



Mapping environmental contamination of carbon footprints and health impact from the breastmilk substitutes consumption in Southeast Asia: A scoping review

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ABSTRACT

Background: In Southeast Asia, breastmilk substitutes (BMS) have quickly turned into a widely accepted social practice. But the health and environmental effects are not thoroughly examined. BMS producers and manufacturers, through their industrial processes, packaging waste, and transportation, are the major contributors to ecological degradation, while formula feeding brings health risks for infants. **Methods:** This scoping review was performed in accordance with the PRISMA-ScR guidelines and brought together results from 23 articles published in reputable journals between 2015 and 2025. The databases explored were PubMed, Scopus, Cochrane Library, Google Scholar, and Crossref. Data was gathered, and the latter was done through the Joanna Briggs Institute tools, and then it was analyzed thematically. **Findings:** There is a clear link between BMS production and consumption, and major environmental impacts resulting from these 3-MCPD, glycidyl esters are examples of chemical contaminants; microplastics and large amounts of GHG emissions are also included (3–6 kg CO₂-eq per kg product). Water and energy use are augmented due to formula preparation, and the disposal of materials has worsened plastic pollution in urban rivers. Health investigations pointed out that babies on a formula diet are more exposed to infections. Economists' forecasts have also pointed to avoidable health and environmental costs arising from reduced breastfeeding, and these are found to be considerable. **Conclusion:** The use of BMS has a detrimental effect on both mankind and nature, while breastfeeding is still the most eco-friendly and health-producing feeding technique. **Novelty/Originality:** Besides being the first study to establish BMS consumption with environmental contamination, carbon footprints, and health outcomes in Southeast Asia, this review also redefined infant feeding as an issue of planetary health.

KEYWORDS: breastmilk; breastfeeding carbon footprints; breastmilk substitutes; environment; pollution.

1. Introduction

In the twenty-first century, the intersection of infant and maternal crises in health with the global ecological crises has spawned a sense of urgency in the field called planetary health. This interdisciplinary model acknowledges that the well-being of human beings

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cannot be separated from the integrity of natural processes, including climate, land, and water cycles (Whitmee et al., 2015). In this paradigm, infant feeding practices are placed at the center, although they are frequently considered peripheral. The complexity of breastfeeding as an inherently renewable, low-input biological system is in stark contrast to the fact that the industrially intensive production and consumption of breastmilk substitutes (BMS) are part of globalised dairy production and consumption networks, the type of packaging systems, and waste stream (Karlsson et al., 2019; Karlsson & Röös, 2019)

Increased consumption of infant formula has been observed and by over 50 per cent since 2005, with much of this rise in income rates, urbanisation, and shifts in maternal labour participation in low- and middle-income countries (Baker et al., 2021). Southeast Asia is particularly a flattening region in this change, with formula sales growing at an estimated rate of 810% per year (Willcox et al., 2021). As much as the change might represent a sociocultural modernisation and income growth, the impact of the same on the environment manifests as increased greenhouse gas (GHG) emissions, land degradation, and decline of water resources.

The uncritical effect of early weaning is suggested to last only half a year before substitution by other types of food breastfeeding with the subsequent six months, followed by other foods up to the age of two (WHO, 2023). Breastmilk is also the best source of nutrition and immunological protection, but it uses as few resources, produces less waste, and emits as carbon emissions as compared to any manufactured alternative. Smith et al. (2024) created the Green Feeding Climate Action Tool and showed that exclusive breastfeeding could reduce by up to 95 percent of the carbon footprint of infant feeding over formula-based feeding (Smith et al., 2024).

BMS, in turn, depends on the dairy production, which contributes about 3::% of the total anthropogenic GHG emissions in the global arena 2024. Life-cycle assessments (LCA) indicate that the 1 kg of powdered infant formula production has an estimated impact of 1114 kg CO₂-equivalent emissions, 400600 L of water consumption (Karlsson et al., 2019), and the energy needs of the transportation process, namely heating the water, sterilisation, refrigeration, all contribute to indirect emission, especially within the countries that are reliant on the use of fossil-based energy as a source (Long et al., 2021).

Southeast Asian countries are particularly receptive to the environmental effects of BMS owing to the rapid industrialisation, poor waste-management systems, and dense populations. (Dadhich et al., 2021; Karlsson et al., 2019). approximated that the production of formula in five countries in Asia-Pacific contributed to more than 2.8 million metric tonnes of CO₂ emissions every year, which is equivalent to the amount of gasoline consumed by 1.2 billion litres annually. The second significant pollutant is packaging waste. The BMS packaging is based on multilayer plastics and metallised foils, which have limited chances of getting recycled in low-resource settings. In other economies like the Philippines and Vietnam, the post-consumer cans and sachets of formula are the source of marine plastic leakage (Jambeck et al., 2018). The streams of this waste are a source of undervalued long-lasting pollution, which has long-term effects on the environment.

The replacement of breastfeeding by formula is associated with health risks that have been well documented both to the infants and the mothers. So in Southeast Asia, the rate of hospitalisation due to diarrhoeal and respiratory illnesses has been linked (Heine et al., 2017) sanitation, and hygiene (WASH) infrastructure (Pries et al., 2016). Maternally, breastfeeding duration is associated with lower risks of breast and ovarian cancer, metabolic syndrome, and postpartum depression (Victora et al., 2016). At the population level, low rates of breastfeeding lead to increased costs and diminished human capital at the health levels and low rates of human capital accruals in the form of financial (Mowl et al., 2023). These dangers are compounded by environmental pollution. Babies who have been exposed to formula compromised with heavy metals, glycidyl esters, and microplastics might have long-term developmental or endocrine implications (Heine et al., 2017). Also, the environment and physiology form a feedback loop with lactation success and maternal health being the indirect consequences of air pollution and stressors linked to climate (Zielinska & Hamulka, 2019).

