Beyond Beauty:
A Life Cycle Assessment of Sustainability in the Aesthetic Industry

(A pilot study of environmental performance in aesthetic medicine)

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Abstract

The healthcare sector contributes approximately 5% of global CO_2 emissions, yet the aesthetic industry remains an overlooked contributor. This pilot study quantifies the environmental impact of two anonymised UK aesthetic clinics through a life cycle perspective, integrating clinic-level environmental audits with comparative Life Cycle Assessment (LCA) of cosmetic packaging materials. Data were collected through direct observations, staff interviews, and secondary environmental databases.

Results indicated fragmented sustainability practices across both clinics, with heavy reliance on single-use consumables, volatile anaesthetic gases, and low engagement with recycling or carbon auditing. Packaging LCAs demonstrated that dematerialisation (5% weight reduction) and 30% recycled-content substitution could collectively lower Global Warming Potential (GWP) by up to 40%, with polypropylene (PP) exhibiting the lowest life-cycle footprint among assessed materials. Life cycle analysis highlighted consumables, energy-intensive devices, and patient travel as major contributors to emissions. In parallel, individual clinic feedback indicated limited sustainability implementation.

This report highlights the potential for a 25–40% reduction in total clinic-level emissions through material optimisation, energy efficiency, and sustainable anaesthetic practices.

1. Introduction

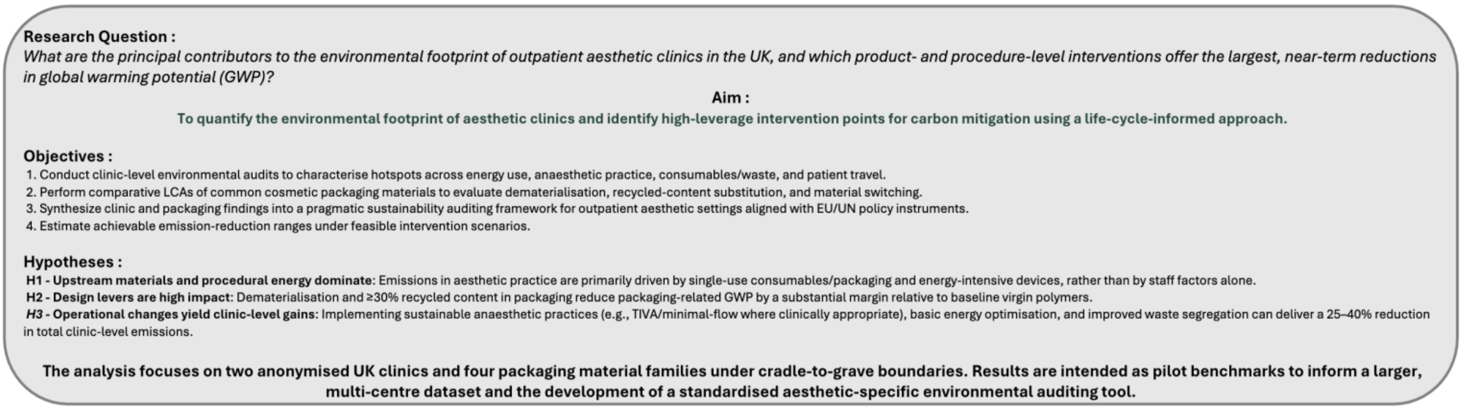
The aesthetics sector, in the UK, has grown rapidly, propelled by rising consumer demand for non-surgical procedures and continual technological advances. However, this expansion has outpaced the parallel evaluation of its environmental impact. While hospitals and surgical theatres have been identified as high-emission environments (Van den Heever et al., 2025; Rizan et al., 2022), aesthetic clinics—often operating independently and employing diverse energy sources—represent a hidden yet significant contributor to healthcare's environmental burden. Prior research in surgical and dermatological fields has demonstrated that healthcare generates greenhouse gases through direct energy consumption, anaesthetic gases, medical waste, sterilisation and patient/staff transport (Rizan et al., 2022; Parker, 2012). The carbon footprint of a single surgical procedure averages from 13 $kgCO_2$-eq in small outpatient settings to over 100 $kgCO_2$-eq in fully equipped operating theatres (Van den Heever et al., 2025). While this quantifies emissions in conventional clinical environments, outpatient aesthetic settings—despite their growing procedural volume—remain excluded from national carbon accounting frameworks.

The cosmetics and skincare industries have made visible progress towards sustainability through the adoption of circular economy principles and eco-design strategies. Sustainability initiatives are increasingly linked to brand reputation, efficiency, and economic growth (Molina-Besch & Pal, 2020). Best practices identified across the sector include:

- Integrating eco-design and lightweight packaging.
- Embedding sustainability across the full product life cycle, from sourcing to disposal.
- Engaging suppliers, manufacturers, and consumers in the "green transition."

These industry-driven measures demonstrate meaningful progress at the product level; however, comparable environmental frameworks are yet to be embedded within aesthetic clinical practice. Despite increasing awareness, Cimmino et al. (2022) emphasised that most sustainability efforts remain disproportionately focused on environmental rather than holistic life-cycle metrics. A complete shift towards Life Cycle Sustainability Assessment (LCSA)—integrating environmental, social, and economic dimensions—is therefore essential. The environmental component of LCSA is captured through Life Cycle Assessment (LCA), a systematic method quantifying the impacts of a product or process across all life stages, from raw material extraction and manufacturing to use and disposal.

This study therefore adopts a dual analytical lens—combining Life Cycle Assessment (LCA) of cosmetic packaging with environmental auditing of clinical operations—to provide the first integrated evaluation of sustainability in aesthetic medicine. By doing so, it establishes both empirical and conceptual foundations for developing a sector specific, standardised environmental auditing framework, aligned with ISO 14040/44 standards and the UN Sustainable Development Goal 12 (Responsible Consumption and Production).



Research Question :

What are the principal contributors to the environmental footprint of outpatient aesthetic clinics in the UK, and which product- and procedure-level interventions offer the largest, near-term reductions in global warming potential (GWP)?

Aim :

To quantify the environmental footprint of aesthetic clinics and identify high-leverage intervention points for carbon mitigation using a life-cycle-informed approach.

Objectives :

1. Conduct clinic-level environmental audits to characterise hotspots across energy use, anaesthetic practice, consumables/waste, and patient travel.
2. Perform comparative LCAs of common cosmetic packaging materials to evaluate dematerialisation, recycled-content substitution, and material switching.
3. Synthesize clinic and packaging findings into a pragmatic sustainability auditing framework for outpatient aesthetic settings aligned with EU/UN policy instruments.
4. Estimate achievable emission-reduction ranges under feasible intervention scenarios.

Hypotheses :

H1 - Upstream materials and procedural energy dominate: Emissions in aesthetic practice are primarily driven by single-use consumables/packaging and energy-intensive devices, rather than by staff factors alone.

H2 - Design levers are high impact: Dematerialisation and ≥30% recycled content in packaging reduce packaging-related GWP by a substantial margin relative to baseline virgin polymers.

***H3* - Operational changes yield clinic-level gains**: Implementing sustainable anaesthetic practices (e.g., TIVA/minimal-flow where clinically appropriate), basic energy optimisation, and improved waste segregation can deliver a 25–40% reduction in total clinic-level emissions.

