



# Health Technology Assessment and Environmental Impact: A Scoping Review of State of Art and Future Perspective

Ippazio Cosimo Antonazzo<sup>1,2</sup> · Giorgia Gribaudo<sup>1,3</sup>  · Lisa Ye<sup>1</sup> · Pietro Ferrara<sup>1,2</sup> · Lorenzo Losa<sup>1</sup> · Paolo Abrate<sup>4</sup> · Fabio Iraldo<sup>5</sup> · Lorenzo Giovanni Mantovani<sup>1,2</sup> · Paolo Angelo Cortesi<sup>1,2</sup>

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## Abstract

**Introduction** Manufacture, distribution, use, excretion, and disposal of health technologies all have environmental impacts (EIs). In the health technology assessment (HTA) definition, EI is recognized as a domain that should be assessed. However, EIs in HTA methods are lacking. The aim of this scoping review was to identify current advances and limitations in incorporating EI in HTA evaluation.

**Methods** We searched two databases, PubMed and Embase (01/01/2019–20/10/2023, updated on 15/05/2025), using the following keywords: “HTA” and “environmental impact.” Articles published in English were included. Additionally, no filters by study design or type of evaluated technology were used.

**Results** In total, 264 studies were screened after duplicates had been removed. Among them, 15 articles were included. Identified publications highlighted the necessity of robust and clear methods of EI assessment and its inclusion in the HTA process. Several authors have outlined the importance of assessing the EI of health technology throughout its life cycle, including raw materials, manufacturing, use, and disposal. However, the EI assessment in HTA presents significant challenges, such as determining a clear domain of EI, the perspective, and the time horizon for the assessment. EI assessment challenges also include the lack of disaggregated data on pollutant emissions and natural resource consumption, as well as recommendations on the use of the EI data by decision makers and HTA agencies. In the literature, different methods and approaches have been proposed to incorporate EI in HTA; some rely on already established assessment methods (“enriched” cost-utility analysis, adjusted willingness to pay, and multicriteria decision analysis) and others proposed more specific approaches, such as “information conduit,” “parallel evaluation,” “integrated evaluation,” and “environment-focused evaluation.”

**Conclusion** HTA framework needs adjustments to incorporate environmental information, including environmental health-care technology impact. Clear and robust methods on EI assessment and inclusion in the HTA process should be provided by HTA agencies and international societies. Further, manufacturers should improve the data generation on the EI of their products, with new studies able to generate individual-level data on environmental technology impact.

## 1 Introduction

The World Health Organization (WHO) recently declared that climate change is a fundamental threat to human health. Climate change affects health in multiple ways, contributing to increasing mortality and illness through the average temperature rise and the extreme weather events such as heatwaves, storms, and floods. It increases the prevalence of zoonotic diseases and those transmitted through food, water, and vectors, while disrupting the food system. Additionally, climate change affects numerous social determinants crucial to health, including livelihoods, equality, access to health-care, and cohesive support structures [1].

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✉ Giorgia Gribaudo  
giorgia.gribaudo@studio.unibo.it

<sup>1</sup> Research Centre on Public Health (CESP), University of Milan-Bicocca, Monza, Italy

<sup>2</sup> Laboratory of Public Health, Auxologico Research Hospital-IRCCS, Milan, Italy

<sup>3</sup> University of Bologna, Bologna, Italy

<sup>4</sup> Struttura Semplice Continuità Farmaceutica Ospedale-Territorio ASL TO4, Ivrea, Italy

<sup>5</sup> Institute of Management, Scuola Superiore Sant’Anna, Pisa, Italy

### Key Points for Decision Makers

Environmental impact (EI) remains a key yet under-assessed domain in current health technology assessments (HTAs).

In this scoping review, 15 studies proposing methods to integrate EI into HTA were identified, highlighting significant gaps in both data availability and methodological guidelines.

There is a clear need for standardized frameworks to support the inclusion of sustainability in future health-care decision-making.

In this context, it is crucial to define the roles of the different stakeholders in providing data, conducting the evaluation, and making data available to ensure the inclusion of EI in HTA.

Globally, healthcare accounts for 1–5% of the total environmental impact (EI). Regarding the emission of greenhouse gases (GHG) and air pollutants, the healthcare sector contributes significantly to the overall footprint, constituting 4.4% of GHG, 2.8% of particulate matter, 3.4% of nitrogen oxides (NO<sub>x</sub>), and 3.6% of sulfur dioxide (SO<sub>2</sub>) [2, 3]. In recent years, there has been a growing focus on the EI of healthcare [2–5]. Within this framework, the manufacturing of pharmaceutical products emerges as a potential source of pollution and therefore deserves careful evaluation.

In this new era, given the increased number of available therapies and devices, it is crucial to incorporate EI considerations into the health technology assessment (HTA). HTA serves the purpose of guiding decision-making processes and promoting equitable, efficient, high-quality, and sustainable health systems [6]. Hence, as reported by WHO, HTA is a systematic and multidisciplinary evaluation of the properties of health technologies and interventions, covering both their direct and indirect consequences. It is a multidisciplinary process designed to assess the value of health technologies and provide guidance on their use within health systems worldwide. HTA is a transparent and accountable approach that helps decision makers and other stakeholders make informed policy-level choices in healthcare by offering evidence on specific technologies [7]. Although different domains are incorporated into HTA, EI data are still under-evaluated/incorporated.

