-making and oral healthcare recommendations.

The aim of this study was to look more broadly at the existing evidence so that we could compare methodologies and get an idea of where we should look for recommendations. This study will comprehensively review the literature that addresses the research question, “What is the sustainability of oral health interventions”? A preliminary search of MEDLINE-Ovid, EMBASE-Ovid, and the Cochrane Library was undertaken, and no current or ongoing scoping reviews on the topic were identified.

## 3.3 Materials and methods

A scoping review was used because it was thought to be the best technique for solving the broad research topic. Scoping reviews are a type of knowledge synthesis that maps the evidence on a certain topic, identifying a major idea, theories, source of data, and research. The methodology established in this review is according to a five stages version of Arksey & O'Malley and the "PRISMA-ScR (PRISMA extension for Scoping Reviews)" (Arksey and O'Malley 2005; Tricco et al. 2018). These stages include (1) selecting the research question; (2) locating the relevant literature; (3) selecting the studies; (4) analyzing the data and (5) reporting and summarizing the findings.

**Review question**

I. To examine the reported range, scope, and impact of existing oral

health interventions on sustainability.

2. Review the methodology used in existing studies.
3. To summarise the findings and provide recommendations for best practice in any future research measuring the sustainability of oral health interventions.

## Eligibility criteria

### Inclusion criteria

All studies which studied environmental sustainability of oral health interventions with direct relation to dentistry. Written in English language and non-English. Discussed the topic sustainability regarding the environment, not the durability or any other meaning. All types of literature, including reviews, reports, commentaries, opinions, and research with no limitation for a year of publication.

### Exclusion criteria

Studies excluded from this review were those that were inappropriate for the research question or contained search terms with different context to the study question. And those which presented with absent or inadequate methodology with poor use of the English language, whether it was translated or written incorrectly.

## Research and study selection

This scoping review involved electronic searching of three key databases "MEDLINEOvid, EMBASE-Ovid, and the Cochrane Library". In addition, we hand searched the references of included papers. No current scoping reviews on the same topic were identified. The databases were searched using "Mesh (Medical Subject Headings)" and key terms in the following ways:

- environmental sustainability AND oral health OR oral hygiene.
- environmental impact AND oral health OR dental hygiene.

- environmental impact AND toothbrush.
- environmental impact AND oral health interventions.
- environmental impact AND oral health interventions.
- environmental impact AND oral prevention.

The MeSH terms, as well as subheadings, were modified to fit the various databases. The titles of the studies found through this search were reviewed first to determine whether articles satisfied the requirements for inclusion. The studies were chosen based on whether the phrases were presented in the titles or in the text.

Titles resulting from the database searches were screened. After reviewing the abstracts, all studies that met the inclusion criteria were retrieved, and read. Then the data extraction was done without methodological quality or risk of bias evaluation because this was a scoping review. Because sustainability is a broad term that includes a wide range of topics such as (carbon emissions, carbon footprint, climate change, plastic, and so on), various searches were conducted to find as many relevant interpretations of the term as possible. There was no limitation on the year of publication. The MeSH terms and subheadings, truncations, and mapping were adapted as appropriate for the various data- bases. See table 3.1 below.

**Table 3.1 Results of search strategy**

| Database | Initial number of articles located |
|---|---|
| Ovid Medline | 8 |
| EMBASE | 13 |
| Cochrane Library | None |
| TOTAL | 21 |

### 3.4 Results

From the 21 citations retrieved, 13 titles remained once duplicates were removed. These titles were screened, and four were selected for abstract review. In addition, one further relevant study was found with hand-searching. See the flow chart in figure 3.1.

Once abstracts were evaluated and compared to the criteria for inclusion, studies were found and read, with the article in the final set reviewed and compared. Collected data are presented below with information on the author, publication date, country of study, and outcomes in table 3.2.

**Figure 3.1 Search and retrieval process flow chart.**

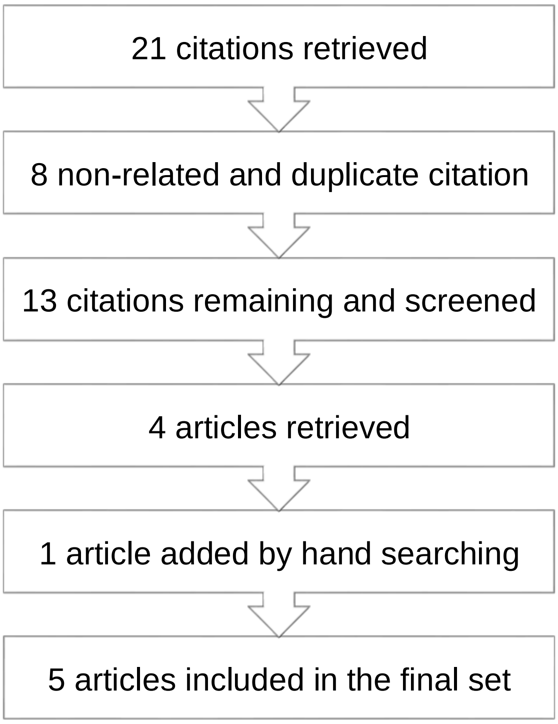


**Table 3.2 List of studies included in this scoping review**

| **Author and Country** | **Intervention area** | **Methods** | **Results** |
|---|---|---|---|
| (Lyne et al. 2020) United Kingdom. | Four types of toothbrushes<br>• Electric toothbrush<br>• Traditional plastic<br>• Bamboo manual<br>• Plastic manual with replaceable heads. | Life cycle assessment (LCA) | Poor sustainability of electric toothbrush. |
| (Duane et al. 2020) United Kingdom. | Toothbrush | Carbon footprint and DALYs. | The toothbrush made of recycled plastic had the smallest DALY loss. |

| | | | |
|---|---|---|---|
| Sao Paulo (2021) Spain | To assess the carbon footprint of six everyday personal care products: dental floss, shampoo, cotton swab, sanitary napkin and adhesive bandage. | Eco Audit tool | The nylon material of floss accounts for 63% of the carbon dioxide emissions, and the packaging is responsible for about 30%. |
| Public Health England report (2018) United Kingdom. | • Fluoride varnish<br>• Fissure sealant | Carbon footprint | Fluoride varnish contributes 19.150t$CO_2$e, about 2.9% of total carbon footprint.<br>Fissure sealants have a carbon footprint of 1.220t$CO_2$e, accounting for 0.2 % of total NHS. |

| | | | |
|---|---|---|---|
| (Bowden, Iomhair, and Wilson 2020) Wales. | 1- Fluoride varnish.<br>2- Supervised toothbrushing | Carbon footprint. | Carbon footprint was estimated to be 388 tonnes with staff travel 31%, business travel f 23%, and procurement 46%. And a million plastic items were estimated. |

This section will briefly summaries all five studies in this review. The first study by (Lyne et al. 2020) looked at the environmental impacts of four different types of toothbrushes over five years. This was the first study to quantify the environmental impact of toothbrushes. The analysis was performed at the Eastman Dental Hospital in London in partnership with the Dublin Dental University Hospital by using LCA methodology, and the software LCA v1.8 was consistent with ISO standards and PEF guide. The study measured 16 environmental impacts, which were explained before broadly (see chapter 2).

The study reported poor sustainability of electric toothbrushes over all other types as they had the greatest environmental impact in all factors except in water scarcity. The climate change was 11 times greater than the bamboo toothbrush. Also, the electric toothbrush was the heaviest product at 1.42 kg, with 47% contributing to the transport.

On the other hand, the bamboo and plastic toothbrushes with replaceable heads had the lowest environmental impact. Overall, all toothbrushes used plastic to make the bristles, and all except the bamboo type used plastic also for the toothbrush handle. The polypropylene material used in the handle is the most significant contributing factor to the environment, with 37% in manual plastic and 33% in manual plastic with replaceable heads. On the contrary, the bamboo toothbrush had the lowest percentage of plastic by 97% of all other types, including plastic manual and plastic with a replaceable head.

The second study by (Duane et al. 2020) which were performed at Trinity College Dublin and University College London. This study focused on measuring the carbon footprint and the human health impact (DALYs) of the toothbrush used in the above research. It has been reported that an electric toothbrush has the most significant impact on DALYs, a total of ten DALY hours (four times worse than the plastic manual toothbrush).

The plastic toothbrushes produced over 2.5 million kg of CO2E and over 43.000 DALYs. The study reported that nylon bristles were responsible for 90% of the carbon footprint, and water used to produce electricity was the greatest contributor to the

DALY. Although the bamboo handle used compared with polypropylene plastic will improved the carbon footprint by 68%, the DALY increased by 26%. According to this study, recycled plastic toothbrushes are the most environmentally friendly choice and result in the fewest DALY losses. The plastic recycling program's model used in this study had the best balance between carbon footprint and DALYs (90 % and 72 %).

The third study, which was found with hand searching, looked at the environmental impact of six everyday personal care products, including dental floss and toothbrushes. They calculated the carbon footprint using educational software called the Eco Audit tool of the CES Edu Pack. An environmental audit, or “eco audit” is a simplified life cycle assessment that allows comparisons between the environmental impacts of different products, materials, and processes with a focus only on energy consumption and CO2 emission as impact indicators.

The study explained the CO2 based on three scenarios regarding the toothbrush and dental floss. The first scenario considers that all the raw material is virgin, and that the destination is the landfill. The second scenario assumes that the raw material of the external packaging and brush handle is made from 100% recycled materials, while the bristles and elastomer are from a primary source, and the destination is a landfill. The third scenario follows the raw material structure of the second scenario. Still, the brush handle is reused, the external packaging is destined for recycling, and there is an exchange of the bristles, these together with the elastomer being destined to the landfill.

Regarding the toothbrush, the carbon footprint of material and manufacturers for all three scenarios were 98.9%, 98,4%, and 98.2%, respectively. It also showed the importance of reuse as an end-of-life option. Regarding dental floss, the nylon material of floss accounts for 63% of the carbon dioxide emissions, and the packaging is responsible for about 30% of the emission.  To our knowledge, this is the only study that measured the environmental impact of dental floss (Cesar Roberto de Farias 2021).

The fourth study is a carbon modelling report published by Public Health England, they used English and Scottish data and quantified the total environmental impact of many dental services and procedures, including fluoride varnish and fissure sealant. They measured carbon footprint by LCA methods. It was documented that applying fluoride varnish to one patient's teeth is estimated to be 5.5kg CO2e. Also, the carbon footprint of applying fissure sealant to one patient's teeth is estimated to be 8.8kg CO2e.

The report also documented the impact of nitrous oxide on the carbon footprint when used with fissure sealant or fluoride varnish. Regarding fluoride varnish, one single procedure with nitrous oxide estimated 39.79kg CO2e. The carbon footprint of a single fissure with nitrous oxide is 77.16kg CO2e. According to report, it is possible to hypothesize that prevention is less expensive and has a lower carbon footprint. Still, no detailed study to supports or refutes this claim

The final study evaluated the annual carbon footprint of the Welsh national childhood programme for oral health improvement called (Designed to smile). This programme included supervised toothbrushing and fluoride varnish. Both aimed to decrease the prevalence of dental caries in children in Wales. The study identified the steps to deliver supervised toothbrush and fluoride varnish and estimated the annual travel miles, financial spend on procurement, the number of plastics used, and water. By using carbon conversion factors, these contributors were converted to carbon emissions. The yearly carbon footprint was estimated at 388 tonnes of $CO_2e$, 31% related to staff travel, 23% to business travel, and 46% to procurement. The study reported (Designed to smile) a sustainable healthcare model (Bowden, Iomhair, and Wilson 2020).

## 3.5 Discussion

Providing oral healthcare has a considerable carbon footprint that is made up of emissions. To the best of our knowledge, this is the first review to assess the environmental impact of oral health interventions. Five studies were found to evaluate the environmental impact of different interventions. The first three looked at specific oral health interventions, toothbrushes, and dental floss. The last two were considered public health interventions, including fluoride varnish, fissure sealants, and supervised toothbrushing.

When we looked across all studies, it was noticed that the environmental impact was carried out using either LCA methodology or carbon footprint. The environmental impact of toothbrushes and dental floss was mainly measured using LCA, while other public health interventions were measured with the carbon footprint.

Regarding the LCA method, the electric toothbrush had poor sustainability except for water scarcity (Lyne et al. 2020). Also, it has a more significant impact on DALYs than a plastic manual toothbrush (Duane et al. 2020). The LCA results were normalised against the reference of an average individual from their daily life in a year. Also, a contribution analysis was carried out for each impact category. However, the authors had to ask the manufacturers for pertinent information to identify all the product materials and manufacturing procedures correctly. Also, assumptions were made based on the author’s understanding of the industry in cases where it was impossible to validate the same material, or the manufacturer was hesitant to provide the information. This would have impacted the LCA inventory's accuracy of study results.

Although toothbrush was extensively studied by LCA (Lyne et al. 2020), disabilityadjusted life years (DALYs) lost due to using toothbrush was also calculated (Duane et al. 2020). DALY was suggested to quantify the negative impact on health. Thus, this study advocates considering human health-related harm, such as DALYs, in addition to environmental damage by carbon emissions. DALY has been widely used for evaluating global and regional burden of diseases.

The carbon footprint was used to analyse the environmental impact of fluoride varnish, fissure sealant, and supervised toothbrushing. The fluoride varnish contributed 19.150t CO2e, while the fissure sealants have a carbon footprint of 1.220 tCO2e of all dental greenhouse gas emissions. The two methodologies of carbon footprinting used in this study were the process model and environmental input-output analysis (England. 2018).

The carbon footprint of dental floss was analysed using the Eco Audit tool software. This educational software tool allows a quick and simplified analysis by measuring two indicators of environmental impact: carbon footprint and energy expenditure. This method is not commonly used, and there was no description of this method. The assessment of this study was further complicated by the fact that the type of dental floss was not mentioned or specified.

Methods of measuring environmental impact can examine a variety of outcomes. For example, LCA methods measure climate change, ecosystem health, human health, and resource use.

Alternatively, one could concentrate on more specialized indicators of environmental degradation (such as climate change and the environment's carbon imprint). The LCA is likely a more comprehensive and widely used method to support sustainable development. It is the most used technique documented in many health-related environmental articles (Jamal et al. 2021) (Lyne et al. 2020). The benefits of using the LCA method are a range of measurements such as carbon emissions and consequences on the ozone layer, water quality, and ecosystem quality, depending on the model. However, LCA mainly relies on a lot of assumptions.

Carbon footprinting is another method alternative to the LCA methodology (Duane, Croasdale, et al. 2019). It is used to estimate greenhouse gas emissions. There are three main methods: the process model, the input-output model, and a hybrid model using both ways.

A process model is a bottom-up approach. It estimates the emissions attributed to each step in the product life cycle from initial production to final disposal of the product. An input-output model is a top-down approach, which can use that may be used to develop a carbon analysis of a specific process or system using financial values connected with carbon, for example, kilos of carbon equivalent emissions per euro spent.

There is no doubt that oral healthcare, in the form of prevention and therapeutic intervention, has an impact on the environment in the form of pollution, increased CO2e, and other environmental impacts. Organizations or governments frequently set targets using specific impacts; in the NHS, the national objective is to provide "net zero" (i.e., carbon) healthcare. Thus, in these conditions, employing a carbon footprinting approach would make sense to ensure that the results align with organizational goals. LCAs, enable a considerably more extensive range of environmental consequences to be examined, and we believe they should be the standard. Using carbon alone runs the risk of oversimplifying the environmental impact. LCA could dominate the protocol for measuring the environmental impact of dental products; this is probably because this approach is favoured by one of the leading research teams in this area (Duane and others).

Moreover, we need to measure the environmental impact of more oral interventions, even professionally given interventions should follow a similar strategy, and data on their clinical efficacy and environmental impact should be measured and published using the proper standard technique, like LCA. It should be discussed whether this information should be provided to product manufacturers or as part of an overall evaluation by evidence-based guidelines groups for oral health therapies.

### 3.6 Conclusion

Due to the limited number of publications specifically related to environmental sustainability within dentistry, it is essential to establish a comprehensive knowledge basis of current oral interventions to reduce carbon emissions and other environmental impacts. All previous studies on sustainability within dentistry have focused on some aspects concerning travel, procurements, and procedures. There is no robust evidence measuring the sustainability of oral interventions.

The NHS should deliver cost-effective oral interventions in a sustainable manner given their recommendation and disposal. Life cycle analysis is beneficial for measuring the environmental impact of dental products and provides a more comprehensive assessment than carbon footprinting alone.

# 4 Survey of paediatric dentists’ perspectives about environmental impact of oral health interventions.

## 4.1 Abstract

**Aim**

The aim of this study was to compare dentists’ perspective about the environmental impact of oral health interventions.

**Materials and methods**

A cross-sectional survey was conducted as an online questionnaire to compare dentist's perspective on the environmental impact of oral interventions. The online survey was distributed using social networks. A modified questionnaire was used to collect information about clinical interventions' sustainability, comprising 15 questions. Microsoft Office 365 form was used to host the survey.

**Results**

The study included 33 participants. Most dentists worked in a hospital 61%, and most were under 35 years old 48%. About 39% of participants did not consider environmental sustainability in clinical treatment choices during work. The majority of dentists, 70%, did not consider sustainability as a factor when recommending the toothbrush as well as dental floss 91%. Most participants (n=30) ranked bamboo toothbrushes and dental floss as the most sustainable interdental cleaning aids. Lack

of enough knowledge regarding the sustainability of clinical interventions was the prime factor that influenced the recommendation of sustainable products.