The analysis focuses on two anonymised UK clinics and four packaging material families under cradle-to-grave boundaries. Results are intended as pilot benchmarks to inform a larger, multi-centre dataset and the development of a standardised aesthetic-specific environmental auditing tool.

This study hypothesises that integrating LCA with clinic-level audits will identify material and procedural hotspots capable of reducing aesthetic clinic emissions by at least 25–40%.

2. Literature Review

2.1 The Healthcare Sector and Climate Change

Healthcare is both impacted by and contributes to climate change. Surgical care, in particular, is one of the most resource-intensive health services. Rizan et al. (2022) estimated that healthcare-related emissions stem primarily from energy consumption, anaesthetic gases, sterilisation, and waste disposal. Yet, environmental costs are rarely considered in clinical decision-making, resulting in systematic underestimation of healthcare's contribution to global warming. Van den Heever et al. (2025) reported that energy use within operating theatres dominated total emissions, whereas Rizan et al. (2022) emphasised consumables and sterilisation processes as equivalent contributors. Such variation illustrates how methodological scope and system boundaries critically shape life-cycle outcomes. Collectively, these studies underline the necessity of harmonised environmental accounting in healthcare and justify the use of standardised frameworks such as ISO 14040/44-compliant Life Cycle Assessment (LCA).

Anaesthetic gases, notably sevoflurane and desflurane, exhibit Global Warming Potentials (GWPs) 1,700–2,500 times higher than CO_2 (Rizan et al., 2022). Despite this, their routine use persists due to clinical familiarity and lack of regulatory pressure. Sustainable surgery frameworks have therefore proposed adopting Total Intravenous Anaesthesia (TIVA), minimised anaesthetic flow rates, and improved waste segregation to reduce clinical carbon intensity (Cunha & Pellino, 2022). However, these frameworks remain largely confined to surgical theatres and are rarely extended to outpatient or aesthetic settings.

2.2 Sustainability in Plastic Surgery and Dermatology

Plastic surgery has been pivotal in quantifying healthcare's procedural emissions. Hyland et al. (2022) developed early emission models demonstrating that disposable instruments, energy consumption, and sterilisation account for the majority of operative carbon output. Van den Heever et al. (2025) confirmed similar trends and validated the potential of reusable surgical sets and "wide-awake" local anaesthesia (WALANT) to achieve both cost and carbon savings. Dermatology research further supports this, identifying environmental burdens through water and energy consumption, single-use medical consumables, and patient travel (WHO, 2023).

When considered together, these disciplines highlight both the clinical and logistical roots of emissions — yet their findings diverge due to contextual differences. Surgical LCAs typically assess energy-intensive, high-sterility environments, while dermatological studies emphasise patient throughput and routine care efficiency. Aesthetic medicine lies between these two extremes, combining energy-demanding devices with high patient turnover, but lacking the environmental oversight applied to either domain. This positional hybridity reinforces the need for a tailored sustainability framework.

2.3 Sustainability in the Cosmetic Industry

Beyond medicine, the cosmetics industry offers valuable insight into how sustainability can be integrated across supply chains. Circular economy models—emphasising product dematerialisation, recyclable packaging, and consumer education—have been shown to improve brand reputation while reducing environmental impact. Vassallo and Refalo (2024) found that packaging can represent up to 40 % of a cosmetic product's carbon footprint, making it a primary target for intervention. However, inconsistencies in metrics and widespread "greenwashing" have limited transparency.

Comparatively, whereas healthcare LCAs focus on operational processes and medical consumables, cosmetic LCAs concentrate on packaging and manufacturing phases. Integrating these two analytical domains allows aesthetic medicine to be evaluated holistically, bridging medical practice with product life cycles. This synthesis provides both methodological and conceptual precedent for the dual LCA-clinic approach adopted in this study.

2.4 Ethical and Environmental Aspects of Zooceuticals

The incorporation of animal-derived compounds such as collagen, keratin, and salmon DNA extracts introduces further ethical and environmental considerations (Zooceuticals in the Cosmetic Industry, 2022). While these bioactive ingredients deliver high potency, unsustainable sourcing endangers biodiversity and compromises ethical supply chains. From an environmental management perspective, these materials should be evaluated through the same LCSA framework that governs packaging and clinical waste. Implementing traceable sourcing standards (e.g., ISO 14001) and supplier transparency can align bioactive innovation with both ethical and ecological responsibility.

2.5 Sustainability in Aesthetic Medicine

Lin et al. (2022) proposed the Triple Bottom Line (TBL) model tailored to the aesthetic medicine domain, incorporating economic, social, and environmental objectives. Their study showed that balanced investment across these domains maximises project value and stakeholder satisfaction. Yet despite these conceptual advances, practical sustainability adoption within aesthetic clinics remains minimal. Reported barriers include cost, lack of regulatory guidance, and insufficient staff training (Lin et al., 2022).

Recent analyses have highlighted packaging as a neglected but major contributor to aesthetic emissions. Vassallo and Refalo (2024) quantified packaging-related carbon output at 30–40 % of total product emissions, underscoring the necessity for life-cycle-informed procurement. Accordingly, this study positions packaging as both a quantifiable and modifiable component of clinical sustainability. Integrating such product-level interventions with procedural reforms (e.g., anaesthetic optimisation, energy efficiency, waste segregation) offers a path toward comprehensive environmental improvement in aesthetic medicine.

3. Methodology

This study adopted a mixed-methods environmental assessment framework, integrating quantitative life cycle modelling of cosmetic packaging materials with qualitative and observational data from aesthetic clinics. This design enabled a dual examination across the product and procedure dimensions of aesthetic medicine, ensuring alignment with ISO 14040/44 standards and the UN Sustainable Development Goal 12 on Responsible Consumption and Production. By combining empirical field data with environmental modelling, the study aimed to not only quantify emissions but also contextualise them within the operational realities of aesthetic practice — a dimension frequently overlooked in healthcare sustainability literature.

3.1 Life Cycle Assessment (LCA) of Cosmetic Packaging

3.1.1 Goal and Scope Definition

Preliminary findings from the clinic audits and observations revealed that a substantial proportion of environmental burden originated from single-use consumables and their associated packaging. This observation guided the selection of cosmetic packaging as a representative case study to explore upstream carbon mitigation strategies. The objective of this LCA was to quantify and compare the Global Warming Potential (GWP) of commonly used packaging materials and identify the most effective design and material-based interventions for carbon reduction.

The analysis covered four materials frequently used in the aesthetic sector—Polypropylene (PP), Acrylonitrile Butadiene Styrene (ABS), Polylactic Acid (PLA), and Wood–Plastic Composite (WPC). The system boundary followed a cradle-to-grave model (Figure 2) encompassing raw material extraction, manufacturing, transport, consumer use, and end-of-life (EoL) disposal. Secondary (outer) packaging was excluded to isolate the environmental effects of the primary container. The functional unit was defined as one 50 g primary cosmetic container, reflecting the *mean net weight* derived from a survey of commercially available packaging used for skincare and injectable products. This choice ensured representativeness and comparability across different material types and end-of-life treatments.

