Awareness and Barriers to Sustainable Dental Practice – A Scoping Literature Review

Sustainable Dental Practice: Awareness and barriers

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Abstract

Objectives. (i) To undertake a comprehensive scoping review of the literature that addresses the research question ‘What is the current state of environmental sustainability in general dental practice?’ (ii) To provide an effective baseline of data that will consider general awareness, barriers and challenges for the implementation of sustainable practice.

Data & sources. The scoping review was conducted for all published literature in the English language that addresses this topic up to the 31st April 2021. The method of the PRISMA-ScR (PRISMA extension for Scoping Reviews) was followed. 128 papers included in this scoping review consisted of: Commentary [Letters, editorials, communication and opinion] (n=39); Research (n=60); Literature reviews (n=25); Reports [Policy and legislation] (n=4). Each included record was analysed for emerging themes that were further classified according to their general relevance. The scoping review is considered over two manuscripts, with this first paper focusing on awareness of the problem and barriers or challenges to the implementation of sustainable care.

Conclusions. Eight diverse but closely interlinked themes that influence the sustainability of oral health provision were identified: Environmental impacts (CO$_2$e, air and water); Reduce, reuse, recycle and rethink; Policy and guidelines; Biomedical waste management; Plastics (SUPs); Procurement; Research & Education; Materials. Barriers to implementation were identified as: Lack of professional and public awareness; carbon emissions arising from patient and staff commute; challenges associated with the recovery and recycling of biomedical waste with a focus on SUPs; lack of knowledge and education into sustainable healthcare provision and; the challenges from the manufacturing, use and disposal of dental materials.

Key words

Sustainability, dentistry, awareness, barriers, scoping review
Introduction

Evidence that climate change is anthropogenic in nature is established [1,2]. Four out of nine planetary boundaries (safe operating limits of planetary health) have been crossed, including climate change, loss of biosphere integrity, land-system change and altered biogeochemical cycles (phosphorus and nitrogen) [3]. Global average temperatures are now significantly higher than pre-industrial levels, an effect that cannot be explained without human activity and greenhouse gas emissions [4]. The impacts of climate change include increased ocean and atmospheric temperatures, the associated impacts of altered precipitation patterns, rising sea levels, acidification of the oceans, increase in the frequency and intensity of extreme weather events and severe flora and fauna species-level extinction. Climate change has also been described as ‘one of the biggest global threats to human health of the 21st century’ [5]. Human health is intrinsically linked to the environment. It is estimated that climatic change currently causes over 150,000 deaths globally per year and between 2030 and 2050 this will increase to 250,000 additional deaths per year [6,7].

Health care delivery is not currently environmentally, socially nor financially sustainable due to high amounts of CO₂ (carbon dioxide equivalent) and waste generation [8]. It is paradoxical that health care, with a central tenet to support and protect health and life, contributes to climate change with consequent increased deaths and reduced quality of life through unsustainable practices. Oral healthcare in particular has previously focused on solely providing optimal patient care, without consideration of environmental impact. This is changing with an increasing awareness of the need for sustainability at all levels of society, government and industry. For example, the signing of the Paris Agreement of 2016, national legislation such as the U.K.’s Climate Change Act of 2008 and global climate change activism. Accordingly, there is a call for Dentistry as a profession, to integrate sustainable development goals into daily practice and support a shift to a green economy in the pursuit of healthy lives and well-being for all through all stages of life [9]. As we strive to implement more sustainable practices, there is a need to understand the current knowledge base, to increase awareness, identify barriers and opportunities to implementation; alongside examples of best practice that can be implemented and translated into wider contexts.

Sustainability within oral health care is an emerging topic with a significant volume of literature outputs covering multiple facets of this domain. It is therefore important to review and compile this existing knowledge in a structured manner to establish a baseline, that will inform and support further research, fill knowledge gaps, drive engagement and establish parameters of best practice.

A scoping review of the current literature base is considered the most appropriate tool to accomplish this by asking the research question, ‘What is the current state of environmental sustainability in general dental practice?’ The aim of this study is to undertake a comprehensive scoping review of the literature to address the research question. Through this process we have undertaken a thematic analysis that describes the general professional and societal awareness of the problem; identifies the barriers or challenges to the implementation of sustainable care; considers the drivers and opportunities to develop and engage with sustainable practice and reviews recommendations and examples of best practice.
Method

A scoping review was employed as considered to be the most appropriate tool for answering the broad research question. The methodology established by Arksey & O’Malley and the PRISMA-ScR (PRISMA extension for Scoping Reviews) were used [10,11].

A thematic analysis as described by Braun & Clarke (2006, 2014) was employed to analyse the emerging themes in accordance with the six-point phases described [12,13]. Through a thematic analysis we have organised, described and interpreted our data set. Themes were identified from common patterns in the included papers. A patterned response relates to ‘prevalence’, in terms both of space within each data item and of prevalence across the entire data set. Items is of low prevalence, or that captured something important in relation to the overall research question, were also included. In this scoping review, we have gone beyond an inductive process of thematic coding and analysis (Frith and Gleeson, 2004) to a more detailed semantic approach (Patton, 1990) in which the data is organised according to semantic content, and is then summarised and interpreted, with an attempt to theorize the significance of the patterns and their broader meanings and implications [14,15]. A thematic analysis was used to identify, analyse and report patterns (themes) that arise through the review process.

The search strategy for the scoping review was undertaken in a series of distinct steps (Figure 1). An initial search included published literature, internet web resources, all topics and all types of documents. A multidisciplinary research platform (Web of Science, Clarivate™ – Institutional licence) was employed for this task as it enables simultaneous cross-searching of a range of citation indexes and databases (Table 1) [16]. Web of Science identified relevant literature, with no restriction on study design, article type (e.g., opinion pieces, editorials or patents etc.), source or date; and these were filtered later. No limitations were placed on the year of publication but only papers in the English language were included; as this is considered to be the main publishing language for scientific articles, governmental and national and international NGO reports. Since sustainability is an umbrella term which encompasses multiple subjects (e.g., climate change, carbon emissions, the use of plastics and many others), numerous searches were carried out with the aim to include as many relevant interpretations of sustainability as possible. The search terms used were: Carbon footprint; climate change; environmental impact; green dentistry; life cycle analysis or LCA; procurement; sustainable healthcare; sustainable dentistry; reduce, reuse, recycle or 3rs; reduce, reuse, recycle, rethink or 4rs; recycl*; single use plastics; waste management; and waste hierarchy. All search terms except sustainable healthcare and sustainable dentistry were compounded with the additional search term: Dentistry or dental care or dental practice or dental office. The search strategy was designed and agreed following consultation with the research team. The search was conducted between April 2020 to 30th April 2021 with this latter date marking the cut off for inclusion. This initial search identified 944 records.

Further screening was conducted by reviewing titles and abstracts with the authors working in pairs according to the inclusion/exclusion criteria and reaching consensual decisions (Table 2). Outputs were further excluded if they were duplicates (n=44), irretrievable (n=56) and not relevant at initial review (false positives) (615 papers). Further outputs were identified by the investigators from the bibliographies of the systematic and narrative reviews (n=95). This process yielded 324 records, for which the full texts were retrieved.
The full text papers were randomly divided into four groups to be analysed by four of the investigators (GG, MC, MS, PA). Each investigator individually read and critiqued a share of papers, summarising each with relative merits. The papers were tabulated in a spreadsheet to enable thematic analysis and coding with further filtering according to the inclusion/exclusion criteria (Table 2). Subsequently, the four investigators, working in pairs, cross-checked every paper. At this point, further papers were excluded. This process resulted in a final count 128 outputs to be included in the review.

The 128 papers included in this scoping review consisted of: Commentary [Letters, editorials, communication and opinion] (n=39); Research (n=60); Literature reviews (n=25); Reports [Policy and legislation] (n=4). Each record included was analysing for emerging themes as described. Key themes from each paper were coded against identified themes (Table 3, Figure 2). Tabulated outputs up to the 31st April 2021 were included as the cut-off date from this scoping review (Table 4).

Results
The outputs are described thematically in eight separate headings as per Table 3. These are further divided into sub sections, where possible, to enable the reader to focus on specific points according to their general relevance. These subsections are detailed in two sequential publications.

Awareness and barriers to achieve sustainable dental practice - A scoping literature review. This publication considers the literature with a focus on: Background, where appropriate; Awareness of society and the profession to the impact of oral health professional activities; and Barriers to develop and engage with sustainable practice.

Drivers, opportunities and best practice to achieve sustainable dental practice - A scoping literature review [17]. This complementary publication considers the same literature review with a focus on: Drivers to develop and engage with sustainable practice; Opportunities to develop and engage with sustainable practice; Recommendations & Best practice for effective sustainable dental practice, based on guidance and real examples.

Theme 1: Environmental impacts - CO2e, air and water

Background
A series of recent articles by Duane et al., consider sustainability in a comprehensive manner and provide a very helpful contemporary context to this domain [18-25]. The introductory article highlights the relationship between planetary health and human health, focusing on an increased professional awareness to be environmentally sustainable but matched by an inability to act on this through lack of knowledge and tools [18]. This article also provides a series of useful definitions of greenhouse gases, global warming potential and CO2e. The topics of air pollution, energy and water use, have a heavy predominance in the literature of this theme. There is a need to consider
sustainability in dentistry within a wider context of modernisation of the dental profession and the services that it provides [26].

