

Review

Not peer-reviewed version

Sustainability in Dentistry: A Systematic Literature Review of Environmental, Economic, and Social Dimensions in Dental Practice

[Chia-Tuo Lee](#) *

Posted Date: 4 November 2025

doi: 10.20944/preprints202511.0160.v1

Keywords: sustainability; dentistry; environmental impact; green dentistry



Preprints.org is a free multidisciplinary platform providing preprint service that is dedicated to making early versions of research outputs permanently available and citable. Preprints posted at Preprints.org appear in Web of Science, Crossref, Google Scholar, Scilit, Europe PMC.

Copyright: This open access article is published under a Creative Commons CC BY 4.0 license, which permit the free download, distribution, and reuse, provided that the author and preprint are cited in any reuse.

Disclaimer/Publisher's Note: The statements, opinions, and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions, or products referred to in the content.

Review

Sustainability in Dentistry: A Systematic Literature Review of Environmental, Economic, and Social Dimensions in Dental Practice

Chia-Tuo Lee

Cathay General Hospital, Taipei, Taiwan; cgh09870@cgh.org.tw

Abstract

Background: While sustainability is increasingly recognized as a priority in dentistry, it remains unclear what the map of the available empirical evidence to guide this transition looks like in terms of its breadth, depth, and quality. This systematic review provides a critical appraisal of the dental sustainability literature to identify its core characteristics, expose critical research gaps, and propose an evidence-based agenda for the future. **Methods:** Following PRISMA guidelines, a systematic search was conducted across PubMed/MEDLINE, Web of Science, and Google Scholar for empirical studies published between 2010 and 2025. Data on study design, geographic origin, sustainability dimensions (environmental, economic, social), and key findings were extracted. A narrative synthesis was performed, focusing on dimensional balance, methodological rigor, and thematic patterns. **Results:** From 140 initial records, 18 studies were included. The findings reveal a field in its infancy, characterized by three profound imbalances. **First, a dimensional imbalance:** research is overwhelmingly focused on Environmental sustainability (89% of studies), with scant attention paid to Economic (17%) and Social (22%) dimensions. **Second, a methodological imbalance:** the evidence base is dominated by low-level descriptive evidence, primarily cross-sectional surveys (61%), with a notable scarcity of intervention studies or objective quantitative research like Life Cycle Assessments (11%). **Third, a geographic imbalance:** research is concentrated in specific regions, with limited evidence from low- and middle-income countries. Publication trends show a marked increase in interest since 2022. **Conclusions:** The map of the current empirical evidence for sustainability in dentistry reveals a landscape that is insufficient to guide robust policy or practice change. It lacks the economic analysis, social inquiry, and high-quality methodological approaches necessary for a truly evidence-based transformation. This review presents a detailed research roadmap, prioritizing a shift towards more balanced, methodologically rigorous, and globally representative research to mature the field from a state of describing problems to one of testing solutions.

Keywords: sustainability; dentistry; environmental impact; green dentistry

1. Introduction

1.1. Context and Urgency

The global healthcare sector's substantial environmental footprint, contributing an estimated 4.4% of global net emissions, has positioned sustainability as a critical priority for all medical disciplines [1]. Within this context, dentistry faces unique sustainability challenges due to its intensive use of single-use materials, energy-intensive equipment, and complex waste streams [2]. The urgency of addressing these challenges is amplified by growing awareness of climate change impacts on public health and the healthcare sector's responsibility to minimize its environmental burden while maintaining high-quality patient care [3].

1.2. Conceptual Framework

Sustainability in healthcare is best understood through the Triple Bottom Line (TBL) framework, encompassing three interconnected dimensions: environmental (reducing ecological impact), economic (ensuring financial viability), and social (promoting equity and community well-being) [4]. This framework aligns with global sustainability goals, such as those outlined in the 2030 Agenda for Sustainable Development [5] and provides a comprehensive lens for evaluating dental practice transformation.

Environmental sustainability in dentistry involves minimizing resource consumption, reducing waste generation, and decreasing carbon emissions through practices such as using energy-efficient equipment, selecting sustainable materials, and optimizing waste management. The discourse surrounding "green dentistry" [6] often focuses on these aspects. Economic sustainability encompasses cost-effective resource utilization, the long-term financial viability of sustainable practices, and value-based care delivery models, aligning with broader principles of value-based healthcare [7]. Social sustainability addresses workforce development, community health equity, and stakeholder engagement in sustainable practice adoption.

1.3. Knowledge Gaps

While general awareness of sustainability is growing, a preliminary review of the literature suggests the evidence base required to inform practice and policy is constrained by specific limitations. This systematic review is designed to rigorously investigate three suspected gaps that may be hindering the translation of sustainability principles into widespread, effective action.

a. The Dimensional Gap: A Potential Imbalance in Research Focus.

The first gap relates to the coverage of the TBL framework. There is a need to determine if the current research landscape is balanced or if it concentrates heavily on the environmental dimension. An overemphasis on ecological topics, while important, would leave practitioners and policymakers without an evidence base for the financial business case (economic dimension) or the impacts on staff, patients, and communities (social dimension). Without this integrated evidence, sustainability initiatives may be perceived as a costly burden rather than a strategic investment, leading to poor adoption rates.

b. The Methodological Gap: Nature and Quality of Evidence.

The second gap concerns the scientific rigor of the existing research. The type of study design determines the strength of its conclusions. Descriptive designs, such as Knowledge, Attitude, and Practice (KAP) surveys, are valuable for establishing baseline awareness but are insufficient for determining the effectiveness of an intervention. They cannot establish causality or provide guidance on which specific practices yield the greatest positive impact. A field dominated by such studies remains in a perpetual state of describing the problem rather than testing solutions. This review will therefore systematically categorize the methodologies employed in the literature to assess the maturity of the field and its capacity to generate actionable, cause-and-effect evidence.

c. The Measurement Gap: A Lack of Standardization.