## Conclusion

Waste from dentistry contributes to worldwide health risks and harm to people's health. According to the current study, participants' knowledge, and practice of sustainability of clinical interventions are not up to mark. As a result, all dentists must contribute at their level by updating their knowledge of the topic to put it into practice during their planned recommendations and help achieve the goal of making green dentistry a global phenomenon.

## 4.2 Introduction

Dentistry uses a lot of resources and has a significant influence on the environment. Oral health care contributes to the environmental burden because of the considerable impact, including air pollution from high water consumption, plastic waste, lack of recyclable packaging, greenhouse gas emissions from anesthetic gases like nitrous oxide, and travel-related carbon dioxide (CO2) emissions. Moreover, Oral health care plays a significant role in the healthcare industries, with about 5% contribution to the global greenhouse gas emissions. (See chapter 1).

Dentists in different clinical settings are responsible for providing basic dental care such as routine examination, teeth filling, maintaining good oral hygiene, and urgent referral. Dentists have focused mainly on providing the best possible patient care by delivering interventions without regard for the environment. However, studies are starting to report on the environmental impact of oral interventions. (See chapter 2 and 3).

Knowing how to perform eco-friendly dentistry is crucial for dental practitioners because dentistry is one of the major healthcare sectors and is also responsible for many worldwide risks. However, there is still a lack of understanding and awareness of how oral health care affects the environment.

Dentists should try to transform the practice of dentistry from a hazardous to a sustainable one by implementing environmental-friendly measures to help in decision making and oral healthcare recommendations.  To do this, they need to understand

and appreciate the inter-relationship between the choice of oral healthcare interventions and the environment.

Dental professionals must be knowledgeable about eco-friendly dental practices because dentistry is a significant healthcare sector and is also responsible for many worldwide risks (VERMA et al. 2020). To achieve significant long term improvements engagement with stakeholders is needed. To drive change and reduce the risk of unintended consequences.

This study aims to address the knowledge and opinions of dentists about the environmental impact of oral health interventions. This study will be an exploratory survey used to investigate and understand the knowledge of dentists about the sustainability of oral health interventions used in dental practice. The survey will be conducted by using a questionnaire. Questionnaires will be administered online.

## 4.3 Methods

### 4.3.1 Study design and setting

This was an exploratory cross-sectional study in the form of a questionnaire that aimed to compare the dentist's perspective on the environmental impact of oral health interventions. The online survey was distributed among dentists using social networks e.g., Twitter. Microsoft Office 365 forms were used to host the survey.

The online survey questionnaire consisted of three parts and contained 15 questions. The study was conducted following the full ethical approval of the Ethics Committee from University College London in July 2022 (reference number: 22553.001). See appendix 7.4. The study's link transferred participants to the study's materials (appendix 7.5 and 7.6) (i.e., information about the study, the consent form, and the survey).

### 4.3.2 Measures and procedures

Once the decision has been made to conduct a survey, the questions were developed and divided into three main sections based on the data which need to be collected. Then, the questions were piloted. The first section included demographic data of the participant dentist. The second section contained 4 rating questions. Dentists will ask questions related to attitudes to environmental sustainability. The third section consisted of 8 questions related to environmental sustainability and clinical choices; those questions will focus mainly on how much environmental considerations would influence the participants in their clinical.

**Section 1: Demographic variables**

Three demographic variables (listed below) were collected from each dentist.

Validated and reliable questions were used to measure these defined variables - see below.

1. Type of dental practice (i.e., primary dental care, hospital, salaried dental service).

2. Age band.
3. To what extent can they influence purchasing and /or choice of clinical interventions in your main place of work.

**Section 2: Dentists attitude about environmental sustainability**

Dentists were asked to respond to 4 questions to know about their attitude to environmental sustainability.

Dentists were given four questions:

1- To what extent do you think consideration of environmental sustainability influences your lifestyle choices outside of dental work.

2- To what extent do you think consideration of environmental sustainability influences your clinical treatment choices during work.

3- There are different ways of measuring the environmental impact of clinical interventions. Dentists were given 7 options

- Life cycle analysis
- Carbon foot printing
- Climate change
- Ecosystem quality
- Human health effect
- Resource use

- Carbon dioxide equivalents (CO2E).

4- In dentistry, which one of the following factors do you think contributes most to adverse environmental impacts, Dentists were given 3 options

- Travel (Patient and/or staff)
- Waste e.g., gloves, towels etc.
- Resource use e.g., electricity/water
- Nitrous oxide release during inhalation sedation

**Section 3: Environmental sustainability and clinical choices**

In this section dentist were asked to respond to 8 questions to know about how much environmental considerations would influence your clinical decision making.

- Do they consider the sustainability of interventions when recommending toothbrushes and other dental cleaning aids such as floss etc.
- Dentists were asked to rank toothbrushing products in order of most sustainable to least (electric toothbrush, recyclable plastic toothbrush, recyclable plastic toothbrush with replaceable head, and bamboo toothbrush).
- Dentists were asked to rank interdental cleaning in order of most sustainable to least (floss tape, bamboo floss, floss picks, and super floss).
- Dentist were asked about the source of their information about the sustainability of oral healthcare interventions such as materials or techniques

- Dentists were asked about the guidelines they used to measure clinical effectiveness and sometimes costs in order to make recommendations.
- Dentists were asked to rank the most importance factors when they are choosing healthcare interventions (environmental impact, clinical effectiveness, and cost).

## 4.4 Results

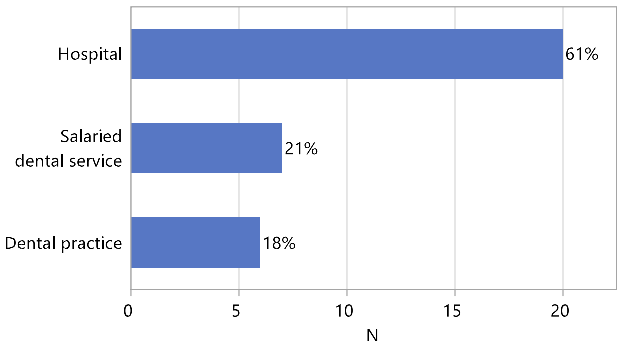
This is an explorative study. Descriptive analyses were performed on the demographic data and general responses of the participants. The sample of this study included 33 participants who were working in different clinical settings and completed the online survey.

### 4.4.1 Characteristics of participants

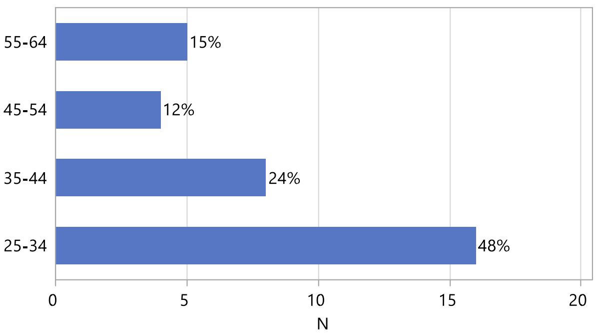
The participants were dentists working in different clinical locations. Most dentists reported their main employment is in a hospital (n=20, 61%) followed by salaried dental service (n=7, 21%), and dental practice (n=6,18%). Most of dentists were under 35 years old (n=17, 48%). Figure 4.1 presents the characteristics of the 33 participants.

**Figure 4.1 Characteristics of participants**

Clinical work location




Age group



### 4.4.2 Participants intention and attitude about environmental sustainability

Figure 4.2 presents participants' intention to provide clinical interventions; almost half of the participants, 52%, had some influence to consider clinical interventions in clinical settings. And about 18% of the participants had a lot of influence. Als in figure 4.3, 18% were very cautious of their lifestyle choices regarding environmental sustainability. Also, figure 4.4 presents that 33% of participants did not consider environmental sustainability in clinical treatment choices during work.

**Figure 4.2 Influence purchasing and/or choice of clinical interventions**

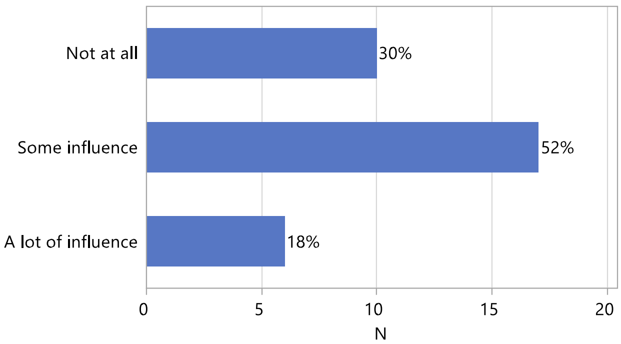


**Figure 4.3 Consideration of environmental sustainability influences my lifestyle choices outside of work.**

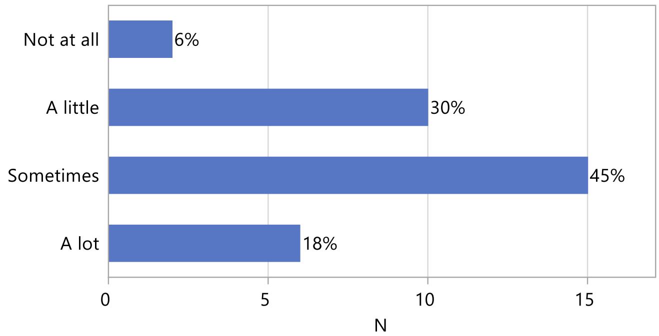
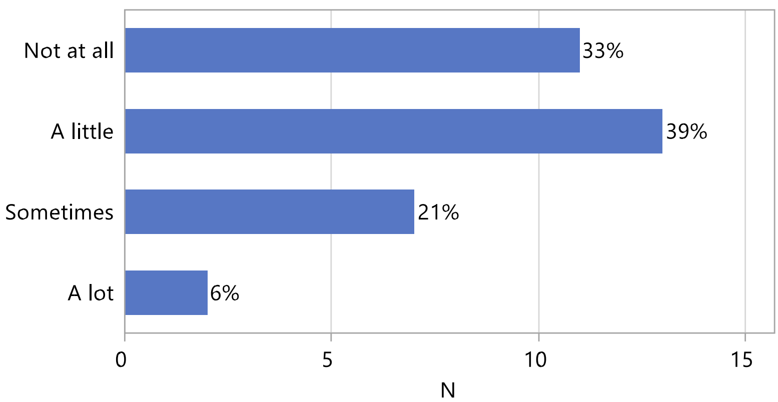


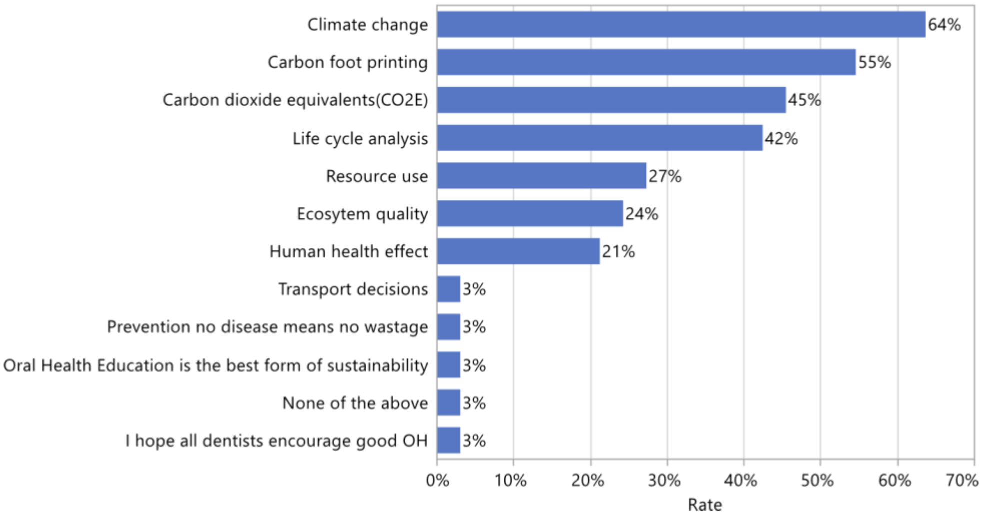

**Figure 4.4 Consideration of environmental sustainability influences my clinical treatment choices during work.**



### 4.4.3 Environmental sustainability and clinical choices

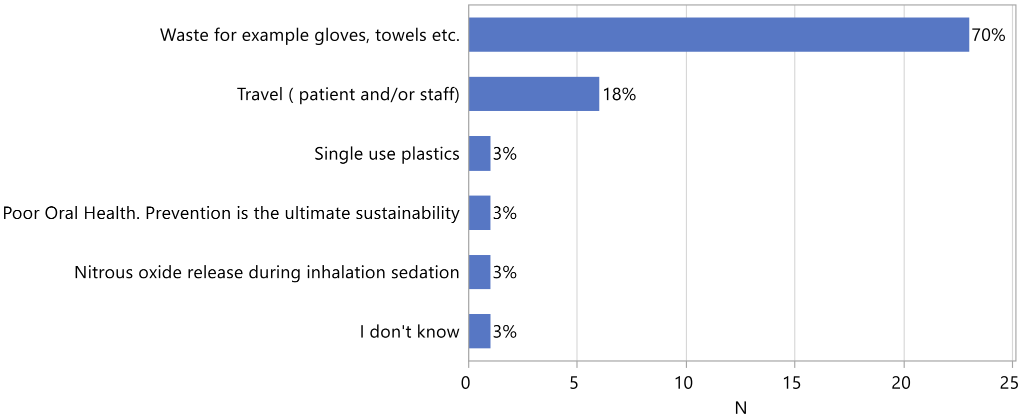
Regarding measuring the environmental impact of clinical interventions, the majority of dentists reported climate change measures as the tool to assess the environmental impact (n=21,64%), followed by carbon foot printing (n=18,55%), carbon dioxide equivalent (n=14, 45%), life cycle analysis (n=11, 42%), followed by use of resources, ecosystem quality, and human health. See figure 4.5.

**Figure 4.5 Measuring the environmental impact of clinical interventions.**




Regarding the most adverse environmental impact caused within dentistry, the majority of dentists, 70%, reported the waste production from dental work, such as gloves and materials, followed by patient and staff travel to the dental clinic by 18%. See figure 4.6.

**Figure 4.6 Most adverse environmental impact caused within dentistry.**




Regarding sustainable oral hygiene products, figure 4.7 and 4.8 showed that the majority of dentists (n= 23, 70%) were not considered sustainability as a factor when recommending the toothbrush as well as for interdental cleaning aids such as dental floss (n=30, 91%).

**Figure 4.7 Do you consider sustainability when recommending toothbrushes**

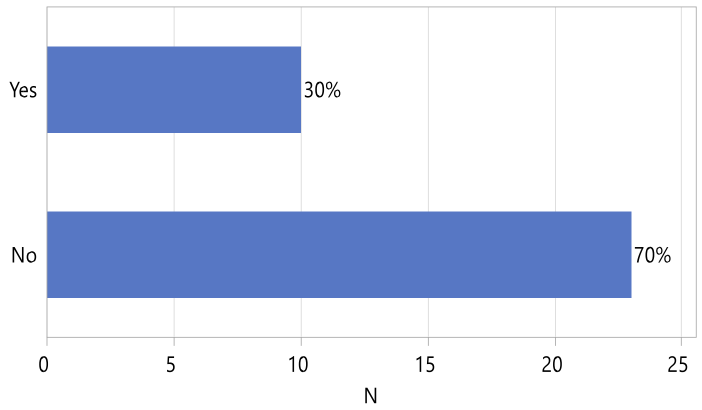
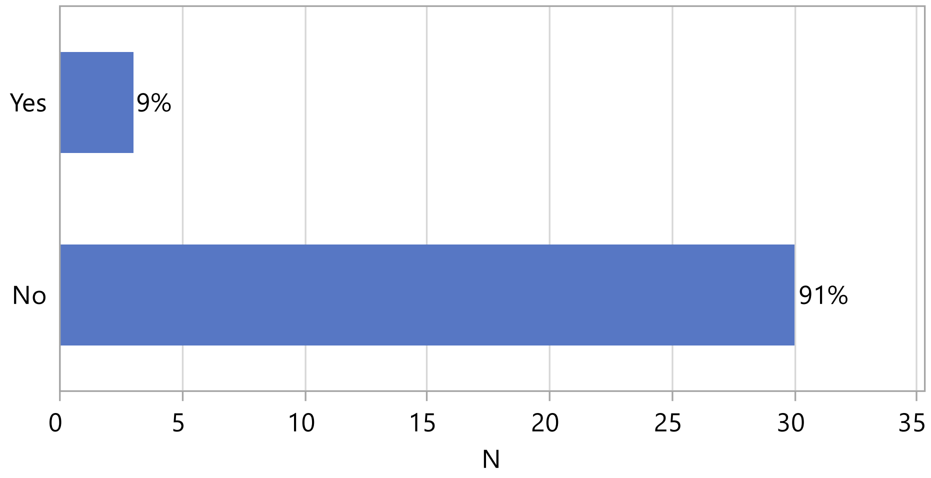



**Figure 4.8 Do you consider sustainability when recommending interdental cleaning aids**



In this study, when we asked the participants to rank the environmental impact of different types of toothbrushes and interdental cleaning aids in order of most sustainable to the least, most of the participants (n=30) ranked bamboo toothbrush as the most sustainable, followed by the electric toothbrush, plastic toothbrush, and plastic toothbrush with a replaceable head. Regarding the interdental cleaning aids, most of the participants (n=28) ranked bamboo floss, followed by floss tape, super floss, and floss picks.