**Air pollution**
At a societal international level, the management of air pollution on a world-wide basis is led through the United Nations’ body, The Intergovernmental Panel on Climate Change (IPCC) [26]. The IPCC aims to ‘provide policymakers with regular scientific assessments on climate change, its implications and potential future risks, as well as to put forward adaptation and mitigation options.’ Air pollution impacts on every living being on the planet Earth and every human citizen has a personal responsibility for managing this at an individual level. The professional literature has highlighted this point, noting that global greenhouse gases need to drop by 45% from 2010 levels in the next 12 years [18].

A major contributor to air pollution arises from petrol and diesel vehicles with significant health effects particularly on young children and people with respiratory and cardiovascular disease. Increased short-term exposure to elevated particulate matter can have adverse health effects [28]; in the UK, air pollution kills 40,000 people every year [9]. Healthcare is identified as a major contributor to CO₂ emissions and in the UK this is estimated to account for 5% of the national emissions [8]. At a level of our professional activities in oral health care, our contribution to air pollution is increasingly being understood and should not be underestimated [18,30-34]. This arises from a number of different sectors, mainly incineration of waste, anaesthetic gases and CO₂ emissions associated with travel and transport; these are all considered separately in this report.

Waste management through incineration further contributes to air pollution. Medical waste incinerators release toxic air pollutants and toxic ash, major contributors of dioxins in the environment; with a reported link to an increased risk of non-Hodgkin lymphoma and serum organochlorine concentrations [35]. Incineration of plastics is a recognised and significant contributor to the release of hazardous dioxins [36].

**Patient and Staff Travel**
Travel and transport accounts for 13% of CO₂ emissions associated with UK-NHS health, public health and social care. Travelling to and from practice by both patients and health-care providers is the highest emission source (64.5%) [8,9,18,36-40].

The air pollution impact of travel related to dentistry is also significant and equates to around 8% of the total UK NHS air pollution impact from travel [21]. One tenth of air pollution emissions are from health care systems [36,41].

Dental-associated travel affects air quality, releasing over 443 tonnes of nitrogen oxides (NOx) and 22 tonnes of particulate matter (PM2.5) annually. The associated reduction in air quality reduces over 325 quality-adjusted life years (QALY) per year and costs £17.5 million a year [8,30]. There is a realisation that the profession’s management of carbon emissions needs to be an integral part of normal sustainable practice [31].

**Energy use**
The energy use of buildings makes up 15% of the carbon footprint of primary dental care [9,36,39]. Without ‘green’ energy saving features, buildings contribute to 24% of the total UK NHS healthcare
system carbon footprint by consuming more than £410 million worth of energy [36]. The annual carbon footprint of NHS dental electricity use is 51,939 tCO$_2$e and for gas 51,649 tCO$_2$e; this equates to 7.7% and 7.6% respectively of the total carbon footprint of NHS dental services in England [19,37]. Older smaller clinics, with no air conditioning and fewer meeting rooms generated lower carbon footprints than newer clinics. This suggests that new buildings are not necessarily more energy efficient [19]; the energy saving building features need have to be balanced against usage. A study by Duane et al. (2019) includes a useful comparative table of energy use within the dental practice [19]; e.g. autoclaves, washer disinfectors and ultrasonics use a lot of energy, although for a relatively low time through the day [19]. Building regulations and advisory groups can assist building owners to rate or create healthy, efficient and cost saving buildings; e.g., LEED (Leadership in Energy and Environmental Design) system in the UK or TERI in India [19,32,33,42-44]. A recent LCA that considers the overall environmental impact of dental examinations highlights their relative low impact, with the caveat for the need to consider the magnifying effect of the number of these procedures undertaken every year [45].

Water consumption

Water consumption also contributes to the carbon footprint; although compared to other activities, the direct impact on carbon emissions from oral care provision is lower. The water industry in the UK contributes 0.8 per cent of annual UK greenhouse gas emissions [46]. The proportion of the carbon footprint directly attributed to water use in the provision of oral health care is only 0.09% of the overall carbon footprint [34,37]. Water is a very precious resource that should be managed more effectively in dental practices. The European Dental Association (EDA) reports that dental offices consume 57,000 gallons (259,000 litres) of water a year [32], with an average water consumption estimated at around 33,000 litres per surgery per year [34]. Other reports estimate that the use of water in dental practices from tooth brushing at plaque stations and hand washing is presumed to be 17,000 gallons (77,284 litres) a year per dental surgery [47]. The indirect impact is significant, as the water used in dental offices needs to be treated before and after in water and sewage works; both requiring significant energy and further contributing to CO$_2$ emissions.

These CO$_2$ emissions contribute in a circular manner to unpredictable water precipitations associated with climate change, creating periods of draught and desertification [48].

Awareness

General individual awareness for carbon emissions and their impact on the environment is high, albeit translation into the professional oral health domains is not as pervasive. Evidence for the effect of the carbon footprint of dentistry is noted with an appreciation for lack of practical action and the need for education of the profession at all levels [2]. Wealthier countries are the largest contributors to carbon footprint but are least affected by the consequences [31].

The provision of oral health care, like any other business or intervention, creates a significant carbon footprint that is not limited to the actual intervention itself, but it is the sum of the emissions created by each stakeholder in the supply chain. The linear economy supply chain is considered as a continuum from mineral extraction, processing and synthesizing of raw materials, to manufacturing and ultimately waste management; with oral health care and dentistry included within it, as the principal intended beneficiaries of these services and products [49] (Figure 3).
In the UK (2013-14), the Government through Public Health England conducted a comprehensive calculation of the carbon emissions of NHS dental services in England to identify the types of dental procedures which are responsible for large amounts of greenhouse gas emissions [37,38]. This included patient travel, staff commuting, business travel, procurement, gas and electricity use, waste disposal, water use and nitrous oxide release. In 2013 to 2014, the total greenhouse gas emissions of NHS dental services in England were 675,706 tonnes of carbon dioxide equivalents (tCO2e). This is equivalent to flying 50,000 times from the UK to Hong Kong and makes up 3% of the overall carbon footprint of the NHS in England. The highest proportion of these emissions is caused by travel, followed by procurement, energy, nitrous oxide, waste and water [18,37,39].

An earlier study for National Health Service (NHS) dental services in Scotland (2004) estimated a contribution of 17.9 kg CO2eq per patient appointment [31]. Both studies provide a breakdown, with travel commute making the largest contribution (46% for Scotland and 64.5% for England) that accounts for 3% of the overall carbon footprint of the NHS in England [21,50]. These studies are indicative of the size of the problem and have the limitation that they do not include full LCA of procedures as there is insufficient data to support this type of study. Some data collection for calculating water and waste are performed only in small regional areas and cannot be considered to be fully representative of the whole population. Nevertheless, these studies provide an invaluable insight into the nature and the size of the CO2 emissions. Equivalent services in USA and Australia contribute 10% and 7% respectively to total CO2 footprint [18]. In 2014, Health and Social Care agreed to reduce the carbon footprint of the NHS in England by 80% by 2050 from the 2008 baseline in accordance with the Climate Change Act. [31,36-40].

A practical guide has been developed in the UK with suggestions on how dental practices can become more sustainable through travel, supplies, energy waste management, biodiversity and green space. It includes real life examples of suggestions made in dental practices and considers cost, return on investment, environmental benefit and ease of implementation of each suggestion [9].

**Barriers to change**

The problem of implementation of sustainability behaviours and attitudes is a significant challenge and even more so in in developing countries; where the greatest barriers are a lack of economic feasibility and knowledge-base [51].

Broad sustainability aims and guidance are beginning to be introduced into health care contracts, but these are neither sufficiently pervasive nor enforceable by the employer or law. For example, in the UK, the NHS England standard contract, contains three clauses which currently are not applicable to primary healthcare [18]: Providers must take all reasonable steps to minimise their impact on the environment; demonstrate their progress on climate change adaptation, mitigation and sustainable development; and provide annual summaries of this to commissioners. Considering travel, the alternatives to the use of private cars, of cycling and walking are not readily available options for many due to the lack of infrastructure that facilitates this [21].

When it comes to the choice of most commonly used dental materials, amalgam and resin-based composites are the greatest exponents. However, the comparative carbon footprint of these two materials is unknown with an absence of more concrete life cycle analysis data for each material.
There is a requirement to provide this analysis so that informed choices can be made by the profession and the public [38,40].

Ultimately, the decision-making for oral health care professionals of cost and inconvenience vs positive impact on the environment is highly subjective and lacks sufficient evidence that will support strong arguments [21].

**Biodiversity**

A recent UNEP report [52], highlights that climate change is causing an ‘unprecedented’ and ‘accelerated’ rate of species extinction across the world with a profound effect on biodiversity that can have catastrophic consequences. Within the UK, 15% of around 8,000 species assessed are facing extinction [22]. In addition to our contribution to global warming through CO₂ emissions, some of our activities in dentistry have a direct negative impact on biodiversity; such as the presence of mercury in waste-water works from dental practices that don’t use traps. Mercury is neurotoxic and teratogenic; it can accumulate as it rises through the food chain and it can also impact the microbiological activity in soil. Manufacturing and distribution of supplies has an environmental impact via mining and procurement of raw materials, manufacturing environmental impacts and transport in the supply chain. This can affect emissions, land and water pollution and changes to landscapes resulting in changes to biodiversity [9].