The third gap pertains to the tools used to collect data. The reliability and validity of research findings are contingent upon the quality of measurement instruments. If researchers predominantly use unvalidated, ad-hoc questionnaires, the ability to compare findings across studies, populations, and settings is severely compromised. This lack of standardization prevents the cumulative synthesis of knowledge—such as through meta-analysis—and forces the field to perpetually "reinvent the wheel" rather than building upon a common foundation of reliable data. An investigation into the prevalence of validated versus non-validated instruments is therefore essential for evaluating the overall robustness of the literature.

1.4. Objectives

To address the gaps, this systematic review has three primary objectives:

1. To systematically map and quantify the distribution of empirical research across the **environmental, economic, and social dimensions** of the Triple Bottom Line framework, thereby providing a clear picture of the field's current focus and identifying any significant imbalances.
2. To conduct a critical appraisal of the **methodological landscape** by categorizing the predominant research designs and assessing the prevalence of validated versus non-validated measurement tools. This will evaluate the overall quality and strength of the existing evidence base.
3. To formulate a targeted, evidence-based **research agenda** based on the synthesis of the identified dimensional, methodological, and measurement gaps, with the aim of guiding future research towards greater rigor, balance, and practical impact.

2. Materials and Methods

2.1. Protocol and Guidance

This systematic review was designed, conducted, and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement [8]. The PRISMA checklist provides a robust, evidence-based framework for ensuring the transparent and complete reporting of systematic reviews. A protocol for this review was established prior to the literature search, outlining the objectives, inclusion criteria, and methods for analysis.

2.2. Information Sources and Search Strategy

A systematic literature search was performed on September 19, 2025, to identify relevant empirical studies published between January 1, 2010, and the search date. The search strategy was developed in consultation with information specialists and designed to be comprehensive, utilizing three major electronic databases recognized for their coverage of medical and interdisciplinary research: PubMed/MEDLINE, Web of Science (Core Collection), and Google Scholar.

The search strategy combined two core concepts: "dentistry" and "sustainability." For each concept, a set of keywords and subject headings (including MeSH terms) were developed. Boolean operators ("AND", "OR") were used to combine the search terms. To ensure comprehensiveness, the reference lists of included studies and relevant review articles were also manually screened. The detailed search terms and syntax used for each core database are provided in Appendix A (Table A1).

2.3. Eligibility Criteria and Study Selection

A two-stage screening process was conducted by two independent reviewers.

1. inclusion and exclusion criteria were established. Studies were included if they were original empirical research published in English between 2010-2025, and focused on at least one dimension of sustainability within a dental context. Non-empirical articles, studies without a specific dental focus, and non-English publications were excluded.
2. the study selection process was executed. All retrieved records were imported into a reference management software for deduplication. Two reviewers then independently screened titles and abstracts against the eligibility criteria. Potentially relevant articles advanced to a full-text screening, which was also conducted independently by both reviewers. Any disagreements at either stage were resolved through discussion and consensus, with a third reviewer available for arbitration if needed.

2.4. Data Extraction and Synthesis

A standardized data extraction form was designed and pilot-tested. One reviewer extracted data for each study, and a second reviewer verified the information for accuracy and completeness. The extracted data included bibliographic details, study characteristics, population, sustainability dimension(s), key findings, and author-reported limitations.

Due to the significant heterogeneity observed in study designs, populations, and outcome measures, a quantitative meta-analysis was not feasible. Therefore, a narrative synthesis approach was employed. The findings were grouped thematically based on the Triple Bottom Line framework and key methodological characteristics to identify patterns, gaps, and areas for future research.

2.5. Quality Assessment (Risk of Bias)

While a formal meta-analysis was not conducted, a quality assessment of the included studies was performed to understand the overall risk of bias in the literature. The Joanna Briggs Institute (JBI) Critical Appraisal Checklists were adapted for this purpose, with specific tools used for cross-sectional, experimental, and qualitative studies. Two reviewers independently assessed the quality of each study, focusing on potential biases in sampling, measurement, and analysis. The results of this assessment were not used to exclude studies but to inform the narrative synthesis, particularly in the discussion of the evidence base's limitations.

3. Results

3.1. Study Selection and Publication Trends

The study selection process is detailed in the PRISMA flow diagram (Figure 1). The search yielded 140 records, from which 18 unique empirical studies were identified as meeting all inclusion criteria. A key characteristic of this body of literature is its recent emergence. As shown in Figure 2, while the review period began in 2010, the vast majority of included studies (n=16, 89%) were published between 2022 and 2025. This trend indicates that dental sustainability is a rapidly accelerating area of research, but as the grouped bars reveal, this growth is predominantly driven by an increase in cross-sectional surveys, with higher-level evidence appearing only sporadically.

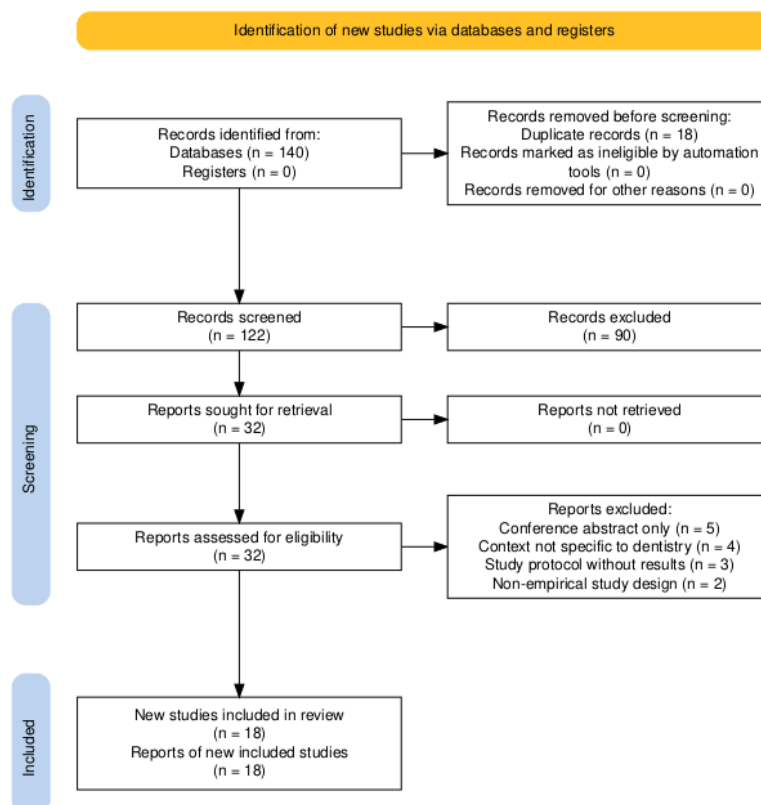


Figure 1. PRISMA 2020 Flow Diagram.



