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Economic Quantification of Environmental Impacts in Health Technology Assessment

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Working group

Eugenio Di Brino[1], Carlotta De Chiara[1], Elena De Medio[1], Filippo Rumi[1], Michele Basile[1], Rossella Di Bidino[2], Dario Sacchini[1,3], Americo Cicchetti[4]

[1] Altems Advisory, Spin off dell'Università Cattolica del Sacro Cuore, Roma, Italia

[2] Fondazione Policlinico Universitario Agostino Gemelli IRCCS, Università Cattolica del Sacro Cuore

[3] Dipartimento di Sicurezza e Bioetica, Sezione di Bioetica e Medical Humanities, Facoltà di Medicina e chirurgia "A. Gemelli", Università Cattolica del Sacro Cuore, Roma

[4] Professore Ordinario di Organizzazione Aziendale, Facoltà di Economia, Università Cattolica del Sacro Cuore, Roma

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info@altemsadvisory.it

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Preface

Environmental sustainability represents one of the main systemic challenges for contemporary healthcare systems. While the mission of healthcare is to protect and promote the health of populations, it is now widely recognized that the healthcare sector contributes significantly to climate-altering emissions, the consumption of natural resources, and the production of waste along increasingly complex and globalized supply chains. In this context, the evolution of Health Technology Assessment (HTA) toward a paradigm capable of incorporating environmental impacts in a structured manner is not only desirable: it is necessary.

This report, developed by Altems Advisory, systematically and rigorously addresses a crucial aspect of this transformation: the economic quantification of environmental impacts within HTA. This work comes at a time when the notion of "value" in healthcare is undergoing a profound rethink. Traditional clinical and economic dimensions, while still central, are no longer sufficient to comprehensively represent the overall effects of healthcare technologies. Indeed, environmental impacts are not marginal externalities, but structural determinants of health, equity, and intergenerational sustainability.

Through a structured review of international scientific literature and analysis of key applied experiences, the document proposes a comprehensive and operational methodological framework. It examines well-established tools, such as Life Cycle Assessment (LCA), alongside monetization models such as the Social Cost of Carbon (SCC), and integrated approaches that translate environmental impacts into health outcomes (DALYs, QALYs) or incorporate them into multi-criteria decision-making models. The emerging picture is one in which methodological maturity is more advanced than often assumed, while the main critical issues lie in the harmonization of standards, data availability, and effective integration into decision-making and procurement processes.

One of the most significant contributions of this work is organizing the evidence according to a strategic logic, from "how" to "what" to measure, to "when" and "where" to integrate sustainability into HTA processes, thus offering public decision makers, evaluation agencies, healthcare professionals, and industry a clear conceptual map to guide change. This isn't about adding another layer of bureaucratic complexity, but rather making explicit existing trade-offs between clinical benefits, economic costs, and environmental impacts, in the knowledge that today's choices will influence the resilience of tomorrow's healthcare systems.

The report also highlights how numerous application experiences, from oncology to diabetology, from telemedicine to vaccination prevention, demonstrate that integrating the environmental dimension can generate clinical, organizational, and economic co-benefits. Sustainability, therefore, emerges not as an external constraint, but as a lever for innovation and systemic efficiency.

Ultimately, this document calls for a qualitative cultural and institutional leap: formally recognizing the environment as an intrinsic component of the value of health technologies. The methodological path is now clear; what remains to be built is a shared regulatory and operational framework capable of transforming pilot experiences into consolidated practice. In an era where human health and the health of the planet are increasingly interdependent, HTA can and must assume a leading role in the ecological transition of healthcare systems, helping to ensure well-being not only for present generations but also for future generations.

Summary

Glossary

DALYs	A population health indicator that combines premature mortality and time lived in less-than-full health into a single measure of overall disease burden.
EIA	Environmental Impact Assessment - A structured assessment of how a product, service or intervention affects the environment (e.g., emissions, resource use, waste), often across its life cycle.
ESG	Environmental, Social, Governance - A set of criteria used to assess an organization's sustainability and responsibility performance across environmental, social, and governance dimensions.
GPP	Green Public Procurement - Public purchasing that favours goods, services or works with lower environmental impact over their life cycle.
HTA	Health Technology Assessment - A structured process that evaluates the effects and impacts of health technologies to inform policy and funding decisions.
LCA	Life Cycle Assessment - A method that quantifies the environmental impacts of a product or service across its full life cycle, from inputs to end-of-life.
MCDA	Multi-Criteria Decision Analysis - A decision approach that compares alternatives using multiple criteria and explicit weighting of preferences.
pLCA	Prospective Life Cycle Assessment - A forward-looking LCA approach that estimates the future environmental impacts of emerging technologies using scenario assumptions.
QALYs	Quality-Adjusted Life Years - A health outcome measure combining survival and quality of life, where 1 QALY equals 1 year in perfect health.
ReCiPe	A Life Cycle Impact Assessment method that converts emissions and resource use into environmental impact indicators, including potential damage to human health and ecosystems.
SCC	Social Cost of Carbon - An estimate of the monetary harm caused by emitting one additional tonne of CO_2.
SROI	Social Return on Investment - A framework that quantifies social value created per unit of investment, expressed as a ratio.

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Executive summary

Strategic Context and Rationale

The systematic integration of environmental impacts into Health Technology Assessment (HTA) represents a pivotal evolution in modern healthcare governance. This shift addresses a critical dual mandate: achieving climate mitigation targets and ensuring the long-term fiscal and structural sustainability of public health resources. Within this framework, environmental sustainability is no longer an "external" variable; it is a structural determinant of health and a cornerstone of organizational resilience.

Methodology and Scope

This report provides a structured narrative review of contemporary scientific literature to identify methodologies for measuring and monetizing the environmental footprint of health technologies. Methodologically, the study is based on a scoping search of the Scopus, PubMed databases, and grey literature utilizing a protocol focused on high-level evidence and recent technological benchmarks. The final analytical sample comprises 38 core studies, spanning a diverse range of methodological frameworks, institutional surveys, and real-world empirical applications.

The findings are categorized into a "5-Dimension Strategic Framework":

- HOW: Methodologies for quantification (LCA, monetization, and decision frameworks).
- WHAT: Evidence base, environmental endpoints, and data limitations.
- WHEN: Timing of assessment across the lifecycle (*ex-ante* vs. *ex post*).
- WHERE: Operational pathways through Green HTA and Public Procurement.
- STRATEGIC SYNTHESIS: Governance, standardization, and innovation incentives.