Recently, the Global Commission on the Economy and Climate issued a call to action, urging the integration of climate impact considerations into economic decision-making processes to reduce carbon emissions effectively [8]. This was reinforced in 2021 during the 26th Conference of the Parties (COP26) conference [9], where 50 countries committed to developing low-carbon and climate-resilient health

systems. In response to this external recommendation, some countries started to consider the inclusion of EI in HTA. For instance, the Swedish government has introduced a voluntary eco-classification or green premium for generic drugs to promote environmentally friendly drug production [10]. The National Institute for Health and Care Excellence (NICE) has outlined its strategy for 2021–2026, expressing the intention to incorporate EI data into its guidance [11], while other organizations are currently exploring the feasibility and methods of integrating EI into HTA [12]. For example, HTA guidelines in Australia and Canada recommend the inclusion of EIs [13, 14].

Despite these initiatives and the growing demand from healthcare stakeholders, incorporating environmental considerations into HTA remains uncommon and it is far from being a standard practice yet. Therefore, this scoping review aims to summarize current methods and approaches discussed and proposed for integrating EI assessment into the HTA process, highlighting strengths and limitations. Additionally, the review seeks to identify potential gaps in this field that require further investigation to facilitate the inclusion of EI in HTA.

## 2 Methods

A scoping review was conducted to summarize strengths and limitations associated with the process of incorporating EI into HTA. The review followed established guidelines, utilizing the Joanna Briggs Institute (JBI) framework for scoping reviews [15], and was reported in accordance with the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) extension for scoping reviews. The study protocol was retrospectively registered in the International Prospective Register of Systematic Reviews (PROSPERO) under registration number CRD42024480136.

### 2.1 Search Strategy

A search strategy was developed using terms related to "HTA" and "environmental impact" to retrieve literature from PubMed and Embase. The search covered the period from 1 January 2019 to 20 October 2023, with an update on 15 May 2025. Given the growing body of evidence and the increasing attention given to this topic in recent years, the search was restricted to this period. However, to ensure a comprehensive overview of the available evidence, published reviews were also included to incorporate relevant findings from prior periods. The full search strategy employed in each database is provided in supplementary Table 1 (see the electronic supplementary material). Zotero

was used to eliminate all duplicates, and manual backward citation analysis was performed for all references included in the studies.

## 2.2 Screening Phase

The literature search results underwent a two-steps screening process. Initially, two independent reviewers (GG and LY) assessed the eligibility of all articles by examining titles and abstracts. Subsequently, full-text screening was conducted for studies that met the eligibility criteria: (1) original articles and reviews published in English; (2) studies focused on practical approaches to incorporate EI into HTA; (3) studies with recommendations to facilitate the inclusion of EI in HTA; and (4) studies that consider any timepoint of the drug/device lifecycle for EI assessment and inclusion into HTA. Any discrepancies between reviewers in title and abstract screening, full-text review, or reasons for exclusion were resolved through group discussion with a third reviewer (ICA). Additionally, to ensure the most comprehensive assessment of available evidence, published reviews on the topic were included in the study.

## 2.3 Data Extraction

A data extraction form was designed ad hoc in Microsoft Excel. This phase involved two independent reviewers (GG and LY). Any discrepancies were resolved through group discussion with a third reviewer (ICA). The reviewers extracted the following data from the included studies: title, first author name, publication year, country, type of study, environmental dimension (CO<sub>2</sub>, water, energy, waste, or other), time for EI evaluation (life cycle, production, transport, post-marketing, or other), inclusion of case study (yes vs no), presence of proposed methods to incorporate EI into HTA, and the inclusion of proposed actions for both companies and regulatory agencies.

## 2.4 Quality Assessment

Although the study protocol initially included a quality assessment of the included studies, this step was ultimately not performed due to the nature of the included records reviewed. Specifically, the heterogeneity in study designs and the broad range of covered topics did not allow us to compare studies directly, and doing so could potentially increase the risk of misleading interpretation of the findings. Given the study's objective of mapping current knowledge and identifying potential limitations in incorporating EI into HTA, a formal quality assessment was deemed unnecessary, in alignment with scoping reviews guidelines [15, 16]. Nevertheless, for each included study, reported strengths and

limitations were documented to highlight potential challenges in integrating EI into HTA. To aid readers of the paper, we standardized the reported strengths and limitations across the studies using consistent terminology. For example, we use the phrase “lack of empirical evidence” when studies referred to a scarcity of real-world findings or expressed similar concerns.

## 2.5 Data Analysis

A descriptive analysis of the included studies was conducted, summarizing key findings and challenges related to EI integration into HTA. The results were categorized based on the nature of the findings and synthesized narratively.

## 3 Results

The literature search resulted in 341 citations, summarized in the PRISMA flowchart (Fig. 1). After removing 23% (80/341) of the records that were duplicates, we screened the remaining 261 publications. After excluding 220 papers by title and 18 by the abstract, as they did not fall within the inclusion criteria, 23 potentially relevant full-text papers remained. The full-article screening led to the exclusion of eight articles (35%): five due to the design of the articles (editorial), two because they were out of scope, and one because of the language. Therefore, after this second screening, ten original articles and five reviews were included. Details on included original articles are reported in supplementary Table 2 in the electronic supplementary material [12, 17–25]. Details on the five reviews are reported in supplementary Table 3 in the electronic supplementary material [26–30]. Additionally, a comprehensive list of references for excluded records was reported in the electronic supplementary material under the section “List of excluded references.”