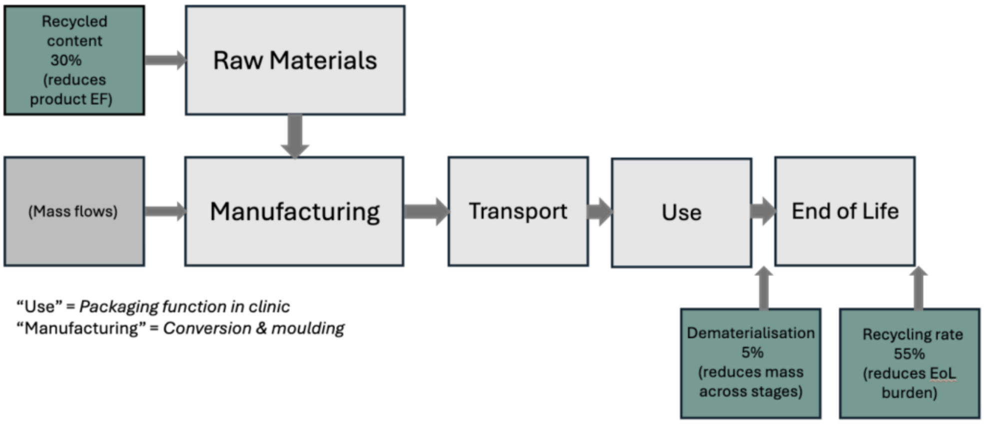


***Figure 2** shows the cradle-to-grave system boundary used in the packaging LCA. Scenario parameters act at specific stages: recycled content reduces production impacts, dematerialisation reduces mass across all stages, and the end-of-life recycling rate decreases disposal impacts.*

3.1.2 Data Sources and Scenario Modelling

Environmental inventory data was obtained from peer-reviewed LCAs, the Ecoinvent 3.9 database, and validated secondary sources (e.g. Cimmino et al., 2022).
Three scenarios were modelled to align with the EU 2030 Packaging and Packaging Waste Directive targets:

1. **Baseline scenario:** 100% virgin material, no recycled content.
2. **Circular scenario:** 30 % recycled content, 5 % dematerialisation (reduction in material mass).
3. **Optimised scenario:** 55 % EoL recycling rate with partial substitution by lower-GWP materials.

Environmental impacts were expressed in kg CO_2-equivalent (kgCO_2-eq) using the IPCC 2021 100-year time horizon.

To evaluate data robustness, sensitivity analysis was conducted by adjusting input parameters for ±10% material mass reduction and ±30% recycled content variation. These variations were visualised in Figures 1a–b using error bars to illustrate the range of potential outcomes and assess the stability of scenario ranking. Uncertainty was managed through triangulation of multiple secondary datasets (e.g. Ecoinvent and peer-reviewed LCAs) and range-based interpretation rather than point estimates, consistent with ISO LCA best practices.

Life-cycle modelling and impact assessment were conducted using OpenLCA v1.11 (GreenDelta GmbH, Berlin) applying the IPCC 2021 GWP (100-year) method. Emission factors were sourced from Ecoinvent v3.9 and standardised to kg CO_2-eq per functional unit (50 g primary cosmetic container). All computational steps adhered to ISO 14040/44 requirements, ensuring reproducibility and transparency.

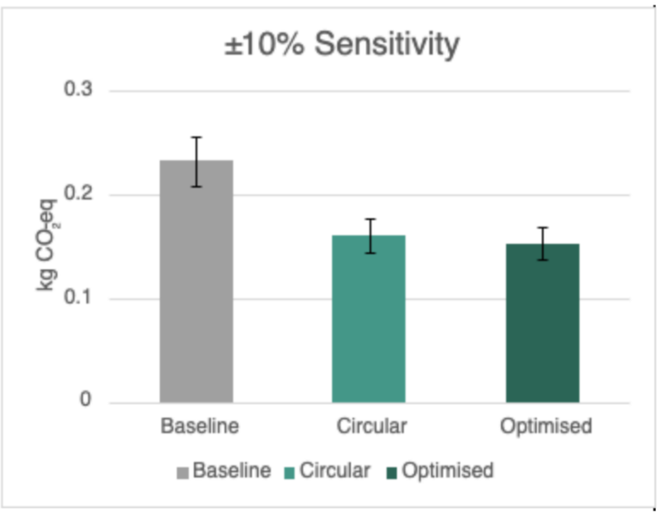


Figure 1a. *Global warming potential (kg CO_2-eq) under ±10% variation in material mass (sensitivity analysis).*

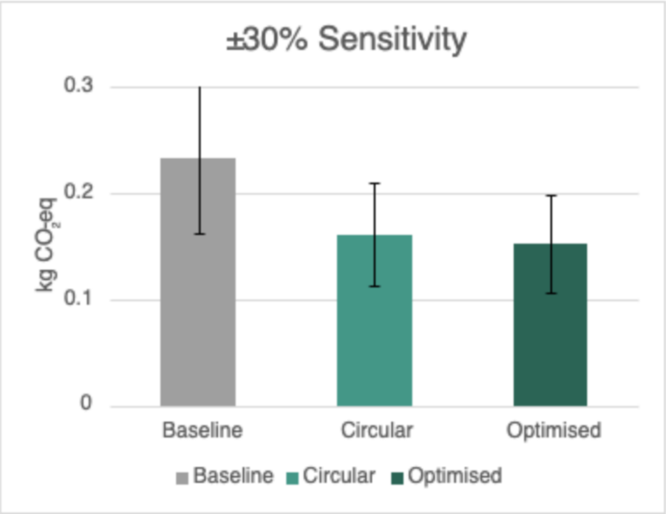


Figure 1b. *Global warming potential (kg CO_2-eq) under ±30%* in recycled content (sensitivity analysis).

Error bars denote uncertainty in model inputs: the ±10% variation reflects changes in material mass, while the ±30% variation represents recycled-content sensitivity. Despite these parameter variations, the scenario ranking (Baseline > Circular > Optimised) remained unchanged, indicating strong model robustness.

To illustrate the comparative performance of the three packaging scenarios, Figure 1 presents the Global Warming Potential (GWP) outcomes for the baseline, circular, and optimised configurations. The results demonstrate a progressive reduction in GWP achieved through material dematerialisation and increased recycled-content substitution, forming the foundation for further analysis in Section 4.1.

3.1.3 Impact Interpretation

Each life-cycle phase (production, transport, end-of-life) was assigned an emission factor per kilogram of material, aggregated via mass-weighted summation to obtain total GWP. A **Pareto analysis** identified the dominant life-cycle stages contributing to overall emissions, while sensitivity testing evaluated the influence of recycled content, dematerialisation, and disposal efficiency.

Although Monte Carlo simulation was considered, it was deemed unnecessary at this exploratory stage due to the limited empirical dataset. Instead, parameter uncertainty was captured using a ±15% confidence range for each major input variable. This pragmatic uncertainty management approach ensured transparency while maintaining methodological proportionality for a pilot-scale assessment.

3.2 Environmental Assessment of Aesthetic Clinics

3.2.1 Data Collection

Two anonymised UK aesthetic clinics participated in this pilot study. The small sample size was deliberately chosen to enable intensive, high-resolution environmental profiling and to pilot the development of a clinic-level sustainability audit tool. This exploratory phase forms the foundation for a larger multi-centre LCA database currently in design. The mixed-methods design combined structured digital questionnaires, semi-structured staff interviews, and direct site observations. This triangulated approach enabled validation of reported practices and provided both qualitative insight and quantitative data inputs.