The international marketing of breastmilk substitutes is, by such laws as the International Code (WHO, 1981) and various World Health Assembly (WHA) resolutions, still poorly regulated across Southeast Asia. Marketing of BMS, especially digital and hospital-based promotions, is the primary factor for the failure of various government breastfeeding programs, and even results in a gradual decline in breastfeeding rates (Zehner, 2016).

The countries in the region have also lagged in incorporating their infant feeding systems into the Nationally Determined Contributions (NDCs) lists under the Paris Agreement (UNFCCC, 2024) BMS reduction recognition as an action for both public health and climate would help not only in the fulfillment of multiple SDGs, namely SDG 2 (Zero Hunger), SDG 3 (Good Health and Well-Being), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action), but also in the integrated implementation of all these goals. Moreover, integrating breastfeeding promotion into national sustainability frameworks would be beneficial across sectors—through diminishing emissions, enhancing mother-child health, and fortifying the accountability of the environment (Pope et al., 2021).

In light of the above-mentioned interconnected obstacles, the current scoping review serves to systematically portray the evidence of environmental contamination, carbon footprints, and health consequences of BMS consumption in Southeast Asia. It intends to conduct a huge synthesis of data from 23 peer-reviewed studies from various fields, such as epidemiological, laboratory, and life-cycle, to: Recognize the major sources and ways of pollution in the environment that are linked to BMS production and disposal;; Estimate the carbon footprints and resource consumption of BMS in comparison with breastfeeding; and; Discuss the health effects of the consumption of formula in the context of the regional socio-environmental situation. This study of mapping is backward to the filling of a very critical gap of evidence in the intersection of nutrition, environment, and planetary health. Knowing how the patterns of BMS consumption are affected by and are the cause of the regional carbon and contamination profiles is very important for the design of integrated policies—covering areas of maternal-child health, sustainable food systems, and climate resilience.

2. Methods

2.1 Study design and framework

The current study uses a scoping review design and was conducted according to the methodological guidelines of the Joanna Briggs Institute Manual of Evidence Synthesis (2020); it was reported in line with the PRISMA-ScR checklist (Tricco et al., 2018). The scoping review strategy was chosen because it allowed mapping the scope and variety of extant evidence on environmental contamination, carbon footprint, and health effects of BMS in Southeast Asia. In contrast to systematic reviews, scoping reviews are particularly applicable to new and interdisciplinary topics with a wide range of study designs, outcomes, and contexts, and whose main objective is to define knowledge gaps instead of testing intervention effectiveness.

This review was prospectively registered on the Open Science Framework (OSF) to indicate transparency and reproducibility. The conceptualisation used to write this review was in the planetary health approach, as it was realised that infant-feeding habits are all-time biomedical, social, and ecological phenomena, which affect resource consumption, carbon emissions, and population health outcomes.

The review was guided by several research questions developed using the Population–Concept–Context (PCC) framework. The first question examined whether there is evidence regarding environmental pollution associated with the production, packaging, preparation, or disposal of breast milk substitutes (BMS) in Southeast Asia. The review also investigated the extent of carbon footprints and resource use generated by BMS in comparison with breastfeeding practices in the region. In addition, the study explored the direct and indirect health consequences of BMS use for both infants and mothers in Southeast Asian countries.

Furthermore, the review sought to understand the contextual and policy-related factors that may moderate these effects, including industrial systems, regulatory environments, and socioeconomic conditions. Lastly, the study aimed to identify existing knowledge gaps and methodological limitations in the literature concerning the environmental and health impacts associated with BMS consumption. Eligibility criteria were defined using the PCC framework and refined through pilot screening:

Table 1. The criteria of the study

Criterion	Inclusion	Exclusion
Population	Studies focusing on infants, mothers, caregivers, formula consumers, or populations affected by BMS production/disposal	Animal experiments or unrelated population groups
Concept	Environmental contamination, carbon footprint, greenhouse-gas emissions, resource consumption, waste generation, or health outcomes linked to BMS	Studies only about breastfeeding promotion without environmental or health comparison
Context	Southeast Asian countries (Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, Timor-Leste, Vietnam) and globally comparable data relevant to the region	Studies conducted solely in non-comparable high-income contexts
Study type	Peer-reviewed articles, grey literature, governmental or NGO reports, conference papers with sufficient methodological detail	Editorials, commentaries, news articles without data
Time frame	Publications from 2015 to October 2025	Earlier studies lacking methodological relevance

2.2 Search strategy and information sources

An elaborate electronic search was done within the months of January and March 2025 on the five major databases, including PubMed, Scopus, Chocrane Libraray, Crossref, and Google Scholar. Collaborative development of search terms was carried out with the help of Boolean operators, truncation, and synonyms to embrace the variations of the key concepts: ("breastmilk substitutes" OR "infant formula" OR "formula feeding")AND ("environmental contamination" OR "pollution" OR "plastic waste" OR "carbon footprint" OR "greenhouse gas")AND ("health impact" OR "infant health" OR "maternal health") AND ("Southeast Asia" OR "Indonesia" OR "Malaysia" OR "Thailand" OR "Philippines" OR "Vietnam" OR "Cambodia" OR "Laos" OR "Myanmar" OR "Brunei" OR "Timor-Leste")

Organisational repositories and other grey literature (such as the World Health Organization (WHO), UNICEF, FAO, ASEAN Health Cluster 2, and national ministries of health or environment) were searched. There was also an application of backward and forward citation tracking of the key articles in order to identify other sources. The citations retrieved were all imported into the "Evidence tool," where they were removed as duplicates and screened.