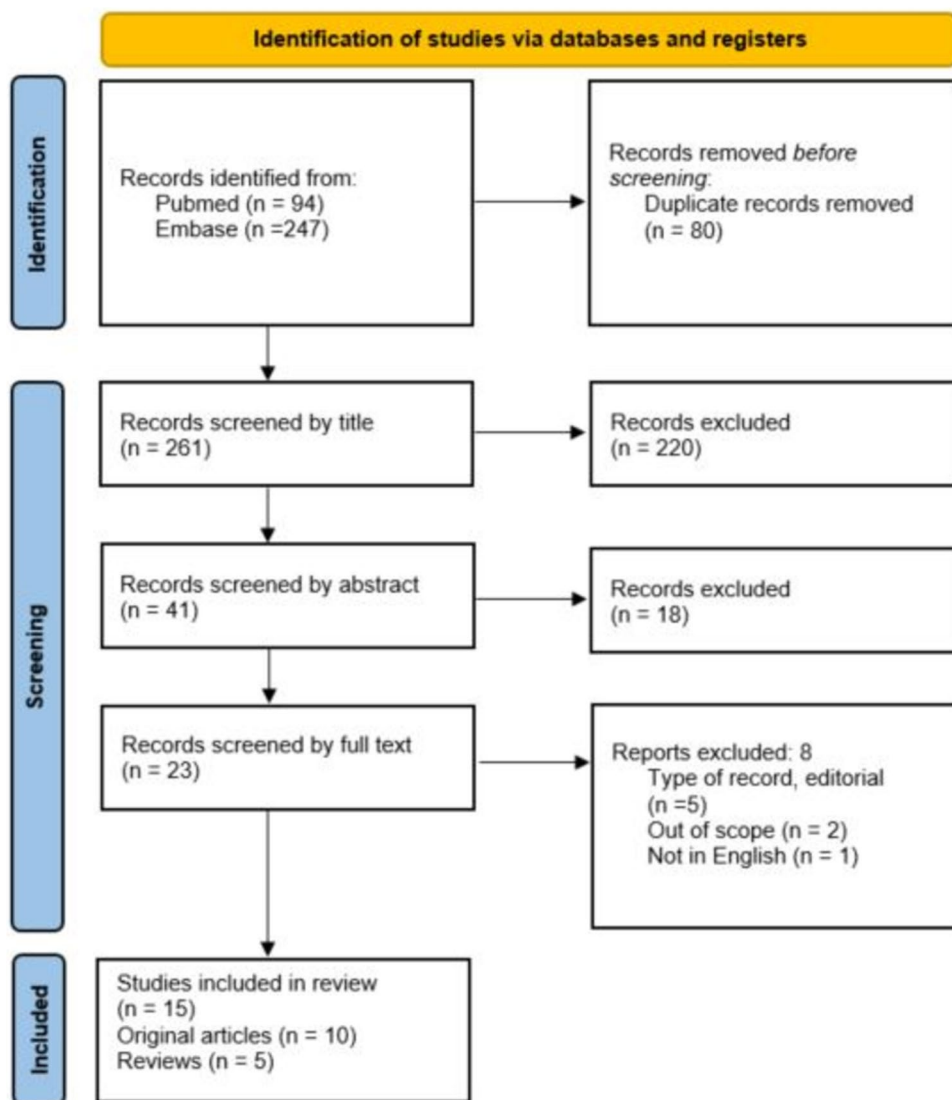
Most of the studies included in this systematic review originated from high-income countries, such as Portugal [18], the UK [22], Australia [20, 21, 30], and Canada [19, 23, 24]. Additionally, three studies resulted from international collaborations: one between Spain and the UK [17], another involving Canada, Colombia, and the UK [12], and one from 20 different countries [25].

Among the ten original articles, six described practical approaches for incorporating EI into HTA [19–23, 25]. The remaining four articles proposed recommendations for various stakeholders, including HTA agencies, pharmaceutical industries, and governments [12, 17, 18, 24].

The five review articles described potential methods for integrating EI into HTA, discussing aspects such as data types and assessment methodologies [26–30].

Regarding the environmental dimension, two studies addressed CO<sub>2</sub> emissions [17, 21], one focused on the

**Figure 1:** Flowchart of the selection process



general environmental dimension [22], one study explored topics such as pharmaceutical and plastic pollution [20], three did not provide explicit details on the environmental dimension [12, 18, 19, 23, 25], and one emphasized sustainability from a system-level innovation perspective rather than quantifying specific dimensions [24].

The five reviews focused on all the environmental dimensions (i.e., water, air, energy consumption, and waste disposal) [26–30].

Desterbecq and Tubeuf reviewed four studies that undertook a full economic evaluation of healthcare products (i.e., use of home vs in-center hemodialysis, use of reusable inhalers, and implementation of a medical program) and included CO<sub>2</sub> emissions in the evaluation. Authors suggested converting EI in cost-adopting monetization methods and including it into HTA as additional costs

(i.e., additional costs in cost–benefit analysis [CBA] and budget-impact analysis) [26].

Guirado-Fuentes et al. suggested a method to include carbon footprint into HTA by using cataract surgical services as an example. They recommended a hybrid life cycle assessment (LCA) approach that combines environmentally extended input–output (EEIO) analysis with a process-based approach to facilitate comparison across HTA assessments [27].

Pinho-Gomes et al. presented seven case studies in their review. A case study incorporated both quantitative and qualitative information and several perspectives into the analysis, as well as presenting the trade-offs and prioritization related to different technology options. This option might be used not only to include EI in HTA evaluation but also other domains. The rest of the case studies proposed to incorporate environmental sustainability directly into the economic evaluation of health technologies by

using methodologies used in green economics, such as the monetization of environmental externalities [28].

Polisena et al. described frameworks and methods to incorporate and summarize the evidence on EI into HTA. The authors recommended an LCA of the technology, an EEIO analysis to estimate carbon emissions generated by each unit of output in a sector, and a process analysis technique involving a detailed analysis of the environmental inputs and outputs across the life cycle, including the use of raw materials and natural resources (e.g., energy, water) and the emission of polluting substances [29].