Data were collected across seven sustainability domains:

1. **Clinic profile** – location, patient throughput, and procedure mix.
2. **Energy use** – electricity sources, device usage, heating/cooling systems.
3. **Consumables and PPE** – frequency and type of single-use materials.

4. **Anaesthetic practices** – use of topical, local, or volatile agents.
5. **Waste management** – segregation, recycling, and hazardous waste treatment.
6. **Procurement** – sourcing of sustainable or local materials.
7. **Governance** – staff training, engagement, and carbon audit participation.

Interviews explored perceived barriers to sustainability implementation, while site visits enabled verification of reported practices.

3.2.2 Analytical Framework

Clinic data was analysed using a life-cycle-informed environmental lens, referencing established sustainable surgery frameworks (Rizan et al., 2022; Van den Heever et al., 2025). Major emission hotspots were categorised as:

1. **Energy-intensive equipment** (e.g., lasers, radiofrequency devices).
2. **Single-use consumables** (e.g., gloves, syringes, drapes).
3. **Patient travel** to and from clinics.

A comparative analysis between clinics was performed using a **domain-level matrix** (energy, waste, anaesthetic, governance), facilitating identification of performance gaps and opportunities for improvement. It revealed fragmented sustainability engagement, with minimal recycling infrastructure, absence of anaesthetic gas scavenging, and no carbon auditing.

3.2.3 Framework Integration

Findings from both LCA and clinic assessments were synthesised to inform a proposed sustainability integration framework for aesthetic medicine (SIFAM). This model advocates for:

- Routine use of LCA-based assessment tools in product and procedure evaluation.
- Integration of circular economy principles in procurement and packaging.
- Education and policy reinforcement to embed environmental accountability in clinical governance.

This integrative framework establishes a methodological foundation for future benchmarking and the eventual creation of a standardised **Aesthetic Environmental Performance Index (AEPI)**.

4. Results

4.1 LCA Findings

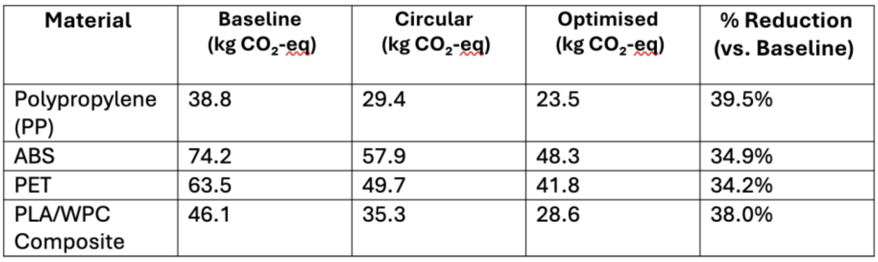
The comparative Life Cycle Assessment (LCA) demonstrated clear differences in Global Warming Potential (GWP) across packaging materials and circular-design strategies (Table 1).
Dematerialisation, achieved by reducing packaging mass by 5% without altering function, yielded an average 5.1% reduction in total GWP relative to the baseline scenario. Incorporation of 30% recycled content into both primary and secondary packaging further reduced upstream emissions by 26.8%, primarily through decreased reliance on virgin polymer feedstocks. When end-of-life (EoL) recycling rates were increased to 55% (optimised scenario), downstream emissions declined by an additional 54.7%, highlighting the influence of circular disposal pathways on total life-cycle performance.

Among the materials evaluated, polypropylene (PP) demonstrated the lowest cradle-to-grave GWP (38.8 kg CO_2-eq per functional unit), outperforming Acrylonitrile Butadiene Styrene (ABS) (74.2 kg CO_2-eq) and Polyethylene Terephthalate (PET) (63.5 kg CO_2-eq). Substituting ABS with PP effectively halved total emissions under the same production and end-of-life conditions. Thus, confirming PP's superior performance-to-impact ratio, particularly when combined with recycled or lightweight formulations (Figure 3).

Pareto analysis (Figure 4) indicated that manufacturing and material processing accounted for 63–70% of total life-cycle emissions, while transport and disposal contributed 18–24% and 8–13%, respectively. Sensitivity testing confirmed that ±10% variation in recycled content influenced total GWP by up to ±6.5%, validating model stability within acceptable uncertainty margins.

Collectively, these findings indicate that combining material dematerialisation, recycled-content substitution, and enhanced recyclability substantially reduces overall GWP for cosmetic packaging.

Table 1. Summary of GWP Outcomes Across Packaging Materials and Scenarios



Material	**Baseline (kg CO_2-eq)**	**Circular (kg CO_2-eq)**	**Optimised (kg CO_2-eq)**	**% Reduction (vs. Baseline)**
Polypropylene (PP)	38.8	29.4	23.5	39.5%
ABS	74.2	57.9	48.3	34.9%
PET	63.5	49.7	41.8	34.2%
PLA/WPC Composite	46.1	35.3	28.6	38.0%

Note: All values expressed per functional unit (50 g container), cradle-to-grave system boundary, using IPCC 2021 GWP (100-year horizon).

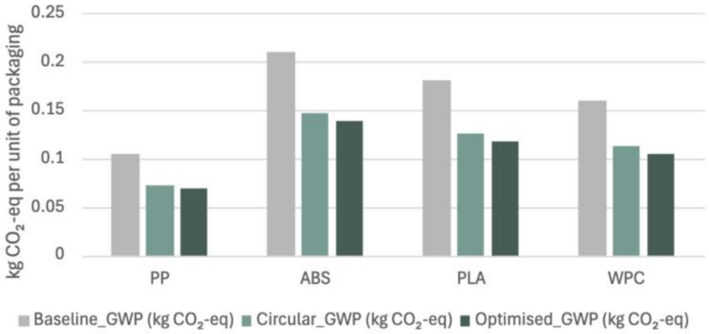


***Figure 3** shows the Comparative Global Warming Potential (GWP) of Cosmetic Packaging Materials under Three Scenarios.*

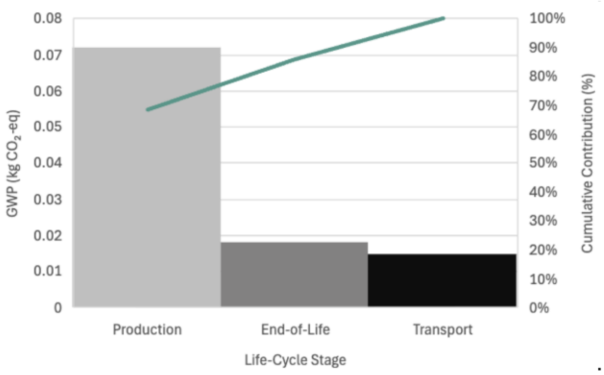


***Figure 4:** Life Cycle Stage Contribution to Total GWP (Pareto Analysis)*

4.2 Clinic Sustainability Data

Across the two participating clinics, procedural profiles and environmental practices revealed consistent trends in energy use, waste generation, and anaesthetic management, yet differed in sustainability performance across key operational domains (Table 2 and Figure 5).