Figure 2. Annual Publication Trend.

3.2. Geographic Distribution of Research

The geographic origins of the included studies reveal a global but uneven distribution of research activity (Figure 3). Research is most concentrated in Asia (n=8) and Europe (n=6). However, the composition of research reveals a critical thematic divergence. In Asia, the research focus is almost exclusively on the Environmental dimension, while Europe is the primary source of the few studies that address the Economic and Social dimensions. This geographic and thematic imbalance suggests that the current evidence base may not fully represent the diverse challenges and contexts of dental practice worldwide.

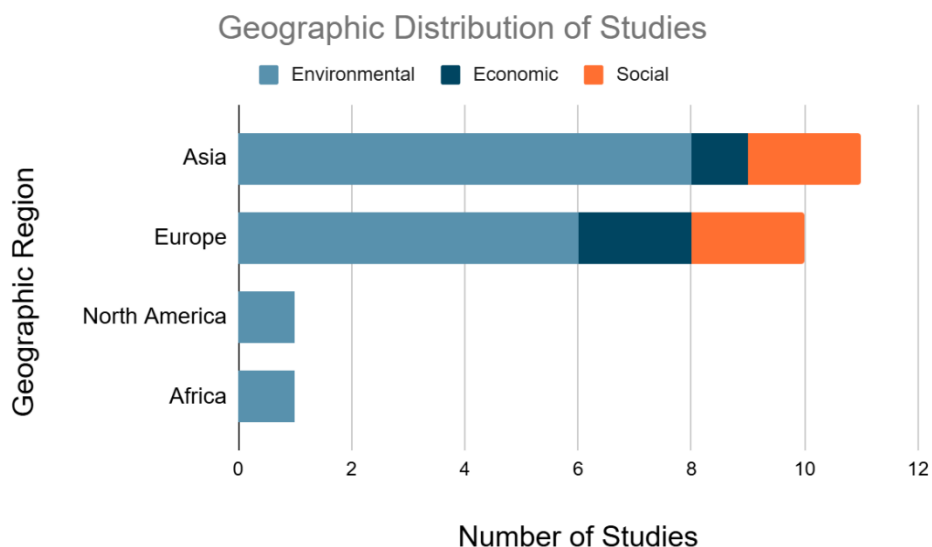


Figure 3. Geographic Distribution of Studies.

3.3. Thematic and Methodological Landscape

The most profound finding of this review is the intertwined nature of the thematic and methodological imbalances within the available evidence. Table 1 provides detailed study-by-study data that forms the basis for the following analysis.

Table 1. Detailed Comprehensive Summary.

| Authors, Year | Methods | Sample | Key Findings | Limitations / Notes |
|------------------------|--|--|---|--|
| R. & Astariyani (2023) | Cross-sectional questionnaire study using a 10-item self-structured questionnaire. | n=135 postgraduate dental students at D.J. College of Dental Sciences and Research, India. | <ul style="list-style-type: none"> • High Awareness: ~80% of students were familiar with the term "green dentistry". • Low Implementation: Despite awareness, most students had not implemented sustainable strategies in their clinical practice. | Abstract provided insufficient detail to identify specific methodological limitations. |
| Dargad et al. (2022) | Cross-sectional e-survey using a validated questionnaire with pilot testing. | n=310 responses from 900 invited alumni of a private dental college in Pune, India. | <ul style="list-style-type: none"> • Varied Knowledge: >60% correct on waste/sterilization, but <40% correct on energy efficiency. • High Compliance (Waste): 95.5% were registered with a biomedical waste disposal service. • Attitude-Practice Gap: Positive attitudes towards sustainability significantly exceeded practical implementation. | Abstract did not report on response rate bias or other potential sampling limitations. |
| Veress et al. (2023) | Cross-sectional online survey with 50 questions across 6 sections. | n=98 dentists recruited via online platforms (location not specified). | <ul style="list-style-type: none"> • High Willingness: 99% were willing to take steps towards sustainability. • Favorable Attitude: 74.5% were favorable to an environmentally friendly practice, but specific behaviors (e.g., waste sorting) varied. | The abstract does not list explicit methodological limitations beyond the need for general guidance. |
| Jamal et al. (2023) | Multi-institution cross-sectional survey. | Dental undergraduate students and faculty across 26 dental schools in Saudi Arabia. | <ul style="list-style-type: none"> • Found a strong positive perception and high level of support for integrating sustainability concepts into the dental curriculum among both students and faculty. | Relies on self-reported data; may not reflect actual curriculum content or teaching practices. |
| Baird et al. (2022) | Cross-sectional questionnaire study. | Adults living in the United Kingdom (patient perspective). | <ul style="list-style-type: none"> • Patients demonstrated positive attitudes and were generally supportive of their dentists adopting more sustainable practices. | Focuses on attitudes, not actual patient behavior (e.g., choosing a "green" dentist). |
| Fisal et al. (2025) | Cross-sectional study. | Dental undergraduate students. | <ul style="list-style-type: none"> • Revealed moderate levels of knowledge, awareness, and practices regarding green dentistry, indicating a clear gap in current education. | Single-institution study, limiting generalizability. |
| Țâncu et al. (2025) | Cross-sectional questionnaire. | Dental students at a university in Bucharest, Romania. | <ul style="list-style-type: none"> • Identified significant gaps in student knowledge regarding specific sustainable practices and | Context-specific to a single European country; findings |