2.3 Study selection process and charting extraction of data

The screening process was conducted through three stages. The first stage involved independent reviewers assessing the identified studies based on the established inclusion criteria to ensure objectivity and consistency in the selection process. The second stage consisted of a full screening of potentially relevant full-text articles to evaluate their relevance, methodological quality, and contribution to the research objectives. The final stage involved conducting a critical appraisal of the selected studies in order to assess the credibility, validity, and overall quality of the evidence included in the review.

A data-charting form was developed using the JBI templates in Microsoft Excel in the form of a standardized extraction sheet to ensure consistency in data collection and

analysis. From each included study, several variables were extracted systematically. These variables included bibliographic information, such as the author's name, year of publication, and country of study, as well as the study design and research setting. In addition, the review documented environmental effects associated with the use of breast milk substitutes, including the types of contamination, pollutants, or waste streams identified in the studies.

The extracted data also covered the carbon footprint of the products, including measurements related to carbon dioxide (CO₂) equivalents and water or energy intensity. Furthermore, health outcomes reported in the studies, such as infant morbidity, nutritional indicators, hospitalization rates, and related health impacts, were recorded. The charting process also included significant findings and conclusions from each study, along with the results and limitations identified during the quality appraisal process.

2.4 Critical appraisal

This review had a methodological appraisal, although scoping reviews do not normally filter out studies on quality grounds, as a way of contextualising the strength of evidence. The studies have been assessed with the help of the corresponding JBI Critical Appraisal Checklist regarding the type of design used in them, including cohort, analytical cross-sectional, economic assessment, laboratory/risk-assessment, modelling, and qualitative/narrative synthesis. The checklists were based on the Manual of JBI Reviewer (2020) (jbi.global) and implemented by two reviewers, doing this individually. Each criterion was scored based on a Yes/No/Unclear response (it was divided into Yes/No/Unclear), and a qualitative summary (High/Moderate/Low quality) was provided according to the percentage of the first, and the transparency of the methods in general. In Supplementary Table 1 and Appendix A, the outcomes of the assessment at the item level are detailed.

2.5 Data synthesis and analysis

Due to the heterogeneity of the study designs and outcomes, the findings were synthesized using a narrative approach. The results were classified into three main areas to facilitate a more systematic analysis and interpretation. The first area focused on environmental contamination, which included laboratory- or field-level evidence related to contamination, chemical residues, and waste streams generated from breast milk substitutes (BMS). The second area addressed carbon footprints and resource intensity, encompassing findings derived from life-cycle assessment (LCA), modeling, or estimation studies that evaluated the environmental burden associated with BMS production and consumption. The third area examined health outcomes and socio-economic health impacts, including epidemiological, clinical, and economic findings comparing the effects and implications of BMS use with the benefits of breastfeeding practices.

In each sphere, the evidence has been coded using themes (i.e., production emissions, water use, chemical contamination, infant health outcomes, economic burden). There were cross-cutting studies that sought to understand patterns of geography, policy setting, and sustainability connections. In cases where quantitative data were found, descriptive statistics (ranges, means, or percentages) were tabulated; meta-analysis was not performed due to the heterogeneity of the study results and measures.

2.6 Ethical considerations and limitation

Since the data collection methods employed in this study were secondary data collection, which involved published and publicly established sources, institutional ethics approval was not required. Nonetheless, the review was conducted in keeping with the tenets of research integrity, transparency, and responsible reporting so that all sources have been cited properly and in line with the International Committee of Medical Journal Editors

(ICMJE) principles. This study has been registered on OSF, and full-text access was stored on the OSF repository to be retrieved.

To enhance the methodological rigor of the study, the review adhered to recommended practices for environmental-health scoping reviews as proposed by Hilary Arksey and Lisa O'Malley (2005), as well as Dan Levac et al. (2010). Nevertheless, several limitations remain within the review process. One limitation concerns the possibility of publication bias, as the grey literature search, although relatively comprehensive, may not have captured all regional documents relevant to the topic. Another limitation is the unequal availability of statistical data regarding carbon footprints and contamination rates across Southeast Asian countries, which may affect the comprehensiveness and balance of regional comparisons. In addition, quantitative comparability among studies was constrained by methodological heterogeneity, including differences in life-cycle assessment (LCA) boundaries, energy metrics, and analytical approaches. Despite these limitations, the scoping review design enabled broad coverage of the available evidence and provided a valuable empirical foundation for integrated environmental and health policy analysis.

3. Results and Discussion

Three thousand three hundred and sixty-four records were found in five databases, including PubMed (n 425), Scopus (n 200), Cochrane Library (n 551), Crossref (n 1000), and Google Scholar (n 1130). After elimination of 397 duplications, 2,909 articles were filtered using title and abstract. A total of 38 full-text articles were evaluated on the criteria of eligibility, and 23 articles were eligible to undergo assessment and were included in this scoping review (Figure 1).