Every sector can contribute in a positive manner by promoting biodiversity within their own operational environments. Biodiversity refers to the variety of living species which interact with one another to form ecosystems: This means, the promotion of the growth and development of green spaces for habituation of insects and animals [9]. Dental practices can consider gravel or grass instead of tarmac; that has an impact on insects (essential building block for biodiversity) and lowers risk of floods. Trees provide shelter and shade, and in this way contribute to a reduction in a building’s energy budget, through reduced air conditioning usage and improved solar gain. Reduction of the use of harmful pesticides when caring for practice gardens/lawns also improves biodiversity [44,53]. Green roofs help mitigate the urban heat island effect (an urban area is significantly warmer than the surrounding countryside), and help with both energy conservation and stormwater management [9]. In addition to the above, dental professionals can offset CO₂ emissions by investing in reforestation campaigns [43]. There is a need for effective quality research that demonstrates the cost benefits of providing a biodiverse space [22].

**Theme 2: Reduce, Reuse, Recycle and Rethink**

**Background**

Within the setting of the dental surgery, the complex and mostly contaminated nature of the waste produced in the delivery of oral healthcare makes it difficult or impossible in some instances to implement policies of reuse, reduce and recycle. Many of the polymers used are highly cross-linked and processed so that they may not be easily broken down into the constituent raw materials or derivatives. Polymer devices used in a clinical environment are at high risk of contamination, and the nature of the polymers and/or the complex shape of the devices makes it costly and difficult to clean, disinfect and sterilize [49,54,55]. Items that are currently easily recycled (e.g., paper, plastic and glass products) should be also be recycled in the workplace, to help reduce the depletion of natural resources and lower carbon emissions [34]. Sustainable activity through the recognised
strategies of reduce, reuse, recycle and rethink are considered in the literature. Although commonly grouped together, the individual distinct focus of each strategy, requires that they should be considered as separate entities in the review of the literature and are considered in detail under the headings of opportunities and best practice in the second part of this review [17].

**Barriers**

Difficulties and barriers to recycling are the main reason for lack of engagement. The following have been identified that affect oral health care provision. The need for additional storage space and the cost of transport for moving waste; staff training and co-operation are essential; the (real and perceived) risks associated with waste segregation need to be managed; availability of waste recycling facilities (especially in developing economies); and a lack of cultural understanding of the need and benefits associated with recycling [34,59,79,126].

**Theme 3: Policy**

**Background**

The provision of health care in dentistry and the management of waste arising from this has to operate within the boundaries of legislative regulation to ensure safety and sustainable practice; thus, presenting a conflicting challenge. These frameworks vary both in their remit from guidelines to legally enforceable laws, and across countries [56,57]. Given that they are designed to operate within their own country, they are normally published in their native language, and thus are excluded from this review if not in English. There is a need to protect the public from communicable infectious diseases, with increased use of SUPs and PPE in dental practices that has a deleterious effect on environmental sustainability in dentistry. An example of this was the introduction of new infection control guidance that was introduced in England and Wales (2009 and revised in 2013) under the Health Technical Memorandum HTM01-05; that focused on management of cross-infection control with no consideration to sustainable practice [29,58]. An in-practice study identified a 58% increase in waste management costs over a four-year period following the introduction of HTM01-05 [29]. In the UK, the Control of Substances Hazardous to Health Regulations (COSHH) requires all dental employers to control exposure to hazardous substances to prevent ill health [9].

Concerning the management of waste, there is an abundance of legislation surrounding the use of hazardous substances in healthcare. The main basis for dental waste management in the European Union is the Waste Framework Directive that requires Member States to take necessary measures to ensure waste is disposed of without endangering human health or the environment. Directive 91/689/EEC addresses hazardous waste and by Decision 2000/532/EC a list of wastes was adopted, which includes dental amalgam waste [59]. Waste management in the UK is governed by the Environmental Protection Act (1990) that imposes legal ‘duty of care’ requirements on waste producers, to ensure the appropriate safe handling and disposal/treatment of waste [60]. The Hazardous Waste Regulations (England and Wales) 2005 outline the legally binding requirements for hazardous waste which must be properly segregated, packaged and labelled [34].
In the UK, confusion often arises around interpretation of HTM01-05 making cross-infection and appropriate waste management difficult to follow creating an unnecessary burden and frustration in the ability to engage with sustainable practice with fear of litigation [40,61,62]. Other examples cite the need for effective legislative frameworks for the safe and environmentally sustainable management of amalgam waste [63]. When designing policy and regulatory frameworks, there is a need to consider sustainability in dentistry within a wider context of modernisation of the dental profession and the services that it provides [26].

**Theme 4: Biomedical Waste Management**

**Background**

The term biomedical waste has been defined as “any waste that is generated during the diagnosis, treatment, or immunization of human beings or animals, or in the research activities pertaining to or in the production or testing of biological and includes categories mentioned in Schedule I of the Biomedical Waste (Management and Handling) rules 1998 [64-70]. Biohazardous waste has been referred to as medical waste, infectious waste, red bag waste, biomedical waste, and regulated medical waste. Most agencies and states assume that biohazardous waste is waste capable of transmitting infectious disease, and therefore includes materials sufficiently contaminated with blood or body fluids to transmit disease. In a physician’s office, this would include supplies or disposable materials saturated with blood or body fluids - Centers for Disease Control and Prevention in Atlanta, EPA (USA definition) [57].

Waste management is a significant and expensive problem for the healthcare sector [49,55]. This is due to the complexity of the waste generated and its contaminated/infectious status. The volume of biomedical waste (BMW) produced across the world is staggering, with a reported 5.5kg of waste/patient/day in the UK-NHS and 0.4 kg/patient/day in Germany [39]. According to WHO and SEARO, the South-East Asian countries, collectively produce approximately 1,000 tonnes a day (approx. 350,000 tonnes of BMW a year [71]. These are pre-COVID pandemic figures and will be much greater during the pandemic with the increased use of single-use disposable PPE that has been necessary [72].

A focus on oral healthcare shows points to a steady increase in biomedical waste over the last decades due to the increased use of plastic barriers, gloves and masks [37,73]. For example, the Eco-Dentistry Association [74], estimated that 1.7 billion sterilization pouches and 680 million patient barriers were disposed by US dental practices every year [31,73,75]. It is of note that high income countries produce more waste than medium and low-income countries [67]. BMW that is inadequately managed, can cause water, air and soil pollution [73,76].

The carbon emissions embedded in the disposal of all dental-related waste streams is approximately 1,493 tCO₂e, which is 0.22% of the overall carbon footprint of NHS dental services in England [37]. However, it is important to bear in mind that it is the actual toxicity of the waste that may have the greatest impact on the environment, rather than the associated CO₂ emissions [37]. Incineration of clinical waste releases greenhouse gases that contribute 1% of Europe’s carbon emissions [39]. Part of the problem is that BMW is not always effectively managed due to practical, logistic or financial reasons, with much that can be recycled ending in incineration and landfill [37]. Incineration of healthcare waste is linked to air pollution affecting public health [34]. A rapid increase in the number...
of healthcare institutions, results in an increased burden of biomedical waste [68,70,77,78].
Generation of BMW, despite being smaller than regular domestic waste, becomes significant when
taking into account the risks associated with pathogens, chemicals and their respective toxicities.

Various European directives provided for specific regimes (take-back, recovery and recycling) to deal
with waste packaging, waste electrical, electronic equipment and waste batteries [34].

**Barriers to change**
Biomedical waste is heterogenous making it difficult to manage [69]. This is particularly the case of
dental waste that uses a wide range of materials [49,61].

Inadequate knowledge and poor attitudes towards the generation and management of biomedical
waste across the world and in particular in developing economies; considered to be no different
from household waste, generating additional work burden and lacking adequate regulatory
frameworks [39,59,62,65,66,77-83].

A good level of knowledge, a positive attitude and effective infrastructure is key to implementing
effective waste management; which are often missing [62,84,85]. These are often lacking due to a
lack of education, financial support and appropriate supportive legislation [34,53,65,79-81,83,86].

An increase in the prevalence of infectious diseases coupled with much greater patient safety
awareness, measures and regulation results in a significant increase in the quantity of SUP solid
waste generated (e.g., plastic barriers, gloves and masks) in dentistry. This accounts for about 90% of
the total solid waste generated [29,41,59,61,62,76]. The increased regulation creates confusion
with regards to managing sustainability [39].
Theme 5: Plastics

Background
Plastics are an integral and essential part of modern life and the global economy and exhibit a range of properties that make them invaluable in clinical settings. Polymers can be assembled in a wide range of combinations using compound multi-layered structures and forming highly specific complex shapes, that create a clinical item or packaging with optimised properties. Plastic items and devices provide clinical and public confidence of using a new clean and/or sterile device every time. The low cost of raw materials and bulk fabrication means that a wide variety of single-use products may be manufactured at exceptionally low costs. The combined manufacturing versatility, cleanliness/sterility guarantee and cost effectiveness of plastic devices makes reusing and/or recycling economically unattractive, with disposal being the more likely solution [49,55]. This results in a highly wasteful linear economy for Single Use Plastics (SUPs) with significant environmental impacts and greenhouse gas emissions affecting biodiversity and health (Figure 3). Eight million tonnes of plastic enter our oceans each year, that does not naturally biodegrade but breaks down into smaller particles ‘micro-plastics’ [9]. Rates of plastic use have grown exponentially since the 1950’s, reaching 350 million tonnes (Mt) globally in 2017. In Europe, production of plastics has been estimated at 60 million tonnes in 2018, which is around a 17% of world’s plastic production [87]. 79% of the plastic produced over the last 70 years has been thrown into landfill sites or into the environment, with only 9% of it being recycled and the rest incinerated.