Core Methodological Trends

The international discourse has transitioned toward a consolidated set of technical standards:

- The LCA Benchmark: Life Cycle Assessment (LCA) is the gold standard for quantifying impacts from "cradle-to-grave." Key metrics include greenhouse gas emissions (CO_2e), resource depletion, and waste intensity, governed by ISO 14040/44 standards.
- Economic Translation: There is an accelerating adoption of monetization tools, such as the Social Cost of Carbon (SCC) and shadow pricing, to bridge the gap between environmental data and traditional cost-effectiveness models.
- Holistic Frameworks: Emergent models such as Multi-Criteria Decision Analysis (MCDA) and Social Return on Investment (SROI) are being utilized to evaluate the "triple bottom line" (economic, social, and environmental value).

- Clinical Integration: Advanced characterization factors now allow for the conversion of environmental burdens into health metrics like DALYs and QALYs, enabling a direct comparison between clinical efficacy and ecological harm.

Critical Barriers to Implementation

Despite methodological maturity, operational integration remains fragmented due to:

- Data Scarcity: Incomplete or inaccessible supply chain data and a lack of primary environmental evidence.
- Standardization Gaps: Absence of harmonized system boundaries and a lack of consensus on a universal minimum indicator set.
- Regulatory Inertia: Cultural and legislative barriers that prevent "environmental cost" from being a decisive factor in reimbursement and procurement.

Future Perspectives

To transition toward a sustainability-aligned HTA paradigm, healthcare systems must move beyond theoretical recognition toward structured, decision-relevant inclusion. Developing integrated evaluative tools and embedding environmental criteria into procurement processes are essential levers. This evolution ensures that technological innovation is compatible with the ecological transition of healthcare, safeguarding the health of both current and future generations.

Introduction

In recent years, sustainability has become a core policy driver in healthcare, prompting renewed attention to the role of health systems in climate change mitigation and adaptation. Although healthcare aims to protect population health, it is also associated with a relevant environmental footprint, including greenhouse gas emissions, energy and resource consumption, waste generation, and impacts along global supply chains. Against this backdrop, Health Technology Assessment (HTA) is increasingly expected to expand beyond traditional clinical and economic endpoints to include the environmental impacts generated by health technologies, both directly (e.g., production, use and disposal of devices and pharmaceuticals) and indirectly (e.g., logistics, organisation of care pathways, infrastructure-related energy consumption and digital technologies) [1–6].

At the same time, the literature increasingly recognises that population health is intrinsically linked to ecosystem stability: environmental degradation is not an external factor, but a structural determinant influencing morbidity, mortality, vulnerability and the burden of both acute and chronic diseases. Consequently, health technologies may generate not only clinical benefits, but also environmental externalities that can translate into long-term health damages and societal costs [2, 7–8].

The aim of this report is to support the inclusion of environmental sustainability within HTA by focusing on the economic quantification of environmental impacts. Specifically, it reviews recent evidence on methods and tools that allow environmental burdens (e.g., emissions, resource use and waste) to be measured and translated into decision-relevant outputs, including monetisation approaches and integrated models linking environmental indicators to health outcomes [1–5].

This focus is increasingly relevant for HTA decision-making. HTA informs adoption, reimbursement and procurement decisions and therefore plays a central role in making trade-offs between clinical effectiveness, costs and sustainability explicit. Historically, while HTA has developed as a multidimensional framework encompassing clinical, technological and organizational, ethical, legal, social (ELSI) domains, analyses within the economic domain have mainly focused on clinical outcomes, quality of life, direct healthcare costs and, more rarely, indirect costs; however, this perspective reflects a concept of value that is largely short-term and based on metrics typical of “conventional” health economics. The climate crisis and emerging policy paradigms suggest the need for a broader understanding of value, incorporating sustainability-related dimensions that affect long-term public health and intergenerational equity [2, 9–12].

Despite growing international attention, current approaches remain fragmented in terms of methods, metrics and decision criteria. Without shared standards, sustainability risks being addressed through isolated initiatives and non-comparable assessments, limiting their policy relevance and hindering institutional uptake. For these reasons, recent contributions emphasise the need for harmonised, or at least interoperable, methodological frameworks to guide the evolution of HTA towards a more systemic and sustainability-oriented perspective [13–14].

Objective

This report provides an overview of the evolving integration of environmental sustainability considerations into HTA, with the aim of supporting more comprehensive and decision-relevant evaluation frameworks. Building on a structured review of recent literature, it seeks to analyse current practices and methodological developments, identify the tools and metrics available for assessing environmental impacts of health technologies, explore approaches to translate such impacts into outputs that can be operationally integrated into HTA processes (including monetisation strategies and links to health outcomes), and highlight key limitations and areas requiring further harmonisation and standardisation to enable wider institutional and regulatory uptake.

Methods

A comprehensive literature review was executed in October 2025 to identify methodologies for the economic quantification of environmental impacts within health technology assessments. Following a PRISMA-consistent protocol, the study synthesized peer-reviewed scientific literature with grey literature and manually sourced evidence to ensure a multi-dimensional perspective on current evaluative tools.

The search was performed in the Scopus and PubMed databases, using the following search strings:

Table 1 – Search string

Scopus Search String
("environmental impact*" OR "environmental effect*" OR "environmental consequence*" OR "sustainability" OR "sustainable development") AND ("economic evaluation" OR "economic assessment" OR "economic measurability" OR "cost-benefit analysis" OR "life cycle costing" OR "life cycle assessment" OR "valuation" OR "environmental accounting") AND ("technology assessment" OR "technological innovation" OR "green technolog*" OR "clean technolog*" OR "sustainable technolog*") AND (method* OR tool* OR framework* OR approach* OR model*) AND (healthcare OR "health care" OR "medical technology" OR "biomedical technology" OR "health technology" OR "clinical technology")

PubMed Search String
("Environmental Impact"[MeSH] OR "environmental impact*" OR "environmental effect*") AND ("Economics"[MeSH] OR "Cost-Benefit Analysis"[MeSH] OR "economic evaluation" OR "cost analysis") AND ("Technology Assessment"[MeSH] OR "technology assessment" OR "sustainable technology" OR "green technology")

Regarding the time limit, studies published in the last 5 years were selected.

Inclusion and Exclusion Criteria

The scientific evidence identified through the search strategy was considered eligible if it met one or more of the following inclusion criteria:

- methodological studies integrating environmental parameters into health economic models;
- empirical applications of LCA, carbon footprint analysis, or environmental monetisation tools;
- scoping reviews and institutional surveys regarding the economic evaluation of environmental impact;
- studies on green procurement, ESG (Environmental, Social, Governance), and integrated assessments;
- empirical studies on stakeholder perceptions and barriers to environmental integration.

The scientific evidence identified through the search strategy was considered ineligible if it met one or more of the following exclusion criteria:

- studies not aligned with the research objectives;

- studies conducted in settings with no methodological applicability or transferability to healthcare technologies;
- study designs not relevant for the purposes of the analysis;
- insufficient information reported on any of the aspects under investigation;
- studies not available in English or Italian;
- studies published more than 5 years ago.