| | | | | |
|------------------------|--|---|--|---|
| | | | the environmental impact of dentistry. | may differ elsewhere. |
| Boukhris et al. (2025) | Survey-based waste analysis. | Dental practices. | <ul style="list-style-type: none"> • Provided a detailed analysis of dental waste streams and assessed the level of adherence to official waste management and disposal protocols. | Self-reported survey data on waste may differ from objective waste audits. |
| Zia et al. (2025) | Pilot psychometric analysis using PLS-SEM and EFA. | Dental school personnel and students in Karachi, Pakistan. | <ul style="list-style-type: none"> • Key Gap Addressed: Successfully developed and validated a KAP questionnaire for green dentistry. • Major Finding: Explicitly highlighted the scarcity of standardized and validated measurement instruments in this research field. | Framed as a pilot study, suggesting findings are preliminary and require larger-scale validation. Sample size not reported in abstract. |
| Künzle et al. (2025) | Life-Cycle Analysis (LCA) based on ISO 14040/14044 guidelines. | A standard tooth extraction procedure performed in a university hospital setting. | <ul style="list-style-type: none"> • Objective Quantification: A single tooth extraction generates 4.9 kg of CO₂-equivalent. • Identified Hotspots: Pinpointed the specific materials, energy consumption, and sterilization processes that are the main drivers of the environmental impact. | As with all LCA studies, results are sensitive to the defined system boundaries and the quality of underlying data sources. |
| Duane et al. (2020) | Life-Cycle Assessment (LCA). | A standard root canal treatment procedure. | <ul style="list-style-type: none"> • Quantified the environmental impact of an endodontic procedure. • Identified specific areas (e.g., single-use instruments, energy use) as key environmental hotspots, providing a basis for targeted interventions. | Study-specific context may limit direct comparison with other procedures or settings. |
| Hijazi et al. (2025) | Laboratory experimental study. | In-vitro setting. | <ul style="list-style-type: none"> • Feasibility Finding: Demonstrated that incorporating recycled Polymethyl Methacrylate (PMMA) particles into new denture bases is technically feasible without significantly compromising key material properties. | Laboratory findings; clinical performance and long-term durability of recycled materials require further investigation. |
| Stelling et al. (2025) | Mixed-methods study (qualitative and quantitative). | Dental workforce in the North East of England. | <ul style="list-style-type: none"> • Social Dimension: Revealed a complex interplay of factors affecting workforce sustainability, including professional value, support systems, and working conditions, especially in underserved areas. | Region-specific findings; may not be generalizable to other healthcare systems. |
| Grose et al. (2018) | Mixed-methods action research. | A single dental practice in the UK. | <ul style="list-style-type: none"> • Implementation Success: Showed that a participatory action research approach is a feasible and effective method for developing and | Single-site case study, limiting generalizability of the specific |

| | | | | |
|--------------------------------|--|-------------------------------------|---|---|
| | | | embedding sustainability practices at the clinic level. | interventions but not the approach. |
| Coronel Zubiarte et al. (2024) | Mixed longitudinal educational intervention. | Dental students. | <ul style="list-style-type: none"> • Intervention Effectiveness: An educational program focused on the environmental impact of dental waste successfully improved students' awareness and knowledge over time. | Focuses on awareness, not long-term behavioral change in clinical practice. |
| Khurshid et al. (2024) | Action research implementation. | A dental practice setting. | <ul style="list-style-type: none"> • Provided a practical case study outlining the successful implementation of various environmental sustainability initiatives in a clinical setting. | Descriptive case study; lacks a control group to measure the impact against. |
| Baras (2022) | Implementation experiment. | A single dental practice in France. | <ul style="list-style-type: none"> • Successfully integrated an eco-responsible approach into daily clinical operations, demonstrating the real-world feasibility and process of such a transformation. | Single-site study; specific facilitators and barriers may be context-dependent. |
| Aydin & Varici (2022) | Case study applying a theoretical framework. | A university dental faculty. | <ul style="list-style-type: none"> • Framework Application: Proposed and applied the Sustainability Balanced Scorecard as a comprehensive tool for measuring environmental, economic, and social performance in a dental institution. | Primarily a conceptual application; empirical data on its effectiveness in driving change is not presented. |

3.3.1. Dimensional Imbalance

Figure 4, a Sankey diagram, provides a powerful visualization of the relationship between thematic focus (TBL dimensions) and the methodological approaches used. The diagram clearly shows that the vast majority of scientific effort, represented by the thickest flow, originates from the **Environmental** dimension and is channeled directly into **Cross-sectional Surveys**. This indicates that the dominant research paradigm is to ask practitioners about their environmental awareness.

In stark contrast, the critically under-researched **Economic** and **Social** dimensions show only weak and scattered flows to various methodologies. The diagram also starkly illustrates that objective methods like **LCA** are applied exclusively to Environmental questions. This cross-analysis reveals a critical disconnect: the methods best suited for determining effectiveness and impact are not being applied to the economic and social questions that are crucial for practice implementation.