For the information about the sustainability of oral healthcare interventions, most of the dentists (n= 26, 79%) did not know where to find the information to support their recommendations for their patients. And (n= 7, 21%) reported different sources of information, including n=1 reported faculty of General Dental Practice in the UK (FGDP), n=2 dental public health (DPH), n=2 the manufacture and equipment's suppliers, n=2 reported NHS. Most dentists, 88%, think the guidelines should add environmental impact to the prevention plan. When we asked the dentist to rank the clinical effectiveness, environmental impact, and cost when choosing healthcare interventions, most dentists ranked clinical effectiveness as the most important, followed by cost, then the environmental impact.

### 4.5 Discussion

This is an online cross-sectional survey aimed to explore dentists' perspectives and views regarding the knowledge about the sustainability of oral health intervention in clinical practice. The study is also designed to investigate which environmental factors may affect dentist's provision of sustainability.

In the present study, most participants worked in hospitals 61%. In my opinion the major difference between the two-healthcare experience primary care setting and hospital setting come down to this. However, Primary care and general practice are important components of the solution and must be regarded and treated as such. There is clear evidence that delivering primary care of a high quality reduces overall cost and improves health outcomes (Ballard 2013).

Almost half of the participants were aged between 25 and 34 years. In my opinion, there is no specific age that helps to implement sustainable healthcare, it is mainly dependent on the education. Based on evidence, there is an increasing awareness of a lack of education in undergraduate and postgraduate curricula, whether formally through continuing professional education programs or informally through formal education (Martin et al. 2021).

When they were asked about the extent which they can influence purchasing or choice of sustainable intervention in clinical work, there was less certainty. Almost half of the participants had some influences to consider sustainable interventions in clinical settings and only 18% were confidant to use a sustainable measure. Whereas 30% were not interested at all in any sustainable items to be purchased in clinics. Similarly, participants' views on their awareness of their choices and environmental sustainability were almost in the same direction, especially among those who were cautious about sustainability. About 18% of the participants were cautious of their lifestyle choices regarding environmental sustainability, while almost half of them were sometimes interested and nearly a third had very little awareness of environmental sustainability in their lifestyle choices.

Within dentistry, environmental sustainability can be measured in several ways. A study (England. 2018) reported measuring sustainability by carbon footprint and carbon dioxide equivalent. Another study reported measuring sustainability by life cycle analysis LCA (Borglin et al. 2021). The advantages and disadvantages for each type were discussed previously. (See introduction). In the present study, most participants reported climate change as a tool to assess the environmental impact (n=21,64%), followed by carbon footprint, carbon dioxide equivalent, and life cycle analysis. This indicates that many dental professionals are interested and have taken action in finding ways to measure environmental impact and transform dentistry to be more sustainable. However, there is little awareness; most dentists don't know how or what dental teams can do to change their daily working lives, this is because of many factors most significantly a lake of awareness due to inadequate research findings (Batsford, Shah, and Wilson 2022).

According to (Duane, Harford, Ramasubbu, et al. 2019), the carbon footprint of the dental industry has been estimated to be 675 kilotonnes of carbon dioxide equivalents ($CO_2e$), around 3% of the overall NHS footprint. Dental clinics use gallons of water, a large amount of electricity, and generate a large quantity of plastic each year (Batsford, Shah, and Wilson 2022). The most significant adverse impact within dentistry is caused by travel (both by patients and employees), contributing 64.5% of the carbon footprint of NHS dental services, followed by energy usage 15.3% and procurement.

This is because travel is related to air pollution, such as noise pollution and accidents, which results in a 14-minute reduction in the population's quality-adjusted life years (England. 2018). In the present study, the majority of participants around 70 % said that the largest contributor was caused by waste generation followed by travel, either staff or patients, by 18%. This is also because of a lack of awareness amongst the participants regarding the harmful effects of travel (Batsford, Shah, and Wilson 2022).

Furthermore, in the present study, most participants said they do not recommend sustainable or eco-friendly toothbrushes or interdental cleaning aids. This is not surprising; lack of enough knowledge was the main factor. Also, according to the study (VERMA et al. 2020), 45.6% of dentists believed that practicing environmentally friendly dentistry would put them under more financial strain and force them to eventually recover their costs from patients.

Moreover, when we asked the participants to rank toothbrushes and interdental cleaning aids from the most sustainable to the least, most of them ranked the bamboo toothbrush as the most environmentally friendly. Many people assumed bamboo toothbrush is the best and this might not be. This was consistent with one study (Lyne et al. 2020) that compared the sustainability of different toothbrushes and showed that bamboo and replaceable-head plastic toothbrushes had the lowest impact in all categories. However, replacement head toothbrush was probably the best, reduced weight of plastic from only replacing the head and not the handle had a greater impact than the fact that the replaceable heads did use a bioplastic with 30% of the polymer generated from starch. Regarding dental floss, most participants reported bamboo floss as the most sustainable; however, no previous study has been done to find the more sustainable dental floss (see chapter two).

Although there is a high level of awareness of carbon emissions and their effects on the environment, translation into the professional oral health domains is not as pervasive. Many participating dentists in this study did not know where to find the information to support their recommendations. The main cause of lack of engagement is the difficulties and barriers to recycling. Also, lack of cultural understanding of the value of recycling (Martin et al. 2021).

Raising awareness is crucial to the practice of sustainable dentistry, thus this would help policymakers better understand consumer behaviour. The government has outlawed the use of plastic and replaced it with paper bags and paper disposal glasses. Therefore, we as dental professionals should also participate actively and support the government to make our country healthy and green by recommending sustainable oral health care to patients. For example, using an eco-friendly toothbrush such as toothbrush made from bamboo will improve teeth health while reducing plastic pollution.

## 4.6 Limitations

The present study was carried out using a small sample size; only 33 participants volunteered. A sample size that is either too small or too large could make it difficult to extrapolate the results and highlight statistical differences that are not clinically significant. As opinions are subject to personal likes and dislikes, a further qualitative study can be conducted involving a mass population of dentists in and around the city.

## 4.7 Further research

This research was intended to explore the dentist’s views and perspective about sustainability measures in clinical intervention. This study observed that dentists who were cautious about sustainability in their lifestyle choices were likely to be interested in considering sustainable intervention in clinical settings. Many studies have been published about environmental sustainability, but dentist views were not commonly investigated. Dentists’ opinions may be affected by general environmental awareness. This is not surprising; we need to drive more attention to environmental sustainability. Investigations into consumer preferences for sustainability in terms of dental products, dental services, and public access to dental care are possible future research topics. This would encourage more sustainable dentistry by assisting policymakers (government, business, industry, non-profit organizations, managers, etc.) in better understanding consumer behaviour.

## 4.8 Conclusion

Waste from dentistry contributes to worldwide health risks and harm to people's health. According to the current study’s findings, participants' knowledge, and practice of sustainability of clinical interventions are not up to the mark. As a result, all dentists must contribute at their level by updating their knowledge of the topic to put it into practice during their planned recommendations and help achieve the goal of making green dentistry a global phenomenon.

# 5 Summary

This doctoral research discussed the environmental impact of interdental cleaning aids from different aspects. All interdental cleaning aids would reduce certain periodontal parameters such as bleeding and gingival. However, daily cleaning with interdental cleaning aids has an environmental footprint that varies depending on the type of product used. Floss picks have the most significant environmental footprint over all other types included in this study bamboo interdental brushes, regular floss, sponge floss, and bamboo floss.

Moreover, this research reviewed the method of measuring the environmental impact of oral interventions. The study looked at specific oral health interventions, including toothbrushes and dental floss. It also looked at public health interventions, including fluoride varnish, fissure sealants, and supervised toothbrushing. Both LCA methodology and carbon footprint were discussed. The decision between the two approaches should be made early in the developing process because it will determine the results that can be provided to the oral health guidelines creation committee.

LCA, enables a considerably more extensive range of environmental consequences to be examined, and we believe they should be the standard. However, when inventory data is challenging to find, the best estimations must be used. Using carbon alone runs the risk of oversimplifying the environmental impact. LCA could dominate the protocol for measuring the environmental impact of dental products; this is probably because this approach is favoured by one of the leading research teams in this area.

Furthermore, this research was also intended to explore the dentist's views and perspective on sustainability measures in clinical intervention via an online questionnaire. Dentists who were cautious about sustainability in their lifestyle choices were likely to be interested in considering sustainable intervention in clinical settings. Many studies have been published about environmental sustainability, but dentist views were not commonly investigated. Dentists' opinions may be affected by general environmental awareness.

**Recommendations**

We need to drive more attention to environmental sustainability within dentistry. Clinicians should consider environmental impact alongside clinical need and cost when recommending interdental cleaning aids to patients.

Investigations into consumer preferences for sustainability in terms of dental products, dental services, and public access to dental care are possible future research topics. This would encourage more sustainable dentistry by assisting policymakers and the government in better understanding consumer behaviors.

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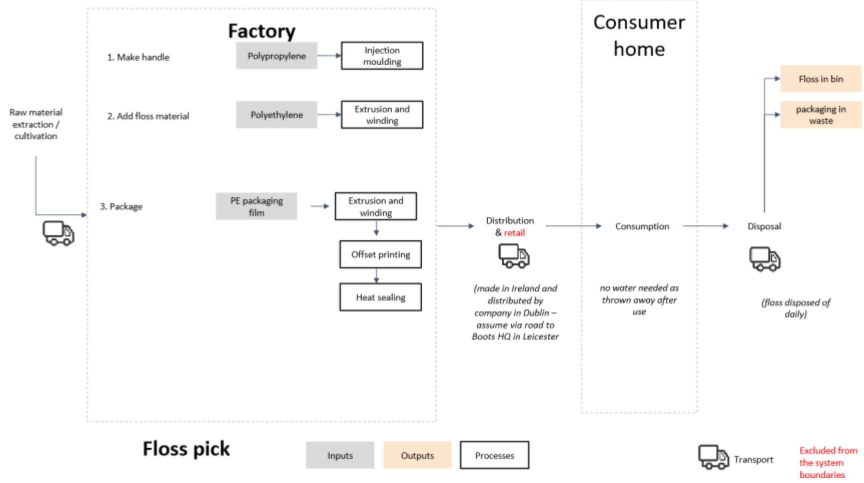
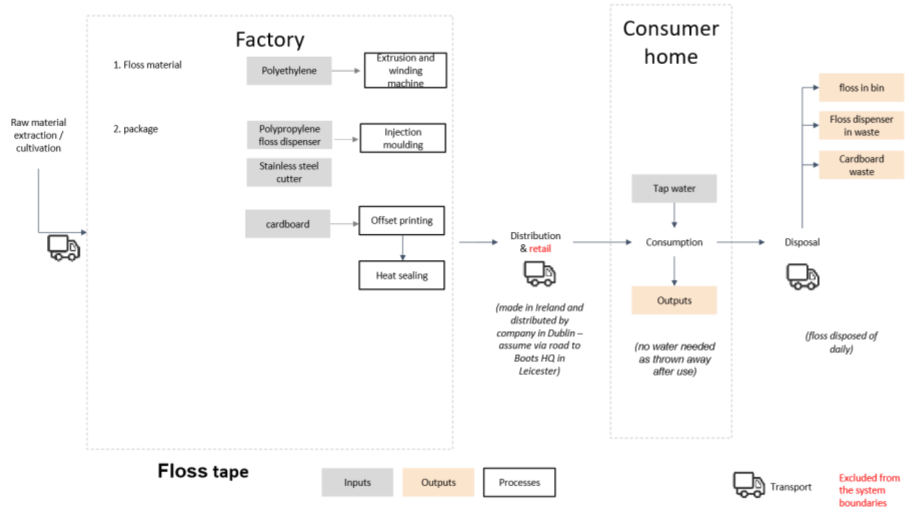
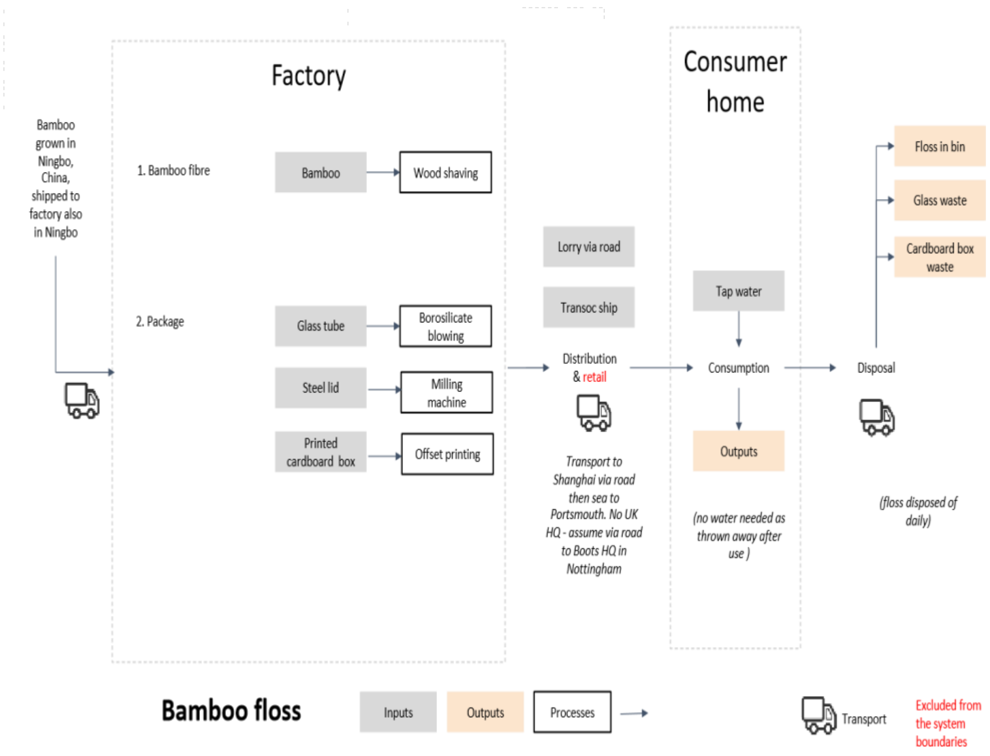
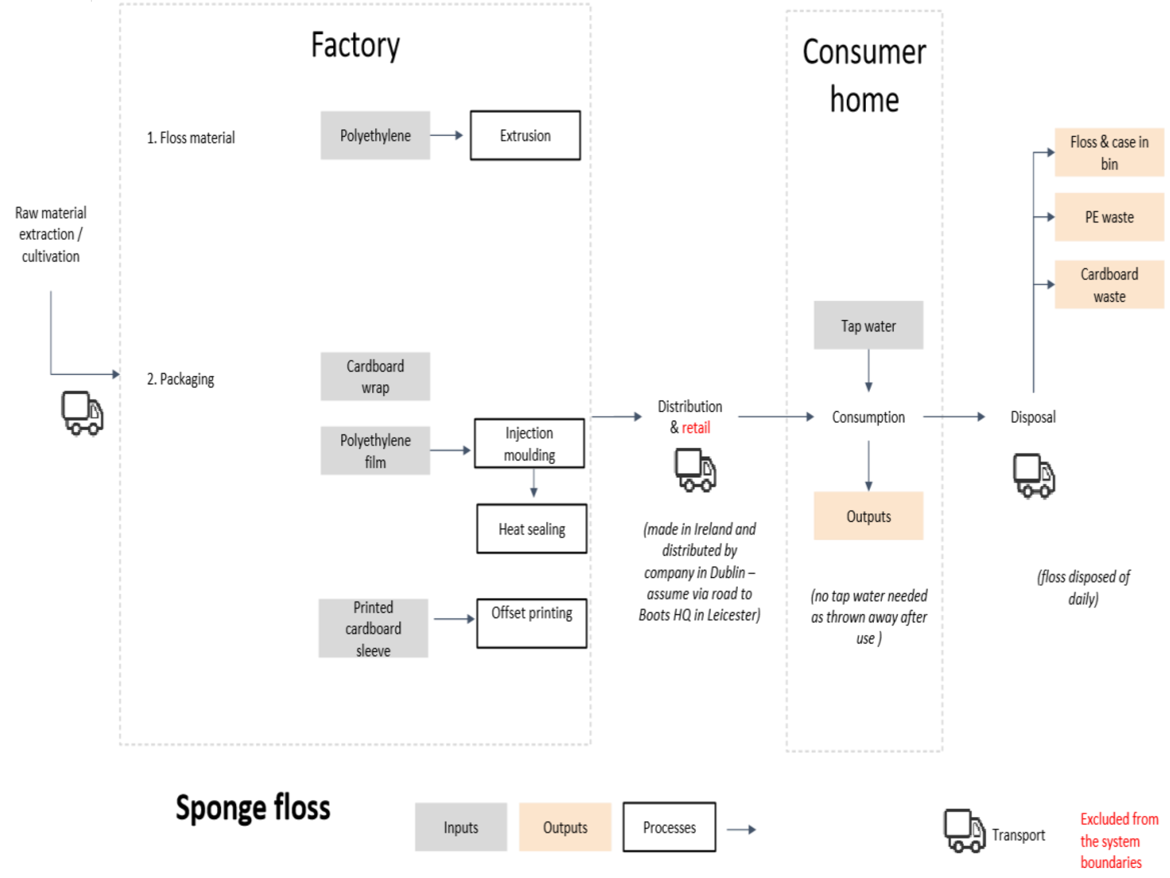
# 7 Appendices