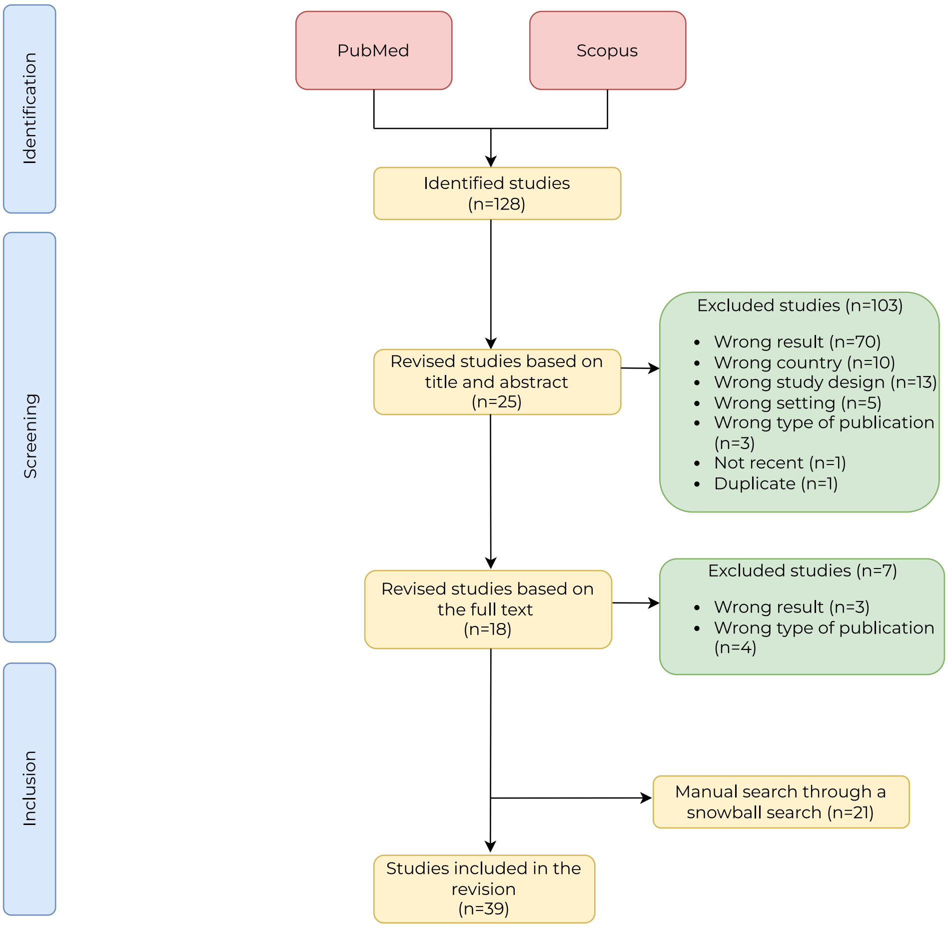
Selection process

The search strategy identified a total of 128 articles (**Figure 1**). After title and abstract screening, 25 articles were selected for full-text review. Full-text assessment led to the exclusion of a further 7 articles and, finally, after the inclusion of 21 articles identified through a snowball search, 39 articles meeting quality and relevance criteria were included in the final qualitative synthesis.

For each included study, the following information was extracted:

- objectives and context;
- environmental assessment methodology used (LCA, SCC, MCDA, etc.);
- approach to integration within HTA economic models;
- main environmental and monetisation indicators;
- operational challenges and proposals for standardisation.

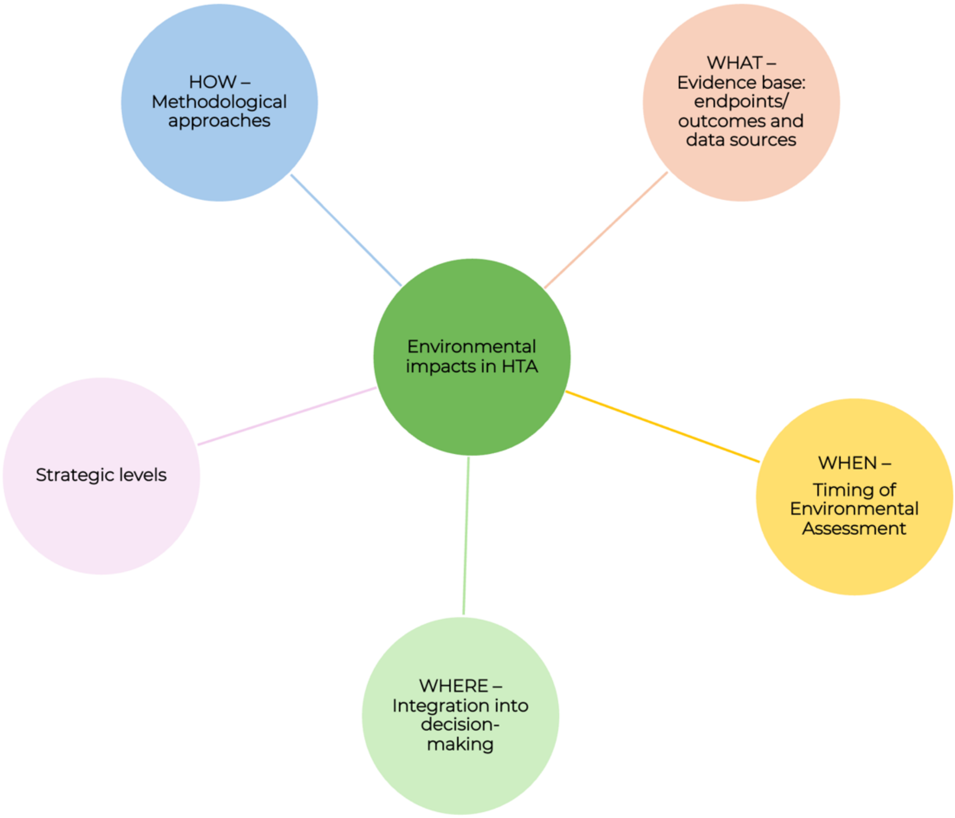
Figure 1 – Study selection process



Results

The results are organised around four complementary dimensions and a concluding strategic synthesis, reflecting the key questions underlying the integration of environmental sustainability into HTA (**Figure 2**). The HOW section outlines the main methodological approaches to quantify and incorporate environmental impacts, including LCA-based methods, economic monetisation tools and decision-support frameworks. The WHAT section summarises the evidence base by describing the environmental endpoints and outcomes considered in the literature, together with the main data sources and evidence limitations. The WHEN section highlights the relevance of assessment timing across the technology life cycle, distinguishing between ex ante, ex post and monitoring approaches, as well as prioritisation mechanisms such as environmental triage. The WHERE section discusses how environmental criteria can be operationally integrated into HTA-related decision-making processes, including Green HTA pathways and Green Public Procurement practices. Finally, the Strategic levels section synthesises cross-cutting implications for implementation, focusing on stakeholder and governance alignment, data infrastructure and standardisation, and early eco-design and innovation incentives.

