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Review article

Drivers, opportunities and best practice for sustainability in dentistry: A scoping review

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ABSTRACT

Objective: To undertake a comprehensive scoping review of the literature to address the research question 'What is the current state of environmental sustainability in general dental practice?' To provide an effective baseline of data that will consider the drivers, opportunities and recommendations 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 second paper focusing on the opportunities, recommendations and best practice to develop and engage with sustainable practice.

Conclusions: Drivers, opportunities and recommendations for best practice to achieve environmentally sustainable goals in oral health care: The lack of public and professional awareness is the greatest driver to engage with a positive change of behaviour and attitudes. Awareness through education is key at all levels and this should be the bedrock of future strategies. Reduction in staff and patient commuter travel through a reduction of the incidence of preventable oral diseases, improved patient care logistics and IT. Reducing waste and increase recycling opportunities, especially for SUPs. Engagement with legislation and policy makers. Engagement with key stakeholders across the dental materials/products supply chain for the management of manufacturing, distribution, procurement, clinical use and waste management.

1. Introduction

Awareness of the environmental impact of oral health care remains low across the profession and more so within the general public. The challenges and barriers to engaging with sustainable oral health care provision are explored in the first paper of this two-part scoping review [1]. The first paper reveals a reassuring desire amongst the profession to consider ways to engage and make a difference through the provision of environmentally sustainable practice . There is a need to identify current drivers, opportunities, recommendations and good practice that can be used to effect change through an increase in awareness.

In the first paper, the authors reported on a comprehensive and thorough scoping review of the literature that asked the research question 'What is the current state of environmental sustainability in general dental practice?' [1]. This review identified eight diverse but closely interlinked themes that influence the sustainability of oral health provision were identified: Environmental impacts (CO_2e, air and water); Reduce, reuse, recycle and rethink; Policy and guidelines; Biomedical waste management; Plastics (SUPs); Procurement; Research & Education; Materials.

The scoping review has established a knowledge baseline of our general awareness, barriers and challenges for the implementation of sustainable practice [1]. Barriers and challenges to implementation focus on a lack of professional and public awareness; high levels of carbon emissions arising from patient and staff commute; the 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, and

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the use and disposal of dental materials. The aim of this second paper is to build on our knowledge base of general awareness and barriers to implementation. The focus is to provide a subsequent baseline that considers the reported drivers, opportunities, recommendations and good practice for the implementation of environmentally sustainable oral healthcare.

2. 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) was used [2,3].

A thematic analysis as described by Braun & Clarke (2006, 2014) was employed to analyze the emerging themes in accordance with the six-point phases described [4,5]. Through a thematic analysis we have organized, described and interpreted our data set. The methodology used for this scoping review is described in detail in the first part of this two-part series [1]. 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 analyzing for emerging themes as described. Key themes from each paper were coded against identified themes. The tabulated outputs from this scoping review included up to the 31st April 2021.

3. Results

The outputs are described thematically in eight separate headings as per Table 1 and further detailed in Martin et al. [1]. These themes 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 sustainability in dentistry: A scoping review [1]. 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 for sustainability in dentistry: A scoping review. This second current paper considers the same body of the scoping 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.

3.1. Theme 1: environmental impacts-CO_2e, air and water

3.1.1. Drivers

As individuals we tend to separate our societal responsibilities of environmental citizenship, from our professional work-related duties in the dental surgery [6]. To drive sustainable behaviour in our professional endeavours, we need to make a conscious and deliberate effort to translate our domestic sustainability behaviours to the dental practice environment. This 'domestic' behaviour needs to be more pervasive and encompass all our activities by becoming a strong attitude across all our living environments [7]. It is noted that the transition of sustainable behaviours from home to practice may be influenced by the lack of direct personal financial impact of mismanaging resources in the work place (water, electricity, heating) [8]. In this context, having open conversations and carrying social, personal and financial responsibility for the use of resources will further drive sustainable behaviours.

The need to establish, maintain and enhance practice reputation through sustainable behaviour is a strong driver. A strong reputation will enhance staff morale and help to build the practice by attracting more patients with shared sustainability values [9,10]. Moreover, marketing of a practice as an early and committed adopter could help to influence change upstream and possibly secure funding and support for future ventures [11].

Sustainability through reduction is likely to result in lower overheads through reduced use of material and equipment [8]. The use of a preventive approach results in fewer appointments and a reduced need and use of materials that results in lower carbon emissions from transport and less waste [53]. In the long term, the implementation of sustainable practice is considered more economically beneficial to the business [12]. Local and national cost incentives such as using solar energy and cycling to work as per the UK examples of the Carbon Trust and the Green Business Fund, that offer incentives in the form of loans or tax relief on equipment [11,13].

3.1.2. Opportunities

3.1.2.1. Reduction via prevention. Dental procedures have a higher travel emission proportionally to other areas of healthcare as appointments are quicker and more numerous and happen more often over a patient's lifetime [14].

A reduction of our carbon footprint is achieved first and foremost through a promotion and implementation of oral health with a strong focus on disease prevention, the provision of high-quality interventions that do not require revising and maintenance plans that are effective and pragmatic [15,16]. Prevention of oral disease results in fewer treatment requirements, that in turn have a reduced environmental impact. Conversely, extensive complex and protracted treatment plans are more resource intensive and contribute more to greater CO_2 emissions [15,17]. This is also associated with greater procurement involvement that is a further contributor to CO_2 emissions [9,18]. Regulatory frameworks that govern contracts for the provision of dental services should value and seek to transform services through appropriate remuneration of prevention-based approaches [17].

There is a need to be understand that although some interventions, such as the use of fluoride varnish to prevent carieshave a large CO_2 footprint, but over time the effect will be compensated by a reduced need for and use of oral health care services. In this way the environmental impact of a single intervention, at a moment in time, will lead to a net reduction in the carbon footprint over the life of the individual due to a reduced need for more complex interventive therapeutic, reparative and restorative care [8]. The same is true for the use of electric toothbrushes that are noted for having the highest carbon footprint compared to other toothbrushes [19]. However, they are equally noted to reduce plaque and gingivitis more than manual toothbrushing in the short and long term; albeit the clinical importance of these findings remains unclear [20]. Further research is needed into the environmental consequences of different prevention strategies [21].