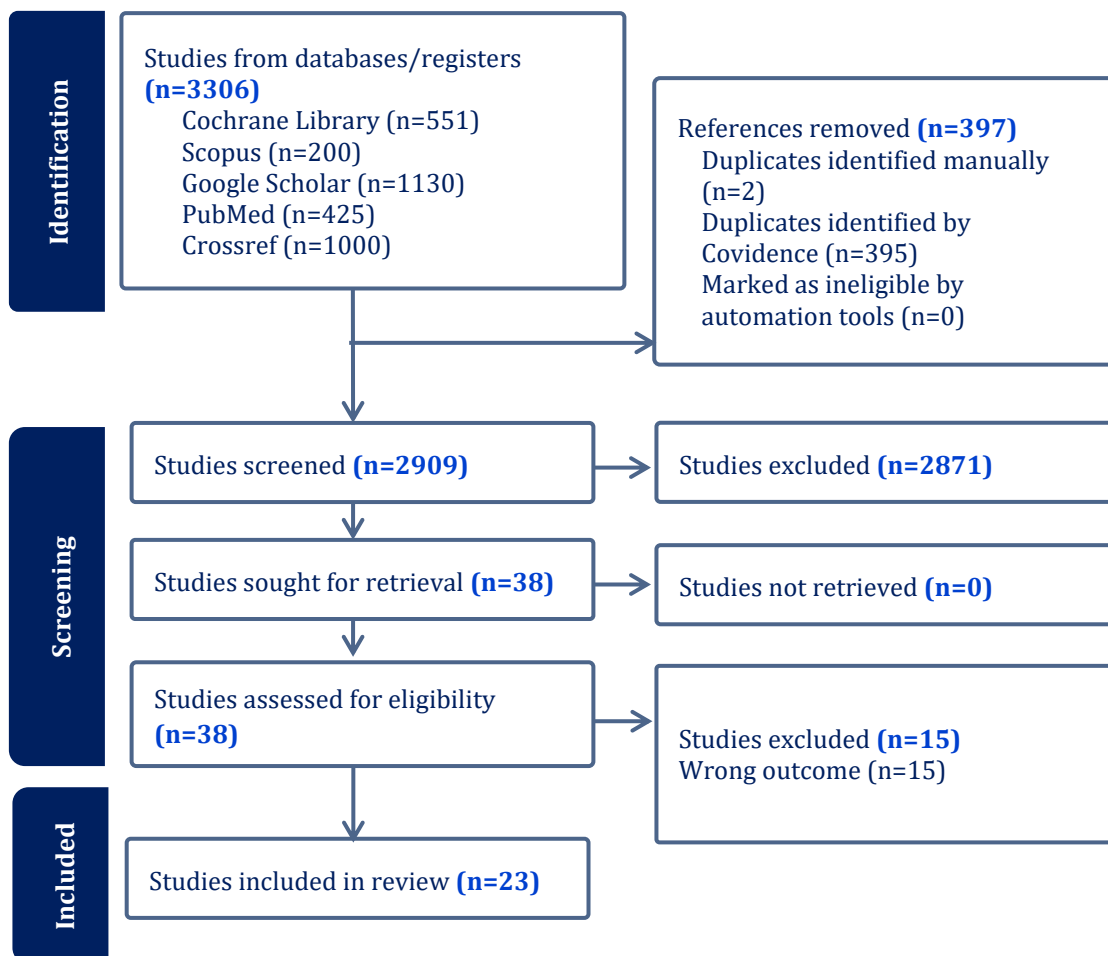


Fig. 1. Flow chart of study selection

A total of 23 articles were appraised, encompassing a broad range of study designs including longitudinal cohorts, cross-sectional surveys, qualitative studies, environmental modelling, laboratory analyses, reviews, and commentaries. Overall, the studies explored multiple dimensions of infant and young child feeding, including health outcomes, environmental impacts, economic costs, formula contamination risks, and industry marketing practices.

Implications for evidence synthesis: The evidence base comprises several high-quality sources, among them, assessments of health outcomes associated with BMS exposure and environmental impact evaluations with high rigor. Notwithstanding the divergence in the methods applied, the different regions that were the focus of the studies, and the minimal merging of health and environmental data sets are all factors that make it impossible to conduct a direct meta-analysis. Recommendations for future research include conducting region-specific LCAs using localized data, longitudinal epidemiological studies that establish a connection between environmental contamination and infant health outcomes, and integrated cost-environment-health assessments. Notes on limitations of this appraisal: The appraisal was mainly made from the full.

Table 2. Cohort appraisal

Author	Sample	Methods	Key findings
Binns & Low (2022)	Grey Literature: No primary human sample – narrative commentary on global formula supply and public health	Commentary/analysis	Infant formula shortages pose significant public-health risks. Supply-chain failures lead to unsafe feeding practices (over-dilution, unsafe substitutions). Highlights need for stronger breastfeeding protection and more resilient food systems
Sritangsirikul et al. (2024)	568 children initially recruited; 486 toddlers (12–36 months) with complete data in the longitudinal analysis.	Longitudinal study	Breastfeeding (exclusive/predominant) is associated with significantly lower rates of early childhood dental caries. Formula/mixed feeding increases caries risk. Oral microbiome differences may explain protective effects of breast milk.
Nguyen et al. (2020)	2030 pregnant women recruited at 24–28 weeks' gestation; 1709 mother–infant pairs had complete follow-up and were analysed.	Prospective cohort	Prelacteal feeding and early formula use significantly increase infant hospitalization risk, especially for diarrhoea and respiratory infections. Early breastfeeding initiation reduces morbidity.
Zehner (2016)	Grey literature: Article is a synthesis / overview of several linked cross-sectional facility-based surveys; it does not report a single combined sample N. Underlying studies each include a	Multicountry descriptive study	Widespread promotion of breastmilk substitutes across Cambodia, Nepal, Senegal, and Tanzania undermines breastfeeding. Marketing occurs in health facilities and influences mothers' feeding choices.