Figure 2 – Environmental impacts in HTA



Source: developed by Altems Advisory

HOW – Methodological approaches

Life Cycle Assessment (LCA) e prospective methodologies

Life Cycle Assessment is unanimously recognized as the primary methodology for quantifying the environmental impacts associated with healthcare technologies, enabling the assessment of parameters such as CO_2-equivalent emissions, resource consumption, and waste generation across the entire life cycle [15–18]. Standardized in accordance with ISO 14040 and ISO 14044, the methodology allows for a systematic analysis of complex environmental scenarios, overcoming fragmented and localized approaches [16–17].

Recent studies have applied LCA using standardized ISO-compliant methods, as well as simplified versions adapted to specific healthcare contexts or emerging technologies with limited data availability. In particular, the approach known as prospective LCA (pLCA) makes it possible to anticipate the future impacts of technologies that are not yet widely deployed, thereby overcoming barriers related to the lack of historical data. This methodological innovation is essential for the ex-ante evaluation of healthcare innovations [17, 19].

Applied examples confirm the relevance of the method, with environmental impacts commonly reported in $kgCO_2e$ per patient and used to compare alternative healthcare technologies and care pathways [18, 20]. In parallel, LCA has been integrated into healthcare Green Public Procurement (GPP) contexts, where sustainability criteria have been embedded in public tenders, including requirements for third-party validation and periodic updates of environmental indicators [5, 21]. This approach links environmental performance outcomes to award criteria in procurement procedures, thereby incentivizing the adoption of lower-impact technologies [21].

Methodological developments therefore highlight the need to adapt LCA to rapidly evolving technologies, especially within complex healthcare systems [13]. However, the application of LCA in healthcare still presents significant methodological challenges: data availability is often incomplete or disaggregated, system boundary definitions are not always consistent, and the impacts of global supply chains can be difficult to attribute accurately [14, 20]. Eleven international reviews indicate that the lack of sector-specific operational guidelines for healthcare limits the comparability of analyses across countries and technologies [10].

Digital health technologies (DHTs), historically difficult to assess from an environmental perspective, are also benefiting from adapted LCA applications, although the attribution of impacts across global supply chains and energy infrastructures external to healthcare systems remains complex [16, 19]. An emerging perspective concerns early eco-design, namely the integration of sustainability principles during the technology development phase, an approach that could significantly reduce post-launch impacts [17, 19].

Moreover, recent methodological recommendations propose the use of LCA in parallel with traditional HTA evaluations, pending the definition of shared standards for the full integration of environmental impacts into decision-making models [10–11, 22].

Tools for the monetization of environmental impacts

The economic integration of LCA is achieved through tools such as the Social Cost of Carbon (SCC), which allows the monetization of environmental damages associated with CO_2 emissions by incorporating them into traditional cost-effectiveness or cost-benefit evaluations [1–3]. Through this monetization, decision-makers can balance clinical effectiveness, healthcare costs, and environmental costs, thereby enriching economic models with the social cost of carbon [2–3].

The SCC represents the discounted value of the economic damage caused by an additional tonne of CO_2 emitted, based on integrated climate–economic models that include health risks related to climate change, extreme events, and reductions in air quality [1].

However, the use of the SCC remains limited by the lack of internationally shared and standardized values, variability in economic discounting scenarios, and the absence of operational guidelines defining its application within HTA assessments [3, 12].

Emerging methodologies are also exploring the integration of monetised environmental impacts into economic models and cost-effectiveness studies, assessing how emission reductions may contribute to the overall value of therapies [23–25]. In parallel, recent studies are investigating the direct inclusion of CO_2 costs in economic evaluation models of healthcare technologies, such as in oncology programs or in the use of long-acting therapies, demonstrating that reductions in carbon footprint can alter the cost-effectiveness outcomes of therapeutic alternatives [22, 24–25].

Other forms of monetization of environmental impacts, such as shadow pricing of scarce resources (e.g., water or land) or the calculation of avoided costs resulting from ecosystem improvements, remain methodologically fragile and highly dependent on context-specific assumptions (e.g., geographic context, energy mix, environmental policies).

The literature therefore indicates that, within healthcare evaluations, these tools may help make the trade-off between clinical benefit and environmental pressure more explicit, thereby encouraging healthcare decisions aligned with long-term sustainability objectives [1, 12, 22].

Despite growing interest, the absence of shared guidelines continues to hinder their full operational adoption [18].

Multi-Criteria Decision Analysis (MCDA) with environmental integration

Multi-Criteria Decision Analysis is emerging as an effective method for simultaneously incorporating clinical, economic, and environmental criteria into the assessment of healthcare technologies, enabling the structuring of decision-makers' preferences and ensuring transparency in trade-offs across different value dimensions [11, 14]. In several applied studies, environmental indicators, such as greenhouse gas emissions, resource consumption, and impacts on material life cycles, have been formally integrated into decision criteria, facilitating more sustainable choices aligned with public health objectives [14, 22].

MCDA also allows for the management of uncertainty and incomplete data by incorporating expert and stakeholder input when quantitative data are unavailable or insufficiently robust [22]. This is particularly useful for digital or emerging technologies, for which environmental impacts may still be difficult to model using approaches based solely on LCA data.

Advanced MCDA models have been proposed to integrate long-term perspectives in therapeutic areas with high social impact, such as long-acting therapies, where organizational efficiency (fewer specialist visits), social value, and carbon footprint reduction are combined in holistic value assessments [25].

Particularly innovative approaches involve the use of MCDA as an environmental triage tool, namely to identify ex ante which technologies should undergo in-depth environmental assessments versus streamlined evaluations, based on their potential environmental impact and the maturity of available data [11]. This organizational approach makes it possible to retain environmental sustainability among HTA criteria without excessively increasing analytical burdens.

A recurring limitation highlighted in the literature concerns methodological robustness: the selection and weighting of environmental criteria remain sensitive to subjective preferences and system-level priorities [10–11, 22]. For this reason, shared guidelines and greater institutional alignment are needed to ensure that MCDA results are fully accepted within HTA processes.