Williams et al. presented a scoping review of methods for including EIs into HTA. They identified monetization of EIs (i.e., shadow pricing), hybrid LCA-multicriteria decision analysis (MCDA) models, and frameworks combining qualitative and quantitative data [30].

The study by Freitas et al. [18] examined the importance of diverse value aspects in evaluating medical devices from stakeholders' perspectives. Although it offered valuable insights into developing frameworks for medical devices assessment and guiding evidence collection, it lacks an in-depth discussion of the methodological challenges involved in translating stakeholder values into practical metrics. A more critical approach could have identified the limitations of these frameworks, particularly in addressing differences in stakeholder priorities and challenges in integrating these perspectives into standardized HTA processes.

Toolan et al. [22] proposed a framework with four practical approaches for incorporating environmental information into HTA decision-making. These methods included the "information conduit," which considers republishing available environmental data without further assessment; "parallel evaluation," which integrates environmental data through new statistical methods; "integrated evaluation," which combines environmental and health economic data; and "environmental-focused evaluation," which applies to technologies offering environmental benefits beyond traditional health outcomes. While the framework was comprehensive, it could be improved by evaluating potential biases from repurposing environmental metrics for healthcare decisions. Moreover, challenges such as the limited availability of high-quality environmental data require further investigation.

Firth et al. [17] addressed the carbon footprint challenges in the pharmaceutical industry, offering tailored recommendations for the National Healthcare System (NHS), the UK Government, and the industry. These recommendations included implementing strategic roadmaps, circular economy models, and the integration of sustainability principles into procurement practices. However, the study lacked a critical evaluation of the practical feasibility of

these recommendations, particularly in the context of systemic barriers such as misaligned incentives and the absence of standardized metrics for tracking progress. Moreover, the delicate balance between fostering innovation and ensuring environmental sustainability within pharmaceutical supply chains remains underexplored, raising questions about the operationalization of these proposals.

Walpole et al. [12] emphasized the broader advantages of incorporating EI into HTA. They highlighted how such integration could enhance data collection and promote sustainable manufacturing practices. Nonetheless, their findings presupposed that HTA agencies possess the capability to standardize and analyze environmental data, an area where existing empirical evidence indicates significant gaps. Furthermore, the authors' emphasis on data-driven decision-making neglects the ethical and equity challenges with prioritizing environmental outcomes over immediate health impacts in resource-constrained settings.

Greenwood Dufour et al. [19] explored methods for incorporating environmental data into HTA deliberations, focusing on three key criteria: pollutant substances, waste management principles, and GHG emissions. However, the study lacked critical examination of the trade-offs involved in prioritizing environmental considerations alongside health outcomes. The reliance on under-researched environmental data introduced uncertainties, and the authors did not address how decision makers can mitigate these risks when incorporating environmental factors into HTA frameworks.

Hensher [20] proposed the inclusion of EI in healthcare economic evaluations by monetizing GHG emissions. The study advocated for the use of shadow pricing to represent the "social cost of carbon" within Healthcare Economic Evaluation (HEE) frameworks. While this approach offered a straightforward mechanism for integrating EI, it failed to engage with potential ethical implications, such as how monetary valuations of environmental harm might disproportionately affect decisions involving vulnerable populations. Additionally, the generalizability of this approach across diverse healthcare systems has yet to be adequately examined.

McAlister et al. [21] proposed incorporating carbon emissions into HTA through methodologies such as linking LCA with decision-analytical models or using emissions as a modifier in MCDA. While these methods provided a robust framework, the reliance on weighted-sum models in MCDA raised concerns regarding the transparency and subjectivity of assigning weights to environmental criteria. Moreover, the integration of LCA, particularly for technologies with fragmented supply chains, was insufficiently addressed, leaving key challenges in practical implementation unresolved.

Alami et al. [23] investigated how environmental sustainability can be embedded in the evaluation and procurement of digital health technologies. Through stakeholder

interviews, they highlighted systemic gaps such as limited awareness, lack of organizational incentives, and insufficient governance tools. The study proposed greater institutional commitment, clearer procurement guidance, and interdisciplinary collaboration to mainstream sustainability into HTA processes.

Lehoux et al. [24] framed HTA within the "responsible innovation in health" paradigm, calling for a reorientation of HTA to better align with long-term health system challenges like environmental degradation. They argued for broader stakeholder engagement and the integration of forward-looking criteria (including sustainability) to foster resilient and equitable health innovation ecosystems.

Bobini and Cicchetti [25] conducted a global stakeholder survey, finding widespread support for including environmental sustainability in HTA. However, they also found considerable uncertainty regarding methodological feasibility, capacity building needs, and the lack of harmonized standards. The authors recommended the development of global guidance and the integration of environmental sustainability training in HTA education.

### 3.1 Summary of the Main Findings of the Scoping Review

In summary, the review identified 15 studies exploring methods for incorporating EI into HTA. These studies fall into two main approaches:

*Integration into economic models:* Several contributions proposed including EI in traditional health economic evaluations. Hensher [20] and McAlister et al. [21] suggested monetizing GHG emissions using shadow pricing or including EI in MCDA. Similarly, the reviews by Desterbecq and Tubeuf [26], Guirado-Fuentes et al. [27], Pinho-Gomes et al. [28], and Polisenia et al. [29] proposed extending cost-utility analysis (CUA), CBA, and budget-impact analysis to incorporate environmental data, using approaches such as the social cost of carbon, life cycle costing, and ecological economics. Despite their theoretical appeal, these methods are limited by the lack of standardized and disaggregated emission data, and by methodological challenges in defining appropriate weighting schemes for environmental criteria [27].