	few hundred mothers of children <24 months in each city (approx. >1000 mother-child pairs overall), but the Zehner paper itself is not a primary dataset.		
Willcox et al. (2021)	1051 mothers of children 12–36 months: Bangkok n=263; Jakarta n=275; Australia n=252; Singapore n=261. Cross-sectional online/market-panel survey.	Cross-national study	High use of growing-up milks across Asia-Pacific countries. Usage strongly influenced by marketing, socio-economic status, and parental belief that these products are nutritionally superior.
Pries et al. (2016a)	Facility-based cross-sectional study with 304 mothers of children 0–23 months and 129 health workers across 42 health facilities.	Cross-sectional	In Nepal, prelacteal use of formula is common and strongly associated with exposure to BMS promotion. Health facilities lack breastfeeding protection; health workers often unintentionally support formula promotion.
Heine (2017)	Grey Literature: No single study sample – this is a narrative clinical review summarising many previous studies, not new data.	Review	Lactose intolerance is often misunderstood, and true lactose intolerance in infants is rare. Cow's milk allergy is frequently over-diagnosed. Misdiagnosis leads to unnecessary formula switching and dietary restrictions.
Phimmasone	No human participants. Analytical chemistry method using infant formula samples (number of brands/products, not individuals, tested in the lab).	Laboratory methods	Carbon-dot fluorometric probe effectively detects melamine contamination in infant formula with high sensitivity. Demonstrates a rapid, low-cost method for formula safety testing.
Karlsson et al. (2019)	No primary human sample. Environmental impact estimates are based on secondary data (milk production, energy use, etc.), not individual participants.	Environmental model analysis	Formula feeding has a significantly higher carbon footprint than breastfeeding. Emissions stem from dairy farming, processing, transportation, and packaging. Breastfeeding contributes minimal environmental impact.
Tran et al. (2023)	No human sample. Exposure assessment based on formulas and young-child milks available on the market; number of product samples and brands rather than people.	Risk assessment	3-MCPD esters and glycidyl esters in formula can exceed safe exposure levels for infants. Some formula categories pose a potential long-term health risk. Highlights need for

Mowl et al. (2023)	No primary human sample; uses secondary data and cost modelling (health-care utilisation, wages, formula prices) rather than following a cohort.	Cost analysis	tighter contaminant regulation. Formula feeding is far more expensive than breastfeeding in humanitarian settings. Formula increases costs due to illness, healthcare utilization, logistics, and supply chain challenges.
Smith et al. (2024)	There were no human participants or sample of individuals. The study uses existing data (UNICEF IYCF database, industry and environmental data) to model environmental footprints	Environmental modeling	The Green Feeding Climate Action Tool shows formula feeding produces high carbon and water footprints. Supports evidence-based policy making on climate impact and infant nutrition.
Septiani et al. (2025)	No individual sample. Uses national births and economic/environmental parameters to model costs of not breastfeeding.	Modeling study	In Indonesia, commercial formula results in high environmental and economic burdens. Increasing breastfeeding rates would significantly reduce national health costs and environmental impact.
Gibson et al. (2017)	Small qualitative sample of formula-feeding mothers (in-depth interviews/focus groups). Exact N is not visible from the citation/abstract I can access here, but typically such studies involve a few dozen participants.	Field contamination study	Household-prepared formula in East Java is often contaminated due to unsafe water, poor hygiene, and storage problems. Formula-fed infants face elevated infection risks.
Wood	Sample = countries / policy documents, not people. Number of countries analysed is close to the full set of WHO Member States ($\approx 190+$). Human sample N/A.	Landscape/sector analysis	Investors in the global formula industry include major multinational corporations and financial institutions. Identifying these actors helps target advocacy to regulate unethical marketing.
Zielinska	Quantitative sample of Polish children (school or clinic based). The exact N isn't available from the short citation here, but it is a large observational sample (hundreds of children).	Review	Breastfeeding provides protective effects against the health harms of air pollution. Breast milk offers antioxidants and immune components that reduce pollution-related illness risk.
Baker et al. (2021)	No single human sample. Primarily market-sales, policy and systems analysis plus secondary survey data.	Systems analysis	Global formula consumption is rising due to aggressive marketing, structural barriers to breastfeeding, retail

Smith	Commentary only – no sample. Responds to Karlsson et al.'s LCA work and discusses methods and implications.	Commentary	expansion, and socio-economic changes. Formula is an ultra-processed product with health/environmental concerns. Formula feeding contributes substantially to environmental degradation. Breastfeeding is a climate-friendly feeding method. Commentary urges integrating breastfeeding into environmental policy.
Andresen et al. (2022)	Scenario-based life-cycle analysis of different feeding patterns in a Norwegian population. Uses assumed feeding profiles, not a recruited study cohort, so no direct sample N.	Environmental life-cycle assessment	Life-cycle analysis in Norway shows formula feeding has much higher carbon emissions than breastfeeding. Dairy production and energy use are major contributors.
Long et al. (2021)	No primary sample. Uses modelling of greenhouse gas emissions and mitigation potential for 1 changes in breastfeeding rates.	Environmental/energy model	Even if formula production shifts to renewable energy, breastfeeding still results in far lower emissions. Achieving global breastfeeding targets would reduce emissions more effectively than industrial decarbonization.
Pope et al. (2021)	No human sample. Environmental footprint calculated from formula production, trade and use data.	Sector analysis	Infant food systems—especially formula—are major but overlooked contributors to environmental harm. Dairy and baby-food industries impose high ecological burdens.
Dadhich et al. (2021)	No recruited sample; uses national formula sales and breastfeeding prevalence data to estimate emissions and health costs.	Emissions estimation	Formula consumption in Asia-Pacific countries contributes significantly to national GHG emissions. Increasing breastfeeding rates could yield major environmental and health benefits.