Integrated models: conversion of environmental impacts into health outcomes

A further methodological development concerns the translation of environmental impacts into health parameters such as Disability-Adjusted Life Years (DALYs) and Quality-Adjusted Life Years (QALYs) through impact characterization models, among which ReCiPe (a life cycle impact assessment model), currently represents one of the most advanced tools for integrating environmental and health dimensions within economic evaluations. ReCiPe is designed to link, in a structured and scientifically robust manner, the emissions generated by a technology (such as greenhouse gases, air pollutants, or toxic substances) to population health effects, thereby overcoming the traditional separation between environmental analysis and health impacts. The model adopts a hierarchical assessment pathway, moving from midpoint indicators—which measure environmental impacts (e.g., climate change, air quality, land use)—to endpoint indicators, which quantify final damage to humans in terms of DALYs, that is, years of life lost or lived with disability.

This conversion enables the creation of integrated economic–environmental indicators, useful both for ex ante decision-making and for long-term comparisons among alternative technologies, facilitating the assessment of trade-offs between clinical effectiveness and sustainability. The ReCiPe model can, for example, simulate how air pollution resulting from the emissions of a healthcare technology may translate into cardiovascular or respiratory diseases, avoided hospitalizations, or reductions in mortality, expressed in health units that are directly comparable with clinical benefits.

This innovation opens the possibility of calculating “environmental” ICERs, namely incremental cost-effectiveness ratios that include not only traditional clinical outcomes but also the reduction of preventable health damage achieved through lower pollutant emissions. However, despite strong theoretical coherence, this approach remains computationally complex and has so far been applied mainly in experimental research settings, in the absence of shared operational standards that would allow its systematic use in regulatory processes [26].

Extended Social Return on Investment with an environmental component

In parallel, the extension of Social Return on Investment (SROI, a method for measuring and monetizing the social, economic, and environmental value created by an intervention or technology) to incorporate environmental data has made it possible to synthesize social, economic, and environmental value into a single indicator. This approach has been used in empirical studies on medical devices and DHTs to quantify overall benefits in terms of CO_2 emission reductions and other social gains. Often referred to as a *triple bottom line* framework (health, economic, and environmental), it provides a holistic view of the value generated by a technology.

A recent application of extended SROI concerned complex rehabilitative technologies, such as exoskeletons, where it was possible to jointly quantify:

- patients' functional recovery;
- the reduction in caregiver burden;
- the decrease in environmental impact across the device life cycle,

thereby arriving at synthetic indicators of the overall value generated for society [37].

Compared with other methodologies, SROI has the advantage of making environmental value visible and easily communicable through an intuitive unit: every euro invested generates X euros of social and environmental benefits. This makes it a particularly useful tool for policymakers, public stakeholders, and procurement decision-makers.

However, extending SROI to include the environmental dimension entails several methodological challenges:

- the monetary valuation of environmental impacts can vary substantially across countries (due to non-uniform shadow pricing and SCC values);
- results are sensitive to assumptions regarding the time horizon, the stakeholders included, and the distribution of benefits;
- the selection of weights and benefits considered remains partly subjective, requiring strong institutional consensus for acceptance within formal HTA processes [11–12, 22].

To date, the literature suggests that extended SROI is more suitable as a complement to traditional models rather than as a substitute, particularly for medical devices and healthcare services with high organizational and social impacts.

Acceptance of the method appears to be greater in contexts where stakeholders are actively involved in defining value indicators and in making responsible innovation choices [27].

WHAT – Evidence base: endpoints, outcomes and data sources

Across the reviewed literature, the environmental evidence base used to support sustainability-informed HTA primarily relies on a set of measurable endpoints derived from Life Cycle Assessment (LCA) and related approaches. The most frequently reported outcomes include greenhouse gas emissions, usually expressed as $kgCO_2e$ per patient, per treatment cycle, or across an entire care pathway, together with indicators of resource consumption (e.g., energy and material use) and waste generation (including packaging and single-use materials) [15–18]. Some applied studies also extend the analysis to additional environmental endpoints, such as impacts related to land and water use, as well as broader supply-chain effects, although these outcomes are less consistently reported and more dependent on context-specific modelling assumptions [16, 18, 20]. Where integrated characterization models are adopted, environmental burdens can be translated from midpoint indicators (e.g., climate change, air pollution, toxicity) into endpoint measures, including human health impacts expressed in DALYs, thereby enabling comparability with health outcomes typically used in HTA frameworks [26].

The availability and quality of environmental evidence are strongly influenced by the underlying data sources. Empirical assessments often require a combination of primary data (e.g., hospital-level activity data, consumables, logistics, and energy use) and secondary data from LCA databases, emission factors, and national energy-mix parameters [14, 20]. In procurement-related contexts, tender documentation and supplier-provided information can contribute to the estimation of technology-specific environmental performance, particularly when supported by third-party verification and periodically updated indicators [21]. However, the literature highlights persistent limitations in data granularity and transparency, including incomplete inventories, heterogeneous system boundaries, and difficulties in attributing impacts across global supply chains, especially for digital health technologies where emissions from ICT infrastructures and data centres may fall outside traditional healthcare accounting frameworks [19, 20]. Overall, these findings indicate that strengthening environmental endpoints and data infrastructure is a prerequisite for improving comparability and supporting more systematic integration of sustainability criteria into HTA decision-making.

WHEN – Timing of environmental assessment

The timing of environmental assessment represents a key operational dimension for the integration of sustainability into HTA processes, as the availability and granularity of data may differ substantially across the technology life cycle. Environmental evaluations can be conducted either ex ante, to support early decision-making for emerging innovations, or ex post, to assess real-world performance once technologies are deployed at scale.

Ex-ante approaches are particularly relevant for rapidly evolving technologies or innovations with limited historical evidence. In this context, pLCA has been proposed as a methodological solution to anticipate potential environmental impacts using scenario-based modelling, enabling early consideration of sustainability in technology development and adoption decisions [17, 19]. Similarly, methodological contributions suggest that the monetisation of CO_2 emissions (e.g., through Social Cost of Carbon) may be incorporated into early-stage economic models to explore how emission reductions could affect the overall value proposition of therapies and alternative care strategies [23–25].

Conversely, ex-post assessments rely on empirical data generated in routine practice and can provide more robust estimates of environmental impacts, supporting comparability and accountability in procurement and policy decisions. However, their applicability is often limited by fragmented datasets and inconsistent system boundaries [14, 20].

To ensure feasibility and proportionality, the literature increasingly highlights the role of environmental "triage" approaches, designed to identify which technologies require comprehensive environmental assessment versus streamlined evaluation. This prioritisation strategy allows HTA bodies to allocate analytical resources efficiently while maintaining sustainability as a relevant criterion in decision-making [11, 22].

WHERE – Integration into decision-making

Integration into Green Public Procurement processes

Green Public Procurement (GPP) integrates LCA analyses and ESG indicators into tendering procedures, rewarding more sustainable technologies and steering healthcare systems toward greater environmental responsibility [5, 11].