3.1.2.2. Patient and staff travel. A 5% shift to walking and cycling in staff commuting would reduce carbon and air pollutant emissions by over six tonnes of NOx and 0.4 tonnes PM2.5, avoiding around £300k in costs to health and society [22].

Better monitoring and measuring of the impact of travel is required. This would enable organisations to reduce the impact they have on air pollution and, ultimately, help to create more holistically sustainable and healthy travel systems [22]. Outreach programmes such as Childsmile www.child-smile.org.uk/ help to reduce travel, reduce carbon emissions and improve air quality [153].

Reduction in CO_2 emissions through prevention reduces the CO_2 footprint as this reduces the number of visits due to less need for future treatment, less need for travel and fewer resources used. There is an increased role for the use of remote clinical consultations as a way to reduce patient and staff commuter travel [9,17,18,21–24].

3.1.2.3. Energy consumption. Consideration is given to a number of complementary strategies such as producing own renewable energy: Solar panels, wind turbines, solar thermal systems and heat pumps [10,21,23,25–29]. At a domestic level, the following energy practices are recommended: Using energy efficient appliances (LED, fluorescent bulbs, sensor lights, dimmer switches, air conditioning, LED monitors/TVs); making use of natural lighting; incorporate an electrical shutdown policy for when electrical appliances will not be used; maintain and upgrade boilers and air conditioning units to more energy-efficient with thermostats and timers; make better use of windows and blinds to regulate temperature before switching on air conditioning; lower temperature by a few degrees on water heaters and washing machines; and maintain all equipment to ensure that it is running efficiently [8,10, 21,23–27,29–45].

3.1.2.4. Water consumption. Mitigating actions are identified to manage the use of water more effectively with reduced waste: The installation of water meters; use of low flow devices; replacement of wet vacuum pumps with dry pumps; turning off the tap when brushing; auditing water consumption; turn off water-consuming equipment when not in use; maintain equipment, taps and avoid leaks; use non-water based products for cleaning where possible; run autoclaves and practice laundry machines when fully loaded; increase staff and patient awareness through the use of motivational stickers/posters against wasting water; use water-saving toilet and collect rainwater for watering and equipment that does not require potable water [23,26–29,32,33,36,37,39–41,45–47].

3.1.3. Best practice

A number of tools and systems to measure, audit and manage CO_2 footprint have been developed by different groups to assess travel, procurement and energy usage. Examples of this are the tools created by the Royal College of General Practitioners, Footprint Reporter; the NUS Green Impact, Toolkit User Guide; the Centre for Sustainable Health, Health Outcomes of Travel Tool; the Carbon Trust and the Global Action Plan to help dental practices become more sustainable [9,11,18,22,41,46].

The dental profession should focus their CO_2 emission reduction strategies on staff travel. Accordingly, electric vehicles are promoted as is an encouragement to employers to further promote and incentivise active travel amongst staff, as this has additional health benefit to staff which could reduce societal costs by around £3 million a year [14,17,18,21–23,27,30]. Other strategies that are widely advocated include the use of public transport and car sharing [17,32]; combining patient appointments and providing multiple procedures in one visit with a greater use of high-end technologies (CAD-CAM and intra-oral scanning) that will reduce the number of appointments and transport to laboratories [24,35,45,48]; see families in one visit or a family appointment [14,23,49]; reduce transport between dental surgery and laboratory with scanned impressions [27,31]; and purchase larger bulk deliveries [21–23,34]. The use of telecommunication should be enhanced for all administrative logistics and for remote clinical consultations [14,18,21–23,27,36,50]. Programs such as 'Childsmile' [153], where only the dental team travels, reduce travel emissions as there are fewer people travelling to provide care [21,22]; on-site preventive care facility in nursing homes [21] and attending to multiple patients together at care homes [14].

Key to success, is staff and patient engagement and this should be driven through a series of proactive approaches, such as staff training, increasing awareness, use of *e*-dentistry resources, online videos, sustainability notices with photographs and leaflets, promotion through social media [11,18,23,27]. This can be achieved by designating a lead sustainability officer in practice or a sustainability working group to embed sustainability into the practice [11,27,46] alongside a waste management leader [11,51,52]. It is essential that sustainability practice and organizational policies and procedures with effective action plans and realistic targets are embedded and normalized within the team so that they become part of day to day running of the practice [11].

3.2. Theme 2: Reduce, reuse, recycle and rethink

3.2.1. 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 [53–55]. There should be an encouragement to recycle items that can be currently recycled to help reduce the depletion of natural resources in terms of paper, plastic and glass products, with associated lower carbon emissions compared to landfill [51]. Sustainable activity through the recognized 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.

3.2.2. Drivers for change

3.2.2.1. Reduce. Of the three Rs, the logical and immediately achievable approach to reducing waste in oral healthcare is by reducing the demand for the products and materials [26,45,46,52,56]. This can be achieved by targeting preventable oral health diseases through a promotion of better health focused on disease prevention coupled with the provision of high-quality interventions that do not require revising and maintenance plans that are effective and pragmatic; all of which involving the patient as a key part of the strategy [15].

3.2.2.2. Reuse. There is support for the reuse of equipment and devices if appropriately cleaned, disinfected and sterilised where appropriate. A case study with dental burs shows this to be the case if the autoclaves are operating efficiently. When their efficiency falls, the impact on the environment of reusable burs is more than that of disposable burs [38]. Some countries offer tax incentives for donating old electrical equipment [31]. Recovery and reconditioning schemes for equipment to be put back into circulation are in existence as per that between single-use instrument manufacturer (Robinson Healthcare Ltd) and the Healthcare Environmental Group (HEG) for single use instruments [56].

3.2.2.3. Recycle. Significant opportunities exist for recycling at all levels and low-level domestic in-practice arrangements should not be dismissed as they have significant additional benefits. Recycling reduces demand on raw materials, reduces demand on landfill and foments individual responsibility for waste management. Some recycling is low cost or no cost, some generates additional income and saves the cost of domestic waste disposal [51,52].