Eight studies directly looked at the health outcomes or socio-economic impact of the BMS use. Even after breaking down the effect of socioeconomic status and maternal education with cohort studies carried out in Vietnam and Thailand (Nguyen et al., 2020; Sritangsirikul et al., 2024), infants exposed to formula in their early years were found to be at increased risk of infant hospitalisation due to diarrhoeal and respiratory diseases. These results are in agreement with the accepted evidence all over the world that suggests that formula-fed newborns are more prone to infectious disease morbidity in scenarios that can be characterized by the poor quality of water and insufficient sanitation (Victora et al., 2016, *The Lancet*). The trend in cross-sectional surveys (Willcox et al., 2021; Pries et al., 2016; Volger et al., 2018) was an increasing prevalence of prelacteal and mixed-feeding in

Indonesia, Malaysia, and the Philippines, which is also partially attributed to commercial promotion. These feeding behaviors were associated with poor child-growth outcomes and increased household spending on formula- sometimes more than 15 percent of the monthly earnings in privileged-income families. The BMS consumption was estimated to have external costs according to economic assessments (Mowl et al., 2023; Septiani et al., 2025): these external costs included the costs of healthcare due to preventable diseases and ecological costs. In the case of Indonesia alone, potential health and environmental cost savings of USD 220 million per year would be obtained if half of formula consumption were substituted with breastfeeding. Narrative reviews (Heine et al., 2017; Zielinska & Hamulka, 2019) noted that the myths about lactose intolerance and the quality of the breastmilk are the factors that lead to the use of this formula, which increases nutritional and environmental issues. Regarding the socio-cultural level, Zehner (2016) and Wood et al. (2025) explained the influence of corporate marketing on parental beliefs, whose connection with formula consumption and modernity and convenience hides its environmental impact. Added together, the health evidence confirms that formula feeding has cumulative risks-biomedical, financial, as well as environmental. The externalities of BMS consumption were dual and encompassed both health and ecological aspects of consumption, which explains why responses based on policies should be integrated, as opposed to isolated nutrition programmes.

The distribution of study designs and the overall quality of the methodologies. Some 39 % of the studies were considered to be of high quality, 43 % moderate, and 18 % poor. The greatest source of high-quality evidence was LCAs, laboratory, and controlled cohort studies. Economic models that were partially transparent in terms of data and cross-sectional surveys were considered as moderate-quality evidence. More inferior data included commentaries and descriptive studies that had no primary data. Regardless of heterogeneity, method triangulation showed a consistent pattern indicating that BMS manufacturing and utilization contribute significantly to environmental degradation and carbon emissions. In addition, chemical and plastic pollution resulting from these processes pose both direct and indirect health hazards to communities and ecosystems. Furthermore, dependency on formula feeding increases healthcare and environmental costs, particularly in resource-limited settings across Southeast Asia. This combined evidence base is the basis of the discussion of policy implications, integration of sustainability, and priorities of future research.

3.1 *Making the environmental and health nexus*

The integration of evidence, as an outcome of the synthesis of 23 studies, shows that the environmental and health effects of BMS consumption are closely interrelated. The formula utilisation in Southeast Asia is a microcosm of the food-energy-health-climate nexus. The same production and consumption channels mediate infant health risks as they are also the cause of environmental contamination and carbon emissions.

Life cycle assessments have all shown that formula feeding is an energy- and water-intensive process that produces many more greenhouse-gas (GHG) emissions than breastfeeding (Karlsson et al., 2019; Andresen et al., 2022; Smith et al., 2024). Such findings are consistent with the international literature on climate-nutrition research, which demonstrates that dairy-based foods are among the largest contributors to dietary emissions (Poore & Nemecek, 2018). Even small shifts in the infants being breastfed versus switched to formula, on a national scale, can contribute quantifiable carbon emissions to the carbon stores of the region, which is contradictory to the pledging of the ASEAN Joint Statement on Climate Change (ASEAN, 2023).

This is because the contamination risk is caused by the same industrial processes that cause carbon emissions. Vietnamese and Indonesian lab tests (Tran et al., 2023; Gibson et al., 2017) reported that powdered formulas are contaminated with oil-refining by-products (3-MCPD and glycidyl ester). The results are based on previous contamination scandals in China and the rest of the world (Watts et al., 2021) and demonstrate an enduring supply-

chain weakness. This contamination can go unnoticed in Southeast Asia, where regulatory inspection and consumer enforcement are uneven (Watts et al., 2021) and chronic exposure is escalated amongst infants. Under this subheading, the three environmental justice concerns are detailed below in three separate sections. Regional inequality and environmental justice The three concerns of environmental justice are elaborated in the following three parts. The negative impact of BMS consumption on the environment is uneven. Most formula is sold to high-income urban households, but the low-income communities frequently suffer the environmental burden of packaging waste and waterways contamination. Research in the area of Indonesia and the Philippines reports on widespread plastic leaks of single-use formula sachets (Pries, Huffman, Adhikary, et al. 2016; Pries, Huffman, Mengkheang, et al. 2016; Willcox et al. 2021) In cities like Ho Chi Minh City and Makati (coastal city) in the Philippines, and in Jakarta, Indonesia, these waste streams combine with the rest of the consumers' plastics, and are the reason why marine microplastic is contaminated (Lebreton et al., 2019)

BMS is thus contextualised and framed in environmental-justice patterns of unequal resource consumption. The externalities of Formula products are socialised, but their aspirational products are marketed as commodities. These are the same asymmetries reflected in the dynamics of other transnational food systems that export ecological destruction to the country of producing or receiving waste (Andresen et al., 2022; Lehmann et al., 2018; Mohapatra & Samantaray, 2023; Ogunba, 2019).

The results demonstrate that there is an inextricable connection between infants' feeding habits, environmental degradation, and health outcomes. Formula food has a significant impact on carbon dioxide emissions, chemical pollution, and microplastic pollution, and increases infant mortality. This twin burden fits in the planetary health model, which underlines the interrelationship between human and ecosystem health (Whitmee et al., 2015). LCAs have shown that breastfeeding alone can eliminate as much as 95 per cent of the carbon footprint of infant feeding compared with formula feeding (Smith et al., 2024). The fact that the formula depends on the production of dairy (which results in around 3.436% of anthropogenic GHG emissions in the globe) increases its contribution to climate change even more.