It is useful to consider the impact of plastic packaging alone discarded by the healthcare sector in the UK is staggering; with over 590,000 tonnes generated annually, more than the entire municipal waste output of Luxembourg (England Chief Medical Officer Report 2016-17) [88].

In dentistry, single-use instruments are common, driven by short-term cost and a perceived drive to infection prevention [73,89]. The industry produces many non-reusable materials, such as single-use plastic tubes of toothpaste, with lids that cannot be recycled [8]. The reasons for an increased use of plastics in dentistry are highlighted as: Improved infection control, ability to manufacture complex sophisticated shaped items, ease of manufacturing and ease of use and ease of disposal [32,76,89]. Ultimately, plastics from dentistry follow the same fate as other plastics with their presence identified in the Mediterranean Sea by this study [90].

A recent study showed that an average of 20 SUP items have been identified that are used for every routine adult primary care dental procedure in the UK [49]. The use of SUP items per adult care procedure is greatest for routine dental fillings, followed by root canal treatment, oral surgery for dental extractions/minor surgical procedures, provision of crowns, bridges and dentures and finally periodontics. The most commonly used products are PPE for the dentist and nurse. On average, more than one pair of gloves, masks, wipes, autoclave-sterilization sleeves and tray liners were used with each patient, independent from the type of procedure delivered. This was compounded by the large number of items necessary for setting-up before and for decontaminating after procedures. In the UK, based on the number of dentists and dental therapists registered with the General Dental Council in 2019 (n=45,000), it is possible to use this data to extrapolate the national usage of the approximate number of SUPs used in a 40-week working year, working four days per week and considering a conservative estimate of five procedures per day. A mean of 20 SUP items/dental
procedure translates to a conservative estimate in excess of 720 million dental SUP items/year that end up as waste in the UK [91]. The SUP items identified in this study were approximately 50:50 single plastics and multiple plastics forming compound structures [48]. This is a situation that is not sustainable in the long-term [76,92]. Disposal of these plastics through high temperature incineration releases the carcinogens dioxin and furan [35,93]. Plastics containing PVC produce acidic gases when incinerated and are difficult to recycle [42,53,94].

To address the impacts that plastics are causing a number of organizations, such as the Ellen McArthur Foundation [95] and WRAP [96], have been at the forefront in helping to push through changes in policy at an international and national level. The UK Plastic Pack initiative led by WRAP, largely focuses on plastic packaging, with major goals to be achieved by 2025 for 100% of all plastic packaging to be reusable, recyclable or compostable, 70% of plastic packaging to be recycled or composted, elimination of single-use plastic packaging and 30% recycled content to be used in all plastic packaging.

**Barriers to change**

The greatest barriers to a reduction in plastic waste are twofold. An apparently overriding requirement to protect patient safety through IPAC processes (Infection Prevention and Control) operating in an increasingly litigious society with sustainability concerns becoming very secondary. The need to comply with control of infection regulations that focus on IPAC processes is a further barrier [97,98]. There is an urgent need to weigh these complex interplaying issues of environmental harm and personal harm [8]. A second factor is the need to understand that the disposal of the actual plastic waste contributes a small percentage to the overall impact on pollution and CO₂ emissions that arises from plastic usage in healthcare. The major contribution comes upstream in the supply chain from manufacturing, processing, distribution and logistics [99].
Theme 6: Procurement

Background
Sustainable procurement, when applied to dentistry, is the practice by which the dental surgery addresses environmental and social/ethical considerations when they purchase goods or services [20]. ‘Green procurement’ is a process whereby public authorities meet their procurement needs by choosing solutions ‘that have a reduced impact on the environment throughout their life-cycle, as compared to alternative products/solutions’ [20].

Each stakeholder of the supply chain, has a significant impact on the environment through the process of procurement of raw materials, manufacture, transport, distribution etc. In the UK, the carbon footprint of dental services provided by the NHS, public health and social care accounts for 72% of the total [36]. This impact is in the form of GHG emissions, land and water pollution and changes to landscapes resulting in changes to biodiversity [8,9]. Procurement is a major hotspot, noted as the 2nd highest contributor (19%) of the UK NHS dentistry’s carbon footprint [9,18,20,37,39]. There is a recognition to coordinate procurement of products that use plastic as a container or packaging with waste management that can recover and recycle this waste [49]. This approach can have significant financial gains by mapping procured plastic (at all levels of packaging) with sustainable recovery and recycling technologies.

Extensive and complex care plans, requiring multiple appointments are more resource intensive. This highlights the need to promote prevention as the most effective way of managing this pollution burden [18,37]. A focus on sustainable purchasing led to lower costs, environmental and health benefits. Importantly, procurement should also be ethical with due regard to products originating from developing economies with regard to labour, safety and human rights of workers [20].

Barriers to change
The limited supply of sustainable products [36] and the user convenience of some products (e.g., disposable gowns) overrides the desire for more sustainable options [20]. There is a lack of knowledge and evidence on best practice that balances safety and sustainability for products. The need to adhere to legally-binding regulations and laws that stipulate patient safety as the main concern. The high cost of some recycled products, such as recycled paper that is twice the price of non-recycled paper is a barrier to its use [20]. An example for the use of effective procurement as a tool to reduce the use of amalgam, in line with Minamata phase down plans, is through sales made only to registered practitioners via a Know Your Customer approach [100]. In this way the volume of sales, suitability, and risks involved can be monitored more effectively.
Theme 7: Knowledge exchange

Awareness
This theme considers knowledge acquisition through research and knowledge delivery through education.

An increasing body of research in sustainable practice is evident through this literature review that pervades all the identified themes (Table 4). A prevailing finding is the paucity of high-quality research into the provision of environmentally sustainable oral health care in general and that is linked to the requirement to provide equally high-quality patient-centred care outcomes [8,23,50,101].

With regards to education, there is a growing awareness of a lack of education in both undergraduate and postgraduate curricula, as part of formal education or informally through continuing professional education programmes [30,65,70,81,102]. This educational provision is inversely proportional to an increasing level of interest in the dental profession for education into approaches for engagement with and the delivery of sustainable practice [18,22,30,65,62,79]. It is also set against a backdrop of generalised lack of awareness and knowledge in this area; as highlighted in the relevant sections for each theme in this review. A study in India reported that 76% of private practitioners were aware of the harm they were doing to the environment; 95% of them reported they felt a responsibility to not harm the environment [75].

Some changes are beginning to take place, with some evidence of sustainability included in the undergraduate curriculum [30,41,79,103]. There is a perceived lack of encouragement from curriculum regulatory and governing bodies [18]. There is a growing and distinct need to reverse this trend with eco-friendly curricula that focuses on the education of staff and students on sustainability using a range of media and resources [9,23,35,40,65,68,71,79,97,104,105].
**Theme 8: Dental materials**

Dental materials, are used in various formats, either for direct clinical application or indirectly associated with oral health care provision. The literature covers a wide spectrum of materials and in the context of sustainability, this theme is undoubtedly the one that goes furthest back in time, with references to a number of materials used directly or indirectly for clinical care; each of these is considered individually.

Dental materials have a high pollution impact, from all levels of the supply chain: Synthesis of raw materials, manufacturing, distribution, procurement, clinical use and ultimately waste management. It is indisputable that these materials are required for the provision of effective oral health care, but there is also a need to understand this impact and how to affect this as a user [49].

**Barriers**

Life cycle analyses are possible but are not specific to the CO₂ footprint due to the lack of analysis of processes that are necessary to make materials suitable for healthcare. Carbon conversion factors for making the manufacturing of materials are not readily available outside industry; making it very difficult to develop appropriate strategies [9,31,37].

For many decades, the dental environmental spotlight has focused on dental amalgam. A greater appreciation and understanding of the pollutant potential of other dental materials should drive further research in this field. Most dental suction units are evacuating by-products of restorations (for example, mercury and particulate waste containing monomers) and, increasingly, derivatives of ceramic products originating from milling, yet very little research exists on their potential harm to the environment [8,106].

**Dental Amalgam**

**Background**

Worldwide consumption of mercury is around 300 tons per annum [73]. Mercury is the heavy metal of primary concern, making up to 50% by weight of dental amalgam. Mercury is bioaccumulating and exposure to mercury is known to have toxic effects in plants, animals and humans. Mercury can be neurotoxic and teratogenic; it can accumulate as it rises through the food chain and it can also impact the microbiological activity in soil. Once in the environment, a number of factors contribute (pH, temperature, oxygen, bacteria) to convert it into the more toxic methylmercury that is more bioavailable and can now accumulate in the food chain [32,33,44,59,61,64,73, 94,103,106-122].

Dental mercury accounts for 3-4% of terrestrial mercury [64,112,115,119,121]. The UNEP Global Mercury Assessment of 2013 revealed that in 2010 an estimated 270–341 metric tonnes of mercury globally were derived from the use of dental amalgam [123]. 75 tonnes of amalgam per annum were used in the EU alone [106]. The subsequent 2018 report notes that the category of ‘mercury-added products’ that includes dental amalgam, remains a major source of mercury release, but according to the latest 2015 global inventory, these levels are in decline, especially in developed countries [125].
Disposal of dental amalgam directly into the sewage system is common practice around the world. A study in Chicago, revealed a discharge of 35mg of mercury (as amalgam) a day into sewers, that contributed around 8-14% of total mercury in wastewater treatment plants [56,125]. Notwithstanding, the mercury waste from dental amalgam, accounts for less than 1% of mercury discharged by human activity into the environment [77,92].