*Standalone environmental assessments within HTA:* Several studies proposed evaluating EIs independently from economic outcomes, using tools like LCA and MCDA [12, 19, 22, 29]. Additional contributions emphasized the role of governance, institutional capacity, and stakeholder involvement in embedding sustainability into HTA. Alami et al. [23] and Bobini and Cicchetti [25] highlighted the need for dedicated tools, clear guidelines, and training, while Lehoux et al. [24] called for a broader conceptual shift toward responsible innovation in health. Although these approaches allow for a more holistic consideration of EIs, they often

lack integration with health and economic outcomes, complicating decision-making. The absence of standardized frameworks reinforces the need for future research to develop shared methods and consensus-based criteria for integrating environmental sustainability into HTA.

Finally, some contributions such as those from Firth et al. [17] and Freitas et al. [18] emphasized the importance of stakeholder engagement, regulatory frameworks, and implementation strategies to facilitate the practical inclusion of EI in HTA, although empirical applications remain limited.

Overall, the literature highlights the absence of a shared methodological framework for determining when and how EI should be prioritized and integrated into HTA. Future research should aim to establish consensus-based standards that allow environmental criteria to be incorporated alongside clinical and economic dimensions.

Further details on included articles and reviews are included in Table 1, which summarizes the main challenges and proposed strategies to include EI into HTA, and Table 2, which summarizes the strengths and limitations of each study.

## 4 Discussion

In this study, ten original articles and five reviews on frameworks and methods used to potentially incorporate EI into HTA were described. The findings suggested that the inclusion of EI into HTA has become an increasingly pressing and cross-cutting need. Although evidence suggested that EI should be evaluated across the entire life cycle of health technology (i.e., production, distribution, elimination, and wastage), the studies revealed a lack of emphasis on which parameters should be considered in the assessment and how this dimension should be integrated in HTA evaluation.

The first issue that should be addressed is the definition of the most appropriate method for the inclusion of EI into HTA. For instance, EI might be included by using new frameworks that employ methods such as information conduit, parallel evaluation, integrated evaluation, or environment-focused evaluation [22]. If EI cannot be integrated into the HTA as a standalone item, it could be converted into monetary units and included as a cost in existing economic evaluation models such as CBA or CEA, or included in the MCDA approach [20, 21].

To date, few studies have incorporated EI into economic evaluation [30]. Fordham and colleagues examined the EI of diabetes management in the UK [31]. Maintaining or improving glycemic control in type 2 diabetes (T2D) patients was associated with reduced carbon emissions. The greatest CO<sub>2</sub> reduction (18%) occurred in patients on the first-line therapy with glycosylated hemoglobin (HbA1c) around 7.0% (53 nmol/mol), mainly due to the prevention

**Table 1.** Main challenges and proposed strategies to include environmental impact into health technology assessment (HTA)

Article	Main challenges	Strategies proposed
Freitas et al., 2023 [18]	<ul style="list-style-type: none"> <li>● Development of appropriate framework</li> </ul>	<ul style="list-style-type: none"> <li>● The study provides important insights to inform such a framework development</li> </ul>
Toolan et al., 2023 [22]	<ul style="list-style-type: none"> <li>● Development of appropriate analytical techniques</li> <li>● Necessity of consensus on method to balance environmental impacts against other costs and benefits</li> <li>● Directing analytical skills and resources to the task</li> <li>● Addressing the consequences of implementation</li> </ul>	<ul style="list-style-type: none"> <li>● Adopting the information conduit approach to avoid the inclusion of societal preferences into HTA evaluation</li> <li>● Included environmental impacts as different items compared with other costs and outcomes (all human outcomes are subsidiary to and dependent on planetary health)</li> <li>● HTA agencies should provide methods to assess environmental impact into</li> </ul>
Firth et al., 2023 [17]	<ul style="list-style-type: none"> <li>● Appropriate incentives and resources for pharmaceutical companies to become more environmentally responsible</li> </ul>	<ul style="list-style-type: none"> <li>● Control cost of healthcare with pharmaceutical prices being explicitly targeted through policies</li> </ul>
Walpole et al., 2023 [12]	<ul style="list-style-type: none"> <li>● Necessity of data on environmental impact of sufficient quality</li> <li>● Agreement on appropriate methods to include environmental data</li> <li>● Agreement on appropriate methods to estimate the impact to include environmental data</li> <li>● Weight to be applied to environmental impact, other costs and outcomes</li> </ul>	<ul style="list-style-type: none"> <li>● Multidisciplinary collaboration, including inputs from environmental science, engineering, economics, and health policy</li> </ul>
Greenwood Dufour et al., 2022 [19]	<ul style="list-style-type: none"> <li>● Necessity of data on environmental impact</li> <li>● Lack of capacity of HTA agency to assess environmental impact (lack of trained staff)</li> </ul>	<ul style="list-style-type: none"> <li>● A triage process might be used by HTA agencies to choose the health technologies for which an assessment of environmental impact is appropriate</li> </ul>
Hensher, 2020 [20]	<ul style="list-style-type: none"> <li>● Complexity of quantification and attribution of GHG emissions</li> <li>● Absence of appropriate methods to estimate GHG</li> <li>● Political barriers and variation across countries</li> <li>● Absence of standardized methods to assess GHG</li> </ul>	<ul style="list-style-type: none"> <li>● Guideline to make accessible estimates for key pollutants and their attribution to various health services</li> <li>● Interdisciplinary approach to integrate concepts and perspectives from ecological economics with health economics</li> </ul>
McAlister et al., 2022 [21]	<ul style="list-style-type: none"> <li>● Necessity of data on environmental impact</li> <li>● Absence of appropriate methods on how carbon costs be incorporated in HTAs</li> </ul>	<ul style="list-style-type: none"> <li>● Estimation of carbon emissions during the LCA methods (two methods: environmentally extended input–output analysis and process-based LCA)</li> <li>● Inclusion into HTA of the carbon emissions data as decision modifier, part of MCDA, or costs</li> </ul>
Alami et al., 2023 [23]	<ul style="list-style-type: none"> <li>● Lack of organizational readiness</li> <li>● Absence of governance tools</li> </ul>	<ul style="list-style-type: none"> <li>● Engage stakeholders in procurement design</li> <li>● Establish governance frameworks</li> </ul>
Lehoux et al., 2025 [24]	<ul style="list-style-type: none"> <li>● Low awareness on environmental issues in digital health procurement</li> <li>● Traditional HTA scope too narrow to capture systemic challenges like environmental sustainability</li> </ul>	<ul style="list-style-type: none"> <li>● Promote interdisciplinary collaboration</li> <li>● Adopt RH approach</li> <li>● Align HTA with long-term system and societal goals</li> </ul>
Bobini and Cicchetti, 2024 [25]	<ul style="list-style-type: none"> <li>● Methodological uncertainty</li> <li>● Limited training</li> <li>● Lack of harmonized standards across HTA agencies</li> </ul>	<ul style="list-style-type: none"> <li>● Develop harmonized guidelines</li> <li>● Invest in HTA training on sustainability</li> <li>● Support international coordination</li> </ul>