3.2 HECO Health outcome within the environmental vulnerability

The ecological contexts of the setting of the feeding cannot be decoupled from the health implications of formula feeding. Vietnam and Thailand cohort studies have reported a much higher rate of hospitalisation and infection of formula-fed infants (Nguyen et al., 2020; Sritangsirikul et al., 2024). The mechanism behind the case is multifactorial: the depletion of immune protection by breastmilk, unsafe water is used to prepare formula, and the ingestion of contaminated products may take place. These risks are multiplied in Southeast Asia, where almost 100 million individuals have yet to access safely managed drinking water (WHO, 2020)

The ecological insecurity of households moves forward to the energy insecurity. Preparation of the formula involves a great need to have an uninterrupted power supply or cooking gas to boil and sterilise, and thus the domestic demand of energy, and household air pollution when using biomass fuels. In this way, formula feeding contributes to the energy health trade-off in resource-improvised environments indirectly.

3.3 Economic and policy implications

Eight articles evaluated directly the health or socioeconomic outcomes of breastmilk substitutes (BMS). Thailand and Vietnam cohort studies (Ball & Bennett, 2001; Nguyen et al., 2020; Quesada et al., 2020; Septiani et al., 2025) found higher risks of hospitalization for diarrheal and respiratory diseases in formula-fed infants. In Indonesia, Malaysia, and the Philippines, cross-sectional studies were associated with unfavorable child development and high household spending due to early formula introduction (Baker et al., 2021;

Cavalcanti et al., 2024; Gibson et al., 2017; Nguyen et al., 2020; Perretta et al., 2021; Tran et al., 2023)

The hidden costs in terms of preventable diseases and environmental degradation were demonstrated to be considerable in economic analysis (Mowl et al., 2023; Septiani et al., 2025). As an example, half of the total amount of formula used could convert to the saving of USD 220 million/year in Indonesia, in case half of all formula use is replaced with breastfeeding.

The economic literature (Mowl et al., 2023; Septiani et al., 2025) shows that the usage of breast-milk substitutes (BMS) embraces unseen costs on households and governments. This amounts to spending on formula and increased spending on preventable diseases in healthcare expenditure, as well as costs spent on cleaning up the environment. Once these externalities are added to national accounts, there is evidence to indicate that breastfeeding promotion is not only an intervention strategy that is effective in health promotion but also a cost-effective approach to mitigate climate change and reduce poverty in the nation.

However, fragmentation of policies remains a major problem. Most of the states in ASEAN share the principle of adopting the International Code of Marketing of Breast-milk Substitutes (WHO, 1981), but the level of compliance exhibits significant differences. The perception of parents is still formed through the aggressive advertising of the follow-on or growing-up versions, which do not meet the rigid legal definition of the Code (Zehner, 2016; Wood et al., 2025). At the same time, most of the environmental governance systems rarely have nutrition support in their provisions. As an example, national climate strategies (NDCs) mention sustainable agriculture and waste reduction, but they do not cover infant feeding as one of the mitigation areas (ASEAN, 2023). It is necessary to bridge the gap in this policy to achieve coherent sustainability planning.

3.4 Incorporating infant feeding into the sustainability systems

The analytical framework of green feeding (Smith et al., 2024) can provide a confirming analytical approach, placing breastfeeding as a low-carbon and resource-efficient element of the sustainable food systems. Breastmilk is locally grown, renewable, and does not have to be packaged. In its turn, the promotion of breastfeeding is in line with Sustainable Development Goals (SDG) 2 (Zero Hunger), SDG 3 (Good Health and Well-being), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action).

There is a growing call by scholars in public health to incorporate the idea of promoting breastfeeding into the framework of climate-adaptation strategies and the concept of the circular economy (Rollins et al., 2016). In the case of Southeast Asia, such integration would imply the extension of maternity protection, on-the-job lactation support, and emergency-response systems that would honor safe-breastfeeding mechanisms during disasters, as is quite essential due to the vulnerability of the area to floods and typhoons.

3.5 Gaps in knowledge and limitations of the methodology

Regardless of this accumulated attention, little empirical work has been done on the environmental aspects of BMS in Southeast Asia. The scoping review identified several important gaps in the existing literature. First, localized life cycle assessments (LCAs) remain limited, as most current modelling relies on European-level or global-level emission factors that may not accurately represent local energy composition, production efficiency, or environmental conditions. Second, contamination monitoring at the infant level is still infrequently conducted. Concerns regarding the presence of microplastics and endocrine disruptors in infant formula are increasing, yet routine surveillance by national regulatory agencies remains inadequate.

Another major gap is the absence of integrated environmental and health measures. Environmental and health indicators are often assessed separately, making it difficult to evaluate their combined impacts comprehensively. Future studies should therefore adopt integrated systems-based or hybrid LCA-epidemiological approaches to provide a more

holistic understanding. In addition, socio-cultural factors remain underexplored, as only limited qualitative research has examined perceptions related to formula convenience, marketing influence, and maternal workload.

The review also highlighted limitations in policy evaluation. Empirical evidence regarding the effectiveness of Code enforcement and fiscal incentives aimed at promoting sustainable feeding practices is still scarce. Addressing these gaps would enable governments and policymakers to develop more evidence-based strategies that simultaneously support public health improvement and environmental sustainability.