Beyond the dental practice, the amalgam legacy in the form of mercury emissions from crematoria will rapidly increase until 2020. This is predicted to plateau around 2035; returning to the lower levels seen in 2000 by 2055 [106].

Pollution pathways for dental amalgam

Mercury from amalgam waste enters the environment as dental waste from the placement and removal of restorations into waste water systems, due to intra-oral degradation of amalgam and release through human excretion, incineration of clinical waste (extracted teeth with amalgam fillings) or at the end-of-life following burial and cremation [32,33,35,53,56,59,63,65,71,73,77,92,106-108,112,115,117; 118,119,120,121,126-131]. A 2005 Scandinavian study revealed that the output of mercury per chair exceeded the maximum recommended output [117]. The incineration of extracted teeth with amalgam as clinical waste releases mercury into the atmosphere [56,59,71,77,81,107,112,115,122,126,127,132]. In a similar manner, inappropriate disposal of Hg to landfill is a further pollution source as this can leach into the environment [77,113,122,127,130]. A 1998 study reported that end-of-life cremation accounted for 7% of Hg emissions in Sweden [112] and a subsequent Malaysian case study reported that in 2013, 3.6 tonnes of Hg were released from the cremation of bodies with amalgam [128]. Dissolved mercury is the most reactive fraction and should be included when considering total mercury emissions as this causes the most severe environmental effects [117].

Dental separators are designed to capture amalgam waste at the point of clinical use in the dental surgery. These are not widely used throughout much of the world and are approximately 90% effective [9,30,18,44,53,58,103,106,112,126,127,133-136]. The amalgam waste that is not captured in a separator, will flow directly into the municipal waste water network. Sediments are likely to accumulate in the pipes of dental practices and in the sewage pipes through natural precipitation. As an example, an average 1.2 kg of mercury per clinic was found during the remediation of abandoned Swedish facilities in 1993-2003 and similar quantities were observed in more recent work [117]. Separators are not 100% effective because mercury can form colloids which are able to pass through traps/separators [117]. Also, fine mercury particles are produced when using high speed handpiece, these are particularly hard to recover and are overlooked in ISO 11143 [117].

Mercury contamination from these routes is cited as a reason to cease the use of amalgam as a dental restorative material [94,112,117,120]. Moreover, it is difficult to control mercury waste as enters the environment in different forms as elemental vapour, amalgam sludge, amalgam scrap or amalgam waste [111,126,136].

Cleaners containing oxidising agents and hypochlorite (sodium hypochlorite and sodium dichloroisocyanate), that are used to disinfect the dental chair and the effluent pipes potentiate the release of mercury [33,92,115,131,135].
Mercury levels in the air were found to be higher than permissible limits in dental surgeries [137]. Reasons for this are: Difficult to implement best practice practices [108], mishandling of materials, lack of ventilation and use of hand mixing rather than capsules [137].

Barriers to change
There is a lack of consistency at an international level and across jurisdictions with regards to the availability of legislation and regulation [63,114,128,138], and limited access to collection agencies and sites for waste amalgam waste [113,114,136].

The low cost of amalgam prevails over sustainability concerns [59,114]. This is especially the case in developing economies, where affordability of dental care is a major concern. In these economies, a switch to a more costly or complex technique or material may exclude a large portion of a population from receiving simple dental care [108,128,139,140]. A lack of knowledge prevails in some countries with limited understanding of the merits of alternative materials [108]. An interesting observation has been raised that an increase in the use of resin-based composites to replace existing amalgam restorations could produce a spike in environmental mercury levels [113].

There is a lack of general knowledge and awareness for the management of amalgam waste and disposal [65,62,81,128,140]; noting that a lack of education on the environmental sustainability of dental amalgam in the undergraduate curriculum [137]. There is significant evidence of inappropriate disposal of amalgam in many countries, with the use of a common bin followed by incineration as common practice [30,59,61,77,103,107,116,130,138].

The use of amalgam separators is not universal, with the main cited reasons being: A lack of equipment in developing countries [84,108], resistance from the dental profession that objected to this being imposed as a mandatory requirement [118] and a combination of inadequate legislative frameworks and failure to implement existing regulations [63].

There is a need to avoid Hg pollution risks high mercury emissions from dental clinics despite amalgam separators [92,103,108,110,137,141].

**Anaesthetic gases**

**Background**
The major atmospheric effects that may arise from the emission of volatile anaesthetics are their contributions to ozone depletion in the stratosphere and to greenhouse warming in the troposphere. These agents are also a recognized greenhouse gas, accounting for around 6% of the heating effect of greenhouse gases in the atmosphere [35]. Nitrous oxide (N\textsubscript{2}O) is a gas with a global warming potential of 298 times that of CO\textsubscript{2}e [34]. N\textsubscript{2}O also causes ozone depletion [142]. Most of the organic anaesthetic gases remain for a long time in the atmosphere, where they have the potential to act as greenhouse gases.

The bromide-containing agent halothane is the most destructive against ozone, although it is rarely used in the United States today. Isoflurane and enflurane (which contains only chloride and fluoride ion substitutions) have a lesser impact [142]
Published atmospheric lifetimes range between 1.4 and 21.4 years for sevoflurane and desflurane, respectively. N\textsubscript{2}O emissions from all of its various environmental sources are currently the single most important ozone-depleting substance emission and are expected to remain the largest throughout the 21st century [142]. On average, 163 litres of N\textsubscript{2}O are used per patient episode, equating to around 90 kg CO\textsubscript{2}e (without considering carbon emissions of producing NO\textsubscript{2} and cylinder rental). Nitrous oxide used by NHS dental services in England is responsible for 1.3% of the total nitrous oxide use of NHS England and makes up 0.9% of the total carbon footprint of NHS dental services in England [34].

Pollution Pathway
2 main pollution pathways are the anaesthetic technique and the actual anaesthetic machine delivery system. Incidents associated with these routes include: Poorly fitting masks, not turning off valves immediately once removed from patient; leakage of gas when re-filling tanks; gas in system may leak into environment if not flushed correctly; underinflated cuff of laryngeal mask; leaks from valves, connectors in circuit, tubing, reservoir bags etc. [142]. Scavenged gas is vented into the outside environment. As anaesthetic gases undergo very little metabolic change inside the body, upon exhalation by the patient these agents remain in a form that may pollute the environment [142].

Gypsum

Background
Gypsum is an essential material that is widely used in dental laboratories for the manufacture of all indirect prosthodontic devices. When this is disposed, it is most likely to go to landfill where it can form H\textsubscript{2}S gas. H\textsubscript{2}S gas can cause irritation to the eyes, nose, or throat and may also cause difficulty in breathing for some asthmatics. Headaches, poor memory, tiredness, and balance problems may also occur. Permanent or long-term effects include headaches, poor attention span, poor memory, and poor motor function. For these reasons, gypsum is a banned waste from normal landfill in many countries, but this practice is not the norm. Gypsum waste should be disposed into a separate cell for high sulphide waste [44,79,143,144].

Resin-based dental composite

Background
Resin-based composite materials (RBCs) are not inert plastic materials and they have an environmental impact associated with the release of microparticles and elution of resin monomer components, including BPA that is of significant environmental concern [106,145].

Barriers
There is a lack of knowledge associated with the environmental impacts of RBCs [20,106,122]. Early studies show tentative results and conclusions with regard to how composite and BPA act in the body as well as in the environment. The impact of certain oestrogenic xenobiotic effects on development, health and reproductive systems are debatable [112].
Lead

Background
Lead is toxic and persists in the environment. Even at low levels of exposure, lead exerts adverse health effects on both children and adults [71,94,97,109,129]. Lead waste can remain in soil for as long as 2000 years where it can be readily picked up by plants and enter food systems [97]. According to the US Environmental Protection Agency (EPA), dental offices generate 4.8 million lead foils a year according [146]. Lead foil from dental radiograph films is the main contributor and if disposed in regular domestic waste, lead can leach and persist for a long time in soil and groundwater [32,33,53,147].

Barriers
There is wide disparity across all dental sectors for the management of radiographic film waste lead, with reports of inappropriate disposal [70,73,78]. Additionally, some manufacturers only report a 5% return rate of lead from film for recycling [136].

Metals

Background
Silver thiosulfate is a solution used to fix the image on exposed dental radiographs that presents a significant environmental concern [107,109,126,134,147,148]. According to the US EPA, dental practices generate 28 million litres of silver thiosulfate x-ray fixer a year [146]. In wastewater treatment plants, this is converted into silver sulphide which settles in sludge [53,76,126,148]. Higher up the supply chain, toxic by-products are released through mining, processing and refining the natural resources and ores. These toxic by-products are leached into the environment creating a major source of environmental pollution [35]. Other metals that are regularly used in dentistry, have the potential for re-using and re-cycling; such as orthodontic brackets and wires. Alternative materials with lower carbon footprints to stainless steel (6.15 kgCO$_2$e/kg), should be considered, such as ceramics (1.14 kgCO$_2$e/kg) and brass (2.42 kgCO$_2$e/kg) [32,36,53,79,149].