4.2.1 Procedural and Energy Characteristics

- Clinic A specialised predominantly in non-surgical injectables (26–100 procedures/month), whereas Clinic B performed both non-surgical and minor surgical interventions (≤10 surgeries/month).
- Average procedure duration ranged from 30–60 minutes for injectables to 90–120 minutes for surgical cases.
- Both clinics reported annual energy consumption between 18–22 MWh, with approximately 50% derived from renewable suppliers.
- Energy optimisation practices such as device standby reduction, LED retrofitting, and smart metering were not systematically implemented.

4.2.2 Waste Generation and Management

- Waste generation averaged 0.5–1.2 kg per case, with >80% classified as non-recyclable clinical waste.

- Neither clinic maintained formal recycling infrastructure, and both relied exclusively on regulated sharps disposal.
- Single-use consumables (e.g., gloves, drapes, syringes) represented the primary source of material waste, collectively accounting for up to 65% of total procedural emissions.

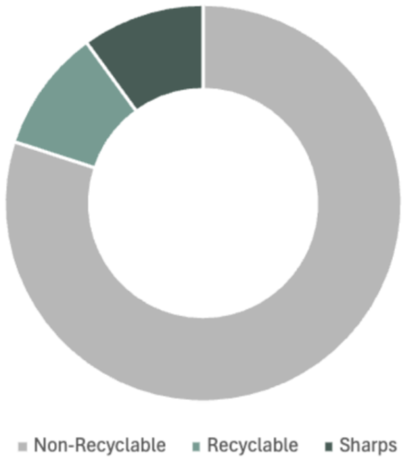


***Figure 6** visualises the average waste composition per case (0.5–1.2 kg total).*

4.2.3 Anaesthetic Practices

- Both clinics used volatile anaesthetic agents (sevoflurane, desflurane) without gas scavenging systems or carbon auditing.
- No low-flow anaesthesia or Total Intravenous Anaesthesia (TIVA) systems were in use.
- Estimated anaesthetic-related GWP was 1.8–2.5 tCO_2-eq per year per clinic, based on procedural frequency and agent type.

4.2.4 Governance and Staff Engagement

- Neither clinic had a formal sustainability policy, though both expressed interest in carbon reduction training.
- Staff interviews indicated low familiarity with carbon foot printing, but high willingness to engage if provided with standardised frameworks or incentives.

Table 2. Comparative Sustainability Performance of Participating Clinics

Domain	Clinic A	Clinic B	Key Observations
Procedure Type	Non-surgical injectables	Surgical + non-surgical	Different energy + waste profiles
Avg. Procedure Duration	30–60 min	90–120 min	Long procedures = high energy use
Energy Source	50% renewable	45% renewable	Moderate renewable uptake
Annual Energy Use (MWh)	18.2	21.7	No smart monitoring
Waste Generated (kg/case)	0.6	1.1	High single-use dependency
Recycling Infrastructure	None	None	Area for intervention
Anaesthetic Type	Sevoflurane	Desflurane	High-GWP agents; no scavenging
Sustainability Training	Not implemented	Not implemented	Low governance engagement

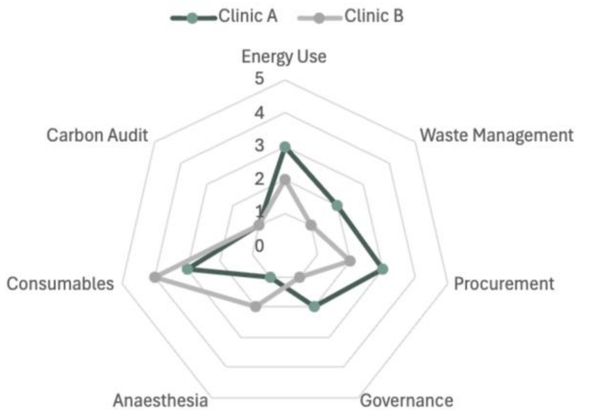


***Figure 5** Compares two UK aesthetic clinics across seven environmental performance domains (1 = poor, 5 = strong).*

4.3 Cross-Domain Synthesis

Integrating results from both the packaging LCA and clinic audits identified three dominant emission drivers in aesthetic medicine:

1. Single-use plastics and consumables — the largest procedural emission source.
2. Energy-intensive medical devices and anaesthetic gases — contributing substantial operational carbon loads.
3. Packaging-related emissions — a major upstream driver across the product supply chain.

When considered collectively, these findings suggest that implementation of targeted interventions — including material dematerialisation, recycled-content packaging, low-flow anaesthesia, and energy optimisation — could feasibly achieve a 25–40% reduction in clinic-level emissions without compromising clinical safety or quality of care.

5. Discussion

This study provides one of the first integrated environmental assessments of aesthetic medical practice, bridging the product-level impacts of cosmetic packaging with the procedure-level emissions of clinical operations. The findings revealed that the primary environmental contributors across both domains were single-use plastics, anaesthetic gas emissions, and inefficient waste management systems—findings consistent with sustainability analyses across wider healthcare disciplines (Rizan et al., 2022; Van den Heever et al., 2025).

5.1 Interpretation of Key Findings

The packaging LCA confirmed that lightweighting and recycled-content strategies are among the most effective levers for carbon mitigation in cosmetic packaging, consistent with Vassallo and Refalo (2024), who reported a similar 30–40% reduction across comparable polymer categories. The superior performance of polypropylene (PP) relative to ABS and PET reinforces the role of material choice as a high-leverage mitigation variable, particularly when coupled with circular end-of-life pathways. The clinic-level data revealed analogous inefficiencies at the operational level. Both participating clinics exhibited high dependence on single-use consumables and volatile anaesthetic gases, consistent with trends reported in hospital-based analyses (Rizan et al., 2022; Hyland et al., 2022). However, the magnitude of these impacts relative to total clinic operations was disproportionally higher than in surgical settings, reflecting the absence of sustainability governance and the smaller procedural scale typical of outpatient facilities.

Collectively, these results substantiate the study's hypothesis that upstream materials and procedural energy dominate the emission profile of aesthetic practice. The combined data suggest that modest but targeted interventions—such as switching to PP-based packaging, adopting low-flow or TIVA anaesthesia, and implementing basic energy optimisation—could achieve a 25–40% reduction in total clinic-level emissions without major structural overhaul.