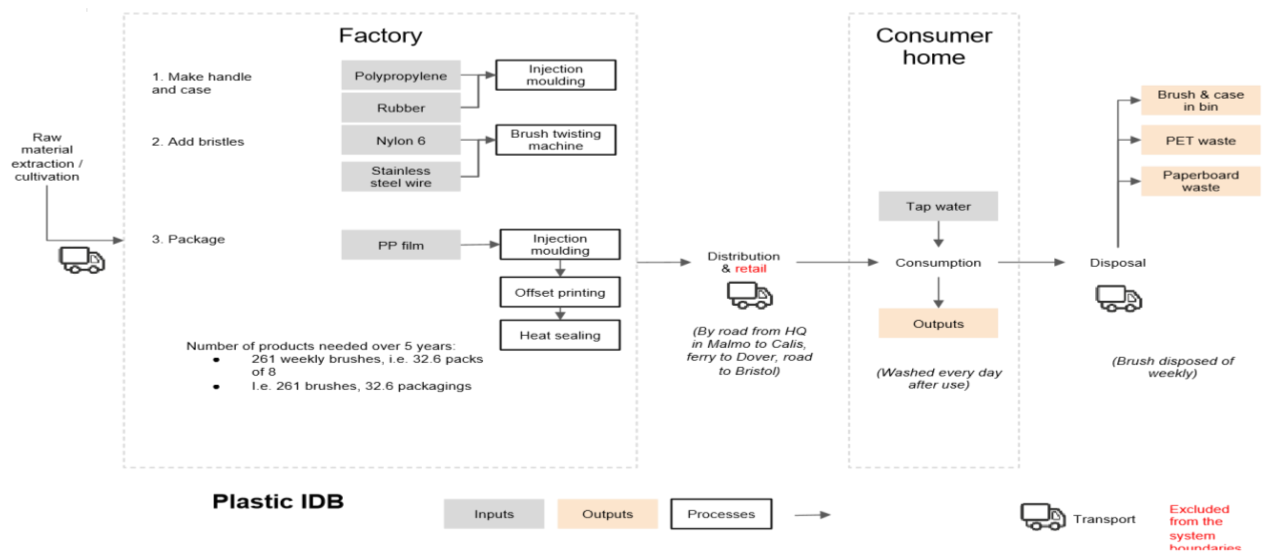
## 7.1 System boundaries for each type of interdental cleaning aids

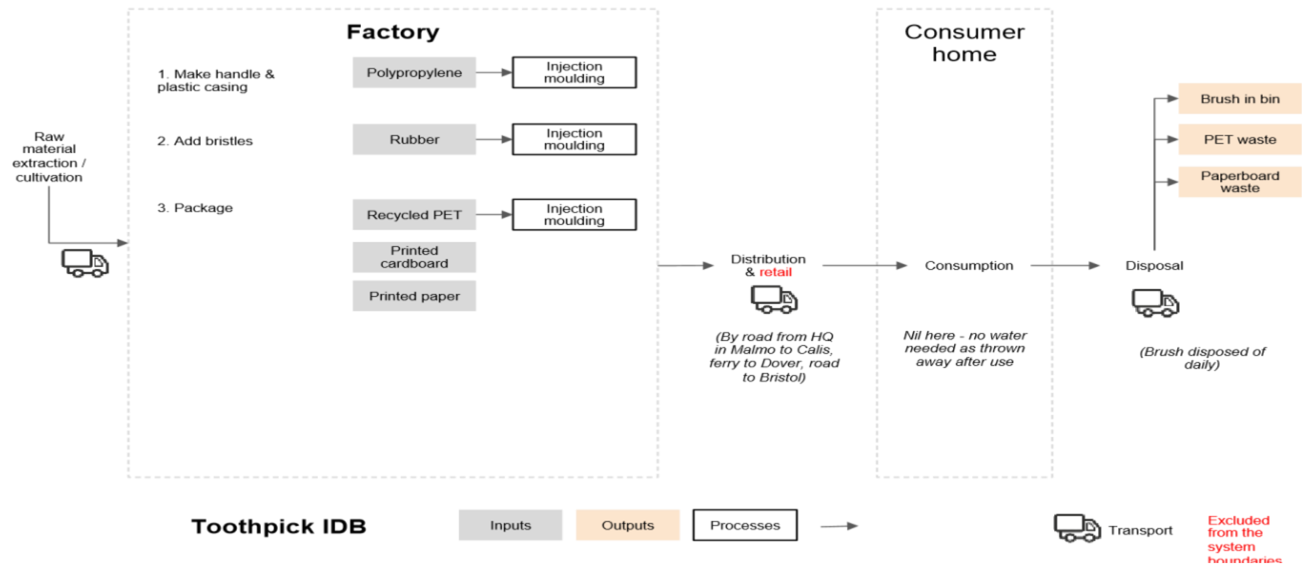


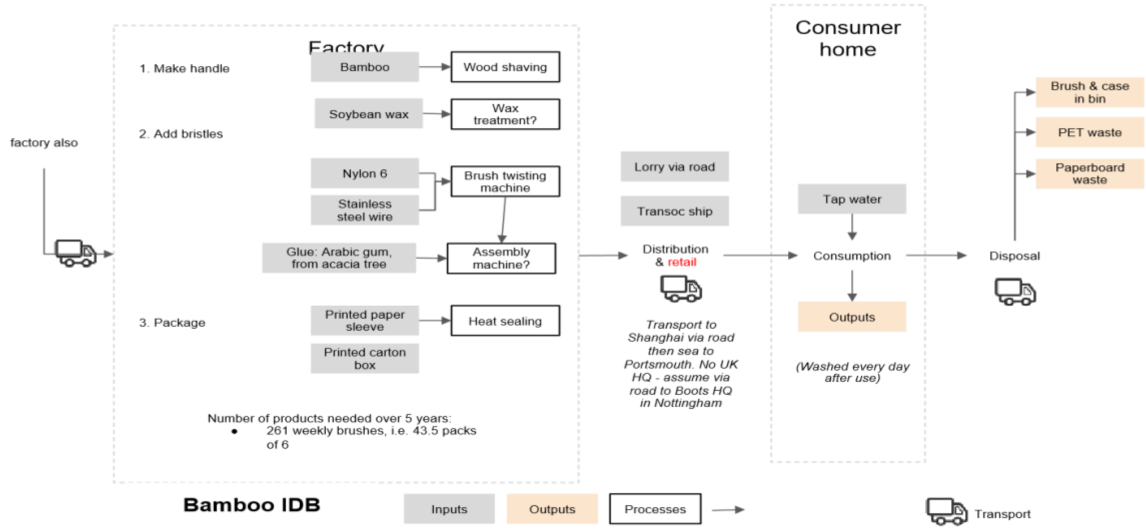



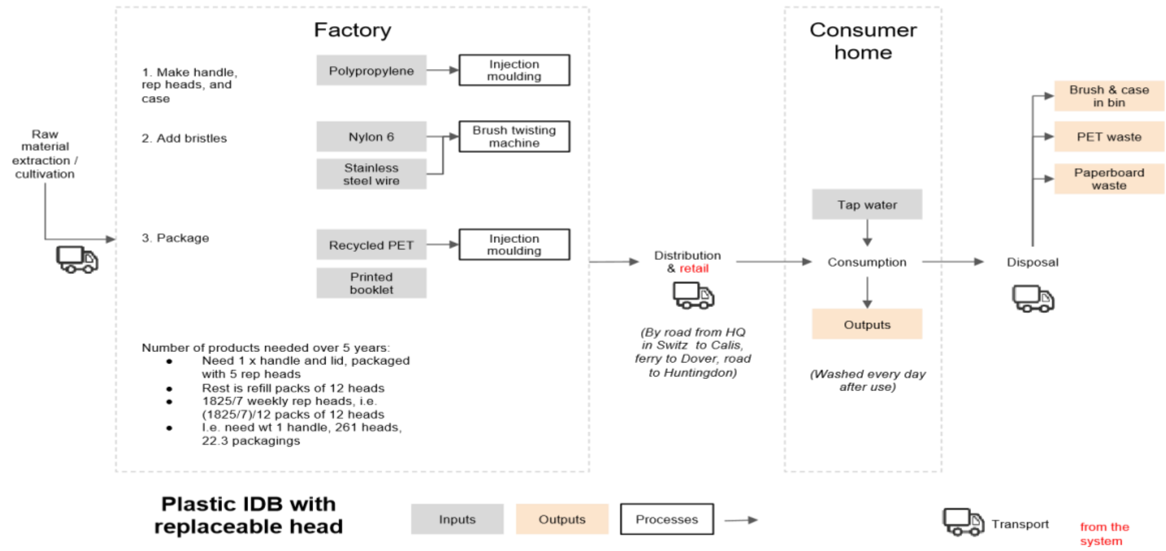

Factory
Consumer home
Bamboo grown in Ningbo, China, shipped to factory also in Ningbo
1. Bamboo fibre
Bamboo
Wood shaving
2. Package
Glass tube
Borosilicate blowing
Steel lid
Milling machine
Printed cardboard box
Offset printing
Lorry via road
Transoc ship
Distribution & retail
Transport to Shanghai via road then sea to Portsmouth. No UK HQ - assume via road to Boots HQ in Nottingham
Tap water
Consumption
Outputs
(no water needed as thrown away after use )
Disposal
Floss in bin
Glass waste
Cardboard box waste
(floss disposed of daily)
Bamboo floss
Inputs
Outputs
Processes
Transport
Excluded from the system boundaries


Factory
1. Floss material
Polyethylene
Extrusion
Raw material extraction / cultivation
2. Packaging
Cardboard wrap
Polyethylene film
Injection moulding
Heat sealing
Printed cardboard sleeve
Offset printing
Distribution & retail
(made in Ireland and distributed by company in Dublin – assume via road to Boots HQ in Leicester)
Consumer home
Tap water
Consumption
Outputs
(no tap water needed as thrown away after use )
Disposal
Floss & case in bin
PE waste
Cardboard waste
(floss disposed of daily)
Sponge floss
Inputs
Outputs
Processes
Transport
Excluded from the system boundaries


Factory
Consumer home
1. Make handle and case
Polypropylene
Rubber
Injection moulding
2. Add bristles
Nylon 6
Stainless steel wire
Brush twisting machine
Raw material extraction / cultivation
3. Package
PP film
Injection moulding
Offset printing
Heat sealing
Number of products needed over 5 years:
• 261 weekly brushes, i.e. 32.6 packs of 8
• I.e. 261 brushes, 32.6 packagings
Distribution & retail
(By road from HQ in Malmo to Calis, ferry to Dover, road to Bristol)
Tap water
Consumption
Outputs
(Washed every day after use)
Disposal
Brush & case in bin
PET waste
Paperboard waste
(Brush disposed of weekly)
Plastic IDB
Inputs
Outputs
Processes
Transport
Excluded from the system boundaries


Factory
Consumer home
1. Make handle & plastic casing
Polypropylene
Injection moulding
2. Add bristles
Rubber
Injection moulding
Raw material extraction / cultivation
3. Package
Recycled PET
Injection moulding
Printed cardboard
Printed paper
Distribution & retail
(By road from HQ in Malmo to Calis, ferry to Dover, road to Bristol)
Consumption
Nil here - no water needed as thrown away after use
Disposal
Brush in bin
PET waste
Paperboard waste
(Brush disposed of daily)
Toothpick IDB
Inputs
Outputs
Processes
Transport
Excluded from the system boundaries


factory also
Factory
1. Make handle
2. Add bristles
3. Package
Bamboo
Wood shaving
Soybean wax
Wax treatment?
Nylon 6
Stainless steel wire
Brush twisting machine
Glue: Arabic gum, from acacia tree
Assembly machine?
Printed paper sleeve
Printed carton box
Heat sealing
Number of products needed over 5 years:
261 weekly brushes, i.e. 43.5 packs of 6
Lorry via road
Transoc ship
Distribution & retail
Transport to Shanghai via road then sea to Portsmouth. No UK HQ - assume via road to Boots HQ in Nottingham
Consumer home
Tap water
Consumption
Outputs
(Washed every day after use)
Disposal
Brush & case in bin
PET waste
Paperboard waste
Bamboo IDB
Inputs
Outputs
Processes
Transport


Raw material extraction / cultivation
Factory
1. Make handle, rep heads, and case
2. Add bristles
3. Package
Polypropylene
Injection moulding
Nylon 6
Stainless steel wire
Brush twisting machine
Recycled PET
Injection moulding
Printed booklet
Number of products needed over 5 years:
Need 1 x handle and lid, packaged with 5 rep heads
Rest is refill packs of 12 heads
1825/7 weekly rep heads, i.e. (1825/7)/12 packs of 12 heads
I.e. need wt 1 handle, 261 heads, 22.3 packagings
Distribution & retail
(By road from HQ in Switz to Calis, ferry to Dover, road to Huntingdon)
Consumer home
Tap water
Consumption
Outputs
(Washed every day after use)
Disposal
Brush & case in bin
PET waste
Paperboard waste
Plastic IDB with replaceable head
Inputs
Outputs
Processes
Transport
from the system

## 7.2 Life cycle inventories and contribution analysis for interdental cleaning aids.

| Description | Amount | Unit | Ecoinvent dataset |
|---|---|---|---|
| ***Regular floss*** | | | |
| **Low density polyethylene** | 0.0945 | kg | market for polyethylene, low density, granulate \| polyethylene, low density, granulate \| Cutoff, U - GLO |
| **Extrusion to create floss** | 0.0945 | kg | extrusion, plastic film \| extrusion, plastic film \| Cutoff, U - RER |
| **Floss winding machine** | 0.560897436 | kWh | market for electricity, medium voltage \| electricity, medium voltage \| Cutoff, U - DE |
| **Plastic for dispenser** | 0.40244645 | kg | market for polypropylene, granulate \| polypropylene, granulate \| Cutoff, U - GLO |
| **Injection moulding for dispenser** | 0.40244645 | kg | injection moulding \| injection moulding \| Cutoff, U - RER |

| | | | |
|---|---|---|---|
| **Steel cutter on floss dispenser** | 5.35E-05 | kg | market for chromium steel removed by milling, small parts \| chromium steel removed by milling, small parts \| Cutoff, U - GLO |
| **Plastic packaging** | 0.0735 | kg | polyethylene terephthalate, granulate, amorphous, recycled to generic market for amorphous PET granulate \| polyethylene terephthalate, granulate, amorphous \| Cutoff, U - Europe without Switzerland |
| **Injection moulding packaging** | 0.0735 | kg | injection moulding \| injection moulding \| Cutoff, U - RER |
| **Printed cardboard back for packaging** | 0.0525 | kg | market for carton board box production, with offset printing \| carton board box production, with offset printing \| Cutoff, U - GLO |
| **Blister packaging machine** | 0.03 | kWh | market for electricity, medium voltage \| electricity, medium voltage \| Cutoff, U - DE |

| | | | |
|---|---|---|---|
| **Land transport (factory-UK)** | 400.0004112 | kg*km | transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified \| transport, freight, lorry, unspecified \| Cutoff, U - RER |
| **Sea transport (factory-UK)** | 26.85361016 | kg*km | transport, freight, sea, ferry \| transport, freight, sea, ferry \| Cutoff, U - GLO |
| **Disposal of floss (household waste)** | 0.09454725 | kg | market for municipal solid waste \| municipal solid waste \| Cutoff, U - GB |
| **Disposal of PET packaging (recycle)** | 0.0735 | kg | market for waste polyethylene terephthalate \| waste polyethylene terephthalate \| Cutoff, U - GB |
| **Disposal of plastic floss dispenser (recycle)** | 0.40245275 | kg | market for waste polypropylene \| waste polypropylene \| Cutoff, U - GB |

| | | | |
|---|---|---|---|
| **Disposal of cardboard packaging (recycle)** | 0.4526 | kg | market for waste paperboard \| waste paperboard \| Cutoff, U - GB |
| ***Floss picks*** | | | |
| **injection moulding for plastic handles** | 2.3725 | kg | injection moulding \| injection moulding \| Cutoff, U - RER |
| **polypropylene, granulate for plastic handles** | 2.3725 | kg | market for polypropylene, granulate \| polypropylene, granulate \| Cutoff, U - GLO |
| **extrusion, plastic to create floss tape** | 2.03E-04 | kg | extrusion, plastic film \| extrusion, plastic film \| Cutoff, U - RER |
| **polyethylene, low density,** | 2.03E-04 | kg | market for polyethylene, low density, granulate \| polyethylene, low density, granulate \| Cutoff, U - GLO |