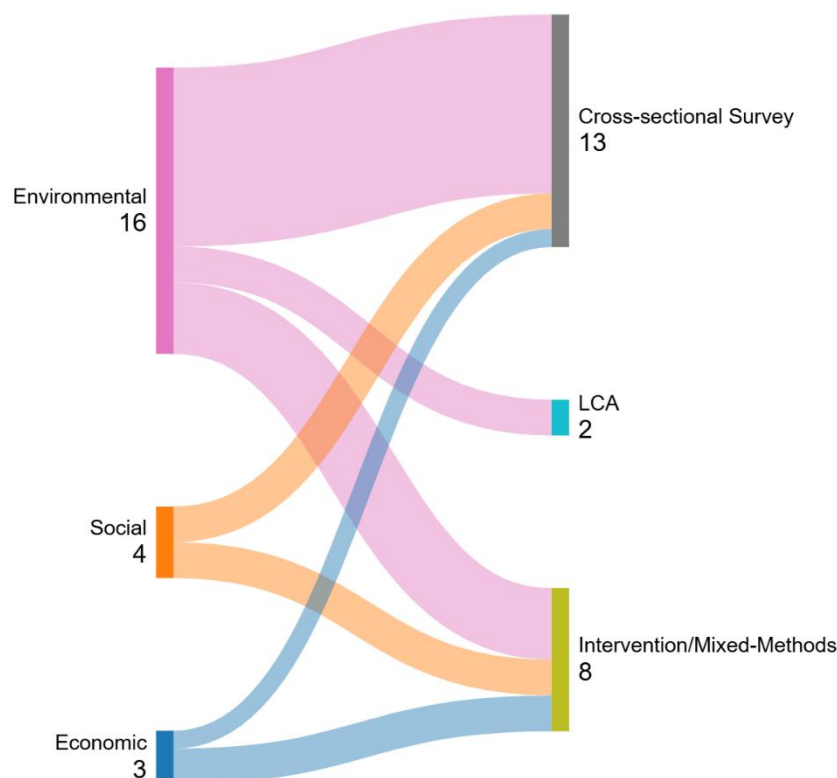


Figure 4. Flow from TBL Dimensions to Methodological Approaches.

3.3.2. Methodological Immaturity

The overall quality of the evidence base is best understood when mapped onto a traditional evidence hierarchy, as shown in Figure 5. This annotated pyramid provides a stark visual summary of the field's methodological immaturity, revealing a structure that is broad at the base but hollow at the top. The following sections provide a deeper analysis of the key findings from each level of this pyramid and the overarching limitations of this evidence base.

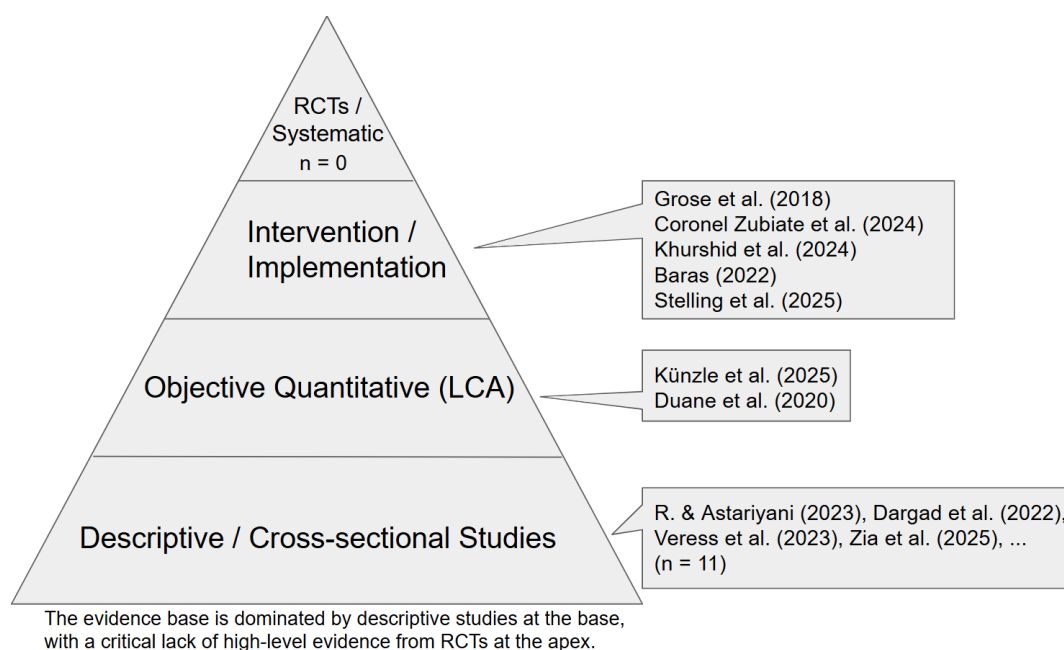


Figure 5. The Evidence Pyramid Hierarchy.

3.4. Key Findings by Study Design and Quality of Evidence

Beyond the thematic focus, the methodological quality of the evidence base is a critical determinant of its utility. The analysis reveals a heavy reliance on descriptive, non-interventional study designs, which has significant implications for the field's capacity to generate actionable, cause-and-effect conclusions. Figure 3 visually represents this methodological landscape.

- **Descriptive Evidence from Cross-Sectional Surveys (n=11, 61%):**

Most of the evidence base consists of KAP surveys. These studies have been instrumental in establishing a baseline understanding of awareness and attitudes [9,10,13]. A recurring theme is the "attitude-practice gap," where a high level of willingness to be sustainable does not translate into consistent implementation. Interestingly, this positive attitude is not limited to practitioners; research also indicates that patients are generally supportive of their dentists adopting more sustainable practices [11]. These surveys also provide detailed analyses of specific topics, such as dental waste management practices [21].

- **Objective Quantification from Life Cycle Assessments (n=2, 11%):**

A small but highly significant cluster of studies utilized Life Cycle Assessment (LCA) to provide objective environmental data. The work which quantified the carbon footprint of a tooth extraction (4.9 kg CO₂-eq) [15], and on endodontic procedures [16], represent a methodological high point. These studies offer the kind of robust, quantitative data necessary to prioritize clinical interventions based on their actual environmental impact, moving beyond subjective perception.

- **Emerging Evidence from Intervention and Implementation Studies (n=5, 28%):**

A nascent but growing body of research includes mixed-methods studies, action research, and educational interventions. For instance, a work demonstrated that targeted educational programs can improve student awareness [12]. Similarly, implementation studies [14,18,24] showed the real-world feasibility of transforming practice. These studies are critical as they begin to answer the "how-to" questions of sustainability, although they are often single-site case studies, which limits their generalizability.