3.2.2.4. Rethink. The fourth R stands for 'rethink'. This applies to all sectors of the supply chain, as a collective and individual stakeholder. We need to move from a linear economy that terminates in landfill and incineration to a circular economy with reduction, reuse and recycling at its heart involving all stakeholders [21,155] (Fig. 2). The environmental impact associated with the provision of the actual clinical procedures is better understood through LCA research; with lessons that can be adopted [19,75,76]. Reviewing and rethinking how to dispose of waste using novel methods of waste management is required, an example would be the use of reusable sharps disposal containers to avoid incineration [24,46].

Ultimately, we need to be proactive in the management of our resources in the dental surgery so that we move to an eco-friendly practice and use forefront materials sustainably and consider how their waste is managed in a sustainable manner [31,59].

3.2.3. Opportunities

3.2.3.1. Reduce. Beyond the dental setting of primary dental care, opportunities exist for a reduction of pre-clinical plastic waste (products and packaging) that arise from manufacturing and distribution prior to being contaminated in a clinical setting upstream in the supply chain. 33% of the waste generated in the dental surgery is packaging [31,35,36,40]. Purchase of products with minimal packaging and use of reusable plastic containers can reduce general waste production [27,31,40,42,52,57]. This concept, illustrated through the waste management hierarchy inverted pyramid, and widely recognized as the preferred strategy for sustainability goals, indicates reduction to be both the most practical and achievable strategy (Fig. 1) [24,31,52,58,59].

The current linearity of the oral healthcare supply chain suggests that the most effective strategy to minimize the impact of healthcare plastic waste on the environment is by adopting a reductionist approach combined with innovative recycling approaches at both pre- and post-clinical contamination [53][58].

Thus, efforts to reduce the pollution impact on the environment from oral healthcare must therefore focus on a strategy of reduction alongside any recycling capabilities wherever possible. A reduction of our carbon footprint and pollution from waste are achieved through the provision of optimal oral healthcare [60]. Strategies for the implementation of a policy of the 4 Rs (with the addition of 'rethink') is considered at varying levels [18,32,41,43,45,59,61]. These include the labelling of bins to aid with segregation to drive recycling and reuse, engagement with suppliers for reducing waste, recycling waste, upcycling and purchasing recycled products [23,28,31,41,42,51,52,62–65]. Notwithstanding, adoption of these practices is hugely variable across the world with minimal efforts to reduce or recycle waste in some countries [65–67].

3.2.3.2. Reuse. There are opportunities for sustainable engagement though for the reuse and upcycle of equipment in the dental practice [51]. The purchase of high-quality durable equipment that is well maintained [23]; use of cloth fabric alternatives for SUP barriers, cleaning, hand towels etc. Reusable PPE (including laboratory coats instead of disposable aprons, reusable face shields, reusable bibs for patients) as reusable gowns have a 2,3-fold reduction in terms of energy, water and carbon emissions and 7-fold reduction in waste [51]. Use of washable cups, dishes and cutlery in the staff break room and re-usable water bottles. Implementation of eco-friendly sterilisation programmes that reduces the need for disposable sterile packaging after (reusable instrument cassette trays) [32,38]. Finally, staff should consider and think about the nature of the waste generated and how this can be reduced [10,27,31,32,35–37,39–43,46,51,52,68].

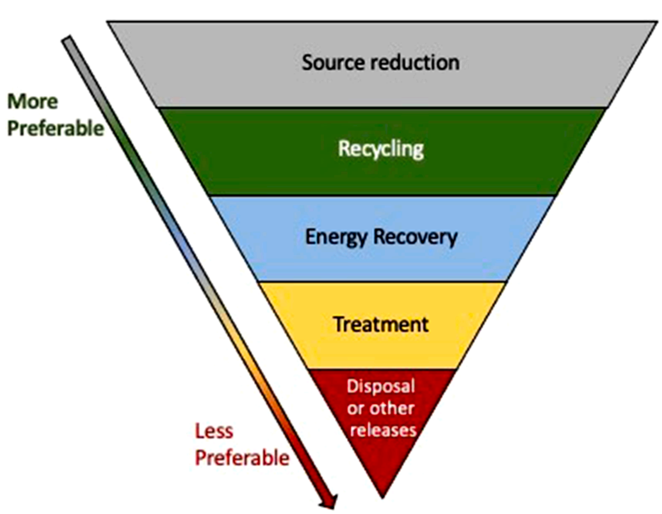

Fig. 1. Waste management hierarchy inverted pyramid-strategy for meeting sustainability goals, with reduction to be both the most practical and achievable measure [154].

3.2.4. Recommendations and best practice

3.2.4.1. Reduce. A number of recommendations and examples of best practice have been identified with much focus on the reduction in the use of paper. Auditing paper consumption as an initial driver for a reduction strategy is considered important [50]. Beyond this, other approaches to paper reduction, focus on: The use of digital technology for patient records; electronic reminders, use of tablets to record patient clinical assessments (especially forms such as medical history); patient investigations (intraoral scanners, digital radiographs); electronic credit card transfers and order forms; and paperless meetings. Paper use can be reduced with smarter and more cost-effective printing (double-sided, thinner paper); stop unsolicited mail and use of scrap paper for internal notes [10,12,23,26,28,29,31,32,35–37,39–41,43,46,47,51,56,59]. Careful planning and execution of clinical procedures should lead to a reduction of materials and equipment such as impression trays, Dappen's pots, prophy cups, suction, syringes, burs etc [10,23,24,26,28,29,31,32,34–37,39–41,45,46,51,66].

3.2.4.2. Reuse. The challenges associated with reusing plastics and instruments in healthcare settings arise from the nature and construction of polymer items and the need to operate in a society-facing role within stringent regulatory frameworks and increased levels of litigation [53].

3.2.4.3. Recycle. Whilst according to the waste management hierarchy inverted pyramid (Fig, 1), recycling is less desirable compared to reduction and reuse, it reduces the need for raw materials to be mined and processed [24]. Mechanical and chemical recycling are increasingly being used in healthcare for the management of SUPs to good effect [54]. A number of recommendations and best practice are identified for recycling: Educating staff about recycling, enabling waste separation for ease of recovery for recycling, improving awareness and liaising with local authorities and support groups [23,28,31,41].