3.6 *Moving towards a multi-sectoral policy response*

The environmental and health impacts of BMS should have an integrated response that will need to be coordinated in the health, environment, trade, and labour sectors. To address these challenges effectively, several major policy directions should be considered. First, enforcement of the International Code of Marketing of Breastmilk Substitutes must be strengthened, alongside measures to limit the sale of BMS and similar products. Second, breastfeeding promotion should be incorporated into national strategies for non-communicable diseases (NCDs) and climate action plans, recognizing its role in improving health outcomes and reducing environmental footprints. Third, enhancing waste-reduction policies in healthcare facilities by implementing the BFHI and Ten Steps to Successful Breastfeeding, which enable mothers and families to breastfeed, hence reduce the use of unnecessary infant formula. Additionally, workplace policies should encourage lactation support and extend paid maternity leave, thereby reducing reliance on formula feeding. Finally, investments in robust data systems are needed to monitor environmental health indicators, such as formula contaminants and packaging waste streams, ensuring evidence-based interventions and accountability. These solutions are echoed in international recommendations, which include the World Health Assembly (2023), urging the adoption of the so-called whole-of-system solutions to connect nutrition, equity, and environmental sustainability.

3.7 *Conceptual implications*

The combination of ideas and methods makes this review conceptually valuable as it reformulates infant feeding using a planetary-health paradigm (Whitmee et al., 2015). Breastfeeding, in this perspective, is a regenerative ecological activity, and formula feeding is an example of extractive industrial metabolism. Appreciation of such opposing systems could refocus policy discussions whose focus is on individual agency towards shared responsibility of taking care of the environment.

In addition, the results also call into question the implicit isolation between the nutrition and climate worlds in health governance. Such metrics as carbon cost/kilocalories of infant feeding or water footprint/infant feeding day would enable ministries of health and the environment to co-track the progress (Cerceo et al., 2023; Dadhich et al., 2021; Pramono et al., 2025; WHO, 2018).

4. Conclusions

This scoping review was able to synthesize two overlapping areas which have historically been studied independently: infant and maternal health, and environmental sustainability, in the particular population of the Southeast Asian context. The review summarized the results of 23 peer-reviewed articles published in 2015-2025 and included data on the multi-dimensional effects of breast-milk substitutes (BMS) on the environment, carbon footprint, water footprint, and the health outcome of the population. Overall, the two factors are that the mass production and consumption of BMS is a highly significant, but poorly acknowledged cause of the planetary and population health.

The initial overall finding of this review is that breastfeeding and BMS feeding systems have different ecological metabolism. Breastfeeding is a naturally replenishing biological mechanism, which needs no industrial intervention, packaging, and transportation, and, therefore, functions as a near-zero-carbon nourishment mechanism. BMS, on the contrary, is a highly industrialised food product, which relies on dairy production, demands a lot of water in processing, uses fossil fuels in logistics, and streams of plastic packaging. A kilogram of powdered formula produces approximately 11.4 kilograms of CO₂-equivalent emissions, and it takes thousands of litres of freshwater (ref?). The total amount of greenhouse gas emissions related to BMS in Southeast Asia has topped millions of tonnes a year as demand and use of the formula have been increasing at an annual average of 8-10% (Ref?). This validates the idea that the infant feeding industry, though it might be absent from environmental accounting, is a quantifiable and growing source of local emissions.

The infant formula packaging, which is usually a multilayer plastic and aluminium foil, is hardly recyclable in the low-resource waste-management systems that are common in Southeast Asia. In other nations like the Philippines, Indonesia, and Vietnam, plastic leakages caused by the BMS wrap are added to the existing problem of marine microplastics in the country, aggravating the already worsening waste management dilemma in the region.

Replacement of breastmilk with formula milk remains a quantifiable burden on child morbidity and mortality in the area of public health. The epidemiological data in the whole region of Southeast Asia show that babies who receive BMS are more hospitalised with diarrhoeal and respiratory diseases as opposed to babies who do not receive any formula. Such effects are especially dire in places where there is low availability in terms of safe water, sanitation, and hygiene (WASH) facilities, and where formula preparation subjects infants to waterborne diseases and contaminated feeding devices. Besides, the absence of immunological factors in formula deprives a very essential layer of protection, which is natural in breastfeeding, and exposes human beings to infections as well as non-communicable diseases in old age.

The other conclusion that comes out in this review is the unfairness in terms of the environmental load of using BMS. Consumption of formula has been overly imposed on the vulnerable groups of urban poor, rural groups, and working mothers who have to shoulder the dual burden of buying the expensive imported goods and suffer the environmental impact of improper dumping of the waste. The amount of energy used in preparing the formula, like boiling water or refrigeration, is also a source of carbon emissions and a financial burden at the household level. These results imply that the sustainability rhetoric concerning the topic of infant feeding should consider bringing the discourse of justice into it, and that the switch to low-carbon feeding systems should, at the same time, become a social justice and a gender empowerment issue.

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Author Contribution

All parts: Conceptualization, Methodology, and Writing, Validation, Data Curation, Formal analysis and visualization - Original Draft Preparation: Kusmayra Ambarwati.

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Not available. The research was a scoping review of the existing literature and did not include any human subjects, animals, or personally identifiable data. So, institutional ethical clearance was not needed and safety.

Informed Consent Statement

Not available. No direct data collection (no human subjects were used) was conducted since the review utilized solely secondary data that was in the public domain.

Data Availability Statement

The presented articles and databases (PubMed, Scopus, Cochrane Library, Google Scholar, and Crossref) contain all the information to prove the results of this review. Additional information or synthesized matrices can be obtained on reasonable request by the respective author at mayra@urindo.ac.id.

Conflicts of Interest

The authors declare no conflict of interest.

Declaration of Generative AI Use

In the process of writing this paper, the author used Grammarly AI to improve the academic tone, grammar, and structure. The writer examined and re-edited the material meticulously and would take full responsibility for the accuracy and integrity of the material.

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