*GHG* greenhouse gas, *LCA* life cycle assessment, *MCDA* multicriteria decision analysis, *RH* responsible innovation in health

**Table 2.** Strengths and limitations of the included articles and reviews

Article	Strengths	Limitations
Freitas et al., 2023 [18]	<ul style="list-style-type: none"> <li>• Large and diverse panel of stakeholders</li> <li>• Additional value to aspects not identified in the existing frameworks' literature</li> <li>• Insights to inform future framework development</li> </ul>	<ul style="list-style-type: none"> <li>• Only Portuguese participants included</li> <li>• Unbalanced across stakeholder groups and small size of the participants' group</li> <li>• Due to the Delphi method being adopted, possibility of cognitive biases and other behavioral influences during the process</li> </ul>
Toolan et al., 2023 [22]	<ul style="list-style-type: none"> <li>• Comprehensive exploration of approaches</li> <li>• Relevance to global sustainability goals</li> <li>• Holistic perspective on environmental impacts</li> <li>• Practical implications</li> <li>• Acknowledgment of technical and methodological challenges</li> </ul>	<ul style="list-style-type: none"> <li>• Lack of empirical evidence</li> <li>• Insufficient critical analysis</li> <li>• Minimal discussion on stakeholder perspectives</li> <li>• Operational feasibility not addressed</li> </ul>
Firth et al., 2023 [17]	<ul style="list-style-type: none"> <li>• Actionable recommendations</li> <li>• Comprehensive framework</li> <li>• Interdisciplinary approach</li> </ul>	<ul style="list-style-type: none"> <li>• Limited empirical evidence</li> <li>• Lack of implementation strategies</li> <li>• Overemphasis on the national context (UK)</li> </ul>
Walpole et al., 2023 [12]	<ul style="list-style-type: none"> <li>• Actionable insights</li> <li>• Comprehensive framework</li> <li>• Emphasis on collaborative efforts</li> <li>• Balancing environmental and healthcare goals</li> </ul>	<ul style="list-style-type: none"> <li>• Lack of empirical evidence</li> <li>• Challenges in data quality and accessibility</li> <li>• Over-reliance on developed health systems</li> <li>• Limited exploration of economic implications</li> </ul>
Greenwood Dufour et al., 2022 [19]	<ul style="list-style-type: none"> <li>• Comprehensive framework</li> <li>• Global perspective</li> <li>• Actionable recommendations</li> <li>• Balancing environmental and healthcare goals</li> </ul>	<ul style="list-style-type: none"> <li>• Limited empirical evidence</li> <li>• Challenges in data quality and accessibility</li> <li>• Resource constraints underexplored</li> <li>• Limited exploration of economic implications</li> </ul>
Hensher, 2020 [20]	<ul style="list-style-type: none"> <li>• Innovative approach</li> <li>• Comprehensive framework</li> <li>• Evidence-based discussion</li> <li>• Practical implications</li> </ul>	<ul style="list-style-type: none"> <li>• Limited empirical evidence</li> <li>• Narrow scope of environmental metrics</li> <li>• Challenges in data quality and accessibility</li> <li>• Over-reliance on developed health systems</li> </ul>
McAlister et al., 2022 [21]	<ul style="list-style-type: none"> <li>• Innovative approach</li> <li>• Practical implications</li> <li>• Comprehensive scope</li> <li>• Interdisciplinary approach</li> </ul>	<ul style="list-style-type: none"> <li>• Lack of empirical evidence</li> <li>• Narrow scope of environmental metrics</li> <li>• Over-reliance on developed health systems</li> <li>• Operational feasibility not addressed</li> </ul>
Alami et al., 2023 [23]	<ul style="list-style-type: none"> <li>• Grounded in stakeholder interviews</li> <li>• Focused on procurement</li> <li>• Practical suggestions for digital health</li> </ul>	<ul style="list-style-type: none"> <li>• No quantitative environmental impact assessment</li> <li>• Limited to digital technologies</li> </ul>
Lehoux et al., 2025 [24]	<ul style="list-style-type: none"> <li>• Strong theoretical foundation</li> <li>• Addresses systemic innovation</li> <li>• Forward-looking perspective</li> </ul>	<ul style="list-style-type: none"> <li>• Conceptual only, no empirical application</li> <li>• No methodological tools provided</li> </ul>
Bobini and Cicchetti, 2024 [25]	<ul style="list-style-type: none"> <li>• Broad international sample</li> <li>• Highlights stakeholder consensus</li> <li>• Identifies capacity-building needs</li> </ul>	<ul style="list-style-type: none"> <li>• No framework tested</li> <li>• Limited detail on practical implementation</li> <li>• Survey self-reporting bias</li> </ul>
Desterbecq and Tubeuf, 2023 [26]	<ul style="list-style-type: none"> <li>• First attempt at studying whether the environment-related dimensions of healthcare products are included in economic evaluations</li> <li>• Comprehensive review</li> <li>• Practical implications</li> </ul>	<ul style="list-style-type: none"> <li>• Language restriction (English and French)</li> <li>• Narrow scope (EU-12 and G20 countries)</li> <li>• Lack of standardization</li> <li>• Data heterogeneity</li> </ul>
Guirado-Fuentes et al., 2023 [27]	<ul style="list-style-type: none"> <li>• Comprehensive scoping review</li> <li>• Interdisciplinary insights</li> <li>• Future directions and challenges</li> <li>• Global perspective</li> </ul>	<ul style="list-style-type: none"> <li>• Data constraints</li> <li>• Limited practical applications</li> <li>• Narrow scope (high-income countries)</li> </ul>
Pinho-Gomes et al., 2022 [28]	<ul style="list-style-type: none"> <li>• Comprehensive scoping review</li> <li>• Interdisciplinary approach</li> <li>• Practical implications</li> <li>• Global perspective</li> </ul>	<ul style="list-style-type: none"> <li>• Limited empirical evidence</li> <li>• Challenges in data quality and accessibility</li> <li>• Narrow scope of environmental metrics</li> <li>• Operational feasibility not addressed</li> </ul>
Polisena et al., 2018 [29]	<ul style="list-style-type: none"> <li>• Comprehensive scoping review</li> <li>• Practical implications</li> <li>• Interdisciplinary approach</li> <li>• Global perspective</li> </ul>	<ul style="list-style-type: none"> <li>• Limited empirical evidence</li> <li>• Challenges in data quality and accessibility</li> <li>• Narrow scope of environmental metrics</li> <li>• Operational feasibility not addressed</li> </ul>