There is a prerequisite to separate plastic and paper from sterile wrapping in order to recycle. Effective separation of sterile wrapping before contamination could save up to 5kg of waste a week. If sterile wrapping is not disposed of as clinical waste, there would be an approximated reduction of around ½ a tonne of greenhouse gases a year [71]. In this context, there is an opportunity to identify and use pre-existing community recycling programs to recycle paper and plastic halves of autoclavable bags and packaging [43].

Beyond paper and plastic, the recovery and recycling of old instruments, waste alloy, old materials and malfunctioning equipment is encouraged [26,31,35,36,45,46]. Recycling of ceramics (zirconia) for the fabrication of dental prosthesis shows some real potential, with a reduction in need for virgin materials [72].

Other items that can be recycled effectively include: Office waste such as plastics, paper and medical shredding, toner and inkjet cartridges that are also cost saving for the practice [10,29,32,40,59,61,73,74].

3.3. Theme 3: Policy

3.3.1. Drivers for change

There is a general consensus within the profession that there needs to be a closer, more effective and more pragmatic alignment of two apparently divergent regulatory frameworks. One that is designed to

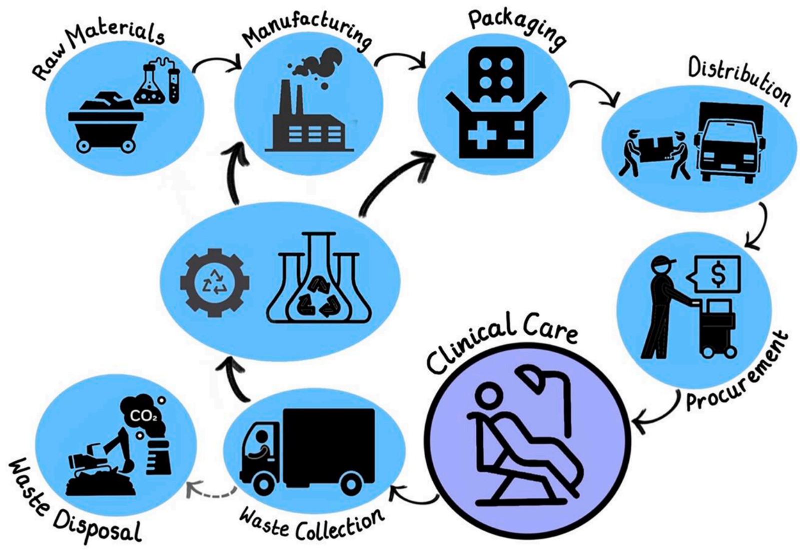

Fig. 2. Circular economy with waste diverted to mechanical and chemical recycling, reducing the burden on raw materials (extraction and synthesis) and disposal (landfill and incineration) [155].

protect the public through the provision of safe clinical practice and at the same time manage the environmental impacts associated with the provision of sustainable practice [64,77].

A clear driver for change of policy and regulatory frameworks comes from the need to protect those who are more vulnerable from long-term effects of global warming and pollution [14,56]. Effective use of policy for the sustainable management of clinical waste is evident in some sectors that requires management of waste disposal to operate within a environment context [78–81]. The need to engage with professions complementary to dentistry, such as oral healthcare workers, dental hygienists and therapists has been highlighted; as these groups are largely missing from the environmental sustainability dialogue [82].

3.3.2. Recommendations and best practice

It is important to ensure that the profession has appropriate representation in the formulation of policy and guidelines that will impact healthcare delivery and sustainable practice. This includes active participation in the use of metrics (e.g waste audit, carbon emissions etc) and consideration of evidence that covers both planetary and public health issues [21]. In this context, a country's dental association can have a pivotal role to support the profession in sustainable practice [28] and should do so with all dental professional groups [82].

There is a need for greater transparency and standardization of measurement or reporting the environmental credentials of a product for manufacturers. Vendor agreements should include the requirement to take back packaging and waste materials in order to discourage inefficient use.

Policy makers must think about political, social, geographical and historical contexts when considering how to influence the sustainability of dentistry changes. Policy makers have to be careful that an intervention designed to improve one system component does not have unintended negative consequences. An example is that not all multiuse devices will be environmentally preferable to single-use ones if they require reprocessing or remanufacture, so a blanket ban on all single-use instruments may not always be appropriate [21].

Specific recommendations identified are: The use of amalgam separators that meet ISO 11143. This shows that the separator removes 95% of waste amalgam when subject to the test method specified [36,42,81,83,84]. Ensure that all waste is handled and disposed of in accordance with appropriate local, national or international regulations to avoid environmental contamination (e.g., In the UK, the Environmental Protection Act 1990, the Controlled Waste Regulations 2012, the Hazardous Waste Directive 2011 and the Carriage of Dangerous Goods Regulations) [52,63]. The encouragement of waste management through financial incentives or disincentives such as subsidies, taxes or penalties has been shown to be effective [51].

An example of how societal action drives policy is the build-up to the Minamata Convention on Mercury (2013). A series of conferences and world environmental summits took place; with the Human Environment (Stockholm, 1972) [145], the Earth Summit (Rio, 1992) [146], the World Summit on Sustainable Development (Johannesburg, 2002) [147], The Montreal Protocol on Substances that Deplete the Ozone Layer (Ozone Secretariat, 2011) [148], Stockholm Convention on Persistent Organic Pollutants (Stockholm Convention, 2008) [149], The Rotterdam Convention (Rotterdam, 2008) [150], Basel Convention (Basel, 2011) [151] and the on the Control of Transboundary Movements of Hazardous Wastes (Basel, 2011) [152].

3.4. Theme 4: Biomedical waste management

3.4.1. Drivers for change

Poor waste management can lead to an increase in hospital-acquired infections (nosocomial) [31,62,66,68,69,85–88]; and through an alteration of the microbial floras in the environment, it can lead to antimicrobial resistance [31,62]. It should be noted that infectious diseases are a major contributor to the high morbidity and mortality rates in developing countries (HIV, TB, Hepatitis) [42,70,78,86,89]. A reduction in waste has financial benefits that can result in improved healthcare opportunities and patient care [51,52]. Awareness of the need to engage with BMW is key to any solution; a trait that is increasing [90]. Notwithstanding, there is a desire for promotion of waste management through education [91].