| | | | |
|---|---|---|---|
| **granulate for floss material** | | | |
| **packaging film** | 0.267666667 | kg | market for packaging film, low density polyethylene \| packaging film, low density polyethylene \| Cutoff, U - GLO |
| **Heat sealing machine** | 0.012673611 | kWh | market for electricity, medium voltage \| electricity, medium voltage \| Cutoff, U - DE |
| **Offset printing on packaging** | 0.267666667 | kg | offset printing, per kg printed paper \| printed paper, offset \| Cutoff, U - RoW |
| **Sea transport (factory - UK)** | 114.0621243 | kg*km | transport, freight, sea, ferry \| transport, freight, sea, ferry \| Cutoff, U - GLO |
| **Land transport (factory - UK)** | 1699.022826 | kg*km | transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified \| transport, freight, lorry, unspecified \| Cutoff, U - RER |
| **Disposal of floss picks and** | 2.646453 | kg | market for municipal solid waste \| municipal solid waste \| Cutoff, U - GB |

| | | | |
|---|---|---|---|
| **packaging (household waste)** | | | |
| ***Sponge floss*** | | | |
| **polyethylene, low density, granulate for floss** | 0.09125 | kg | market for polyethylene, low density, granulate \| polyethylene, low density, granulate \| Cutoff, U - GLO |
| **extrusion of LDPE (create floss tape)** | 0.09125 | kg | extrusion, plastic film \| extrusion, plastic film \| Cutoff, U - RER |
| **cardboard wrap (inner packaging)** | 0.0876 | kg | market for folding boxboard carton \| folding boxboard carton \| Cutoff, U - RER |
| **packaging film (inner packaging)** | 0.06935 | kg | market for packaging film, low density polyethylene \| packaging film, low density polyethylene \| Cutoff, U - GLO |

| | | | |
|---|---|---|---|
| **printed cardboard sleeve (outer packaging)** | 0.365 | kg | market for carton board box production, with offset printing \| carton board box production, with offset printing \| Cutoff, U - GLO |
| **Land transport (factory - UK)** | 393.6744 | kg*km | transport, freight, lorry, all sizes, EURO4 to generic market for transport, freight, lorry, unspecified \| transport, freight, lorry, unspecified \| Cutoff, U - RER |
| **Sea transport (factory - UK)** | 26.42892 | kg*km | transport, freight, sea, ferry \| transport, freight, sea, ferry \| Cutoff, U - GLO |
| **Disposal of floss & non recyclable packaging (household waste)** | 0.1606 | kg | market for municipal solid waste \| municipal solid waste \| Cutoff, U - GB |

| | | | |
|---|---|---|---|
| **Disposal of cardboard packaging (recycle)** | 0.4526 | kg | market for waste paperboard \| waste paperboard \| Cutoff, U - GB |
| ***Bamboo floss*** | | | |
| **Raw bamboo** | 0.11558 | kg | Bamboo cultivation - CN (authors own dataset - see Lyne et al 2020 for details) |
| **Transport (raw bamboo - factory)** | 36.9856 | kg*km | market group for transport, freight, lorry, unspecified \| transport, freight, lorry, unspecified \| Cutoff, U - GLO |
| **Wood chipping (turn raw bamboo into bamboo chips)** | 0.11558 | kg | market for wood chipping, industrial residual wood, stationary electric chipper \| wood chipping, industrial residual wood, stationary electric chipper \| Cutoff, U - GLO |
| **Pulp production (bamboo chips - bamboo pulp)** | 0.11558 | kg | market for chemi-thermomechanical pulp \| chemi-thermomechanical pulp \| Cutoff, U - GLO |

| | | | |
|---|---|---|---|
| **Electricity for yarn spinning machine (turn bamboo pulp - fibre)** | 0.2704572 | kWh | market for electricity, low voltage \| electricity, low voltage \| Cutoff, U - CN-SGCC |
| **Heat for yarn spinning (turn bamboo pulp - fibre)** | 0.4426714 | MJ | market group for heat, district or industrial, natural gas \| heat, district or industrial, natural gas \| Cutoff, U - GLO |
| **Floss winding machine (turn fibre thread into wound spool of floss)** | 6.64E-07 | kWh | electricity voltage transformation from high to medium voltage \| electricity, medium voltage \| Cutoff, U - CN-SGCC |
| **Glass tube packaging** | 0.304166667 | kg | market for glass tube, borosilicate \| glass tube, borosilicate \| Cutoff, U - GLO |

| | | | |
|---|---|---|---|
| **Steel lid packaging** | 0.057791667 | kg | market for chromium steel removed by milling, small parts \| chromium steel removed by milling, small parts \| Cutoff, U - GLO |
| **Printed cardboard box packaging** | 0.085166667 | kg | market for carton board box production, with offset printing \| carton board box production, with offset printing \| Cutoff, U - GLO |
| **Sea transport (factory - UK)** | 12207.61531 | kg*km | transport, freight, sea, container ship \| transport, freight, sea, container ship \| Cutoff, U - GLO |
| **Land transport (factory - UK)** | 306.958305 | kg*km | market group for transport, freight, lorry, unspecified \| transport, freight, lorry, unspecified \| Cutoff, U - GLO |
| **Disposal of floss (household waste)** | 0.11558 | kg | market for municipal solid waste \| municipal solid waste \| Cutoff, U - GB |

| | | | |
|---|---|---|---|
| **Disposal of glass tube (recycle)** | 0.30417 | kg | market for waste glass \| waste glass \| Cutoff, U - GB |
| **Disposal of metal lid (recycle)** | 0.05779 | kg | market for scrap steel \| scrap steel \| Cutoff, U - RoW |
| **Disposal of cardboard packaging (recycle)** | 0.08517 | kg | market for waste paperboard \| waste paperboard \| Cutoff, U - GB |
| ***Regular IDB*** | | | |
| **injection moulding IDB handle and lid** | 0.32305 | kg | injection moulding \| injection moulding \| Cutoff, U - RER |
| **polypropylene, granulate for IDB handle** | 0.2704 | kg | market for polypropylene, granulate \| polypropylene, granulate \| Cutoff, U - GLO |

| | | | |
|---|---|---|---|
| **polypropylene, granulate for IDB lid** | 0.02145 | kg | market for polypropylene, granulate \| polypropylene, granulate \| Cutoff, U - GLO |
| **synthetic rubber for IDB handle** | 0.0312 | kg | market for synthetic rubber \| synthetic rubber \| Cutoff, U - GLO |
| **Brush twisting machine** | 0.072222222 | kWh | market for electricity, medium voltage, label-certified \| electricity, medium voltage, label-certified \| Cutoff, U - CH |
| **Nylon 6 for IDB bristles** | 0.0026 | kg | market for nylon 6 \| nylon 6 \| Cutoff, U - RER |
| **Steel for IDB wire** | 0.0026 | kg | market for steel, low-alloyed \| steel, low-alloyed \| Cutoff, U - GLO |
| **Creating wire from steel** | 0.0026 | kg | wire drawing, steel \| wire drawing, steel \| Cutoff, U - RER |
| **Heat sealing machine** | 0.006770833 | kWh | market for electricity, medium voltage, label-certified \| electricity, medium voltage, label-certified \| Cutoff, U - CH |

| | | | |
|---|---|---|---|
| **Injection moulding packaging** | 0.0585 | kg | injection moulding \| injection moulding \| Cutoff, U - RER |
| **polypropylene, granulate for packaging** | 0.0585 | kg | market for polypropylene, granulate \| polypropylene, granulate \| Cutoff, U - GLO |
| **Offset printing of packaging** | 0.0585 | kg | offset printing, per kg printed paper \| printed paper, offset \| Cutoff, U - RoW |
| **Land transport (factory - UK)** | 551.7568875 | kg*km | transport, freight, lorry >32 metric ton, EURO6 \| transport, freight, lorry >32 metric ton, EURO6 \| Cutoff, U - RER |
| **Sea transport (factory - UK)** | 16.668925 | kg*km | transport, freight, sea, ferry \| transport, freight, sea, ferry \| Cutoff, U - GLO |
| **Tap water used to clean IDB between uses** | 547.5 | kg | market for tap water \| tap water \| Cutoff, U - Europe without Switzerland |

| | | | |
|---|---|---|---|
| **Waste tap water** | 547.5 | l | market for wastewater, unpolluted, from residence \| wastewater, unpolluted, from residence \| Cutoff, U - RoW |
| **Disposal of IDB and packaging (household waste)** | 0.38675 | kg | market for municipal solid waste \| municipal solid waste \| Cutoff, U - GB |
| ***IDB picks*** | | | |
| **injection moulding for IDB handle and case** | 0.80249 | kg | injection moulding \| injection moulding \| Cutoff, U - RER |
| **polypropylene, granulate for handle** | 0.309743056 | kg | market for polypropylene, granulate \| polypropylene, granulate \| Cutoff, U - GLO |

| | | | |
|---|---|---|---|
| **polypropylene, granulate for case** | 0.49275 | kg | market for polypropylene, granulate \| polypropylene, granulate \| Cutoff, U - GLO |
| **injection moulding for IDB bristles** | 0.05475 | kg | injection moulding \| injection moulding \| Cutoff, U - RER |
| **synthetic rubber for IDB bristles** | 0.05475 | kg | market for synthetic rubber \| synthetic rubber \| Cutoff, U - GLO |
| **Cardboard packaging** | 0.089222222 | kg | market for carton board box production, with offset printing \| carton board box production, with offset printing \| Cutoff, U - GLO |
| **Injection moulding for packaging** | 0.431916667 | kg | injection moulding \| injection moulding \| Cutoff, U - RER |
| **Polyethylene terephthalate,** | 0.431916667 | kg | market for polyethylene terephthalate, granulate, amorphous \| polyethylene terephthalate, granulate, amorphous \| Cutoff, U - GLO |

| | | | |
|---|---|---|---|
| **granulate for packaging** | | | |
| **Printing on plastic packaging** | 0.021291667 | kg | offset printing, per kg printed paper \| printed paper, offset \| Cutoff, U - RoW |
| **Land transport (factory - UK)** | 1996.839206 | kg*km | transport, freight, lorry >32 metric ton, EURO6 \| transport, freight, lorry >32 metric ton, EURO6 \| Cutoff, U - RER |
| **Land transport (factory - UK)** | 60.325777 | kg*km | transport, freight, sea, ferry \| transport, freight, sea, ferry \| Cutoff, U - GLO |
| **Disposal of IDB (household waste)** | 0.5475 | kg | market for municipal solid waste \| municipal solid waste \| Cutoff, U - GB |
| **Disposal of cardboard packaging (recycle)** | 0.110513889 | kg | market for waste paperboard \| waste paperboard \| Cutoff, U - GB |

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|---|---|---|---|
| **Disposal of PET packaging (recycle)** | 0.431916667 | kg | market for waste polyethylene terephthalate \| waste polyethylene terephthalate \| Cutoff, U - GB |
| **Disposal of IDB case (recycle)** | 0.309743056 | kg | market for waste polypropylene \| waste polypropylene \| Cutoff, U - GB |
| ***Replaceable head IDB*** | | | |
| **injection moulding for handle and plastic part of brush head** | 0.01314 | kg | injection moulding \| injection moulding \| Cutoff, U - RER |
| **polypropylene, granulate for reusable handle** | 0.00274 | kg | market for polypropylene, granulate \| polypropylene, granulate \| Cutoff, U - GLO |
| **polypropylene, granulate for** | 0.0104 | kg | market for polypropylene, granulate \| polypropylene, granulate \| Cutoff, U - GLO |

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|---|---|---|---|
| **replaceable heads** | | | |
| **brush twisting machine** | 0.043333333 | kWh | market for electricity, medium voltage, label-certified \| electricity, medium voltage, label-certified \| Cutoff, U - CH |
| **Nylon for bristles of IDB** | 0.0026 | kg | market for nylon 6 \| nylon 6 \| Cutoff, U - RER |
| **Steel for IDB wire** | 0.0026 | kg | market for steel, low-alloyed \| steel, low-alloyed \| Cutoff, U - GLO |
| **wire drawing, steel** | 0.0026 | kg | wire drawing, steel \| wire drawing, steel \| Cutoff, U - RER |
| **injection moulding for PET packaging** | 0.118613333 | kg | injection moulding \| injection moulding \| Cutoff, U - RER |
| **polyethylene terephthalate,** | 0.118613333 | kg | market for polyethylene terephthalate, granulate, amorphous \| polyethylene terephthalate, granulate, amorphous \| Cutoff, U - GLO |

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|---|---|---|---|
| **granulate, for packaging** | | | |
| **Printed paper insert** | 0.065493333 | kg | market for printed paper, offset \| printed paper, offset \| Cutoff, U - GLO |
| **Land transport (factory - UK)** | 194.94972 | kg*km | transport, freight, lorry >32 metric ton, EURO6 \| transport, freight, lorry >32 metric ton, EURO6 \| Cutoff, U - RER |
| **Sea transport (factory - UK)** | 8.725164 | kg*km | market for transport, freight, sea, ferry \| transport, freight, sea, ferry \| Cutoff, U - GLO |
| **Tap water to clean replaceable IDB heads between uses** | 547.5 | kg | market for tap water \| tap water \| Cutoff, U - Europe without Switzerland |
| **Waste tap water** | 547.5 | l | market for wastewater, unpolluted, from residence \| wastewater, unpolluted, from residence \| Cutoff, U - RoW |

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|---|---|---|---|
| **Disposal of replaceable heads (household waste)** | 0.01834 | kg | market for municipal solid waste \| municipal solid waste \| Cutoff, U - GB |
| **Disposal of paper packaging (recycle)** | 0.065493333 | kg | market for waste paperboard \| waste paperboard \| Cutoff, U - GB |
| **Disposal of plastic packaging (recycle)** | 0.118613333 | kg | market for waste polypropylene \| waste polypropylene \| Cutoff, U - GB |
| ***Bamboo IDB*** | | | |
| **Raw bamboo** | 0.2106 | kg | Bamboo cultivation - CN (authors own dataset - see Lyne et al 2020 for details) |

| | | | |
|---|---|---|---|
| **Shaping wooden handle** | 2.816666667 | kWh | market for electricity, medium voltage, label-certified \| electricity, medium voltage, label-certified \| Cutoff, U - CH |
| **Wax** | 0.0026 | kg | market for soybean oil, refined \| soybean oil, refined \| Cutoff, U - GLO |
| **Transport of raw bamboo** | 67.392 | kg*km | transport, freight, lorry 16-32 metric ton, EURO6 \| transport, freight, lorry 16-32 metric ton, EURO6 \| Cutoff, U - RoW |
| **Brush twisting machine** | 0.072222222 | kWh | market for electricity, medium voltage, label-certified \| electricity, medium voltage, label-certified \| Cutoff, U - CH |
| **Nylon bristles** | 0.0026 | kg | market for nylon 6 \| nylon 6 \| Cutoff, U - RoW |
| **Steel wire** | 0.0026 | kg | market for steel, low-alloyed \| steel, low-alloyed \| Cutoff, U - GLO |
| **Wire drawing** | 0.0026 | kg | wire drawing, steel \| wire drawing, steel \| Cutoff, U - GLO |