For example, in Italy the Umbria region has adopted minimum environmental criteria in the procurement of pharmaceuticals and medical devices, including:

- third-party verification of LCA;
- periodically updated environmental indicators;
- award scores for certified reductions in carbon footprint.

This direct linkage between environmental impacts and purchasing decisions represents an operational and systemic application of HTA extended to sustainability. Overall, this experience can be considered at an early implementation stage, as the integration of environmental indicators into procurement processes is still developing and not yet fully standardized across the healthcare system [21].

International experiences, such as those promoted by NICE (UK) and CADTH (Canada), although not yet formalized into binding regulations, indicate a growing institutional willingness to include the environment as a relevant criterion in evaluation and procurement processes [9, 10]. However, the heterogeneity of the approaches adopted suggests the need for coordination and standardization to prevent cross-country differences from generating disparities in access to sustainable innovation [10–11].

A particularly relevant aspect is that integrating GPP into HTA decision-making cycles anticipates environmental impacts along the value chain and makes sustainability a competitive attribute, directly influencing industrial choices and design (eco-design), logistics, packaging, and the reuse and recycling of healthcare materials.

Sustainable procurement therefore represents one of the most immediately applicable regulatory tools to accelerate the transition toward low-emission healthcare systems.

Practical experiences and operational challenges

Recent studies have developed environmental triage approaches to identify when and how to integrate environmental assessments into HTA decisions, avoiding unnecessary complexity where environmental impacts are negligible (**Table 2**).

This preventive framework enables HTA agencies to:

- allocate analytical resources efficiently;
- define transparent priorities;
- focus on technologies with greater potential impact, in line with pilot initiatives implemented in European institutional contexts [11, 22].

In the field of telemedicine, significant reductions in carbon footprint have been demonstrated due to the elimination of patients' physical travel to healthcare facilities.

An Italian national study on 2,091 teleconsultations estimated savings of approximately 13 kg of CO_2 per teleconsultation, corresponding to a total of 16 tonnes over the period analysed, with direct economic benefits for patients and caregivers as a result of reduced transport costs [28]. This evidence suggests that digital health services may represent strategic levers to reconcile quality of care, equity of access, and environmental sustainability. However, the environmental impact of ICT infrastructures and data centres remains underestimated and requires further LCA studies specifically focused on avoiding potential cost-shifting towards the energy component [19].

Overall, these findings indicate that integrating telemedicine into care pathways can generate environmental, social and economic co-benefits, contributing to the resilience of healthcare systems.

The application of environmental assessment methodologies in real healthcare settings is expanding across several therapeutic areas and geographical contexts. Pilot studies conducted in European hospitals have shown the usefulness of integrating ESG indicators and LCA analyses within decision-making processes, influencing procurement choices and resource use strategies [5, 10-11].

For example:

- Evidence from oncological optimization models indicates that strategic de-escalation of trastuzumab regimens can significantly mitigate environmental burdens without compromising therapeutic parity. Specifically, reducing adjuvant treatment duration from 12 to 6 months, and extending administration intervals, is estimated to decrease greenhouse gas emissions by 4.5% in neoadjuvant, 18.7% in adjuvant, and 14.6% in metastatic settings. These efficiencies are primarily driven by the rationalization of clinical throughput, including fewer hospital visits and reduced material intensity. Furthermore, the transition from intravenous to subcutaneous formulations of monoclonal antibodies yields a superior carbon profile per cycle, with cumulative savings potentially reaching hundreds of kg CO2e per patient cohort due to streamlined administration and decreased patient mobility requirements [29-30].
- In the respiratory field, a study based on prescription data from the English NHS estimated that pressurised metered-dose inhalers (pMDIs) generated approximately 635 kt CO_2e/year in 2017, highlighting that a progressive switch to devices with a lower global warming potential (DPIs) could avoid around 58 kt CO_2e/year for every 10% reduction in pMDI use. Achieving a mix in which at least 50% of inhalers consist of low-climate-impact devices would enable a reduction of approximately 288 kt CO_2e/year, without documented compromises in clinical outcomes and with overall economic scenarios that are broadly neutral or favourable for the healthcare system [31].

- In ophthalmology, the use of the Eyefficiency tool in several cataract surgery centres recorded phacoemulsification procedure durations ranging from 13 to 72 minutes and waste production varying from 0.19 to 4.27 kg per case, with an estimated carbon footprint between 41 and 130 kg CO_2e per procedure. These data enabled the identification of marked performance differences across facilities and the use of the most efficient hospitals as benchmarks for organisational improvement interventions, optimisation of material use, and the definition of environmental criteria in surgical planning and procurement processes [32].
- In the field of infectious diseases, a model applied to a universal immunisation programme against respiratory syncytial virus (RSV) in infants in the UK estimated that current standard of care generates approximately 32.9 kilotonnes (kt) of CO_2e per year along the care pathway, whereas the introduction of nirsevimab for all newborns could avoid up to 21.7–22.3 kt CO_2e annually, corresponding to approximately 30–32 kg CO_2e saved per immunised child [33].

In addition, in diabetes, recent studies have shown that integrating environmental metrics into care pathways can improve overall disease management, supporting more efficient organisational models, lower environmental impact, and better use of healthcare resources. In diabetes, the sector contributes about 0.72 megatonnes (Mt) of CO_2e to the global healthcare system's environmental impact; innovations such as reusable insulin pens reduce plastic waste by 89% and emissions by 40% compared to disposable ones, while modular tubeless pumps generate 13.6 kg CO_2e/year versus 15.5 kg for less recyclable models [38]. These large-scale HTA (assessments conducted across entire patient populations or healthcare systems, rather than small pilot studies) analyses suggest the feasibility of introducing environmental sustainability as a decision-making criterion also in high-prevalence chronic diseases. Evidence shows that environmental factors contribute significantly to the incidence and progression of highly prevalent chronic conditions such as diabetes, reinforcing the importance of sustainable approaches in care pathways [7]. Altogether, these examples show that integrating the environmental dimension is not only technically feasible but can also generate systemic benefits without compromising therapeutic effectiveness.

Despite the progress documented in real-world settings, systematic adoption of environmental assessments in HTA is still hindered by numerous barriers. One of the main critical issues is the limited availability and insufficient granularity of healthcare environmental data, which makes it difficult to accurately quantify the specific impacts of each technology throughout its life cycle [2, 34].