Barriers
A significant challenge to reusing metallic devices is a very protectionist and negative psychological reaction towards reusing medical/dental devices [36]. There is a lack of regulation and control with regard the disposal of potentially toxic solutions. For example, silver thiosulfate x-ray fixer is poorly regulated in parts of the world, with most of this going into the municipal waste water drains [59,70].

Nanotechnology

Background
Nanotoxicology defines dangerous exposure that considers the entry routes of air, water/soil via ingestion together with the circuit of nanomaterials in the abiotic and biotic environment. Their size enables a wide distribution and uptake by the smallest life forms and some nano-particles that are not naturally present in the environment, such as nano-silver, nano-copper and nano-zinc that have antimicrobial properties, have the potential to pose great threat to microbial communities [28].
Healthcare is a significant contributor of microplastics as part of the waste stream that can enter the food chain; these can absorb other chemicals, poisoning wildlife, destroying ecosystems and putting human health at risk [9,106]. The dangers of ingestion of particles by marine life are four-fold: toxicity from ingesting the particle itself, contaminants leaching from the microplastics, ingestion of attracted pollutants bound to the microplastics and accumulation of particles within the organism [9].

**Disinfectants**

Disinfectants such as hypochlorite, glutaraldehydes, iodophors, phenolic derivatives, alcohol-based preparations can inactivate essential biological systems [35,53,92].

**Conclusions**

This scoping review has identified 128 records that contribute to our understanding of environmentally sustainable oral healthcare. The thematic analysis highlights eight diverse but closely interlinked themes that influence the sustainability of oral health provision on a world-wide basis: Environmental impacts (CO$_2$e, air and water); Reduce, reuse, recycle and rethink; Policy and guidelines; Biomedical waste management; Plastics (SUPs); Procurement; Research & Education; Materials. The following headline conclusions are encapsulated with a focus on the levels of awareness and the real and perceived barriers to develop and engage with sustainable practice.

Public awareness of the need to decarbonise and reduce pollution from our activities on a global basis is at an all-time high and this is directly proportional to the increasing urgency to engage with this problem. Professional awareness is much lower as there is a perceived disengagement between citizenship responsibility and that of our professional activities, that are led by the aims of the core professional activities. This is a constant theme throughout the literature and undoubtably both the greatest barrier and opportunity to engage in effective and impactful sustainable outcomes.

The greatest forms of carbon emissions arise from patient travel, staff commuting, business travel, procurement, gas and electricity use, waste disposal, water use and nitrous oxide release. Of these, patient and staff commuter travel account for the greatest contribution to the profession’s carbon footprint. A number of studies support the preliminary evidence that provides a heightened level of awareness into the source and magnitude of these emissions.

The greatest barrier to the implementation of sustainability is set behaviours and attitudes within the profession and even more so in developing countries; where the greatest barriers are a lack of economic feasibility and knowledge-base.

In addition to our contribution to global warming through CO$_2$ emissions, some of our activities in dentistry have a direct negative impact on biodiversity; such as the presence of mercury in wastewater works from dental practices that don’t use amalgam traps. The manufacturing, distribution and poor waste management of equipment, sundries and associated packaging, that are part of a linear economy supply chain, presents a pollutant environmental impact.
The provision of oral health care in a clinical setting creates complex and contaminated waste that makes it difficult or impossible in some instances to implement policies of reuse, reduce and recycle. This is especially poignant in respect of single use plastics that are found in the form of different complex polymer combinations. Plastic is an indispensable component of modern safe health care and their use is unavoidable. Plastic items and devices provide clinical and public confidence of using a new clean and/or sterile device every time. The combined manufacturing versatility, cleanliness/sterility guarantee and cost effectiveness of plastic devices makes reusing and/or recycling economically unattractive. The challenge is that these devices are costly and difficult to clean, disinfect and sterilize. Recovery for recycling is often not cost-effective, possible and not supported by appropriate legislation.

The provision of health care in dentistry and the management of waste arising from this has to operate within the boundaries of legislative regulation to ensure safety and sustainable practice. There is a recognised conflict between the need to operate within the regulatory frameworks of safe health provision and doing so in a sustainable manner. Most states and agencies assume that biohazardous waste is waste capable of transmitting infectious disease, and consequently its management automatically favours of incineration and discounts any form of recovery. Waste management policies are often not sophisticated enough to identify and compel stakeholders to establish effective pathways for segregation of waste to enable effective recovery for recycling. Current waste management focuses on land fill and incineration, both with significant environmental impacts. There is a lack of awareness and understanding of the actual impact of disposal of plastic waste. Most of the CO₂ emissions have occurred upstream in the supply chain. Ease, convenience and availability of low-cost products with high environmental impacts override a desire for more sustainable options. Procurement is also driven by the need to adhere to regulatory frameworks, that focus on clinical effectiveness and do not consider environmental impacts.

Lack of knowledge, awareness and educational programmes are pervasive throughout the literature and identified as a common barrier to engagement and change in all themes. There is a distinct lack of quality research that supports and enables the provision of environmentally sustainable oral health provision.

Dental materials present the highest level of pollution, at all levels of the supply chain, from manufacturing, through to distribution, procurement, clinical use and ultimately waste management. The impact from dental materials is material-specific, with much of the evidence focused on dental amalgam. There is a distinct need to establish effective life cycle analysis studies to provide baseline data for key restorative materials and subsequently identify ways to minimise their use and facilitate recovery.
Conflict of Interest and Source of Funding

I confirm that there is no conflict of interest.

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Figure 1: Flow chart for record retrieval and inclusion (to 30th April 2021)
Figure 2: Themes identified according to the number of records. Clockwise, red (most) to yellow (least).
Figure 3: Linear economy supply chain: Mineral extraction, processing and synthesizing of raw materials >> Manufacturing and packaging of the dental restoratives, sundries and equipment products >> Distribution and purchase of these products >> Clinical procedure with further energy expenditure, water use and indirect material use >> Collection and disposal of waste associated with different levels of contamination, mostly managed through landfill and incineration.

Table 1. Search databases, search domains and search terms through Web of Science (16)

<table>
<thead>
<tr>
<th>Database</th>
<th>Search domains</th>
</tr>
</thead>
<tbody>
<tr>
<td>Web of Science Core Collection</td>
<td><strong>Publications</strong>: Journals (including open access), conference proceedings, books. Sources: Science Citation Index Expanded (1900-2021); Social Sciences Citation Index (1900-2021); Arts &amp; Humanities Citation Index (1975-2021); Conference Proceedings Citation Index—Science (1990-2021); Conference Proceedings Citation Index—Social Science &amp; Humanities (1990-2021); Book Citation Index—Science (2005-2020); Book Citation Index—Social Sciences &amp; Humanities (2005-2020); Emerging Sources Citation Index (2015-2020); Current Chemical Reactions (1985-2020) (includes Institut National de la Propriete Industrielle structure data back to 1840); Index Chemicus (1993-2021).</td>
</tr>
<tr>
<td>BIOSIS Citation Index</td>
<td><strong>Publication</strong>: Journals (including open access), meeting, patents, and books. Domains: Pre-clinical and experimental research, methods and instrumentation, animal studies</td>
</tr>
<tr>
<td>BIOSIS Previews</td>
<td><strong>Publication</strong>: Journals (including open access), meeting, patents, and books. Domains: Pre-clinical and experimental research, methods and instrumentation, animal studies.</td>
</tr>
<tr>
<td>Current Contents Connect</td>
<td><strong>Publication</strong>: Complete tables of contents and bibliographic information from the world’s leading scholarly journals. Domain: Social &amp; Behavioural Sciences (1998-2021); Clinical Medicine (1998-2021); Life Sciences (1998-2021)</td>
</tr>
<tr>
<td>Data Citation Index</td>
<td><strong>Publication</strong>: Research data sets and data studies. Domain: Science (1900-2021); Social Sciences &amp; Humanities (1900-2021).</td>
</tr>
<tr>
<td>Derwent Innovations Index</td>
<td><strong>Publication/Domain</strong>: Combines patent information indexed in the Derwent World Patent Index (1963-2020) with patent citations indexed from the Derwent Patents Citation Index (1973-2021).</td>
</tr>
<tr>
<td>KCI-Korean Journal Database</td>
<td><strong>Publication</strong>: Bibliographic information for scholarly literature published in Korea. Domain: National Research Foundation of Korea and contains</td>
</tr>
</tbody>
</table>
Table 2: Inclusion and exclusion search criteria.

**Inclusion criteria**
- Direct relation to dentistry
- English language
- Discussed sustainability in relation to the environment (not durability or other meanings)
- All types of sources, including commentaries, opinion, reviews, reports and research.

**Exclusion criteria**
- Contained search terms in a different context to the research question
- Poor use of English language, poorly written or poorly translated, that prevented understanding
- Papers not relevant to the research question
- Research papers with absent or inadequate methodology

Table 3: Themes identified in the review of the literature.