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|---|---|---|---|
| **Cardboard packaging** | 0.199333333 | kg | market for carton board box production, with offset printing \| carton board box production, with offset printing \| Cutoff, U - GLO |
| **Heat sealing paper insert** | 0.009027778 | kWh | market for electricity, medium voltage, label-certified \| electricity, medium voltage, label-certified \| Cutoff, U - CH |
| **Paper insert** | 0.032066667 | kg | market for printed paper, offset \| printed paper, offset \| Cutoff, U - GLO |
| **Land transport (factory-UK)** | 456.3988 | kg*km | transport, freight, lorry >32 metric ton, EURO6 \| transport, freight, lorry >32 metric ton, EURO6 \| Cutoff, U - RoW |
| **Sea transport (factory-UK)** | 12254.04117 | kg*km | transport, freight, sea, container ship \| transport, freight, sea, container ship \| Cutoff, U - GLO |
| **Tap water** | 547.5 | kg | market for tap water \| tap water \| Cutoff, U - Europe without Switzerland |

| | | | |
|---|---|---|---|
| **Waste tap water** | 547.5 | l | market for wastewater, unpolluted, from residence \| wastewater, unpolluted, from residence \| Cutoff, U - RoW |
| **Household waste** | 0.33345 | kg | market for municipal solid waste \| municipal solid waste \| Cutoff, U - GB |
| **Paper recycling** | 0.2314 | kg | market for waste paperboard \| waste paperboard \| Cutoff, U - GB |

| | Climate change | Acidification | Freshwater ecotoxicity | Freshwater eutrophication | Marine eutrophication | Terrestrial eutrophicatio | Carcinogenic effects | Ionising radiation | Non-carcinogenic effects | Ozone depletion | Photochemical ozone formation | Respiratory inorganics | Water use | Fossil use | Land use | Mineral and metal use |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Regular floss** | | | | | | | | | | | | | | | | |
| Polypropylene dispenser | 31.16% | 42.36% | 15.16% | 14.52% | 34.85% | 41.56% | 33.05% | 7.99% | 27.72% | 15.66% | 46.17% | 50.39% | 35.29% | 53.27% | 13.36% | 56.61% |
| Injection moulding (case) | 14.90% | 24.06% | 7.35% | 27.33% | 17.71% | 18.49% | 22.43% | 55.58% | 22.60% | 46.98% | 16.47% | 12.63% | 28.85% | 18.04% | 44.23% | 13.20% |
| Manufacturing machinery (floss winding & blister packaging) | 11.25% | 8.52% | 2.78% | 45.49% | 11.74% | 9.36% | 9.56% | 19.18% | 14.78% | 7.43% | 6.34% | 4.02% | 5.80% | 9.67% | 8.08% | 6.60% |
| LDPE floss | 7.93% | 11.37% | 3.90% | 4.85% | 9.80% | 11.43% | 8.62% | 3.71% | 8.15% | 4.37% | 15.22% | 13.22% | 13.01% | 12.78% | 3.93% | 13.89% |
| Disposal of PP dispenser | 22.57% | 1.42% | 31.81% | 0.12% | 5.29% | 3.21% | 3.86% | 0.20% | 7.47% | 1.61% | 2.36% | 2.06% | 2.47% | 0.28% | 1.45% | 0.34% |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PET packaging | 2.89% | 3.68% | 5.32% | 3.33% | 4.61% | 4.18% | 11.68 % | 6.20% | 5.65% | 7.21% | 3.46% | 4.60% | 2.84% | 2.34% | 5.29% | 5.24% |
| Land transport | 1.67% | 2.91% | 5.15% | 0.33% | 4.23% | 5.20% | 2.61% | 1.34% | 4.94% | 10.13 % | 4.16% | 6.32% | 0.39% | 1.35% | 6.50% | 1.68% |
| Extrusion PE (to make floss) | 1.26% | 2.07% | 0.84% | 2.46% | 1.73% | 1.73% | 2.30% | 4.84% | 2.37% | 2.06% | 1.31% | 1.43% | 9.10% | 1.30% | 8.58% | 1.11% |
| Cardboard packaging | 1.03% | 1.82% | 1.45% | 1.25% | 1.91% | 1.95% | 2.04% | 0.78% | 1.75% | 3.24% | 2.33% | 3.85% | 1.40% | 0.77% | 7.85% | 1.05% |
| Disposal of PET | 3.34% | 0.31% | 20.42 % | 0.02% | 3.49% | 0.73% | 0.52% | 0.04% | 1.97% | 0.30% | 0.52% | 0.39% | 0.35% | 0.05% | 0.27% | 0.06% |
| Disposal of floss | 1.89% | 0.35% | 5.67% | 0.27% | 3.45% | 0.68% | 2.49% | 0.07% | 2.46% | 0.49% | 0.60% | 0.90% | 0.47% | 0.08% | 0.41% | 0.10% |
| Sea transport | 0.10% | 1.10% | 0.05% | 0.01% | 1.16% | 1.45% | 0.20% | 0.06% | 0.05% | 0.50% | 1.04% | 0.14% | 0.01% | 0.06% | 0.02% | 0.03% |
| Steel cutter part | 0.01% | 0.03% | 0.10% | 0.02% | 0.03% | 0.03% | 0.64% | 0.01% | 0.09% | 0.02% | 0.02% | 0.05% | 0.02% | 0.01% | 0.03% | 0.09% |
| Disposal of cardboard packaging | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| **Floss picks** | | | | | | | | | | | | | | | | |
| Polypropylene handle | 49.33 % | 51.00 % | 25.15 % | 30.08 % | 40.29 % | 50.19 % | 40.84 % | 12.72 % | 33.10 % | 20.08 % | 54.84 % | 48.90 % | 39.79 % | 66.34 % | 7.33% | 67.37 % |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Injection moulding | 19.94 % | 24.49 % | 10.31 % | 47.88 % | 17.31 % | 18.88 % | 23.44 % | 74.81 % | 22.82 % | 50.93 % | 16.54 % | 10.37 % | 27.51 % | 18.99 % | 20.53 % | 13.29 % |
| Printing on packaging | 6.85% | 10.35 % | 9.32% | 11.23 % | 11.59 % | 12.36 % | 11.43 % | 4.49% | 19.11 % | 11.34 % | 10.36 % | 23.89 % | 17.62 % | 4.12% | 64.53 % | 8.25% |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Disposal (household waste) | 14.24% | 2.00% | 44.66% | 2.63% | 18.92% | 3.92% | 14.64% | 0.56% | 13.93% | 2.99% | 3.40% | 4.15% | 2.53% | 0.47% | 1.07% | 0.57% |
| Packaging film | 7.56% | 8.63% | 4.33% | 7.34% | 7.35% | 8.81% | 7.12% | 5.69% | 6.69% | 4.80% | 10.38% | 8.16% | 12.19% | 8.76% | 3.94% | 9.01% |
| Land transport | 1.90% | 2.53% | 6.16% | 0.49% | 3.52% | 4.53% | 2.31% | 1.55% | 4.25% | 9.36% | 3.56% | 4.42% | 0.32% | 1.21% | 2.57% | 1.44% |
| Sea transport | 0.12% | 0.96% | 0.05% | 0.01% | 0.96% | 1.26% | 0.18% | 0.06% | 0.04% | 0.47% | 0.88% | 0.10% | 0.01% | 0.06% | 0.01% | 0.03% |
| Machinery (assembly, heat | 0.06% | 0.04% | 0.02% | 0.34% | 0.05% | 0.04% | 0.04% | 0.12% | 0.06% | 0.03% | 0.03% | 0.01% | 0.02% | 0.04% | 0.02% | 0.03% |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| sealing packets) | | | | | | | | | | | | | | | | |
| LDPE (floss) | 0.00% | 0.00% | 0.00% | 0.00% | 0.01% | 0.01% | 0.00% | 0.00% | 0.00% | 0.00% | 0.01% | 0.00% | 0.01% | 0.01% | 0.00% | 0.01% |
| Extrusion of PE (make floss) | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| **Sponge floss** | | | | | | | | | | | | | | | | |
| Cardboard insert | 11.96% | 18.47% | 12.91% | 24.62% | 14.22% | 16.97% | 16.81% | 36.72% | 35.47% | 18.37% | 11.44% | 30.28% | 19.31% | 12.88% | 63.95% | 17.75% |
| Cardboard box packet | 16.49% | 24.10% | 24.98% | 29.55% | 18.40% | 23.32% | 26.46% | 16.44% | 16.74% | 38.46% | 26.04% | 28.26% | 15.39% | 14.73% | 22.76% | 16.87% |
| Film packaging insert | 16.75% | 20.82% | 9.90% | 18.40% | 13.43% | 19.20% | 16.35% | 16.47% | 11.77% | 9.76% | 21.45% | 13.54% | 26.09% | 29.68% | 4.57% | 26.64% |
| LDPE (floss) | 17.60% | 20.87% | 9.33% | 15.94% | 13.10% | 19.01% | 15.49% | 10.80% | 10.83% | 7.21% | 23.59% | 13.46% | 19.84% | 34.08% | 1.58% | 30.91% |
| Disposal of cardboard | 23.03% | 3.29% | 4.27% | 0.75% | 23.10% | 5.34% | 7.75% | 0.94% | 9.55% | 3.45% | 5.64% | 4.69% | 3.61% | 0.94% | 0.71% | 1.11% |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Land transport | 3.77% | 5.45% | 12.58% | 1.09% | 5.77% | 8.82% | 4.76% | 4.01% | 6.69% | 17.05% | 6.56% | 6.57% | 0.61% | 3.66% | 2.67% | 3.80% |
| Extrusion of PE | 2.78% | 3.81% | 2.01% | 8.08% | 2.31% | 2.88% | 4.14% | 14.10% | 3.14% | 3.41% | 2.04% | 1.46% | 13.88% | 3.48% | 3.45% | 2.47% |
| Disposal of floss/plastic film | 7.40% | 1.14% | 23.91% | 1.54% | 8.11% | 2.01% | 7.87% | 0.37% | 5.75% | 1.42% | 1.62% | 1.61% | 1.26% | 0.37% | 0.30% | 0.39% |
| Sea transport | 0.22% | 2.06% | 0.11% | 0.03% | 1.57% | 2.45% | 0.37% | 0.16% | 0.07% | 0.86% | 1.62% | 0.14% | 0.02% | 0.17% | 0.01% | 0.07% |
| **Bamboo floss** | | | | | | | | | | | | | | | | |
| Steel lid (packaging) | 23.23% | 16.71% | 71.72% | 31.32% | 13.83% | 12.85% | 87.00% | 34.11% | 46.52% | 18.86% | 14.17% | 23.11% | 36.55% | 24.14% | 8.93% | 57.11% |
| Glass bottle (packaging) | 33.59% | 37.46% | 12.45% | 37.07% | 35.75% | 43.72% | 7.93% | 34.22% | 24.33% | 36.06% | 39.33% | 41.18% | 32.63% | 37.19% | 27.40% | 28.99% |
| Create bamboo pulp | 9.89% | 7.17% | 2.63% | 15.30% | 6.54% | 4.99% | 1.02% | 17.37% | 9.65% | 7.29% | 5.53% | 12.63% | 13.53% | 11.14% | 14.59% | 4.05% |
| Sea transport | 5.42% | 23.57% | 1.21% | 0.61% | 21.53% | 23.86% | 1.08% | 4.71% | 1.01% | 18.27% | 24.69% | 2.15% | 0.78% | 5.43% | 0.17% | 0.84% |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Create bamboo yarn | 15.46% | 10.18% | 1.97% | 9.73% | 8.17% | 8.69% | 1.19% | 3.09% | 8.22% | 3.08% | 9.05% | 13.75% | 6.18% | 15.02% | 1.56% | 5.34% |
| Raw bamboo | 1.22% | 0.80% | 0.41% | 0.55% | 6.37% | 0.97% | 0.13% | 0.40% | 4.37% | 0.98% | 0.56% | 0.55% | 2.53% | 0.71% | 42.03% | 1.52% |
| Cardboard box (packaging) | 2.43% | 1.63% | 1.50% | 3.78% | 1.51% | 1.36% | 0.42% | 2.74% | 1.38% | 4.83% | 2.39% | 2.49% | 3.95% | 2.72% | 3.16% | 0.99% |
| Land transport | 2.19% | 1.67% | 2.85% | 0.66% | 2.24% | 2.44% | 0.30% | 2.37% | 2.13% | 8.08% | 2.78% | 2.59% | 0.60% | 2.64% | 1.44% | 0.88% |
| Disposal of floss | 3.36% | 0.24% | 4.43% | 0.61% | 2.06% | 0.36% | 0.38% | 0.19% | 1.45% | 0.55% | 0.46% | 0.44% | 1.01% | 0.21% | 0.13% | 0.07% |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Disposal of glass bottle | 0.36% | 0.31% | 0.58% | 0.14% | 0.40% | 0.44% | 0.43% | 0.45% | 0.26% | 1.48% | 0.54% | 0.70% | 1.40% | 0.52% | 0.47% | 0.14% |
| Disposal of cardboard box | 2.76% | 0.18% | 0.21% | 0.08% | 1.54% | 0.25% | 0.10% | 0.10% | 0.63% | 0.35% | 0.42% | 0.33% | 0.75% | 0.14% | 0.08% | 0.05% |
| Create bamboo chips | 0.07% | 0.05% | 0.02% | 0.14% | 0.03% | 0.03% | 0.02% | 0.21% | 0.04% | 0.04% | 0.04% | 0.03% | 0.08% | 0.10% | 0.01% | 0.01% |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Disposal of metal lid | 0.02% | 0.03% | 0.02% | 0.01% | 0.03% | 0.04% | 0.00% | 0.04% | 0.01% | 0.13% | 0.04% | 0.05% | 0.01% | 0.04% | 0.03% | 0.01% |
| **Regular IDB** | | | | | | | | | | | | | | | | |
| Polypropylene (handle/lid) | 20.55% | 31.82% | 11.68% | 17.05% | 25.74% | 31.27% | 8.13% | 6.88% | 13.59% | 10.62% | 35.43% | 23.97% | 7.10% | 47.77% | 4.23% | 34.02% |
| Waste tap water | 8.65% | 9.03% | 19.83% | 6.67% | 10.89% | 12.52% | 26.39% | 3.54% | 11.14% | 10.06% | 10.77% | 23.51% | 71.22% | 4.71% | 5.53% | 20.60% |
| Injection moulding (handle/lid) | 22.73% | 16.91% | 5.30% | 30.03% | 12.24% | 13.02% | 5.17% | 44.77% | 10.37% | 29.82% | 11.83% | 5.62% | 5.43% | 15.14% | 13.10% | 7.42% |
| Tap water | 8.93% | 12.15% | 20.56% | 19.91% | 9.90% | 10.66% | 42.43% | 25.35% | 34.26% | 10.10% | 9.66% | 9.06% | 4.07% | 7.76% | 3.56% | 7.04% |
| Printing on packaging | 8.11% | 11.47% | 7.69% | 11.31% | 13.15% | 13.69% | 4.05% | 4.31% | 13.94% | 10.66% | 11.89% | 20.81% | 5.59% | 5.27% | 66.08% | 7.40% |
| Rubber handle | 8.42% | 5.59% | 2.52% | 3.80% | 4.07% | 4.90% | 2.13% | 4.70% | 3.45% | 16.37% | 6.24% | 6.23% | 1.72% | 5.39% | 1.98% | 12.67% |
| Disposal of IDB | 11.26% | 1.48% | 24.64% | 1.78% | 14.36% | 2.90% | 3.47% | 0.36% | 6.79% | 1.87% | 2.61% | 2.42% | 0.54% | 0.40% | 0.74% | 0.35% |
| Polypropylene packaging | 6.58% | 6.38% | 2.34% | 3.42% | 5.16% | 6.27% | 1.63% | 1.38% | 2.72% | 2.13% | 7.10% | 4.80% | 1.42% | 9.58% | 0.85% | 6.82% |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Injection moulding packaging | 2.66% | 3.06% | 0.96% | 5.44% | 2.22% | 2.36% | 0.94% | 8.11% | 1.88% | 5.40% | 2.14% | 1.02% | 0.98% | 2.74% | 2.37% | 1.34% |
| Land transport | 0.63% | 0.48% | 1.76% | 0.13% | 0.47% | 0.58% | 0.21% | 0.43% | 1.02% | 2.61% | 0.64% | 1.19% | 0.03% | 0.46% | 1.05% | 0.26% |
| Steel wire for brush | 0.20% | 0.23% | 2.29% | 0.34% | 0.24% | 0.24% | 5.16% | 0.14% | 0.46% | 0.21% | 0.26% | 0.34% | 0.10% | 0.12% | 0.09% | 0.30% |
| Nylon bristles | 1.22% | 1.12% | 0.32% | 0.08% | 1.28% | 1.20% | 0.13% | 0.00% | 0.05% | 0.03% | 1.16% | 0.92% | 0.23% | 0.64% | 0.00% | 1.36% |
| Blister packaging machine | 0.04% | 0.07% | 0.01% | 0.04% | 0.07% | 0.12% | 0.14% | 0.02% | 0.29% | 0.04% | 0.07% | 0.08% | 1.44% | 0.01% | 0.38% | 0.38% |
| Sea transport | 0.02% | 0.20% | 0.01% | 0.00% | 0.20% | 0.26% | 0.01% | 0.01% | 0.01% | 0.08% | 0.19% | 0.02% | 0.00% | 0.01% | 0.00% | 0.00% |
| Brust twisting machine | 0.00% | 0.01% | 0.09% | 0.00% | 0.01% | 0.01% | 0.01% | 0.00% | 0.03% | 0.00% | 0.01% | 0.01% | 0.13% | 0.00% | 0.04% | 0.04% |
| **IDB pick** | | | | | | | | | | | | | | | | |
| PET packaging | 21.29% | 26.80% | 11.22% | 18.17% | 22.81% | 7.11% | 33.87% | 11.00% | 25.80% | 95.87% | 26.87% | 30.09% | 28.16% | 24.31% | 11.99% | 46.29% |
| Polypropylene handle/case | 29.18% | 34.29% | 10.37% | 20.66% | 28.28% | 2.03% | 24.83% | 7.80% | 21.70% | 0.53% | 38.58% | 34.49% | 28.44% | 46.85% | 9.03% | 32.60% |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Injection moulding (rubber bristles) | 0.81% | 16.47% | 4.25% | 32.88% | 12.17% | 35.10% | 14.25% | 45.87% | 14.96% | 1.35% | 11.64% | 7.32% | 19.66% | 13.41% | 25.26% | 6.43% |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Injection moulding (packaging) | 6.35% | 8.86% | 2.29% | 17.70% | 6.54% | 3.51% | 7.67% | 24.69% | 8.05% | 0.73% | 6.26% | 3.93% | 10.58% | 7.22% | 13.60% | 3.45% |
| Disposal of IDB | 5.15% | 0.83% | 11.26% | 1.10% | 8.12% | 27.40% | 5.44% | 0.22% | 5.58% | 0.05% | 1.46% | 1.79% | 1.11% | 0.20% | 0.81% | 0.17% |
| Disposal of PET packaging | 9.23% | 0.74% | 41.15% | 0.09% | 8.36% | 1.38% | 1.16% | 0.10% | 4.54% | 0.03% | 1.29% | 0.79% | 0.83% | 0.14% | 0.52% | 0.11% |
| Land transport | 2.66% | 2.53% | 7.42% | 0.76% | 2.43% | 1.05% | 3.06% | 2.32% | 7.74% | 0.62% | 3.31% | 8.15% | 0.54% | 2.13% | 10.64% | 1.17% |
| Rubber bristles | 2.35% | 3.84% | 1.43% | 2.95% | 2.85% | 1.40% | 4.14% | 3.40% | 3.51% | 0.52% | 4.34% | 5.72% | 4.41% | 3.37% | 2.70% | 7.75% |
| Printing on packaging | 0.95% | 1.64% | 0.90% | 1.81% | 1.91% | 1.68% | 1.63% | 0.65% | 2.95% | 0.07% | 1.71% | 3.96% | 2.96% | 0.68% | 18.68% | 0.94% |
| Injection moulding (handle/case) | 11.80% | 1.12% | 0.29% | 2.24% | 0.83% | 13.20% | 0.97% | 3.13% | 1.02% | 0.09% | 0.79% | 0.50% | 1.34% | 0.93% | 1.72% | 0.44% |
| Disposal of PP case | 8.16% | 0.44% | 8.39% | 0.07% | 1.66% | 1.82% | 1.12% | 0.07% | 2.26% | 0.02% | 0.76% | 0.54% | 0.77% | 0.09% | 0.38% | 0.08% |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cardboard packaging | 0.82% | 1.26% | 0.84% | 1.52% | 1.32% | 0.90% | 1.31% | 0.65% | 1.17% | 0.09% | 1.66% | 2.25% | 0.96% | 0.57% | 4.52% | 0.52% |
| Disposal of cardboard packaging | 1.15% | 0.17% | 0.16% | 0.04% | 1.66% | 3.10% | 0.38% | 0.04% | 0.67% | 0.01% | 0.37% | 0.37% | 0.23% | 0.04% | 0.14% | 0.03% |
| Sea transport | 0.10% | 1.01% | 0.03% | 0.01% | 1.06% | 0.32% | 0.17% | 0.06% | 0.05% | 0.02% | 0.96% | 0.10% | 0.01% | 0.06% | 0.01% | 0.02% |
| **Replaceable head IDB** | | | | | | | | | | | | | | | | |
| PET packaging | 27.74% | 29.04% | 9.17% | 17.56% | 22.64% | 26.80% | 9.25% | 12.08% | 14.62% | 96.66% | 29.37% | 19.92% | 5.84% | 39.77% | 4.46% | 45.82% |
| Waste tap water | 13.28% | 13.96% | 19.26% | 10.25% | 15.73% | 18.20% | 29.02% | 5.84% | 13.34% | 0.67% | 16.98% | 29.66% | 78.35% | 10.00% | 5.82% | 25.82% |
| Tap water | 13.62% | 18.73% | 19.97% | 30.89% | 14.31% | 15.50% | 46.71% | 41.75% | 41.05% | 0.67% | 15.22% | 11.40% | 4.48% | 16.46% | 3.77% | 8.85% |
| Printed paper packaging | 14.25% | 20.33% | 8.70% | 19.75% | 21.91% | 23.08% | 5.12% | 8.19% | 19.01% | 0.85% | 21.71% | 29.94% | 6.89% | 12.83% | 78.03% | 10.73% |
| Injection moulding (rep head) | 8.28% | 9.60% | 1.89% | 17.11% | 6.49% | 6.95% | 2.15% | 27.12% | 0.51% | 0.08% | 0.76% | 2.60% | 0.24% | 1.31% | 0.56% | 3.42% |
| Dispolsa of PET packaging | 12.02% | 0.81% | 34.00% | 0.18% | 8.35% | 1.78% | 0.32% | 0.11% | 2.57% | 0.03% | 1.41% | 0.52% | 0.11% | 0.23% | 0.19% | 0.10% |
| Injection moulding handle | 0.92% | 1.06% | 0.21% | 1.90% | 0.72% | 0.77% | 0.23% | 3.00% | 4.51% | 0.73% | 6.85% | 0.29% | 2.19% | 11.79% | 5.06% | 0.38% |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Polypropylene (handle/heads/lid) | 2.29% | 2.22% | 0.51% | 1.19% | 1.63% | 2.05% | 0.40% | 0.51% | 0.73% | 0.03% | 2.51% | 1.36% | 0.35% | 4.56% | 0.20% | 1.90% |
| Land transport | 1.23% | 0.97% | 2.18% | 0.26% | 0.86% | 1.08% | 0.30% | 0.91% | 1.56% | 0.22% | 1.28% | 1.92% | 0.04% | 1.24% | 1.41% | 0.41% |
| Nylon bristles | 1.88% | 1.73% | 0.36% | 0.12% | 1.85% | 1.71% | 0.14% | 0.01% | 0.06% | 0.00% | 1.83% | 1.15% | 0.25% | 1.32% | 0.02% | 1.70% |
| Steel wire for brush | 0.32% | 0.35% | 2.27% | 0.53% | 0.37% | 0.34% | 5.74% | 0.24% | 0.62% | 0.01% | 0.41% | 0.42% | 0.11% | 0.26% | 0.09% | 0.49% |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Disposal of paper packaging | 3.23% | 0.46% | 0.26% | 0.08% | 3.55% | 0.68% | 0.33% | 0.15% | 0.81% | 0.02% | 0.85% | 0.58% | 0.17% | 0.13% | 0.11% | 0.07% |
| Disposal of heads | 0.84% | 0.11% | 1.13% | 0.13% | 0.98% | 0.25% | 0.18% | 0.03% | 0.39% | 0.01% | 0.19% | 0.14% | 0.03% | 0.04% | 0.04% | 0.02% |
| Sea transport | 0.07% | 0.57% | 0.04% | 0.01% | 0.55% | 0.71% | 0.02% | 0.04% | 0.01% | 0.01% | 0.56% | 0.04% | 0.00% | 0.05% | 0.00% | 0.01% |
| Brush twisting machine | 0.03% | 0.06% | 0.05% | 0.04% | 0.06% | 0.10% | 0.09% | 0.02% | 0.21% | 0.01% | 0.07% | 0.06% | 0.95% | 0.01% | 0.24% | 0.28% |
| **Bamboo IDB** | | | | | | | | | | | | | | | | |
| Tap water | 14.43% | 12.95% | 21.78% | 31.62% | 6.57% | 8.95% | 44.00% | 60.77% | 32.69% | 13.19% | 10.26% | 12.09% | 2.39% | 28.27% | 1.19% | 10.07% |
| Waste tap water | 13.97% | 9.63% | 21.01% | 10.60% | 7.22% | 10.51% | 27.37% | 8.48% | 10.63% | 13.14% | 11.44% | 31.35% | 41.75% | 17.17% | 1.83% | 29.46% |
| Sea transport | 8.80% | 47.29% | 2.13% | 0.87% | 29.91% | 48.28% | 3.03% | 6.25% | 1.36% | 24.32% | 44.22% | 4.73% | 0.07% | 11.26% | 0.10% | 1.73% |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Machine to shape handle | 3.65% | 4.18% | 5.88% | 3.73% | 2.78% | 6.06% | 8.61% | 2.58% | 16.62% | 3.30% | 4.42% | 6.52% | 50.61% | 2.56% | 7.51% | 32.26% |
| Raw bamboo | 5.54% | 4.50% | 2.01% | 2.11% | 24.74% | 5.48% | 1.04% | 1.50% | 16.32% | 3.64% | 2.79% | 3.38% | 0.66% | 4.10% | 68.58% | 8.68% |
| Cardboard box packaging | 9.21% | 7.65% | 6.19% | 12.20% | 4.90% | 6.44% | 2.73% | 8.47% | 4.29% | 15.02% | 9.96% | 12.79% | 0.86% | 13.12% | 4.30% | 4.74% |
| Printed paper insert | 7.35% | 6.87% | 4.66% | 9.90% | 4.92% | 6.53% | 2.36% | 5.82% | 7.41% | 8.14% | 7.16% | 15.49% | 1.80% | 10.79% | 12.03% | 5.98% |
| Disposal of IDB | 15.69% | 1.36% | 22.51% | 2.42% | 8.21% | 2.10% | 3.10% | 0.74% | 5.59% | 2.11% | 2.39% | 2.78% | 0.27% | 1.27% | 0.21% | 0.43% |
| Land transport (factory - UK) | 3.14% | 1.68% | 5.59% | 0.74% | 0.98% | 1.54% | 0.67% | 2.89% | 2.96% | 10.16% | 2.10% | 4.83% | 0.05% | 5.09% | 1.04% | 1.12% |
| Soybean oil (wax handle) | 2.43% | 0.73% | 2.62% | 24.46% | 2.57% | 0.84% | 0.38% | 0.57% | -1.97% | 1.30% | 0.91% | 0.69% | 0.18% | 0.70% | 2.67% | 1.53% |
| Disposal of paper/cardboard packaging | 12.04% | 0.98% | 0.99% | 0.29% | 5.76% | 1.38% | 0.75% | 0.46% | 2.29% | 1.26% | 2.02% | 1.98% | 0.19% | 0.79% | 0.12% | 0.29% |
| Land transport (forest - factory) | 1.35% | 0.65% | 1.75% | 0.32% | 0.35% | 0.54% | 0.31% | 1.12% | 1.00% | 4.01% | 0.72% | 1.52% | 0.02% | 2.03% | 0.24% | 0.71% |
| Nylon bristles | 1.98% | 1.21% | 0.36% | 0.13% | 0.86% | 1.03% | 0.14% | 0.02% | 0.06% | 0.07% | 1.26% | 1.25% | 0.13% | 2.36% | 0.00% | 1.95% |
| Steel for wire | 0.35% | 0.24% | 2.42% | 0.54% | 0.17% | 0.21% | 5.35% | 0.28% | 0.44% | 0.28% | 0.27% | 0.48% | 0.07% | 0.44% | 0.03% | 0.44% |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Brush twisting machine | 0.06% | 0.07% | 0.10% | 0.06% | 0.05% | 0.10% | 0.14% | 0.04% | 0.28% | 0.05% | 0.07% | 0.11% | 0.84% | 0.04% | 0.13% | 0.54% |
| Heat sealing machine (paper insert) | 0.01% | 0.01% | 0.01% | 0.01% | 0.01% | 0.01% | 0.02% | 0.01% | 0.03% | 0.01% | 0.01% | 0.01% | 0.11% | 0.01% | 0.02% | 0.07% |