3.4.2. Recommendations and best practice

It is important to establish a baseline of knowledge of current practice so that this can be compared against desired (gold) standards and establish a practical waste management plan. An assessment of baseline practice is best done through an audit process of waste management [8,18,23,32,36,46,51,52,58,61,63,66,92–94].

A practical waste management plan should consider the waste management hierarchy (Fig. 1) [32,61]: Implementation of a policy of the 4 Rs (Reduce, reuse, recycle and rethink) [41,43,59]; and a focus on avoidance and reduction at source as best practice [24,31,58].

Core to the implementation of local waste management plan is a high level of staff awareness and engagement through effective education and training [42,51,52,62,64,66,78,94]. This should include: Education of staff on the need for waste management and the impacts of doing so; provision of regular and effective staff training [58]; ensure engagement from every individual in the team as a collective effort [80]; display effective and simple waste segregation flowcharts and clear local rules to enable training and implementation [23,52,51].

Effective education should commence at an early point of the staff development at undergraduate school and as a continuum through postgraduate and professional life [78,87,88]. This should include a research curiosity into the environmental consequences of dental waste products [21].

Engage with and lobby regulatory bodies, healthcare providers, professional dental associations and local/national government to enable effective waste disposal and avoid environmental pollution [63,66,79,81,85,89,95]. These organizations, as well as regulating lawful practice, can provide valuable training resources to assist with the development and implementation of a waste management plan [27,86,92].

Further best practice recommendations include: The use of waste disposal services close to the practice to reduce carbon emission from transportation of waste and implementing a practical waste segregation disposal system [27,52].

3.4.2.1. Segregation of waste. Effective segregation at a local level will enable recycling of household waste, significantly reduce the burden of contaminated waste and avoid accidental harm (eg. needlesticks) [69,89,94]. The converse is true, that poor waste segregation leads to non-clinical waste being disposed of in the clinical waste stream, increasing the cost to the practice and potential harm to the environment from incineration [23,26,51,52,66,71,78,91,92,94,96]. Paper is the highest type of waste in a dental practice and it is easily segregated and recycled [71]. Effective waste collection and segregation can be achieved through the use of: Color coded and clearly labelled bins [28,41,62,64,65]; durable bags/containers for blood-soaked gauze, cotton and dressings [69,74]; non-chlorinated bag/containers for waste collection; durable containers that can be reused [58] and dedicated bins for all sharps [74].

3.4.2.2. Waste contractors. Beyond waste management at a local practice level, the plan should extend to include effective engagement with waste contractors. Firstly, ensure that waste contractors are complying with the appropriate local and national legislation at all levels, from collection to disposal [44,63,81,97]; use licensed handlers for off-site recycling of hazardous materials [43] and ensure that they have a recycle clause [23,33,52]. Beyond this, try and have a contract which uses total waste management; encourage contractors to diversify to include recycling opportunities; innovate new solutions for reducing waste [52] and use incineration facilities with energy recovery [24].

3.4.2.3. Medicine waste. A reduction approach is the most widely advocated approach to the management of medical waste. Medicine waste poses a significant pollution problem as pharmaceutical residue dissolved in waste water can re-enter the food chain [9,23]. Effective management strategies to reduce the impact of this include: Reduction of prescribing, especially antibiotics; only prescribe the required amount and encourage patients to return unused medication to the pharmacy for safe disposal, and not down sink or toilet [23,51].

3.4.2.4. Food waste. Food waste in healthcare facilities is a further source of environmental pollution. A primary care survey in the Republic of Ireland, identified that 15% of the waste within healthcare facilities was attributed to food. In Scottish dental practices, if more than 5 kg of food waste is produced per week this must also be collected separately.

This can be managed through legislation, requiring special arrangements for the collection of food waste [50]. Also, the use of waste collectors and converted into energy by anaerobic digestion with a return of revenue. Installation of composting and worm farms to create soil conditioner that can also be a source of revenue [51].

3.4.2.5. Healthcare waste treatment technologies. Health care waste treatment options include incineration, microwaving, autoclaving, hydro-pulping and compaction [98].

Incineration is suitable for all types of waste and reduces volume of waste up to 95%. However, it requires high investment costs and emits unwanted pollutants [64,98]. Incineration with energy recovery is increasingly being adopted accounting for approximately 25% of all EU waste [51].

Knowledge of where practice waste goes would inform choice and could be sent to a waste-to-energy plant which convert energy from incineration to usable energy [24].

Alternative technologies for processing of healthcare waste have been suggested: (i) Microwaving has a lesser impact on the environment compared to incineration because there are no combustion emissions produced by the system. It can reduce the waste volume by approximately 80%. However, it is not suitable for pathological waste and requires a strict monitoring system; (ii) Autoclaving is suitable for sterilizing hazardous waste. However, the volume of waste cannot be reduced in this process. and it is not suitable for clinical waste with body parts. (iii) Hydro-pulping is used for domestic paper/cardboard waste but not indicated for clinical waste treatment; (iv) Compaction of waste can reduce the volume up to 60% but sterilization is not possible in this method [98].

3.5. Theme 5: Plastics

3.5.1. Opportunities

Sustainable alternatives to plastics in healthcare are being developed. Examples of technologies currently under research are; the use of chitosan (A polysaccharide obtained from the hard outer skeleton of shellfish) [99] and already in extensive use is Polyvinyl alcohol (PVOH) [100]; both used as a bag for soiled linens which then dissolve in domestic laundering (washing machines).

3.5.2. Recommendations & best practice

The literature identifies that dentists should conduct environmental audits of their practice following the principles of the International Chamber of Commerce [101,102]. This should include a waste audit to establish a baseline for amount of plastic being used [23].

Efforts should be made to try and minimize single use plastics as much as possible. In this context, manufacturers and distributors should be encouraged to concentrate on optimizing and reducing packaging, such as that for dental burs; as this has been was shown to be the biggest contributor to environmental impact of disposable burs [38]. The use of latex elastics in orthodontics is promoted as a way of promoting forestation [29].

There is a gap in our knowledge of easily manageable hot spots of dental waste and if interventions such as an environmental audit can decrease the amount of waste [101].