Table 2 – Summary of environmental impact case studies

Case study / Technology	Clinical area	Data sources	Environmental outcomes	Ref.
Digital health applications	Digital health / service delivery	LCA approaches adapted to DHTs; assessment complicated by global ICT supply chains and data centres	Evidence suggests potential emission reductions through service redesign (e.g., avoided travel), but system boundaries and ICT-related impacts remain uncertain and frequently underestimated	[18]
Telemedicine (teleconsultations)	Digital health / service delivery	National observational dataset (2,091 teleconsultations); avoided travel emissions	~13 kg CO_2 saved per teleconsultation; ~16 tonnes CO_2 saved overall; additional savings from reduced transport costs	[27]
IV vs SC monoclonal antibodies	Oncology	Carbon footprint analysis; LCA-based comparative assessment per treatment cycle	Subcutaneous administration associated with lower emissions than intravenous; potential cumulative reduction for treated cohorts	[29]
Alternative trastuzumab regimens	Oncology	Optimisation model including organisational parameters (visits, treatment duration), emissions linked to resource use	Emission reductions: 4.5% neoadjuvant; 18.7% adjuvant; 14.6% metastatic setting, mainly via fewer visits/material use	[28]
Switching inhaler types (pMDIs → DPIs)	Respiratory diseases	Prescription data (England NHS); carbon footprint factors applied to device mix scenarios	pMDIs ≈ 635 kt CO_2e/year (2017); every 10% reduction in pMDI use avoids ~58 kt CO_2e/year; ≥50% low-impact mix reduces ~288 kt CO_2e/year	[30]
Cataract surgery efficiency (Eyefficiency tool)	Ophthalmology / surgical procedures	Eyefficiency auditing tool; cross-centre benchmarking; waste and time tracking	Waste: 0.19–4.27 kg/case; footprint: 41–130 kg CO_2e/procedure; identification of best-performing centres for improvement	[31]
Universal RSV immunisation programme (nirsevimab)	Infectious diseases / prevention	Model-based pathway analysis; carbon footprint across care pathway	Standard of care: ~32.9 kt CO_2e/year; nirsevimab could avoid ~21.7–22.3 kt CO_2e/year (~30–32 kg CO_2e saved per immunised child)	[32]
Diabetes technologies (pens, pumps)	Chronic disease management (diabetes)	LCA/environmental metrics across devices and care pathways	Reusable insulin pens: −89% plastic waste and −40% emissions vs disposable; tubeless modular pumps: 13.6 kg CO_2e/year vs 15.5 kg for less recyclable models	[37]

In addition, the lack of shared guidelines and international methodological standards leads to substantial heterogeneity in approaches and results, reducing study comparability and limiting the reliability of environmental integration in traditional HTA models [3, 10, 25]. Even when robust environmental data are available, their integration into economic and clinical models remains operationally complex, as it requires specialised expertise that is not always available within agencies and assessment teams [11, 22]. At an institutional level, cultural and organisational barriers persist: HTA professionals' training rarely includes environmental aspects, and constant pressure on healthcare budgets tends to prioritise short-term economic and clinical outcomes over environmental benefits, which materialise over longer time horizons [2-3, 34].

Finally, the integration of environmental impacts into decision-making and procurement procedures remains largely voluntary or experimental, lacking a binding regulatory framework defining obligations, modalities, and minimum reporting requirements [10-11, 25].

Therefore, the transition from pilot experiences to consolidated practice will require a genuine systemic shift, capable of simultaneously involving governance, competencies, and incentive models. Difficulties in harmonising environmental data and integrating them into HTA processes are also confirmed by recent scoping reviews reporting cross-cutting operational challenges across different national healthcare systems [20, 35].

Strategic levels

Stakeholder and governance alignment

The integration of environmental sustainability into HTA requires a shared institutional vision and stronger alignment among key stakeholders, including HTA agencies, regulators, procurement bodies, clinicians, patients, manufacturers and payers. While methodological tools are increasingly available, their implementation remains uneven due to fragmented responsibilities across decision-making levels and the absence of a clear governance framework. Strengthening coordination mechanisms and promoting stakeholder engagement, particularly to support consensus on evaluation criteria, weighting of environmental outcomes and decision rules, represents a foundational step to move from pilot initiatives to systematic adoption [5, 10, 22].

Data infrastructure & standardisation

A major barrier to operational uptake remains the limited availability, granularity and comparability of environmental data across technologies and healthcare settings. Advancing sustainability-informed HTA will therefore require investment in data infrastructures that enable reliable environmental measurement throughout the life cycle of health technologies, including supply-chain impacts where feasible. At the same time, greater methodological standardisation is needed to ensure consistent system boundaries, harmonised endpoints and transparent reporting requirements. The development of sector-specific guidance and shared reference values (e.g., for carbon monetisation) would substantially improve cross-study comparability and support institutional acceptance [14, 18, 20].

Early eco-design and innovation incentives

Beyond assessment, sustainability considerations should increasingly inform the design and development of healthcare technologies. Early-stage evaluation approaches—including prospective LCA and environmental triage, can support eco-design principles by identifying high-impact components and guiding innovation toward low-emission solutions. In parallel, aligning procurement and reimbursement incentives with verified environmental performance could stimulate manufacturers to incorporate sustainability as a competitive attribute, affecting product design, packaging, logistics and end-of-life strategies. Overall, embedding environmental sustainability early in the innovation pathway may yield the greatest long-term impact while reducing the burden of retrofitting sustainability criteria post-launch [19, 21, 27].

Conclusions

The reviewed evidence indicates that integrating environmental impacts into Health Technology Assessment is no longer a theoretical ambition, but an increasingly feasible and necessary extension of value assessment in healthcare. Sustainability-related impacts can already be quantified, compared across alternatives, and—under specific methodological assumptions—translated into decision-relevant economic and health metrics. However, the literature also shows that without shared standards and enforceable reporting requirements, environmental assessment risks remaining confined to non-comparable pilots, limiting its relevance for institutional decision-making [3, 10, 21].

From a methodological standpoint, Life Cycle Assessment emerges as a cornerstone methodology for the standardized quantification of environmental impacts across the entire life cycle of healthcare technologies, particularly due to ISO 14040/14044 standardization and its ability to systematically and comparably analyse resource use, emissions, and waste generation [15–17]. More recent developments, such as prospective and streamlined LCA, further enable the overcoming of limitations related to emerging technologies or data scarcity, extending the applicability of the method to the ex-ante assessment of innovation [17–19]. Alongside measurement tools, the literature reports significant progress in the monetization of environmental impacts and in their conversion into health outcomes. The adoption of the Social Cost of Carbon and the use of integrated impact models such as ReCiPe represent concrete methodological pathways to enable direct comparisons between health benefits and environmental damages within economic evaluations, moving HTA closer to the goal of jointly assessing clinical, economic and environmental value [8, 26, 36]. Similarly, multicriteria approaches such as MCDA and socioeconomic tools such as extended SROI have demonstrated potential in capturing equity considerations, as well as social and organizational impacts, thereby broadening the evaluative perspective beyond strictly clinical outcomes [11, 37]. This evolution reflects increasing alignment with the principles of ecological economics, which view the health of natural systems as a fundamental determinant of human well-being and economic sustainability [2].