## 7.3 Paper submitted for publication

**TITLE**

An Environmental Impact Study of Interdental Cleaning Aids

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## ABSTRACT

**Aim.** The aim of this study was to compare the environmental footprint of eight interdental cleaning aids using life cycle analysis (LCA).

**Materials and methods.** A comparative LCA was conducted based on an individual person using interdental cleaning aids every day for 5 years. The primary outcome was a life cycle impact assessment, consisting of 16 environmental impact categories, including a carbon footprint. Secondary outcomes included normalised data, disability adjusted life years (DALYs) and a contribution analysis.

**Results.** Interdental cleaning using floss picks had the largest environmental footprint in 13 out of 16 impact categories. Depending on the environmental impact category measured, the smallest environmental footprint came from daily interdental cleaning with either bamboo interdental brushes (5 impact categories, including carbon footprint), replaceable-head interdental brushes (4 impact categories), regular floss (3 impact categories), sponge floss (3 impact categories) and bamboo floss (1 impact category).

**Conclusion.** Daily cleaning with interdental cleaning aids has an environmental footprint that varies depending on the product used. Clinicians should consider environmental impact alongside clinical need and cost when recommending interdental cleaning aids to patients.



## KEYWORDS

Floss, interdental brush, oral hygiene aid, environment, sustainability, life cycle assessment, carbon footprint.

## INTRODUCTION

There are many environmental challenges facing our planet, including climate change and global warming, pollution, and ozone depletion. These challenges impact not only the health of the planet, but also the health of the planet's human population. Environmental damage, therefore, is a public health issue. [Costello et al, 2009]

Healthcare itself has a significant carbon footprint [Faculty of Public Health, 2020] and dentistry is no exception. [Duane et al, 2017] Services and products designed to improve oral health come with an associated environmental cost that will ultimately impact global human health. It is important, therefore, to consider ways to make oral health care more environmentally sustainable.

Periodontal disease is a common global oral disease, with studies suggesting the prevalence of mild periodontitis is as high as 50%, and severe periodontitis 7.4%. [Sanz et al, 2020; Billings et al, 2018; Kassebaum et al, 2017] It has a wide range of health consequences, including tooth loss, masticatory dysfunction, and reduced quality of life. [Sanz et al, 2020] In addition, the burden of periodontal disease has a huge socio-economic cost, with the global cost of lost productivity due to severe periodontitis projected at 54 billion USD per year. [Tonetti et al, 2017] Preventing periodontal disease, therefore, is of utmost importance, and supported by the European Federation for Periodontology. [Sanz et al, 2020]

Daily mechanical plaque removal is the cornerstone of preventing periodontal disease and controlling periodontal health. Using dental floss and interdental brushes helps to remove plaque and food particles in areas between the teeth where a regular toothbrush cannot reach. A recent systematic review [Worthington et al, 2019] found that using interdental cleaning aids (in addition to toothbrushing) may reduce gingivitis compared to toothbrushing alone. [Sanz et al, 2020]

There are a range of interdental cleaning aids available in the European and UK market. Traditionally, floss and interdental brushes were made from plastic. However, new products with 'eco-friendly' branding have come to market recently, for example using bamboo or replaceable brush heads. Previous studies of different types of toothbrush [Lyne et al, 2020; Duane et al, 2020] suggest that there is variation in the environmental footprint of different oral healthcare products, with bamboo and replaceable head brushes performing better than traditional plastic and electric toothbrushes. The environmental impact of different types of floss and interdental brushes, however, has not previously been quantified.

Environmental sustainability can be measured in different ways. Carbon footprinting is the most common measure and relates to climate change potential from the collective greenhouse gases of a product or service. Life cycle analysis (LCA) is a more comprehensive assessment of a product's environmental footprint that encompasses not only climate change, but a range of measures relating to global human health (for example: ionizing radiation, ozone depletion, and respiratory disease from particulate matter), ecosystem quality (for example: freshwater ecotoxicity, marine eutrophication, and terrestrial acidification), and planetary resource use (for example: land use, fossil fuel use, and water use). LCA methodology is recommended by the European Union. [European Commission, 2018] and considers the entire life of a product, including raw materials, manufacture and packaging, transport, use, and disposal.

The aim of this study was to use LCA methodology to quantify and compare the environmental footprint of different types of interdental cleaning aids.

## MATERIALS AND METHODS

A comparative LCA of eight interdental cleaning aid products was undertaken at the Eastman Dental Institute (University College London, UK), in partnership with the Dublin Dental University Hospital (Trinity College Dublin, Ireland).

In order to compare the different products, a baseline scenario was used; an individual person using interdental cleaning aids every day over 5 years. This is called the functional unit and allows for equal comparison between products with different usage. The 5 year period was chosen as the functional unit to aid the comparison of results with a previous LCA of toothbrushes. [Lyne et al, 2020]

Four floss products and four interdental brush products were compared using this functional unit.

### Sample selection

A review of interdental cleaning aids on the Amazon UK website was used to identify varieties of floss and interdental brush (IDB) products available on the UK market. [Amazon UK, 2021] The following product types were identified and chosen for this study:

1. Regular floss – a roll of nylon floss in a plastic dispenser.

2. Sponge floss – a pre-cut length of spongy or expanded floss designed to use around appliances and prosthetics.

3. Floss picks – a length of nylon floss fixed to a plastic handle.

4. Bamboo floss – a roll of bamboo floss in a glass jar.

5. Regular IDB – an IDB with a plastic handle, changed weekly.

6. IDB picks – a rubber brush head on a plastic handle, designed for single use.
7. Replaceable head IDB – an IDB with a reusable handle and replaceable brush heads, changed weekly.

8. Bamboo IDB – an IDB with a bamboo handle, changed weekly.

A sample product was chosen to represent each type of interdental cleaning aid. Products were chosen from the Amazon UK website with the best-selling product chosen for each type. [Amazon UK, 2021] All product brands and manufacturers have been anonymised in this study.

**Data collection**

The entire product life cycle was mapped using a system boundaries diagram. Figure 1 shows the system boundaries for a regular interdental brush as an example. The entire product system was considered, including the geographic location of the manufacture. For each type of dental floss and interdental brush, a life cycle inventory was produced. A detailed list of assumptions for each product is available in Appendix 1, and outlined below:

1. Raw materials. To identify and weigh the component materials, a sample of each product (and it's packaging) was dismantled and weighed to the nearest 0.01g. Components that were less than 0.01g were excluded. The quantity of products required for daily use over 5 years was calculated (for example, an individual using a IDB that comes in packets of 6, where each brush lasts for 1 week, would need 43.3 products over 5 years).
2. Manufacture. Individual manufacturers were contacted to obtain information about manufacturing and packaging processes. All products were confirmed as manufactured and packaged in the same factory location. For manufacturing machinery, the machine's energy consumption (kilowatt/per hour/kWh) was used, assuming the machine was being used at maximum capacity. Machinery maintenance and servicing was excluded. Any waste materials from the manufacturing and packaging were assumed to be recycled back into the process.
3. Transport. Transport of the product from the factory to the UK was allocated based on weight of the products (kg), distance travelled (km), and method of travel (lorry for land transport, freight ship for sea transport). Six out of eight products were manufactured in Europe, and two were manufactured in China. The transport was modelled from the factory location to the manufacturer's UK headquarters. Transport from the European locations was assumed to be via lorry from the factory to Calais; then via ferry to Dover; and then again via lorry to the UK headquarters for that manufacturer. Transport from the Chinese location was assumed to be via lorry from the factory to Shanghai port; then via ship to Southampton port; and then again via lorry to the UK headquarters/ storage facility for that

company. All distances were estimated using Google Maps (2021) in km and the shortest route chosen. The exact locations have been concealed to anonymise the individual manufacturers.