3.5.2.1. Gloves. Disposable examination gloves, of the type used in the dental profession, form a very large part of the waste stream [73]. There is a conflict between the greater environmental credentials of natural rubber latex (NRL) and the more polluting but less allergenic nitrile gloves. NRL is an environmentally sustainable material, which is also naturally biodegradable, enabling hospitals to meet their 'green' purchasing requirements [32,103]. The production process for the raw materials for NRL gloves is 16 GJ/ton for NRL which is an order of magnitude lower than that for nitrile gloves (108 to 174 GJ/ton).

Moreover, synthetic nitrile gloves are derived from oil chemistry with higher economic costs for the raw materials, that in themselves are a non-renewable source.

It should be noted though, that NRL gloves, although biodegradable, are invariably incinerated as contaminated clinical waste, producing toxic emissions [27]. The main challenge with NRL gloves is its potentially severe allergenic potential; leading the profession, public and regulatory opinion to lean away from their use on the grounds of patient safety [27]. Notwithstanding, there is a body of opinion that considers that the reduced incidence of allergic reactions, the availability of specific and sensitive testing for the selection of low-allergen gloves, competitive costs and lower environmental impact, make NRL gloves an excellent choice of material for medical gloves and should continue to be used [73,103].

3.6. Theme 6: Procurement

3.6.1. Recommendations

Carbon emissions and air pollution impact can be reduced with better coordinated distribution logistics, suggestions include: Transport products in the same delivery, transported from the same logistics center, and ideally produced locally [22,27,28,35]. Improved logistics should consider the combination of deliveries for bulk orders to reduce the environmental impact of transport from supplier to practice [36,56].

There is a need for research that will provide the evidence base for sustainable products to create a set of sustainable product options for oral healthcare professionals [21]. Practices should select products with minimal packaging that is easy to recycle [24,31,42,46,52]. Purchase should seek eco-friendly alternative dental materials [41] and those that originate from recycled sources [42]; such as toilet tissue, paper towels and office furniture [28,32,42,43,46,52]. Furniture from renewable sources such as bamboo [31] and from reforested wood [29].

Office supplies and paper use is both a significant hotspot and an easily achievable target to address. Recommendations include: Review use and buy accordingly to avoid unnecessary waste [18,23,27]; purchase recyclable materials [18,23,24,28,32,43,51,52,61]; durable office equipment with long warranties [104]; Purchase stationery in bulk [28,34]; purchase tea/coffee from Fairtrade [105] or Rainforest Alliance [106] sources [56]; avoid the use of glossy, coloured or plastic coated paper [56].

3.6.1.1. Engagement with suppliers. Working and engaging with suppliers to assess their sustainability practices is a necessity to improve the environmental impact of procurement [8,14,21,23,56,52]. Sustainability should be included as a procurement requirement alongside fitness for purpose, financial and ethical considerations [14,18,21,23,24,30].

A professional move towards a more sustainable dental practice will embed core sustainability values and consequently put pressure on suppliers to engage in a similar manner [21,24,27,56]. This might include consolidation of delivery, reducing and reusing packaging and the quality of the packaging itself [45]. Manufacturers should provide recycling information for medical equipment components in user manuals and/or offer to recycle the equipment they produce. Requesting such information might put additional pressure on manufacturers to meet the sustainable needs of their customers [17,56]. Manufacturers also need to redesign products to improve useful life, reduce energy consumption, reduce packaging, eliminate toxicity in the composition of products, and prioritize the use of renewable material [18,51]. A desire to reduce the costs of procurement provides a financial incentive to improve logistics throughout the supply chain and make this more sustainable as a secondary outcome [27]. Examples of good practice are the cradle-to-cradle circular economy concept that is promoted as a strategy to redevelop the production methods of products to eliminate and reuse all waste produced, using green energy suppliers [10].

Effective internal stock management in the dental practice is key to sustainable procurement. There is a need to regularly audit stock to check for expiry dates and monitor usage [23,18,24,27,51,61]; alter orders according to usage once audits have been completed [23]; undertake stock rotation to ensure items closest to their use by date are used in preference to newer stock [51]; and only order as it is required, reducing excess waste [51,77].

3.7. Theme 7: Knowledge exchange

3.7.1. Opportunities and recommendations

Given the urgency of the need to address the pollution crisis, there is a need for more focused high quality and high impact research. Research into best practice and evidence-based provision, should be supported with an environmental analysis with appropriate expertise, with appropriate support from funding bodies for the need of this combined approach. Oral health research should also include an investigation of the complex internal drivers and external forces that influence sustainability, including the behaviour of each stakeholder and that of the supply chain as a whole [53]. High quality life cycle analyses (LCA) are required to identify hot spots in the supply chain, dental products, procedures and care provision with provision of evidence for decisions between the use of different materials, single use vs reusable or manual vs electric products, and the impact of different travel methods [19,75,76]. There is a need to understand the environmental impact of home based and professionally delivered prevention, so that effective translation of good practice can take place [21].

Governments and funding bodies should consider the importance of health care sustainability within their portfolio of health research [14]. Funding should be focused to support areas where evidence is lacking and to support innovation [21].

Within education, there is an increasing level of interest in the dental profession on sustainable practice, but this is against a backdrop of generalized lack of awareness and knowledge in this area; as highlighted in the relevant sections for each theme in this review. This is compounded with a lack of knowledge of how to engage [9,12,65,70,95,107]. 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 [47].

Sustainability is now a major topic of discussion in the Association for Dental Education in Europe (ADEE), as evidenced by a recent consensus paper that suggests eight pillars as a framework to promote best practice for the teaching of sustainability in dentistry [16]. This report suggests four main themes as a foundation of a consensus to embed sustainability in the undergraduate curricula: Disease prevention and health promotion, Patient education and empowerment, Lean service delivery and Preferential use of strategies with lower environmental impact. Encouraging evidence of this progressing to further stages is noted through work undertaken by the ADEE [108] and the Centre for Sustainable Health, UK [109], among others.