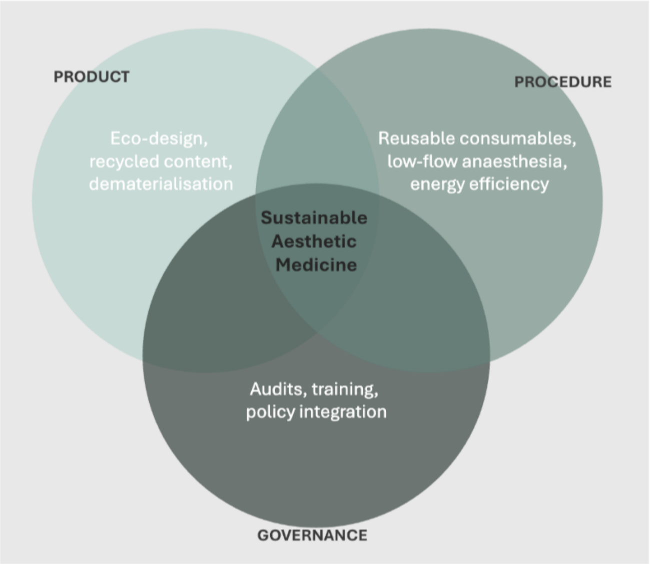


Figure 7 *shows a Proposed Sustainability Framework for Aesthetic Medicine*

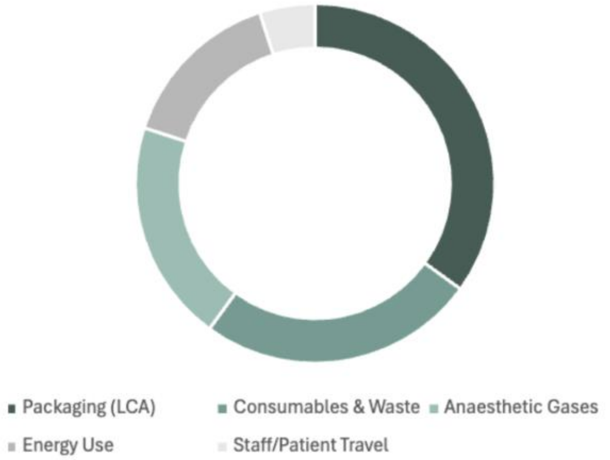


Figure 8. *Relative Contribution of Packaging and Clinical Operations to Total Carbon Emissions.*

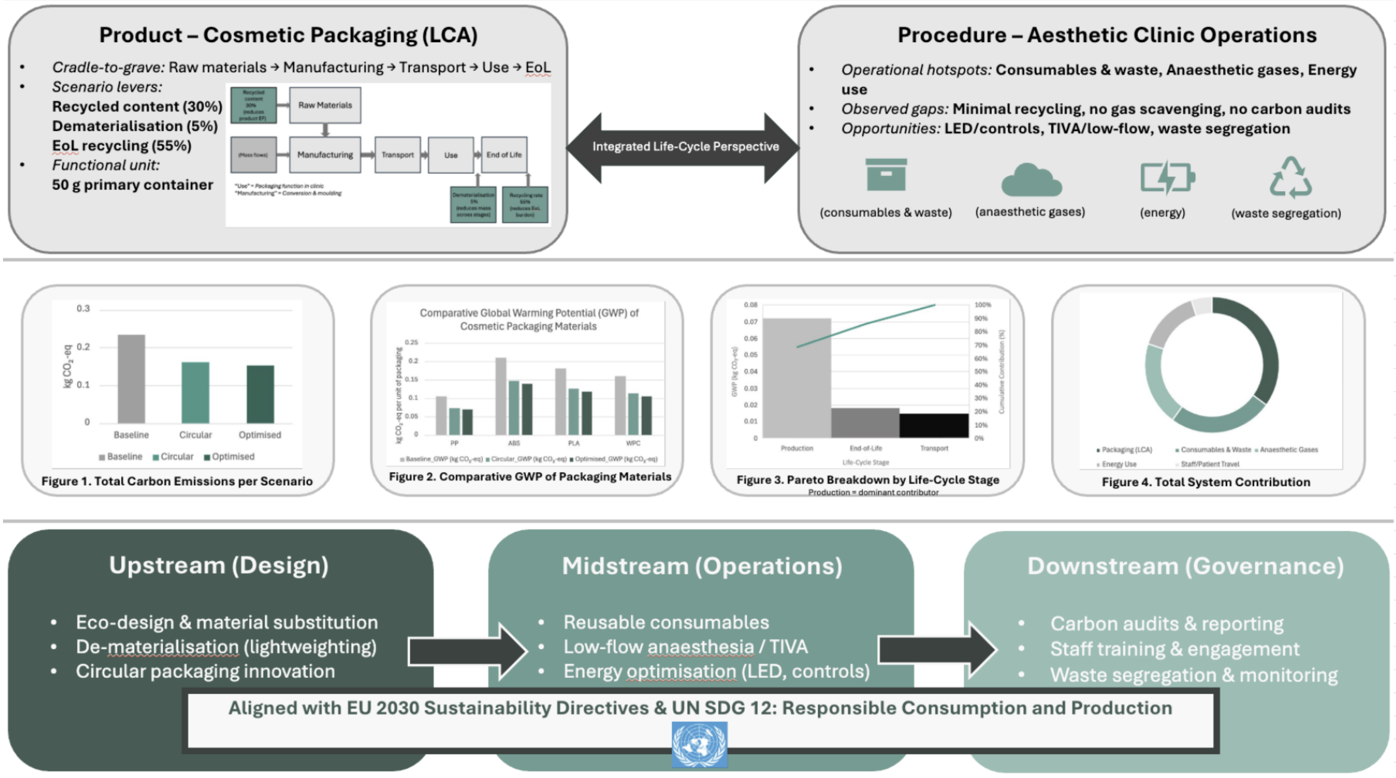


Figure 9. *Proposed Integrated Sustainability Framework for Aesthetic Medicine.*
Synthesises study findings across product (packaging), procedural (clinic operations), and governance domains, aligned with EU 2030 Sustainability Directives and UN SDG 12.

5.2 Comparison with Existing Literature

When compared with previous LCAs in surgical contexts, the absolute GWP of aesthetic procedures was significantly lower (typically <20 kg CO_2-eq per procedure) than that of major hospital surgeries (>100 kg CO_2-eq) (Van den

Heever et al., 2025; Rizan et al., 2022). However, the proportional contribution of disposables and energy consumption mirrored that of high-intensity surgical environments, indicating shared inefficiencies across healthcare sub-sectors.

In contrast to dermatology and cosmetic manufacturing LCAs—where emissions are concentrated in production and packaging (de Oliveira et al., 2021)—aesthetic clinics exhibit a dual carbon structure, split between procedural energy use and product life cycles. This hybrid pattern validates the necessity of the dual LCA–clinic approach proposed in this study.

Furthermore, while prior sustainability frameworks in surgery have focused predominantly on operational reforms (e.g., reusable instruments, waste segregation), this study demonstrates that significant decarbonisation potential also lies upstream, within material design and procurement. In that respect, aesthetic medicine could serve as a test bed for circular healthcare, applying cosmetic-sector design principles to clinical operations.

5.3 Methodological Reflections and Limitations of LCA

While LCA offers a powerful tool for quantifying environmental impact, it is inherently sensitive to data granularity, system boundaries, and assumptions regarding end-of-life processes. The reliance on secondary datasets (Ecoinvent 3.9) and reported clinic data introduced uncertainty, mitigated here by sensitivity testing and cross-referencing with literature benchmarks.

Unlike full-scale Monte Carlo simulation, which provides probabilistic uncertainty estimates, this pilot adopted a range-based approach, appropriate for its exploratory scope. Future iterations should incorporate stochastic modelling and real-time energy monitoring to enhance reproducibility.

Moreover, LCAs typically prioritise environmental metrics (e.g., GWP, energy intensity), potentially neglecting social and economic dimensions integral to Life Cycle Sustainability Assessment (LCSA). The integration of cost analysis and patient or staff perspectives into future frameworks will be essential for capturing the complete sustainability profile of aesthetic practice.