3.5. Methodological Quality and Limitations

A comprehensive synthesis requires a critical appraisal of the methodological rigor of the included studies. Three primary limitations pervade the current literature, constraining the strength of any conclusions that can be drawn and highlighting the immaturity of the field.

1. **Predominance of Self-Reported Data:** With over 60% of studies relying on surveys, the evidence base is heavily skewed by self-reported data. This introduces a high risk of social desirability bias (participants reporting what they believe is the "correct" or desirable answer) and recall bias. This reliance limits the validity of the findings, as stated attitudes and practices may not reflect real-world behaviors.
2. **Lack of Standardized and Validated Instruments:** A significant weakness identified is the scarcity of standardized measurement tools. Most KAP surveys employed ad-hoc, unvalidated questionnaires. This was explicitly identified as a major research gap [22], whose work focused on the psychometric validation of a KAP tool. Without common, validated instruments, it is nearly impossible to compare findings across studies, conduct meta-analyses, or reliably track progress in the field over time.
3. **Limited Generalizability:** Many studies, particularly the interventional and implementation research, were conducted in single-institution settings (e.g., a single dental school or clinic), as noted in Table 1 for studies like [14,18]. While providing valuable proof-of-concept, the findings from these studies may not be generalizable to different cultural, economic, or healthcare contexts. The field currently lacks the multi-site, large-scale studies needed to generate broadly applicable evidence.

4. Discussion

4.1. The Self-Reinforcing Cycle of Low-Level Evidence

The findings of this review, when synthesized, suggest more than just a series of isolated gaps. Instead, they point towards a systemic issue: a self-reinforcing cycle of low-level evidence that currently defines the field of dental sustainability, as conceptualized in Figure 6. This cycle provides a deeper explanation for why the evidence map (Figure 3) is so uneven and why the evidence pyramid (Figure 5) is hollow at the top.

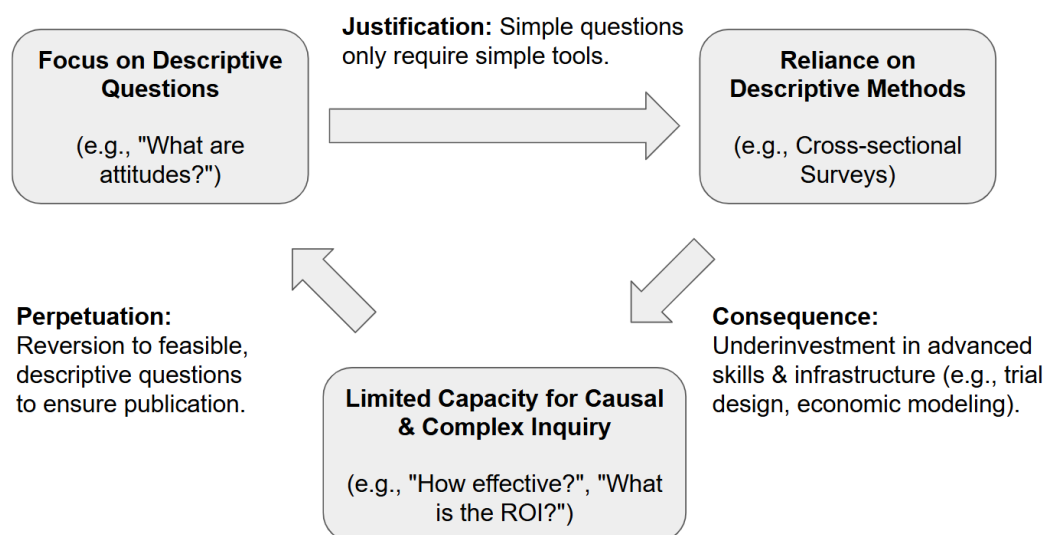


Figure 6. The Self-Reinforcing Cycle of Low-Level Evidence in Dental Sustainability.

The cycle begins with a focus on readily answerable, descriptive questions (e.g., "What are dentists' attitudes?"). This narrow focus contributes directly to the dimensional imbalance seen in Figure 4, as environmental awareness is easier to measure than complex economic or social outcomes. This, in turn, necessitates only reliance on simple, descriptive methods, primarily cross-sectional surveys. The long-term dominance of these methods means the field has underinvested in the skills and infrastructure needed for more complex research. This results in an inability to answer complex, causal questions (e.g., "What is the ROI of this intervention?"). Faced with this complexity, researchers may revert to the more feasible, descriptive questions, thus perpetuating the cycle. Breaking this cycle is the central challenge for maturing the field.

It is important to frame this cycle not as a failure, but as a marker of a necessary, completed first phase. The descriptive studies [9–11,13,19–21] that form the base of the pyramid (Figure 5) were essential for establishing the field, identifying the core "attitude-practice gap" [9], and confirming broad support for sustainability [11,18]. The central argument of this review is not to devalue this foundational work, but to declare it 'mission accomplished.' The risk now lies in perpetuating this first phase. This evidence map suggests the field has now built a sufficient descriptive foundation and is ready—and required—to mature collectively toward the next phase of testing solutions.

4.2. Comparison with Existing Literature and Contribution of This Review

These findings align with earlier narrative reviews that called for a multifaceted approach [26,27]. However, this systematic review makes three unique contributions. First, it quantifies the problem through a suite of novel data visualizations (Figures 2–5). Second, it moves beyond describing the gaps to proposing an explanatory model for their existence—the self-reinforcing cycle (Figure 6). While some studies have successfully demonstrated an integrated approach [25], our review reveals these are exceptions rather than the norm. Third, this review translates its diagnosis

into a strategic, evidence-based roadmap designed to break the cycle (Table 2), offering a clear path from a descriptive to an interventional science.