Table 2. (continued)

Article	Strengths	Limitations
Williams et al., 2024 [30]	<ul style="list-style-type: none"> <li>• Comprehensive scoping review</li> <li>• Clear synthesis of methods</li> <li>• Practical examples</li> </ul>	<ul style="list-style-type: none"> <li>• Limited to available literature</li> <li>• Variability in terminology</li> <li>• Lack of quality assessment</li> </ul>

of renal complication. A similar trend was noted with third-line therapy (13%), though first-line therapy showed fewer complications. Various products contribute to EI, such as a glucose sensor, batteries, test solution, test strips, box for test strips, insulin pens, and pumps [32]. Considering the increased number of individuals with T2D, using products with longer lifespans, less frequent administration, and minimal packaging could reduce EI, provided efficacy is maintained.

McAlister and colleagues estimated the EI of morphine's life cycle, from poppy farming to producing 100 mg in 100 mL of intravenous morphine [33]. Over 60% of its carbon footprint came from sterilization and packaging. Comparing different opiates and administration routes may help identify lower-impact therapies. This supports including EI in HTA to guide sustained choices [33]. Assessing opioids' post-use impact such as residual in water and toxicological effects is also crucial [34]. Similar considerations apply to anesthetic drugs [5]. Evaluating their EI could help clinicians choose effective treatments while reducing environmental damage. In some cases, lowering anesthetic gas emissions may reduce health risk linked to air pollution [5].

Although evidence underscored the importance of EI data in HTA, the debate over who should generate such data remained unresolved (see Table 1). Some suggested that companies should be responsible for providing these data, similar to efficacy and safety data, while others suggested that agencies should either generate these data themselves or encourage collaboration with companies [12]. In this context, considering the different approaches adopted by health agencies worldwide in evaluating health technology, it is reasonable to suppose that agencies would be better positioned to provide guidelines on data generation methods rather than produce the data themselves. Establishing such guidelines could contribute to the creation of standardized data that could be used by different stakeholders and aligned with national and international recommendations.

Authors particularly debated on the methods to include one specific impact category indicator, namely GHG, into HTA. Pekarsky and colleagues [35] warned that differences in regulatory requirements between the GHG reduction and health sectors could create asymmetries in evidence availability. Conversely, new medical devices designed to reduce GHG emission might require more robust evidence, as existing health regulations prioritize safety and efficacy. Integrating GHG assessment into HTA could introduce complexity

and costs, prompting discussion on whether a selective approach, based on potential decision-making impact, was preferable. Moreover, existing GHG reduction schemes already provide financial and regulatory incentives, complicating the introduction of additional payments for GHG reduction through health technologies.

Recent studies further enrich this debate by offering both empirical insights and theoretical frameworks. Alami et al. [23] investigated how environmental sustainability can be embedded in the procurement and assessment of digital health technologies, highlighting the lack of institutional readiness and appropriate governance tools. Their findings suggest that stakeholder engagement and tailored procurement guidelines are essential for integrating environmental considerations into HTA. Bobini and Cicchetti [25], through a global stakeholder survey, confirmed a strong interest in integrating EI into HTA, but emphasized the need for harmonized methodological standards, specialized training, and improved data accessibility. Lehoux et al. [24] proposed a more conceptual rethinking of HTA through the lens of responsible innovation in health, advocating for the inclusion of societal and environmental values in the early stages of health technology development and evaluation. These studies highlight the need for HTA bodies to broaden their perspective beyond conventional economic and clinical dimensions, developing new competencies and fostering cross-sector collaborations to effectively incorporate sustainability into decision-making.