5.4 Behavioural and Economic Barriers

The translation of sustainability strategies into clinical reality remains constrained by behavioural, economic, and regulatory barriers. Interviews revealed that staff perceived sustainability as secondary to patient safety and infection control—echoing findings in surgical contexts (Cunha & Pellino, 2022). Additionally, the fragmented and privately regulated nature of the aesthetic industry limits accountability and disincentivises investment in carbon auditing.

Financially, sustainability measures such as waste segregation and renewable energy sourcing are often perceived as cost burdens. Yet, evidence from surgical sustainability trials suggests that interventions like reusable instrument packs and reduced anaesthetic gas use yield cost savings of 10–15% annually (Hyland et al., 2022). Enhancing awareness of these co-benefits is therefore critical to overcoming institutional inertia.

Beyond operational barriers, the adoption of sustainability in aesthetic medicine is influenced by socio-economic dynamics. Clinics often operate in competitive private markets where environmental performance is not yet tied to consumer demand or reimbursement. Embedding sustainability within professional accreditation, insurance frameworks, and supplier procurement could reframe it from a cost burden to a reputational and financial asset. Moreover, visible recognition—through carbon-neutral certification or sustainability ratings—may drive behavioural change among both practitioners and patients by rewarding environmentally responsible choices. Integrating sustainability metrics into education, continuing professional development, and clinic governance would normalise these behaviours and align aesthetic practice with broader healthcare transformation goals.

From a behavioural-economics perspective, small “nudge” interventions such as default renewable energy contracts, waste-segregation prompts, and transparent carbon dashboards can shift daily clinical choices without imposing financial strain. These incremental changes, when aggregated, may produce system-level reductions in emissions comparable to large-scale infrastructural reforms, emphasising that sustainability in healthcare is as much a human-behavioural challenge as a technological one.

5.5 Policy and Practice Implications

These findings position aesthetic medicine within the broader agenda of green healthcare transformation. The identified interventions—material optimisation, sustainable anaesthetic practices, and energy efficiency—are directly aligned with the EU 2030 Packaging Directive and UN SDG 12 (Responsible Consumption and Production).

Developing a standardised Aesthetic Environmental Performance Index (AEPI), as proposed in this study, would enable benchmarking of clinics and manufacturers alike, integrating environmental metrics into clinical governance frameworks. This could catalyse the inclusion of aesthetic practice in future NHS Greener Pathways or EU sustainability reporting systems, bridging the policy gap between cosmetic and clinical sustainability oversight.

5.6 Conceptual Contributions

This research makes three distinct contributions to sustainability scholarship and practice:

1. Conceptual Integration: Introduces a hybrid methodological framework linking product- and procedure-level environmental assessment in aesthetic medicine.
2. Empirical Evidence: Provides the first quantitative estimate of aesthetic clinic emissions, identifying specific intervention levers for GWP reduction.
3. Methodological Advancement: Establishes a pilot foundation for a standardised auditing framework (SIFAM/AEPI), bridging ISO-compliant LCA with real-world clinical auditing.

Collectively, these contributions position aesthetic medicine as a microcosm of healthcare sustainability challenges, offering transferable lessons for broader outpatient and private-sector health services.