Real-world applications documented across multiple clinical areas (oncology, diabetes, respiratory diseases, ophthalmology, vaccination, and telemedicine) clearly show that attention to environmental impacts does not compromise the clinical performance of healthcare technologies. On the contrary, these experiences demonstrate systemic co-benefits such as optimized organizational processes, reduced operational costs, improved accessibility, and enhanced resilience of healthcare services [28–30, 33, 38]. These applied case studies support the conclusion that sustainability can function as a lever for efficiency and quality improvement rather than as an external constraint.

Despite these encouraging signals, significant barriers remain that limit the systemic adoption of environmental assessments within HTA. One of the main challenges is the limited availability and low transparency of environmental data along healthcare supply chains, which increases uncertainty and undermines the robustness of estimates [2–3, 34]. Moreover, the lack of internationally formalized guidelines and binding requirements for company submissions leads to substantial heterogeneity in approaches and reduced comparability of results [10, 25]. This is compounded by the need for specialized competencies that are not yet widespread within HTA agencies and by the difficulty of reconciling the inherently long-term environmental perspective with decision-making processes often driven by short-term cost containment [11, 22, 34]. In addition, evidence from the digital health sector indicates that the systematic integration of environmental criteria into HTA evaluations and procurement processes requires strong stakeholder engagement, as awareness and maturity regarding sustainability as a dimension of innovation value remain limited [39].

The environment therefore continues to play a largely marginal role in decisions regarding the adoption and reimbursement of technologies, despite the numerous pilot projects and institutional initiatives undertaken by bodies such as NICE, CADTH, and IETS, which nevertheless indicate a gradual openness toward a broader revision of the concept of healthcare value [4, 10]. In this transitional phase, the evolution toward a “Green HTA” requires alignment among methodological innovation, cultural transformation, and multilevel governance, with greater involvement of manufacturers in ensuring transparency of environmental data and a clear definition of regulatory obligations and reporting criteria. This also highlights the importance of considering the ELSI domains within HTA, given their relevance for responsible technology design, stakeholder engagement, and regulatory compliance. Increased attention to the responsible design of technologies, based on sustainability criteria from the earliest stages of development, could make a decisive contribution to reducing impacts across the entire life cycle [18]. Overall, a picture emerges in which sustainability does not represent a constraint on healthcare performance, but rather a lever to improve efficiency, quality, and the social responsibility of healthcare systems. The potential is already evident in the applied cases examined; however, to translate pilot experiences into established practice, an institutional and regulatory leap will be required to formalize the role of the environment as a determinant of health and an indispensable component of technology value. In other words, the methodological pathway is increasingly defined, but the next step is to transform it into a shared and binding operational strategy, enabling HTA to make a decisive contribution to the ecological transition of healthcare systems [8, 11, 22]. Indeed, the assessment of environmental spillovers could further broaden the estimation of the value generated by healthcare systems within society [12].

Recommendations

The economic measurability of environmental impacts represents both a critical methodological challenge and a major opportunity for the evolution of HTA. While the literature already provides robust tools, such as life cycle assessment and monetization approaches (SCC), translating environmental impacts into health and economic outcomes (e.g., DALYs, QALYs), and a growing set of real-world applications. However, the transition from pilot initiatives to systematic implementation requires coordinated action at methodological, organisational, and policy levels. In particular, progress depends on strengthening standardisation, improving environmental data availability, expanding institutional capacity, and embedding sustainability criteria into procurement and decision-making mechanisms. In this context, the following recommendations outline priority steps to enable the structured and decision-relevant integration of environmental sustainability into HTA:

- Promote the systematic integration of environmental sustainability into HTA process.

  Environmental sustainability should be treated as an integral component of value assessment, rather than as an optional add-on. Formal inclusion within HTA frameworks would support climate mitigation goals while also promoting long-term sustainability in public resource allocation.

- Catalyse international harmonisation and standardisation of healthcare-specific LCA methodologies

  Greater comparability and reliability of environmental evidence require harmonised methodological standards, particularly regarding system boundaries, emission factors, and the use of validated and interoperable environmental databases tailored to healthcare technologies.

- Develop frameworks and guidelines for environmental impact monetisation.

  To ensure environmental impacts are decision-relevant and comparable, it is essential to institutionalize operational guidelines for monetization. This requires the harmonization of reference values, specifically for the Social Cost of Carbon (SCC), and the development of robust protocols for integrating environmental externalities into traditional economic metrics. Establishing clear directives on how these values should be incorporated into Incremental ICER estimates and cost-benefit analyses will ensure that sustainability is no longer an ancillary consideration, but a core component of HTA.

- Advance the implementation of integrated eco-health evaluative models.
  To achieve a unified decision-making architecture, healthcare systems must prioritize models that synthesize environmental impacts with clinical outcomes. By utilizing advanced characterization frameworks, such as ReCiPe, environmental burdens can be converted into health metrics (e.g., DALYs/QALYs), enabling a direct comparison between ecological damage and therapeutic gain. This integration facilitates the calculation of "Environmental ICERs", which augment traditional Incremental Cost-Effectiveness Ratios

by incorporating the net health benefits of mitigated emissions and pollution. Establishing shared operational standards for these outputs is essential to transition from experimental applications to the systematic, evidence-based inclusion of environmental value within HTA and regulatory frameworks.

- Enhance institutional technical capacity and environmental data interoperability.

  Operational implementation depends on improved access to granular environmental data across supply chains and life-cycle stages. In parallel, HTA agencies require dedicated competencies, training, and methodological expertise to handle environmental assessment and integrate it into traditional clinical-economic evaluations.

- Embed environmental criteria into Green Public Procurement and healthcare planning.

  Procurement represents a major lever for implementation, as it translates sustainability goals into actionable purchasing decisions. Progressively integrating environmental indicators and reporting requirements into procurement processes would allow economic leverage to align more effectively with sustainability objectives.

- Leverage real-world evidence demonstrating clinical and organisational co-benefits.

  Existing evidence indicates that lower-impact technologies and delivery models (e.g., telemedicine, optimised treatment regimens, sustainable devices) can reduce environmental burden without compromising clinical effectiveness. These solutions may also enhance service resilience, improve efficiency, and expand access to care pathways.

- Frame the sustainability transition as a strategic necessity to ensure equity and long-term system responsibility.

  Environmental impacts influence population health and healthcare demand over time, meaning sustainability is directly linked to equity and intergenerational responsibility. HTA must evolve accordingly to avoid reinforcing short-term decision-making at the expense of long-term societal costs.

- Integrating environmental sustainability with other HTA domains.

  Achieving a comprehensive value assessment requires aligning all HTA dimensions in a coherent framework that is transparent, comparable, and operational. This represents a crucial step toward innovative healthcare systems capable of actively contributing to both planetary health and the health of present and future generations.

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