<table>
<thead>
<tr>
<th>Code</th>
<th>Theme Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Environmental impacts - CO₂e, air and water</td>
</tr>
<tr>
<td>2</td>
<td>Reduce, reuse, recycle and rethink</td>
</tr>
<tr>
<td>3</td>
<td>Policy and guidelines</td>
</tr>
<tr>
<td>4</td>
<td>Biomedical waste management</td>
</tr>
<tr>
<td>5</td>
<td>Plastic (SUPs)</td>
</tr>
<tr>
<td>6</td>
<td>Procurement</td>
</tr>
<tr>
<td>7</td>
<td>Research &amp; Education</td>
</tr>
<tr>
<td>8</td>
<td>Materials</td>
</tr>
</tbody>
</table>
Table 4: Thematic description of the literature (Eight tables: One table per theme). The 128 papers included in this scoping review are all published literature and consist of: Commentary [Letters, editorials, communication and opinion] (n=39); Research (n=60); Literature reviews (n=25); Reports [Policy and legislation] (n=4). Tables include outputs with primary focus (bold) and secondary focus (italic).

Theme 1: Environmental impacts - CO$_2$e, air and water (n=21)

<table>
<thead>
<tr>
<th>Author</th>
<th>Title</th>
<th>Year</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Borglin et al. [45]</td>
<td>The life cycle analysis of a dental examination: Quantifying the environmental burden of an examination in a hypothetical dental practice</td>
<td>2021</td>
<td>Research</td>
</tr>
<tr>
<td>Wilson et al. [40]</td>
<td>What impact is dentistry having on the environment and how can dentistry lead the way?</td>
<td>2020</td>
<td>Commentary</td>
</tr>
<tr>
<td>Duane et al. [18]</td>
<td>Environmentally sustainable dentistry: a brief introduction to sustainable concepts within the dental practice</td>
<td>2019</td>
<td>Review</td>
</tr>
<tr>
<td>Duane et al. [22]</td>
<td>Environmental sustainability and biodiversity within the dental practice</td>
<td>2019</td>
<td>Review</td>
</tr>
<tr>
<td>Duane et al. [19]</td>
<td>Environmentally sustainable dentistry: energy use within the dental practice</td>
<td>2019</td>
<td>Review</td>
</tr>
<tr>
<td>Duane et al. [23]</td>
<td>Environmental sustainability: measuring and embedding sustainable practice into the dental practice</td>
<td>2019</td>
<td>Review</td>
</tr>
<tr>
<td>Duane et al. [21]</td>
<td>Environmental sustainability and travel within the dental practice</td>
<td>2019</td>
<td>Review</td>
</tr>
<tr>
<td>Naggal et al. [51]</td>
<td>Green Dentistry: Daunting for Developing Countries</td>
<td>2019</td>
<td>Commentary</td>
</tr>
<tr>
<td>Duane &amp; Dougall [41]</td>
<td>Guest Editorial: Sustainable Dentistry</td>
<td>2019</td>
<td>Commentary</td>
</tr>
<tr>
<td>Hurley &amp; White [37]</td>
<td>Carbon modelling within dentistry</td>
<td>2018</td>
<td>Report</td>
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<tr>
<td>Phillipson J. [39]</td>
<td>The need for sustainable dentistry</td>
<td>2018</td>
<td>Commentary</td>
</tr>
<tr>
<td>Grose et al. [149]</td>
<td>Developing sustainability in a dental practice through an action research approach</td>
<td>2018</td>
<td>Research</td>
</tr>
<tr>
<td>Duane et al. [38]</td>
<td>An estimated carbon footprint of NHS primary dental care within England. How can dentistry be more environmentally sustainable?</td>
<td>2017</td>
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<tr>
<td>Sachdev et al.</td>
<td>Green route indeed a need for dental practice</td>
<td>2017</td>
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<td>Aggarwal et al. [151]</td>
<td>Go green: A new prospective in dentistry</td>
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<tr>
<td>Mulimani et al. [152]</td>
<td>Green dentistry: The art and science of sustainable practice</td>
<td>2017</td>
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<td>Richardson et al. [29]</td>
<td>What’s in a bin: A case study of dental clinical waste composition and potential greenhouse gas emission savings.</td>
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<td>Carney et al. [47]</td>
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<tr>
<td>Duane et al. [153]</td>
<td>Green Dentistry - Motivating change</td>
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<td>Holland C. [154]</td>
<td>Greening up the bottom line</td>
<td>2014</td>
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<td>Avinash et al. [133]</td>
<td>Going Green with Eco-friendly Dentistry</td>
<td>2013</td>
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<tr>
<td>Duane et al. [31]</td>
<td>Taking a bite out of Scotland’s dental carbon emissions in the transition to a low carbon future</td>
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**Theme 2: Reduce, reuse, recycle and rethink (n=17)**

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<tr>
<td>Bowden et al. [101]</td>
<td>Evaluating the environmental impact of the Welsh national childhood oral health improvement programme, Designed to Smile</td>
<td>2021</td>
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<td>Su et al. [155]</td>
<td>Additive manufacturing of dental prosthesis using pristine and recycled zirconia solvent-based slurry stereolithography</td>
<td>2020</td>
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<td>Lyne et al. [25]</td>
<td>Combining evidence-based healthcare with environmental sustainability using the toothbrush as a model</td>
<td>2020</td>
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<tr>
<td>Duane et al. [24]</td>
<td>Incorporating sustainability into assessment of oral health interventions</td>
<td>2020</td>
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<td>Duane &amp; Dougall [41]</td>
<td>Guest Editorial: Sustainable Dentistry</td>
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<td>Khanna et al. [156]</td>
<td>Green dentistry: A systematic review of ecological dental practices</td>
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<td>Grose et al. [50]</td>
<td>Developing sustainability in a dental practice through an action research approach</td>
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<td>Pithon et al. [149]</td>
<td>Sustainability in Orthodontics: what can we do to save our planet?</td>
<td>2017</td>
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<td>Kakkar et al. [43]</td>
<td>Go green: a new prospective in dentistry</td>
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<td>Sachdev et al. [134]</td>
<td>Green route indeed a need for dental practice: A review</td>
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<td>Ranjan et al. [79]</td>
<td>Awareness about biomedical waste management and knowledge of effective recycling of dental materials among dental students</td>
<td>2016</td>
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<td>Rupa et al. [53]</td>
<td>Taking a Step Towards Greener Future: Practical Guideline for Eco-Friendly Dentistry</td>
<td>2015</td>
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<td>Chadha et al. [158]</td>
<td>Establishing an Eco-friendly Dental Practice: A Review</td>
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<td>Rastogi et al. [111]</td>
<td>Green Dentistry, A Metamorphosis Towards an Eco-Friendly Dentistry: A Short Communication</td>
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<td>Rahman et al. [159]</td>
<td>Green Dentistry - Clean Dentistry</td>
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<td>Al Shatat et al. [103]</td>
<td>Jordanian dentists’ knowledge and implementation of eco-friendly dental office strategies</td>
<td>2013</td>
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<td>Chadha et al. [105]</td>
<td>Establishing an Eco-friendly Dental Practice: A Review</td>
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<td>Wilson et al. [40]</td>
<td>What impact is dentistry having on the environment and how can dentistry lead the way?</td>
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<td>Chopra et al. [161]</td>
<td>Green Dentistry: Practices and Perceived Barriers Among Dental Practitioners of Chandigarh, Panchkula, and Mohali (Tricity), India</td>
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<td>Akkajit et al. [163]</td>
<td>Assessment of Knowledge, Attitude, and Practice in respect of Medical Waste Management among Healthcare Workers in</td>
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**Theme 3: Policy & Guidelines (n=5)**

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<td>Chadha et al. [105]</td>
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<td>Fan et al. [125]</td>
<td>Laboratory evaluation of amalgam separators</td>
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**Theme 4: Biomedical waste management, including amalgam (n=49)**

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<td>Musliu et al. [63]</td>
<td>The use of dental amalgam and amalgam waste management in Kosova. An environmental policy approach</td>
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<td>Akkajit et al. [163]</td>
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<tr>
<td>Tompe et al. [83]</td>
<td>A Systematic Review to Evaluate Knowledge, Attitude, and Practice Regarding Biomedical Waste Management among Dental Teaching Institutions and Private Practitioners in Asian Countries</td>
<td>2020</td>
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<td>Subramanian et al. [85]</td>
<td>Biomedical waste management practice in dentistry</td>
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<td>Choudhary et al. [163]</td>
<td>Assessment of Knowledge and Awareness About Biomedical Waste Management among Health Care Personnel in a Tertiary Care Dental Facility in Delhi</td>
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<td>Aghalari et al. [164]</td>
<td>Determining the amount, type and management of dental wastes in general and specialized dentistry offices of Northern Iran</td>
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<td>Makanjuola et al. [165]</td>
<td>Managing the phase-down of amalgam amongst Nigerian dental professionals and students: A national survey</td>
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<td>Duane et al. [34]</td>
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<td>Duane &amp; Dougall [41]</td>
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<td>Sultan et al. [166]</td>
<td>Establishing mercury-free medical facilities: a Malaysian case study</td>
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<td>Phillipson J. [39]</td>
<td>The need for sustainable dentistry</td>
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<td>Mulligan et al. [106]</td>
<td>The environmental impact of dental amalgam and resin-based composite material</td>
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<td>Ilić-Živojinović et al. [167]</td>
<td>Knowledge and Attitudes on medical waste management among Belgrade medical and dental students</td>
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<tr>
<td>Singh et al. [68]</td>
<td>Awareness of Biomedical Waste Management in Dental Students in Different Dental Colleges in Nepal</td>
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<tr>
<td>Momeni et al. [73]</td>
<td>Composition, Production Rate and Management of Dental Solid Waste in 2017 in Birjand, Iran</td>
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<td>Teixeira et al. [168]</td>
<td>Waste diagnosis in public dental facilities in Recôncavo Baiano county: contributions to integrated waste management</td>
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<tr>
<td>Eram et al. [93]</td>
<td>Eco Dentistry: A new wave of the future dental practice</td>
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<tr>
<td>Richardson et al.</td>
<td>What's in a bin: A case study of dental clinical waste composition</td>
<td>2016</td>
<td>Commentary</td>
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and potential greenhouse gas emission savings. 