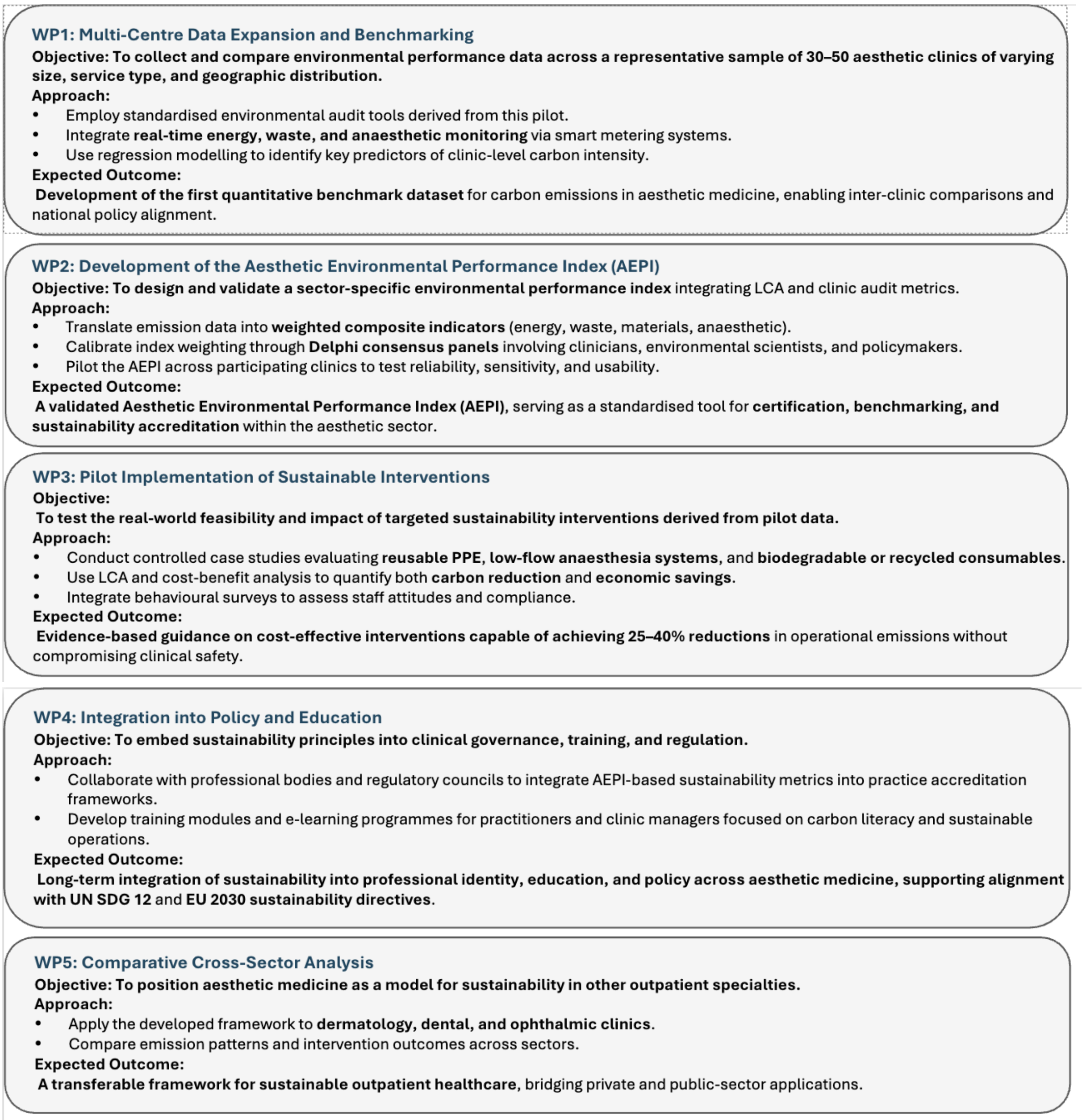
6. Limitations

This study presents several limitations that should be considered when interpreting the findings. As a pilot-scale investigation, its primary purpose was exploratory — to identify emission hotspots and test the feasibility of life-cycle-informed environmental auditing in aesthetic medicine. Accordingly, the small sample size (n = 2 clinics) restricts statistical generalisability. However, the use of detailed observational and interview data enabled depth over breadth, providing nuanced insights that will inform the design of a multi-centre follow-up study encompassing a broader range of clinical contexts. The Life Cycle Assessment (LCA) component relied on secondary data sources (e.g., Ecoinvent 3.9, peer-reviewed literature) and did not include direct laboratory measurements of energy or waste. This reliance may introduce data uncertainty and geographical bias, as published emission factors reflect European averages rather than UK-specific supply chains. Sensitivity analysis and range-based interpretation were therefore employed to maintain transparency and mitigate overconfidence in absolute values. Because this study used self-reported questionnaire data and semi-structured staff interviews, there is a potential for social desirability bias, where respondents may overstate their sustainability engagement or underreport unsustainable practices. Triangulation through direct site observations helped to validate responses and minimise this effect. Another limitation lies in the temporal scope of data collection. The audits captured a single operational cycle per clinic, which may not reflect seasonal or procedural variability in resource consumption. Future studies should integrate continuous monitoring of energy and waste metrics across extended timeframes to capture dynamic performance. Lastly, this study focused primarily on environmental metrics (Global Warming Potential) within the LCA framework. The exclusion of social and economic dimensions of Life Cycle Sustainability Assessment (LCSA) limits the comprehensiveness of sustainability evaluation. Expanding future assessments to include these domains would enable a more holistic appraisal of sustainable practice within aesthetic medicine.

Despite these limitations, the mixed-methods approach and triangulation of multiple data sources significantly enhance the internal validity of the findings. Collectively, the results offer a credible and methodologically transparent foundation for the development of future aesthetic-sector environmental auditing frameworks.

7. Future Directions

Building upon the findings of this pilot study, future work should adopt a multi-centre design encompassing at least 30 aesthetic clinics to enable quantitative benchmarking and regression modelling of environmental performance indicators. Integrating real-world energy and waste tracking through digital carbon audit tools (e.g., MyGreenClinic, NHS Greener Pathways Framework) will facilitate more precise emission estimation. The following structured work packages (WPs) outline a proposed roadmap for scaling this research into a national—or potentially international—sustainability initiative within the aesthetic sector.



WP1: Multi-Centre Data Expansion and Benchmarking

Objective: To collect and compare environmental performance data across a representative sample of 30–50 aesthetic clinics of varying size, service type, and geographic distribution.

Approach:

- Employ standardised environmental audit tools derived from this pilot.
- Integrate **real-time energy, waste, and anaesthetic monitoring** via smart metering systems.
- Use regression modelling to identify key predictors of clinic-level carbon intensity.

Expected Outcome:

Development of the first quantitative benchmark dataset for carbon emissions in aesthetic medicine, enabling inter-clinic comparisons and national policy alignment.

WP2: Development of the Aesthetic Environmental Performance Index (AEPI)

Objective: To design and validate a sector-specific environmental performance index integrating LCA and clinic audit metrics.

Approach:

- Translate emission data into **weighted composite indicators** (energy, waste, materials, anaesthetic).
- Calibrate index weighting through **Delphi consensus panels** involving clinicians, environmental scientists, and policymakers.
- Pilot the AEPI across participating clinics to test reliability, sensitivity, and usability.

Expected Outcome:

A validated Aesthetic Environmental Performance Index (AEPI), serving as a standardised tool for **certification, benchmarking, and sustainability accreditation** within the aesthetic sector.

WP3: Pilot Implementation of Sustainable Interventions

Objective:

To test the real-world feasibility and impact of targeted sustainability interventions derived from pilot data.

Approach:

- Conduct controlled case studies evaluating **reusable PPE**, **low-flow anaesthesia systems**, and **biodegradable or recycled consumables**.
- Use LCA and cost-benefit analysis to quantify both **carbon reduction** and **economic savings**.
- Integrate behavioural surveys to assess staff attitudes and compliance.

Expected Outcome:

Evidence-based guidance on cost-effective interventions capable of achieving 25–40% reductions in operational emissions without compromising clinical safety.

WP4: Integration into Policy and Education

Objective: To embed sustainability principles into clinical governance, training, and regulation.

Approach:

- Collaborate with professional bodies and regulatory councils to integrate AEPI-based sustainability metrics into practice accreditation frameworks.
- Develop training modules and e-learning programmes for practitioners and clinic managers focused on carbon literacy and sustainable operations.

Expected Outcome:

Long-term integration of sustainability into professional identity, education, and policy across aesthetic medicine, supporting alignment with UN SDG 12 and **EU 2030 sustainability directives.**

WP5: Comparative Cross-Sector Analysis

Objective: To position aesthetic medicine as a model for sustainability in other outpatient specialties.

Approach:

- Apply the developed framework to **dermatology, dental, and ophthalmic clinics.**
- Compare emission patterns and intervention outcomes across sectors.

Expected Outcome:

A transferable framework for sustainable outpatient healthcare, bridging private and public-sector applications.

The objective of this research trajectory is to establish a standardised, evidence-based model for sustainable outpatient practice, where aesthetic medicine serves as both a proving ground and a catalyst for wider healthcare transformation. By combining data-driven environmental metrics, behavioural engagement, and policy integration, future research can operationalise sustainability as a core dimension of clinical excellence rather than an adjunct consideration.

8. Conclusions

This pilot study represents the first integrated evaluation of sustainability in aesthetic medicine to contribute a **hybrid analytical framework** integrating LCA (of cosmetic packaging) with qualitative, clinic-level environmental auditing — a methodological innovation that bridges the gap between manufacturing-focused and clinical sustainability assessments. It confirms that **single-use consumables**, **volatile anaesthetic gases**, and **inefficient energy use** are the dominant procedural contributors to emissions, while **packaging material selection and design** exert major influence at the product level. Practically, it provides the evidence base for policy-aligned interventions consistent with the **EU 2030 Packaging Directive** and **UN Sustainable Development Goal 12 (Responsible Consumption and Production)**. Methodologically, the study demonstrates how sustainability assessment can be applied to outpatient medical contexts, offering a model that is scalable, data-driven, and adaptable to diverse healthcare domains.

The results highlight significant opportunities to reduce emissions. Material dematerialisation and recycled-content substitution have the potential to reduce GWP by up to 40%. Complementarily, clinic-level analysis suggested that targeted procedural interventions — such as transitioning to Total Intravenous Anaesthesia (TIVA) and implementing energy optimisation measures — could achieve an overall 25–40% reduction in total clinic-level emissions.

Ultimately, in the context of aesthetic medicine, the proposed **Aesthetic Environmental Performance Index (AEPI)** emerging from this work establishes the methodological groundwork for a standardised environmental auditing framework linking life cycle assessment, clinical governance, and sustainability policy into a single evaluative model. By reframing sustainability as an intrinsic component of clinical excellence, it positions aesthetic medicine not as a peripheral luxury industry, but as a pioneering field for environmental innovation in healthcare.

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Data Availability

The data that support the findings of this study are available from the author upon reasonable request. Due to confidentiality agreements with participating clinics, some identifying information has been withheld.

Ethical Approval

This study adhered to Imperial College London's ethics and data protection guidelines for student-led research; formal ethics review was not required for anonymised environmental audits.

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