Table 2. A Proposed Research Agenda for Maturing the Field of Dental Sustainability.

| Identified Gap | High-Priority Research Question | Recommended Methodology | Rationale / Expected Impact |
|------------------------------------|---|---|--|
| Economic Gap | What are the cost-effectiveness and ROI of key sustainability interventions (e.g., digital scanners vs. traditional impressions)? | Cost-Effectiveness Analysis; ROI Studies | To provide the "business case" required for practice owners to invest in sustainable technologies. |
| Methodological Gap (Impact) | What is the comparative environmental impact of common dental procedures (e.g., restorations, extractions)? | Standardized Life Cycle Assessment (LCA) | To generate objective data for evidence-based prioritization of clinical interventions. |
| Methodological Gap (Effectiveness) | What implementation strategies are most effective for promoting adoption of evidence-based sustainability practices? | Cluster Randomized Controlled Trials (RCTs) | To move beyond describing the problem to rigorously testing solutions for practice change. |
| Social Gap | How do sustainability-focused changes impact patient satisfaction, clinical outcomes, and health equity? | Mixed-Methods Studies; Equity Analysis | To ensure sustainability enhances, rather than compromises, patient care and equitable access. |
| Measurement Gap | How can sustainability KAP and behaviors be reliably and validly measured across different settings? | Psychometric Validation Studies | To create a foundation of reliable and comparable data for robust synthesis and assessment. |

4.3. Implications for Policy, Education, and Practice

The identified gaps have profound implications for different stakeholders within the dental community.

- **For Practitioners and Clinic Managers:** The lack of economic data is a major barrier to adoption. Without clear evidence of return on investment or long-term cost savings, transitioning to sustainable—and often more expensive—materials and equipment remains a financially risky proposition. The findings of this review should caution practitioners against adopting trends without first demanding robust evidence of their environmental, economic, and clinical efficacy.
- **For Dental Educators:** The documented knowledge gaps among students [19,20], coupled with strong support from both students and faculty for curriculum integration [18], underscore the urgent need for curriculum reform. However, this reform must be evidence-based. It is no longer sufficient to teach "green dentistry" as a set of aspirational principles. Curricula must be developed to teach sustainability as a science, grounded in concepts from LCA, health economics, and implementation science. The development of validated competency assessment tools, building on the work of [22], is a critical first step.
- **For Policymakers and Professional Associations:** Given that even foundational practices like waste management are not universally optimized [21], this review suggests that the current evidence base is likely insufficient to support strong, specific policy mandates. Policymakers should prioritize funding research that addresses the gaps identified here, particularly multi-site intervention studies and economic analyses, before issuing widespread guidelines.

4.4. A Proposed Research Agenda for the Future

To accelerate the field's maturation from describing problems to testing solutions, this review proposes a structured research agenda. This agenda, detailed in Table 2, is directly derived from the dimensional, methodological, and measurement gaps identified in the Results section. It is designed to guide future research towards greater rigor and balance by recommending specific high-priority research questions and the advanced methodologies required to answer them.

4.5. Strengths and Limitations of This Review

The primary strength of this review is its rigorous construction of the available evidence map. However, the most significant limitation of this map—and a core finding in itself—is that the available evidence base is small. This review does not claim the entire field is methodologically immature; rather, it concludes that the portion of the field that is currently visible through the lens of peer-reviewed, empirical research is methodologically immature.

This distinction is critical. The findings, particularly the 'Economic Gap' and 'Social Gap,' should therefore be precisely understood as a lack of *academic, empirical publications* on these topics, not as a definitive claim that *no practical data* (e.g., in manufacturer reports or non-empirical white papers) exists. This review's focus on peer-reviewed, empirical evidence [179, 180] was a deliberate methodological choice to map the *scientific* evidence base. This potential 'academic-practice gap' itself reinforces this review's core conclusion: the urgent need to translate these critical economic and social questions into rigorous, peer-reviewed research.

5. Conclusions

The map of the peer-reviewed evidence on sustainability in dentistry reveals a field of stark contrasts: rapid growth in interest is coupled with a profound lack of methodological rigor and dimensional balance. The evidence base is geographically concentrated, thematically narrow, and built upon a foundation of low-level evidence, rendering it insufficient to guide meaningful policy or practice transformation. To mature, the field must undergo a strategic and collective shift, moving away from describing awareness towards rigorously testing the effectiveness, cost, and equity of sustainability interventions. The research agenda proposed in this review (Table 2) offers a clear, evidence-based roadmap for this essential transformation.

Author Contributions: Conceptualization, methodology, investigation, data curation, writing—original draft preparation, writing—review and editing, visualization, C.-T.L. The author has read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available in the article. The list of included studies can be found in Table 1.

Acknowledgments: During the preparation of this manuscript, the author used Gemini 2.5 for the purposes of language polishing. The authors have reviewed and edited the output and take full responsibility for the content of this publication.

Conflicts of Interest: The author declares no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

TBL Triple Bottom Line

LCA Life Cycle Assessment

KAP Knowledge, Attitude, and Practice
RCT Randomized Controlled Trial

Appendix A

Table A1. Detailed Search Strategy and Syntax.

| Database | Search Terms Combination |
|----------------|---|
| PubMed/MEDLINE | ("Dentistry"[MeSH Terms] OR "Oral Health"[MeSH Terms] OR "dental practice"[Title/Abstract]) 'AND' ("Sustainability"[Title/Abstract] OR "green dentistry"[Title/Abstract] OR "Environmental Sustainability"[MeSH Terms] OR "Conservation of Natural Resources"[MeSH Terms]) TS=("dentistry" OR "dental" OR "oral health") |
| Web of Science | 'AND' 'TS=("sustainability" OR "sustainable" OR "green" OR "eco-friendly" OR "environmental impact")' |