There is also a recognition of the need to involve and engage with professions complementary to dentistry, such as oral health care workers, dental hygienists and therapists [82]. Awareness training should recognize that single use products and disposable items come at high environmental price and the dental team should be educated in best sustainable practice for waste management [14,23,41,87]. Patients should be educated to adopt environmentally sustainable practices, such as turning the tap off when brushing teeth [26,32,41,43,45,110] and most importantly, the benefits of good oral health through preventive regimes to reduce the number and complexity of interventions over their lifetime [9,17,18,21,23,27,42].

3.8. Theme 8: Dental materials

In this theme, the literature identifies a number of materials used directly or indirectly for clinical care and opportunities for their use in a sustainable manner are considered individually.

3.8.1. Best practice

Consideration should be given to the use of approved standards that recognize sustainable sourcing, such as the US-based Green Seal Verification system [46,111]. Ensuring longevity of dental materials and avoiding waste is key to sustainable practice through their correct use and implementation [97].

3.8.2. Dental amalgam

Worldwide consumption of mercury is around 300 tons per annum [68]. 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 [26,31,37,39,43,44,49,57,59,62,68,69,74,77,97,112–124].

Dental mercury accounts for 3,4% of terrestrial mercury [62,97,115,119,123]. 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 [125]. 75 tonnes of amalgam per annum were used in the EU alone [112]. 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 [126].

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 [73,83]. Notwithstanding, the mercury waste from dental amalgam, accounts for less than 1% of mercury discharged by human activity into the environment [45,79].

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 [112].

3.8.2.1. Opportunity. There is a world-wide drive to phase-down/eliminate the use of dental amalgam to reduce the pollution impact of mercury in the environment. The Minamata Convention on Mercury [127] requires that signatory countries should phase-down mercury use and aim to eliminate dental amalgam by 2030 [18,23,28,112]. In this context, the European Union has adopted phase-down policy of the use of dental amalgam driven by these environmental concerns [24,27]. The literature identifies a wider series of recommendations to reduce the environmental impact of mercury from dental amalgam that can be categorized into the following themes:

1 *Source reduction and elimination* as the best way to reduce waste [41,57,97,124,128,129], with the following strategies: Source reduction that can also be provided as part of preventive dentistry approach [49,117,118,124]; use dental amalgam as little as possible to reduce waste produced [42,74]; use capsulated amalgam to reduce waste [59,[130]]; lobby for insurance policies to promote mercury free-alternatives and encourage the profession to take up policies that support amalgam alternatives [49]; the development and use of alternatives wherever possible [10,12,23,27,34,36,37,42,49,56,113,120,121].
2 *Knowledge acquisition.* There is much emphasis of the need for more knowledge acquisition at all levels of the profession: There are calls for the adoption of more preventive and adhesive dentistry [129] [131]; and the provision of effective training in the handling and disposal of mercury (including extracted teeth with amalgam restorations) [31,34,36,39,41–43,57,59,74,81,132,133].
3 *Waste management* features heavily with recommendations in two areas.
   a A need to avoid local 'chairside' Hg pollution risks [23,31,34,36,39,42,57,69], by means of: An overall reduction in exposure [49,74,93]; use of water-spray cooling and high-volume vacuum suction during amalgam removal in order to significantly reduce environmental mercury vapour [43,36,62,97,116]; the use of effective chairside traps, vacuum filters and amalgam separators, amalgam separators that meet ISO11143, that are 95% effective [12,23,26,28,31–33,37,39,41–43,45,58,59,62,63,67–70,73,74,97,112,118,120,126,132,134]; avoid the use of hypochlorite cleaners, as they increase dissolution of mercury [43,84,[135]]. Effective and safe storage of amalgam features with the following recommendations: Have an amalgam spill-kit for spills of elemental mercury; use a dedicated special container in accordance with relevant regulations; ensure that this has a mercury suppressant; that the container is tightly sealed and; stored in a cold environment [31,36,43,62,70,74,79,81,89,94,97,113,115,116,120,132].
   b General waste management:There is a need to enact existing legislative frameworks[136] and follow simple guidelines for mercury waste handling [115]. The US Environmental Protection Agency [137] provides detailed guidelines on the management of dental effluent and dental amalgam [26,62]. Recommendations: Recycle waste amalgam with effective collection, separation and recovery of mercury and silver through approved biological waste management companies; the establishment of mercury-free medical/dental facilities to avoid local environmental pollution should be considered [28,35,37,49,73,74,81,94,112,117,119,126,131,134]. Also, the removal of amalgam restorations from cadavers prior to cremation (similar to removal of pacemakers before cremation) has been suggested [117].

3.8.3. Anaesthetic gases

3.8.3.1. Recommendations & Best Practice. NO_2e levels can be reduced by capturing and neutralizing the gas during its use, a technology that is commonly used in hospitals but not in dentistry [51,138]. Use of effective protocols and standard operating procedures can avoid the pollution routes identified.

The use of recycling systems (e.g. Dynamic Gas Scavenging System is recommended [139], which collects and reuses 99% of anaesthetic gases without chemically altering them in the process and with significant reduction in energy consumption [138].

There is a need for further research to: (i) Establish the optimal (lowest environmental impact) fresh gas flow rate to aid a reduced aesthetic use [138]; (ii) reduce the impact of NO2 waste [23]; (iii) cost effective methods of NO2 reversal technology [138].

3.8.4. Gypsum

3.8.4.1. Opportunities. Recovery and recycling of dental gypsum is possible and effective with the recycled gypsum powder reported to be 99% as good as virgin gypsum [31,140]

Other opportunities to reduce the impact of gypsum waste is to use alternative biodegradable impression materials [31]. It is also possible to avoid the use of impressions and casts through the use of intraoral scanners [8,24,27,34,35].

3.8.5. Resin-based dental composite

3.8.5.1. Opportunities. An understanding of the pollution pathways is essential to enable identification of pollution reduction strategies. The pathways of RBC materials to the environment are: (i) Waste from expired composite compules or syringes, that becomes municipal waste and discarded in landfill. Once in the landfill, leachate can react with RBC allowing the release of its components. The temperature, pH and oxygen content of the landfill leachate solution change over time, affecting the reactivity of the solution. (ii) Microparticles from finishing or removing RBC restorations or from grinding CAD/CAM ingots. Microplastics not only act as direct pollutants, there is also evidence that they can attract and bind to biotoxins known as persistent organic pollutants (POPs). (iii) These monomers are detectable in saliva and urine, and it is therefore accepted that leached monomers of dental composite are released into the environment via human excretion after dental procedures involving RBC. (iv) End of life through cremation and interment. Methacrylates also exhibit high log Kow values, suggesting that these compounds are bio-accumulative, immobile, persistent, and have low water solubility. For these compounds, bioaccumulation through the food chain is of concern [17,112,141].