The methods to include EI data in HTA and the methods to generate evidence on the EI of new technologies (i.e., type of studies necessary to generate data on EI, methods for EI quantifications, and type of EI that should be assessed) do not represent a unique gap in this field. Another limit to include EI into HTA is represented by the perspective that should be adopted into the evaluation. Generally, the HTA is conducted by adopting the NHS perspective; however, to include this new domain in the assessment, it is necessary to adopt the broader societal perspective. Furthermore, it is crucial to consider the time horizon for the evaluation. This aspect, as well as the segment of the life cycle of the technology included in the HTA, is crucial. In this regard, the time horizon and the segment of the life cycle of technology might depend on the type of health technology evaluated. Considering the importance of these aspects for the evaluation of the new technology itself, but also future reassessment and comparison with other technologies, the regulatory

agencies should provide new guidelines in order to guarantee high standards and transparency of the evaluation.

The implementation of any health technology incurs costs and outcomes across economic, clinical, and non-clinical sectors. In this context, the EI of existing and new technologies is a critical factor that should be assessed throughout their life cycles. Although a growing body of evidence has explored methods to incorporate EI into HTA, further research is required to address key challenges and define gold standards for the methodological approaches.

In the upcoming years, numerous new health technologies will be approved, and others will be repurposed. Given limited economic resources, it is crucial to prioritize therapies with lower EI to minimize their societal and healthcare system impact. Enhancing transparency regarding the EI of new technologies necessitates continuous monitoring and regulation of manufacturer-provided data by international and national regulatory agencies. Furthermore, independent research by high-caliber institutions, such as universities, should be encouraged.

Regarding methodologies to include EI into HTA, the availability of multiple approaches ensures better adaptability to various health technologies. Future research could leverage innovation such as artificial intelligence to integrate different data sources and provide new insight into the EI of health technologies. To achieve this, HTA agencies must develop expertise in environmental assessment and incorporate environmental data into their evaluation. A critical first step involves establishing consensus guidelines to standardize EI evaluation procedures across HTA agencies. Similarly, regulatory agencies and manufacturers must reach a consensus on the type of data required to assess the EI of a technology. The HTA is crucial for determining whether to use a technology and, most importantly, for assessing whether the healthcare system/country can sustain its economic impact. For this reason, if in the future the EI domain will be included in all HTA, it will be necessary to reconsider the definition and value of the current thresholds and criteria in place in different countries, regarding the reimbursement eligibility of a technology. In addition, considering the impact of healthcare technologies on soil, air, and water, further studies are needed to develop methods capable of estimating the EI of them through their entire life cycle (from production to usage and eventually disposal) and on different matrices.

This review examined potential methods and associated advantages and limitations of incorporating EI into HTA and highlighted potential areas for further investigation. Increased awareness of EI among companies, regulatory agencies, and policymakers could accelerate the integration of EI into HTA processes. Given the novelty of this field, the review identified key areas that warrant additional research. For instance, it is essential to determine which specific types of EI, based on the

affected matrices (i.e., air, soil, water), should be included in HTA. Additionally, identifying the most appropriate segment of a technology's life cycle for EI evaluation is crucial for comprehensive assessment. Finally, as the availability of data in this field continues to grow, it will be vital to develop innovative methods that integrate EI data with economic metrics to create actionable indicators for stakeholders. Furthermore, given the limited economic resources available for such evaluations, it is important to clearly define the roles of regulatory agencies and manufacturers in this process.

The findings of this review should be interpreted in light of limitations. First, we employed a stringent search strategy focusing on articles explicitly mentioning "HTA" and "environmental impact." This approach may have excluded some papers that used broader or less specific terminology. To mitigate this limitation, we included published reviews on the same topic that used broader search strategies. In addition, due to the novelty of the field and the growing body of evidence in recent years, we limited the analysis to more recent studies to focus on the most recent methods indicated in the literature, avoiding significant overlap with papers included in prior reviews. Second, like other similar reviews, we did not assess the methodological quality of the selected studies, as the primary goal was to identify cases and challenges. Third, considering the novelty of this topic, potential publication bias cannot be completely excluded. Finally, the restriction to English-language publications led to the omission of non-translated publications in other languages. However, a grey literature search using a search engine was performed to include potential missing records.

## 5 Conclusion

EI is emerging as an important criterion for conducting a complete and comprehensive HTA. However, its inclusion is challenging, due to the lack of clear national and international guidelines on methods and approaches to include this domain in HTA. Additional challenges include limited data available on the EI of technologies, unclear responsibilities for data collection, process gaps, and the limitations of the existing methods. Further research is urgently needed to identify the most appropriate methods for incorporating and weighting this criterion based on the type of health technology being evaluated. Additionally, studies should focus on testing the frameworks already proposed for integrating EI into HTA. Collaboration between health agencies and companies is essential to generate robust evidence on the EI of technologies.

Given the complexity of incorporating EI into HTA, standardized methodologies should be developed for outcome measures, EI assessment, and monetization methods. Moreover, clear guidelines are needed to establish EI as

a new domain within HTA [27]. In this context, it is also crucial to generate new evidence on the EI of technologies across different matrices, including soil, water, and air, throughout their life cycle. Furthermore, exploring methods to integrate multiple data sources related to the EI of technologies is essential for a more comprehensive evaluation. Finally, EI should be considered in HTA, not only for therapies and devices used in chronic and prevalent diseases (e.g., cardiovascular and metabolic diseases), but also for those targeting rare diseases and emerging therapies expected to become available in the coming years. Strengthening cooperation between health agencies and companies could facilitate the integration of EI into HTA, ultimately contributing to both healthcare system efficiency and environmental sustainability.

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