4. Retail. The retail processes (e.g. shopping travel distances, supermarket resources) were excluded as this was assumed to be the same for all products.
5. Consumer use. It was assumed that the individual person would use the product as directed by the manufacturer every day for 5 years. It was assumed this individual was located in the UK and used unheated tap water to clean the products where needed (e.g. for the weekly IDBs).
6. Disposal. It was assumed that the individual would dispose of the product in the UK as per manufacturer's recommendations, and place materials in recycling where possible.

The final life cycle inventory for each product is available in Appendix 2.

**Data analysis**

An attributional LCA was undertaken utilising physical allocation by mass. The software OpenLCA v1.8 was used for the LCA, alongside the reference database Ecoinvent v3.7. The LCA methodology following International Standard Office and EU Product Environmental Footprint recommendations. [ISO, 2015; European Commission, 2018]

The primary outcome was a life cycle impact assessment (LCIA) with 16 environmental impact categories. A description of each impact category and the LCIA method and units are described in Table 1.

Secondary outcomes included:

- Normalised LCIA results. Normalisation of the LCIA results against an average person's annual environmental footprint allows for comparison between impact categories. As per PEF guidelines, the toxicity categories were excluded from normalisation while the LCIA methods are under review. [9] Impact categories with the higher normalised values are more significant within the overall environmental footprint compared to categories with smaller normalised values.

The burden of human health can be measured in DALYs. It is the number of years of life lost in human population because of morbidity (disease and disability) and mortality (death). [WHO, 2020] LCA modelling can be used to calculate DALYs lost across the global population based on the human health related impact categories. DALYs were calculated using ReCiPe 2016 Endpoint (H) [The Netherlands Institute for Public Health and the Environment, 2018] and presented in minutes rather than years.

A contribution analysis was reported to assess which aspect of each product life cycle contributed the most to the environmental impacts.

## RESULTS

### Life cycle impact assessment (LCIA)

The results of the life cycle impact assessment (LCIA) for each type of the dental floss and the interdental brush are shown in Table 2. Interdental cleaning using floss picks had the largest environmental footprint in 13 out of 16 impact categories. Interdental cleaning with bamboo IDBs had the lowest environmental impact in 5 categories (climate change, freshwater eutrophication, ionising radiation, fossil use, and mineral/metal use), followed by replaceable head IDBs in 4 categories (acidification, marine eutrophication, terrestrial eutrophication, and photochemical ozone creation), regular floss in 3 categories (noncarcinogenic effects, respiratory inorganics, and land use), sponge floss in 3 categories (freshwater ecotoxicity, carcinogenic effects, and ozone layer depletion), and bamboo floss in 1 category (water use).

**Normalised results**

The normalised results are shown in Figure 2. The most important impact categories for each product were:

Regular floss and sponge floss: freshwater eutrophication, climate change, and mineral/metal use.

Bamboo floss: mineral/metal use, acidification, and climate change.

Plastic IDB and Bamboo IDB: water use, climate change, and freshwater eutrophication.

IDB picks: ozone layer depletion, climate change, and mineral/metal use.

Replaceable head IDB: ozone layer depletion, water use, and climate change

**Disability-Adjusted Life years (DALYs)**

Figure 3 shows the DALY results (presented in minutes). The highest DALY impact was the floss pick (7.5 minutes) followed by IDB picks (4.1 minutes). The lowest DALY impact came from bamboo floss (1.2 minutes). The DALY result for all products came from the same 2 human health impact categories: climate change (44-99%) and carcinogenic effects (0-64%). All other human health impact categories (ozone depletion, ionising radiation, respiratory inorganics, noncarcinogenic effects, water use, and photochemical ozone formation) formed less than 1% of the DALY result combined.

### Contribution analysis

A contribution analysis was carried out for each impact category. Figure 4 illustrates the contributions for each type of interdental cleaning aids to the climate change impact. The full contribution analysis for all impact categories is provided in Appendix 3.

## DISCUSSION

This study found variation in the environmental footprint between eight interdental cleaning aids available on the UK market. Overall, the worst environmental footprint came from the floss picks which had the highest environmental impact in 13 out of 16 categories, followed by the interdental brush picks. No single product had the ‘best’ environmental footprint, although perhaps the bamboo interdental brush preformed the best overall, with the lowest impact in 5 out of the 16 categories.

This study highlights the fact that carbon footprinting alone is not a comprehensive measure of environmental sustainability. The normalisation of the results (allowing for comparison between different impact categories) found that, overall, the most significant impact categories were ozone layer depletion, climate change, and freshwater eutrophication. Sponge floss performed the best for ozone layer depletion, producing the equivalent of 26% less CFCs than regular floss. The bamboo interdental brush performed the best for climate change and freshwater eutrophication, producing the equivalent of 48% less CO2 than a regular interdental brush, and 37% less phosphorus (the measure of water eutrophication).

This trend continues with the Disability Adjusted Life Years (DALYs), presented in this paper as minutes. DALYs combine the human health impact categories to provide the global human quality of life loss of a product. Using the floss picks as an example, one individual using floss picks for 5 years means that the global human population will lose the equivalent of 7.4 minutes of life. The DALY impact of regular floss was 75% less than floss picks; and the DALY impact of regular interdental brushes was 57% less than that of interdental brush picks.

The contribution analysis shows which aspects of the product's life cycle contributed the most to the environmental impact. For floss picks, it was the polypropylene plastic handle that contributed the most to the environmental impact (for example, the handle formed 49% of the carbon footprint). This is due to the sheer weight of plastic needed to use these floss picks every day for 5 years. In comparison, the bamboo handle of the bamboo interdental brush contributed just 5% to the product's carbon footprint. To the authors knowledge, this is the first study to quantify the environmental impact of different types of interdental cleaning aids, such as floss and interdental brushes.

Data collection and analysis was performed in line with European Union Product Environmental Footprint guidance (PEF) European Commission, 2018], and offers a holistic view of environmental sustainability over carbon footprinting alone.

However, the main limitation of this study was in data collection and analysis. The authors relied on manufacturers information to form the basis of the life cycle inventory model, and where this information was not available, a reasonable assumption was made, and this may have impacted on the results. These assumptions are listed in Appendix 1. Ideally, it would be the responsibility of any product manufacturer to report their environmental footprint, however there is currently no legal obligation for this, even for products using labels such as 'eco-friendly' or 'sustainable'.

This study used eight sample products, selected as best-selling products on the Amazon UK website. However, this may not be representative of the range of products available in the UK and other countries. Also, this study did not include any electronic forms of interdental cleaning, such as water or air flossing products, because it was assumed, they would have a greater environmental impact than manual products, based on a previous study of manual and electric toothbrushes. [Lyne et al, 2020] This study was based in the UK; therefore the impact of transport may vary for these same products in other countries. Transport by land and sea to the UK accounted for between 1.3% and 10.2% of the carbon footprint of the products.

LCA methodology, although more comprehensive than carbon footprinting, is limited when it comes to interpretation in a healthcare setting. Currently, LCA methodology does not allow for data analysis or results including p values and confidence intervals, and so data needs to be interpreted based on descriptive statistics alone, making it difficult for clinicians and the public to easily interpret. Furthermore, PEF guidance itself points out that the data analysis methods for the 3 toxicity impact categories are currently under review, meaning that results in these categories need to be interpreted with caution (freshwater ecotoxicity, carcinogenic effects, and noncarcinogenic effects). [European Commission, 2018]

The results of this LCA highlight the difficulty in naming the ‘best’ eco-friendly product. Although the bamboo interdental brush performed the best in climate change, bamboo is not an ideal sustainable material – it requires water and fertilizers to grow, and the land used for the crop will result in a reduction in biodiversity. Previous studies on toothbrushes found that although bamboo toothbrushes have a lower climate change impact compared to plastic toothbrushes, recycled plastic toothbrushes are even better. [Duane et al, 2020] As the popularity of bamboo products increases, the environmental impact of producing bamboo may worsen, feed global demand for this material.

Comparing these LCIA results to a previous LCA study of toothbrushes, we find that the environmental impact of all the interdental cleaning aids in this study is less than that of a plastic toothbrush (for example, using a plastic toothbrush over 5 years produces 25.6kg $CO_2e$, compared to 11.4kg $CO_2e$ using floss picks over 5 years). [Lyne et al, 2020]

The results of this study could be used by both individuals (when choosing an interdental cleaning aid) and dental healthcare professionals. Dental healthcare professionals who are recommending interdental cleaning aids should consider clinical, cost, and environmental effectiveness of different products.

Interdental cleaning aids are recommended in clinical guidelines. The European Association of Periodontology recommend inter-dental cleaning, preferably with interdental brushes, is professionally taught to patients with gingival inflammation. [Sanz et al 2020] All interdental cleaning aids, such as those included in this study, will reduce certain periodontal parameters such as bleeding and gingival indices. [Christou et al 1998, Kotsakis et al 2018] Admittedly, the quality of evidence to recommend one product over another is poor, perhaps with some preference for interdental brushes over traditional floss. [Worthington et al 2019] Interdental brushes have been shown to remove plaque up to 2mm below the gingival margin [Salzer et al 2000] and are favoured over floss by European experts. [Chapple et al 2015] For individual patient oral health, it is best to form a tailored solution based on their oral health status and risk profile.

Where floss is clinically recommended; regular, sponge or bamboo floss products are preferable for the environment over floss picks. Where interdental brushes are clinically recommended; weekly brushes are preferable over daily ‘single use’ brush picks, and those with a bamboo handle or a plastic reusable handle are preferable over plastic handles. The bamboo interdental brush was overall the most environmentally effective interdental cleaning aid in this study.

**Conclusion**

Interdental cleaning is part of periodontal disease prevention and management and can have a positive impact on the oral health of patients. However, this study demonstrated that all floss and interdental brush products have an environmental footprint that negatively impacts planetary health. Floss picks (a short piece of floss fixed to a plastic handle) had the worst environmental footprint of the eight products included in this study. There was no single best environmentally friendly product, however the bamboo interdental brush had the lowest environmental impact in 5 out of 16 categories, including climate change. Healthcare professionals could use the results of this study when making product recommendations to patients, incorporating environmental sustainability alongside the clinical and financial needs of the patient.

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**TABLE, FIGURE, AND APPENDIX LEGENDS**

Table 1. Impact categories and LCIA methods [European Commission, 2018]

Table 2. LCIA results

Figure 1. System boundaries diagram for regular IDB

Figure 2. Normalised results

Figure 3. Disability Adjusted Life Years (DALYs)

Figure 4. Contribution analysis for climate change

Appendix 1. Assumptions and limitations

Appendix 2. Life cycle Inventory

Appendix 3. Contribution analysis data.

## 7.4 University College London Ethical approval letter

4th July 2022

Professor Paul Ashley

Faculty of Medical Sciences

UCL

Cc: Rawan Abed

Dear Professor Ashley

**Notification of Ethics Approval**

**Project ID: 22553.001**

**Title: Environmental sustainability of oral health interventions in dental practice.**

Further to your satisfactory responses to the reviewer's comments, I am pleased to confirm that your study has been ethically approved by the UCL Research Ethics Committee until **4th July 2023.**

Ethical approval is subject to the following conditions:

**Notification of Amendments to the Research**

You must seek Chair's approval for proposed amendments (to include extensions to the duration of the project) to the research for which this approval has been given. Each research project is reviewed separately and if there are significant changes to the research protocol you should seek confirmation of continued ethical approval by completing an 'Amendment Approval Request Form' - https://www.ucl.ac.uk/researchethics/responsibilities-after-approval

**Adverse Event Reporting – Serious and Non-Serious**

It is your responsibility to report to the Committee any unanticipated problems or adverse events involving risks to participants or others. The Ethics Committee should be notified of all serious adverse events via the Ethics Committee Administrator (ethics@ucl.ac.uk) immediately the incident occurs. Where the adverse incident is unexpected and serious, the Joint Chairs will decide whether the study should be terminated pending the opinion of an independent expert. For non-serious adverse events the Joint Chairs of the Ethics Committee should again be notified via the Ethics Committee Administrator within ten days of the incident occurring and provide a full written report that should include any amendments to the participant information sheet and study protocol.

Office of the Vice Provost Research, 2 Taviton Street

University College London

Tel: +44 (0)20 7679 8717

Email: ethics@ucl.ac.uk

http://ethics.grad.ucl.ac.uk/

The Joint Chairs will confirm that the incident is non-serious and report to the Committee at the next meeting. The final view of the Committee will be communicated to you.

**Final Report**

At the end of the data collection element of your research we ask that you submit a very brief report (1-2 paragraphs will suffice) which includes in particular issues relating to the ethical implications of the research i.e. issues obtaining consent, participants withdrawing from the research, confidentiality, protection of participants from physical and mental harm etc.

In addition, please:

- ensure that you follow all relevant guidance as laid out in UCL's Code of Conduct for Research
- note that you are required to adhere to all research data/records management and storage procedures agreed as part of your application. This will be expected even after completion of the study.

With best wishes for the research.

Yours sincerely

[redacted]

**Professor Michael Heinrich**

**Joint Chair, UCL Research Ethics Committee**

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## 7.5 Consent sheet for participants

**Consent form: The purpose of this research project is to measure dentists' knowledge about the sustainability of oral health intervention in the Department of Paediatric Dentistry at EDH.**

**This is a research project being conducted university college London. You are invited to participate in this research project because you are a dental clinician Your participation in this research study is voluntary. You may choose not to participate. If you decide to participate in this research survey, you may withdraw at any time. If you decide not to participate in this study at any time, you will not be penalized.**

The procedure involves filling an online survey that will take approximately 2 minutes. Your responses will be confidential, and we do not collect identifying information such as name or email address. There is no promise or guarantee of benefits have been made to encourage you to participate. We will do our best to keep your information confidential. All data is stored in a password protected electronic format. To help protect your confidentiality, the surveys will not contain information that will personally identify you. The results of this study will be used for scholarly purposes only and may be shared with SurveyMonkey

University representatives. This research has been reviewed according to SurveyMonkey University IRB procedures for research involving human subjects.

I voluntarily agree to take part in this study.

- Agree
- Disagree

## 7.6 Questionnaire form for the participants

**Section 1 About you**

Please give us some information about yourself

1. Where do you work clinically? Please choose one, if you work in more than one place choose the place you consider to be your main employment

- Dental practice
- Hospital
- Salaried dental service

2. What is your age group?

- 18-24 • 25-34 • 35-44 • 45-54
- 55-64
- 65+

3. To what extent can you influence purchasing and/or choice of clinical interventions in your main place of work

Not at all

Some influence

A lot of influence

**Section 2 Environmental sustainability**

In this section we want to know about your attitudes to environmental sustainability

4. To what extent do you think consideration of environmental sustainability influences your lifestyle choices outside of work?

- Not at all
- A little
- Sometimes
- A lot

5. To what extent do you think consideration of environmental sustainability influences your clinical treatment choices during work?

- Not at all
- A little
- Sometimes
- A lot

6. There are different ways of measuring the environmental impact of clinical interventions. Which of the following are you aware of (tick all that apply)?

- Life cycle analysis
- Carbon foot printing
- Climate change
- Ecosystem quality
- Human health effect
- Resource use
- Carbon dioxide equivalents (CO2E)

7. In dentistry, which one of the following factors do you think contributes most to adverse environmental impacts?

- Travel (Patient and/or staff) • Waste eg gloves, towels etc.
- Resource use eg electricity/water
- Nitrous oxide release during inhalation sedation

**Section 3 Environmental sustainability and clinical choices**

In this section we want to find out how much environmental considerations would influence your clinical decision making

8- Do you consider the sustainability of interventions when recommending toothbrushes?

- Yes
- No

9. Do you consider the sustainability of interventions when recommending other dental cleaning aids eg floss etc.?

- Yes
- No

10. Please rank the following products for toothbrushing in order of most sustainable to least from 1 to 6 (where 1 is most sustainable and 4 is the least)

- Electric toothbrush
- Recyclable Plastic toothbrush
- Recyclable Plastic Toothbrush with replaceable head
- Bamboo toothbrush

11. Please rank the following products for interdental cleaning in order of most sustainable to least from 1 to 6 (where 1 is most sustainable and 4 is the least)

- Floss tape
- Bamboo floss
- Floss picks
- Super floss

12. Do you know where to find the information about the sustainability of oral healthcare interventions e.g., materials or techniques

- Yes
- No

13. If the answer to question 10 was no, please write down below who should provide that information?

……………………………………………………………………………………………………

………..

14. Dentists and organisations often choose clinical interventions based on advice from guidelines. Guidelines will use measures of clinical effectiveness and sometimes cost to make recommendations. Do you think they should also look at the impact of the interventions on the environment?

- Yes
- No

15. Please rank the following in importance when choosing healthcare interventions

(Where 1 is most important and 3 is the least) Environmental impact. …..

Clinical effectiveness ….

Cost ….