References

- Karliner, J.; Slotterback, S.; Boyd, R.; Ashby, B.; Steele, K. Health Care's Climate Footprint: How the Health Sector Contributes to the Global Climate Crisis and Opportunities for Action; Health Care Without Harm: Reston, VA, USA, 2019.
- Duane, B.; Harford, S.; Steinbach, I.; Stancliffe, R. Environmentally sustainable dentistry: Energy use within the dental practice. *Br. Dent. J.* 2019, *227*, 259-264.
- Martin, N.; Mulligan, S.; Fuzesi, S.; Brookes, Z.; Jamous, I.; Loukaidis, M.; et al. The environmental sustainability of oral healthcare: A position paper by the Sustainable Dentistry Special Interest Group. *Br. Dent. J.* 2021, *230*, 345-353.
- Elkington, J. Partnerships from cannibals with forks: The triple bottom line of 21st-century business. *Environ. Qual. Manag.* 1998, *8*, 37-51.
- United Nations. Transforming Our World: The 2030 Agenda for Sustainable Development; United Nations General Assembly: New York, NY, USA, 2015.
- Mulimani, P. Green dentistry: The art and science of sustainable practice. *Br. Dent. J.* 2017, *222*, 954-961.
- Porter, M.E.; Teisberg, E.O. Redefining Health Care: Creating Value-Based Competition on Results; Harvard Business Review Press: Boston, MA, USA, 2006.
- Page, M.J.; McKenzie, J.E.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ* 2021, *372*, n71.
- Dargad, P.; Shetiya, S.H.; Agarwal, D. Knowledge, attitude and practice regarding green dentistry amongst the alumni of a private dental college in Pune, Maharashtra – A questionnaire study. *Ecol. Environ. Conserv.* 2022, *28*, 021.
- R.; Astariyani. Awareness, attitude and practice towards green dentistry among the postgraduate dental students of D.J College of Dental Sciences and Research Modinagar. *Int. J. Multidiscip. Res.* 2023, *5*, 1517.
- Baird, H.M.; Mulligan, S.; Webb, T.L.; Baker, S.R.; Martin, N. Exploring attitudes towards more sustainable dentistry among adults living in the UK. *Br. Dent. J.* 2022, *233*, 910-916.
- Hijazi, M.; Alqahtani, S.M.; Alqahtani, A.S.; Alqahtani, N.; Alqahtani, A.; Vohra, F.; Abduljabbar, T. Incorporation of recycled PMMA particles into heat-cured denture base materials for improved sustainability. *BMC Oral Health* 2025, *25*, 943-1.
- Veress, S.; Kerekes-Máthé, B.; Szekely, M. Environmentally friendly behavior in dentistry. *Med. Pharm. Rep.* 2023, *96*, 473.
- Khurshid, Z.; Alqurashi, H.; Ashi, H. Advancing environmental sustainability in dentistry and oral health. *Eur. J. Gen. Dent.* 2024, *13*, 99.
- Künzle, A.; Frank, M.; Paris, S. Environmental impact of a tooth extraction: Life cycle analysis in a university hospital setting. *Community Dent. Oral Epidemiol.* 2025, *53*, 3.

16. Duane, B.; Borglin, L.; Pekarski, S.; Saget, S.; Duncan, H.F. Environmental sustainability in endodontics: A life cycle assessment (LCA) of a root canal treatment procedure. *BMC Oral Health* 2020, 20, 337.
17. Stelling, D.; Brown, J.; Burford, B.; Blaylock, Z.; Vance, G. Valuing and retaining the dental workforce: A mixed-methods exploration of workforce sustainability in the North East of England. *BMC Health Serv. Res.* 2025, 25, 803-9.
18. Jamal, H.; Marghalani, A.A.; Shinawi, A.M.J.; Gaffar, B. Exploring the perception of dental undergraduate students and faculty on environmental sustainability in dentistry: A cross sectional survey in 26 dental schools in Saudi Arabia. *Dent. J.* 2023, 11, 103.
19. Țâncu, A.M.C.; Imre, M.; Iosif, L.; Pițuru, S.M.; Pantea, M.; Sfeatcu, R.; et al. Is sustainability part of the drill? Examining knowledge and awareness among dental students in Bucharest, Romania. *Dent. J.* 2025, 13, 114.
20. Faisal, S.; Rohani, M.M.; Aziz, A.A.; Hussain, N.H.N.; Fuad, M.D.F. Knowledge, awareness, and practices of green dentistry among dental undergraduate students: A cross-sectional study. *J. Dent. Educ.* 2025, 89, 959.
21. Coronel Zubiate, F.T.; Farje-Gallardo, C.A.; Rojas de la Puente, E.E. Environmental impact of waste in dental care: Educational strategies to promote environmental sustainability. *Vide. Tehnologija. Resursi (Environment. Technology. Resources)* 2024, 2, 100.
22. Zia, N.; Doss, J.G.; Danaee, A.; John, J.; Panezai, J. Psychometric analysis of a KAP questionnaire on green dentistry using PLS-SEM and EFA: A pilot study. *BMC Oral Health* 2025, 25, 745-1.
23. Baras, A. Acting for the health of the planet by integrating an eco-responsible approach in dental practices: A French experiment in a dental office. *Int. Health Trends Perspect.* 2022, 2, 1713.
24. Aydin, A.; Varici, İ. The use of the sustainability balanced scorecard method in performance measurement: An application in the faculty of dentistry. *Muhasebe ve vergi uygulamaları dergisi (Journal of Accounting and Tax Applications)* 2022, 15, 606.
25. Grose, J.; Burns, L.; Mukonoweshuro, R.; Richardson, J.; Mills, I.G.; Nasser, M.; Moles, D.R. Developing sustainability in a dental practice through an action research approach. *Br. Dent. J.* 2018, 225, 738-744.
26. Khanna, S.; Dhaimade, P.A. Green dentistry: A systematic review of ecological dental practices. *Environ. Dev. Sustain.* 2019, 21, 1345-1367.
27. Duane, B.; Steinbach, I.; Stancliffe, R.; Al Yazeedi, A.; Lyne, A.; Bashford, J.; et al. Sustainability in dentistry: A multifaceted approach needed. *J. Dent. Res.* 2020, 99, 998-1003.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.