3.8.5.2. Best practice. The use of BPA-free RBCs and base-plates for orthodontic oral appliances should be promoted [31,46]. A preventive regime that seeks to reduce the need for interventive RBC restorations should be pursued as best practice for oral health outcomes and reduced pollution arising from this family of materials.

3.8.6. Metals

3.8.6.1. Best practice. Best practice for base metals is to either recycle them [17,32]; or use digital radiography to avoid the need for silver thiosulphate x-ray fixer [23,26,28,31,42,57,142].

The greatest opportunity comes from the transition to digital radiography. Whilst using conventional wet-film radiography, the literature highlights the ease of recycling of lead foil and that this should be facilitated at a local level through the following actions: Segregation of the lead foil from the other components from of the film packet; and avoidance of disposal of film in domestic municipal waste that will end up as land fill and incineration [26,28,32,36,37,44,58,59,62,73,78,96,134,142]. Alternatives to lead aprons for shielding are also considered [46].

Effective management of radiographic fixer is essential and key non-polluting practices should be followed: (i) Radiographic fixer and developer should not be mixed prior to disposal [43,63]; (ii) Used radiographic fixer must not be washed down the drain but sent for silver recovery and the developer should be neutralized prior to disposal [31,42,58,59,78,134]; (iii) certified waste carriers should be used to dispose of the waste, ideally by recycling [28,32,42,59,81,143].

Ceramic endosseous implants materials have a lower environmental impact, generating fewer emissions of greenhouse gases (GHGs) and consuming lower amounts of water and energy, when compared to metals; although with the recognition that the data only considers primary production and not processing and finishing [133].

3.8.7. ***Nanotechnology***

3.8.7.1. Recommendations. A review of the literature reveals a significant knowledge gap, focused on dentistry that will support practical recommendations to reduce the potential harmful effects of nanotechnology in healthcare. In this context, we need to consider nanoparticles in the wider context of healthcare to find relevant reports. This paper highlights both the knowledge gap in this field and the increasing evidence of nanosilver toxicity to human and nature [144]. Further targeted research and knowledge is required.

3.8.8. Disinfectants

3.8.8.1. Recommendations. Consideration should be given to the use of ultrasonic, steam or dry heat for sterilization instead of these toxic cleaning agents [27,29,35,36,41,45]. Waste management in the dental practice should make effective provision for the adequate disposal of these toxic pollutant solutions and not into the municipal waste water sewerage system. These include, monomers and associated reagents such as initiators, accelerators and inhibitors [24,61].

A recognised pollutant pathway for dental amalgam, is through the use of certain cleaners containing hypochlorite (sodium hypochlorite and sodium dichloroisocyanate) as they potentiate the release of mercury from effluent pipes [43,45,84,115,134].

4. 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_2e, air and water); Reduce, reuse, recycle and rethink; Policy and guidelines; Biomedical waste management; Plastics (SUPs); Procurement; Research & Education; Materials. The levels of awareness and the perceived barriers to engagement in sustainable practice has been reported by the authors in a preceding publication [1]. Public awareness of the need to improve our environmentally sustainable practices at all levels is high. However, professional awareness is much lower as there is a perceived disengagement between citizenship responsibility and that of our professional activities. This is a constant theme throughout the literature and presents both the greatest barrier and the opportunity to engage in effective and impactful sustainable outcomes.

The following headline conclusions from this study are encapsulated with a focus on the drivers, opportunities, recommendations and examples of best practice to develop and engage with sustainable practice.

Patient and staff commuter travel account for the greatest contribution to the profession's carbon foot print and this should be the focus of our activities through the adoption of different strategies. Opportunities to impact in this area focus on the use of smart clinical appointments with shared care, the use of technology for remote consultations and the adoption of a reductionist approach through the promotion of high standards of oral health that focuses on preventable diseases. The consequence of good oral health is a reduced need for interventive operative care that carries with it a reduced carbon foot print and a reduced waste pollution impact.

Reducing and recycling present the greatest opportunities for sustainable impact of our activities. The use of best practice guidelines through the adoption of technology, effective logistical management systems and environmental regulations are key to a more sustainable practice.

Professional engagement with policy making at all levels, from a domestic in-practice level to regional, national or international is essential for the formulation and promotion of best-practice guidelines. These should consider in a balanced manner, both patient wellbeing and environmental impacts; as both are inextricably linked to general planetary and human health.

Waste management should shift its focus from simply the segregation and efficient disposal of waste to satisfy safety regulations. This should also include sustainability drivers.

Plastic is an indispensable component of modern safe health care and this is unavoidable. Focus should consider the effect of reducing the volume at a local level and through the supply chain, including the use of packaging. Recycling (mechanical and chemical) should take a much greater role in the management of clinical SUPs (including PPE) and packaging.

Coordinated logistics and efficient procurement that ties in with waste management is important so that sustainable practice can take place. This approach can have significant financial gains by mapping procured plastic (at all levels of packaging) with sustainable recovery and recycling technologies.

Education is key to an increase of professional awareness and this is considered a 'low hanging fruit' that can be adopted through undergraduate university degree programs and through continuing professional development – This is a high priority activity as there is a need to establish a normalized attitudinal change amongst the next generation of professionals to provide oral health care in a sustainable manner. Academic environments have a responsibility to engage with this level of knowledge exchange and the associated research that will drive and identify sustainable solutions.

Dental materials, in a generic form, present the highest level of pollution. This is associated with the sourcing of constituents, the chemistry used, the packaging and transport incurred. The effects are noted at all levels of the supply chain, from manufacturing, through to distribution, procurement, clinical use and ultimately waste management. There is a pressing need to engage with all elements of the dental materials/products supply chain in a coordinated and systemic manner to reduce these environmental impacts.

Declaration of Competing Interest

None.

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