**Mahmood et al. [137]**  
Mercury exposure in the work place and human health: dental amalgam use in dentistry at dental teaching institutions and private dental clinics in selected cities of Pakistan  
2016  
Research  

**Ranjan et al. [79]**  
Awareness about biomedical waste management and knowledge of effective recycling of dental materials among dental students  
2016  
Research  

**Abhishek et al. [62]**  
Awareness-Knowledge and Practices of Dental Waste Management among Private Practitioners.  
2016  
Research  

**Shah et al. [169]**  
Knowledge, Attitude and Practices of Interns, Graduates and Postgraduate Students at Private Dental Colleges in Ahmedabad Regarding Bio Medical Waste Management  
2015  
Research  

**Rupa et al. [53]**  
Taking a Step Towards Greener Future: Practical Guideline for Eco-Friendly Dentistry  
2015  
Commentary  

**Allen [143]**  
Disposing of clinical and dental waste  
2015  
Commentary  

**Bathala et al. [170]**  
“There’s plenty of room at the bottom”: The biomedical waste management in dentistry  
2014  
Commentary  

**Chopra, et al. [33]**  
Eco Dentistry: The environment-friendly dentistry  
2014  
Commentary  

**Raghuwar et al. [78]**  
Mercury and Other Biomedical Waste Management Practices among Dental Practitioners in India  
2014  
Research  

**Rastogi et al. [111]**  
Green Dentistry, A Metamorphosis Towards an Eco-Friendly Dentistry: A Short Communication  
2014  
Commentary  

**Unger et al. [89]**  
Comparative life cycle assessment of reused versus disposable dental burs  
2014  
Research  

**Holland C. [58]**  
Greening up the bottom line  
2014  
Commentary  

**Govan P. [86]**  
Waste management in dental practice  
2014  
Commentary  

**Kapoor et al. [172]**  
Knowledge and awareness regarding biomedical waste management in dental teaching institutions in India- A systematic review  
2014  
Review  

**Bansal et al. [70]**  
Knowledge, Attitudes and Practices of dental care waste management among private dental practitioners in Tricity (Chandigarh, Panchkula and Mohali)  
2013  
Research  

**Avinash et al. [133]**  
Going Green with Eco-friendly Dentistry  
2013  
Commentary  

**Nabizadeh et al.**  
Composition and production rate of dental solid waste and  
2012  
Research  

**Note:** The table above lists research and commentary articles related to waste management in dentistry, including references to Malaysian and Swiss studies. The information includes the authors, year of publication, type of study, and a brief description of the study's focus.
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<td>Investigating composition and production rate of healthcare waste and associated management practices in Bandar Abbass, Iran</td>
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<td>De Souza et al. [113]</td>
<td>Improper Waste Disposal of Silver-Mercury Amalgam</td>
<td>2012</td>
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<td>Investigating composition and production rate of healthcare waste and associated management practices in Bandar Abbass, Iran</td>
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<td>Yasny &amp; White. [142]</td>
<td>Environmental Implications of Anesthetic Gases</td>
<td>2012</td>
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<td>Rudraswamy et al. [78]</td>
<td>Staff's attitude regarding hospital waste management in the dental college hospitals of Bangalore city, India</td>
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<td>Bharath Kumar et al. [110]</td>
<td>Green dentistry; eco-friendly dentistry: beneficial for patients, beneficial for the environment.</td>
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<td>Sood &amp; Sood. [71]</td>
<td>Dental perspective on biomedical waste and mercury management: A knowledge, attitude, and practice survey</td>
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<td>Muhamedagic et al. [126]</td>
<td>Dental Office Waste - Public Health and Ecological Risk</td>
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<td>Investigating composition and production rate of healthcare waste and associated management practices in Bandar Abbass, Iran</td>
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<td>Guedes et al. [174]</td>
<td>First detection of lead in black paper from intraoral film An environmental concern</td>
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<td>Investigating composition and production rate of healthcare waste and associated management practices in Bandar Abbass, Iran</td>
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<td>Al-Khatib &amp; Darwish. [59]</td>
<td>Dental solid and hazardous waste management and safety practices in developing countries: Nablus district, Palestine</td>
<td>2009</td>
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<td>Sudhakar and Chandrashekar. [80]</td>
<td>Dental health care waste disposal among private dental practices in Bangalore City, India</td>
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<td>Hiltz [172]</td>
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<td>Iano et al. [175]</td>
<td>Optimizing the procedure for mercury recovery from dental amalgam</td>
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<td>Batchu et al. [135]</td>
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<td>Zeri et al. [177]</td>
<td>Floating plastics in Adriatic waters (Mediterranean Sea): From the macro-to the micro-scale.</td>
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<td>Nesci et al. [178]</td>
<td>Chitosan-triclosan films for potential use as bio-antimicrobial bags in healthcare sector</td>
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<td>Nasser et al. [179]</td>
<td>Evidence summary: can plastics used in dentistry act as an environmental pollutant? Can we avoid the use of plastics in dental practice?</td>
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<td>Palosuo et al. [180]</td>
<td>Latex Medical Gloves: Time for a Reappraisal</td>
<td>2011</td>
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<td>Salivary bisphenol-A levels detected by ELISA after restoration with composite resin.</td>
<td>2005</td>
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**Theme 6: Procurement (n=2)**

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<th>Author</th>
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<tr>
<td>Joy et al. [100]</td>
<td>Mercury in Dental Amalgam, Online Retail, and the Minamata Convention on Mercury</td>
<td>2020</td>
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<tr>
<td>Wilson et al. [40]</td>
<td>What impact is dentistry having on the environment and how can dentistry lead the way?</td>
<td>2020</td>
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</table>
Duane et al. [20]  Environmental sustainability and procurement: purchasing products for the dental setting  2019  Commentary  Aw

Phillipson J. [39]  The need for sustainable dentistry  2018  Commentary  Dri

**Theme 7: Knowledge Exchange: Research & Education (n=8)**

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<tr>
<td>Borglin et al. [45]</td>
<td>The life cycle analysis of a dental examination - Quantifying the environmental burden of an examination in a hypothetical dental practice</td>
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<tr>
<td>Duane et al. [182]</td>
<td>Environmental sustainability in endodontics. A life cycle assessment (LCA) of a root canal treatment procedure</td>
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<td>Lyne et al. [25]</td>
<td>Combining evidence-based healthcare with environmental sustainability - using the toothbrush as a model</td>
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<tr>
<td>Duane et al. [183]</td>
<td>Embedding environmental sustainability within the modern dental curriculum— Exploring current practice and developing a shared understanding</td>
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<td>de Leon [184]</td>
<td>Barriers to environmentally sustainable initiatives in oral health care clinical settings</td>
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<td>Wilson et al. [40]</td>
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<td>Ilić-Živojinović et al. [81]</td>
<td>Knowledge and Attitudes on medical waste management among Belgrade medical and dental students</td>
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<td>Knowledge, Attitudes and Practices of dental care waste management among private dental practitioners in Tricity (Chandigarh, Panchkula and Mohali)</td>
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<tr>
<td>Prathima et al. [102]</td>
<td>Knowledge, attitude and practices towards eco-friendly dentistry among dental practitioners</td>
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**Theme 8: Materials (n=20)**

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<tr>
<td>Shiyo et al. [185]</td>
<td>Recycling of Plaster of Paris 2020  Research  Op</td>
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<td>Ecological footprint of biomaterials for implant dentistry: is the metal-free practice an eco-friendly shift? 2019  Review  Be op</td>
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<td>The environmental impact of dental amalgam and resin-based composite material</td>
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<td>Gavrilescu et al. [28]</td>
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<td>Waste diagnosis in public dental facilities in Recôncavo Baiano county: contributions to integrated waste management</td>
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<tr>
<td>Bakhurji et al. [188]</td>
<td>Dentists’ perspective about dental amalgam: current use and future direction</td>
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<td>Pithon et al. [149]</td>
<td>Sustainability in Orthodontics: what can we do to save our planet?</td>
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<td>Kakkar et al. [43]</td>
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<tr>
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<td>Recovery of Mercury from Dental Amalgam Scrap. Indian Perspective</td>
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<td>Khwaja et al. [137]</td>
<td>Mercury exposure in the workplace and human health: dental amalgam use in dentistry at dental teaching institutions and private dental clinics in selected cities of Pakistan</td>
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<td>Establishing an Eco-friendly Dental Practice: A review</td>
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<td>Observance of proper mercury hygiene practices Jordanian general dental practitioners</td>
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<td>Dental office waste - public health and ecological risk</td>
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<td>Godoy Iano et al.</td>
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<td>Jokstad et al. [127]</td>
<td>Amalgam waste management</td>
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<td>Batchu et al. [135]</td>
<td>Evaluating amalgam separators using and international standard</td>
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<td>Amalgam Toxicity - environmental and occupational hazards</td>
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<td>The environmental effects of dental amalgam</td>
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