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INTEGRATING LEAN HEALTHCARE AND PREDICTIVE ANALYTICS FOR SUSTAINABLE HOSPITAL WASTE MANAGEMENT: A NARRATIVE REVIEW FROM A BLUE-GREEN ECONOMIC PERSPECTIVE

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Abstract:

Operational efficiency, clinical quality and environmental sustainability are increasingly difficult to balance in the modern healthcare system. Lean Healthcare has proven to be a methodology for waste elimination in processes, but its static nature often limits its responsiveness to dynamic healthcare environments. However, predictive analytics offers advanced forecasting capabilities but often fails to integrate with operational workflows. This narrative review aims to fill this conceptual and practical gap by exploring how the combination of Lean Healthcare and predictive analytics generates a Blue-Green Economic Synergy to transform hospital waste management. Synthesizing literature published between 2015 and 2026 retrieved from Scopus, this review explores four core themes: operational waste reduction via Lean deployment, predictive analytics and artificial intelligence applications in waste forecasting, circular economy integration within blue-green frameworks, and organizational, technical, and policy implementation dynamics. The synthesis shows that combining Lean process discipline with algorithmic foresight may enable proactive resource optimisation, may reduce the gradual accumulation of energy inefficiency, and has the potential to reduce Scope 1–3 emissions. Furthermore, this review extends the Natural Resource-Based View and Dynamic Capabilities Theory by showing how process-based pollution prevention capabilities complement algorithmic sensing mechanisms in digital healthcare operations. In practical terms, this paper may offer health system managers and policymakers a conceptual framework for transitioning hospital operations toward circular waste ecosystems.

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Keywords:

Blue-Green Economic Synergy, Circular Economy, Hospital Waste Management, Lean Healthcare, Narrative Review, Predictive Analytics, Sustainable Healthcare

Introduction

Today's healthcare systems are challenged with the dual mandate of providing quality patient care and reducing their environmental impact and operational inefficiencies. Historically, hospitals have tended to be resource-intensive institutions, producing large amounts of hazardous and municipal waste, using large amounts of energy and suffering from supply chain redundancies (Goh et al., 2026; Iskandar Shah et al., 2026). In response to these operational challenges, healthcare institutions have increasingly embraced Lean Healthcare (LH) principles to eliminate non-value-added activities, streamline clinical workflows, and optimise material usage (Ong et al., 2023; Sêneda Filho et al., 2025; Veres et al., 2026). Simultaneously, the advent of Industry 4.0 technologies has introduced predictive analytics, artificial intelligence (AI) and machine learning (ML) that can predict demand, aid in equipment maintenance and foresee patterns of waste generation in real-time (Ahtasham Mushtaq et al., 2025; Leong & Leong, 2026; Uysal et al., 2026).

Conceptually, the LH and predictive analytics combine to create a "Blue-Green Economic Synergy" with two engines – green eco-efficiency (process waste elimination) and blue digital innovation (data-driven forecasting) to facilitate circular hospital operations (Allahham et al., 2023; Marfu et al., 2026). The scale of healthcare waste generation continues to be a pressing challenge that threatens institutional viability and public health, despite the potential of this combination. Hospitals are functioning under operational pressure which leads to excessive provision of clinical supplies, poor segregation of waste and energy inefficiency (Adnan et al., 2023; Iskandar Shah et al., 2026). The environmental impact is not limited to solid waste streams but also includes Scope 1, 2, and 3 greenhouse gas emissions generated in the operations and supply chains of healthcare facilities (Goh et al., 2026).

Although traditional Lean Hospital (LH) practices, such as Kaizen and Value Stream Mapping (VSM), may reduce visible process waste, they do not consider the dynamic, non-linear fluctuations in patient load and resource utilisation (Marjane et al., 2026; Oktaviza et al., 2025). However, specialised predictive analytics software can record complex waste patterns and demand forecasts, but this tends not to result in significant changes in operations when used in rigid, non-optimised administrative systems (Goel et al., 2025; William et al., 2025). This operational disconnect suggests the need for an integrated operational–analytical framework.

The primary research gap in the existing literature is the limited integration between process-oriented Lean Healthcare methodologies and data-oriented predictive technologies. Most existing studies appear to evaluate these paradigms as parallel, independent mechanisms rather than as interdependent, synergistic capabilities (Marjane et al., 2026; Oktaviza et al., 2025). Second, the sectoral evidence is inconsistent. Empirical applications are mainly focused in some departments such as operating rooms and central pharmacies, and less in systems that manage waste across the whole facility (Sêneda Filho et al., 2025; Uysal et al., 2026). Third, there is a major inconsistency in the literature in the use of terms like “lean-green”, “smart sustainability” and “blue-green synergy” interchangeably without clear theoretical boundaries (Allahham et al., 2023; Marfu et al., 2026). Finally, implementation models vary considerably across geographic regions and hospital types due to differences in policy environments, institutional capacities, and leadership commitment (Adnan et al., 2023; Ong et al., 2023; Veres et al., 2026).

Therefore, a full narrative review is urgently needed to connect these disparate threads into a coherent theoretical and practical framework. Previous reviews have either focused narrowly on the human-centric leadership aspects of Lean transformations (Veres et al., 2026) or the purely technical mechanics of AI-driven waste prediction (Uysal et al., 2026; William et al., 2025) without the strategic integrative lens of the blue-green economy. This review aims to bridge this knowledge gap by critically reviewing the use of the intersection of LH and predictive analytics in order to operationalise blue-green economic principles within the hospital context. Specifically, the objective of this narrative review is to critically analyse the theoretical and empirical relationships between Lean Healthcare practices and predictive analytical instruments, synthesise their combined effect on waste reduction and resource optimisation in hospitals, and develop an integrated framework for blue-green economic synergy in healthcare operations.

The rest of this paper is organised into four main sections to this end. The second part is dedicated to the theoretical background and the basic principles of Lean Healthcare, predictive analytics and the Blue-Green Economic Synergy framework in healthcare settings. The third section integrates empirical evidence across operational applications such as waste forecasting, supply chain optimisation and predictive facility maintenance. The fourth section discusses the main barriers to integration, such as technical interoperability, organisational culture and policy gaps, and offers an integrated strategic framework for hospital decision makers. The last, fifth section ends with a discussion of policy implications and outlines important directions for future empirical research.

Review Approach

To ensure academic rigor, transparency, and reproducibility while maintaining the expansive synthesis characteristic of a narrative review, a structured, pre-defined process of literature

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identification and selection was performed. While narrative reviews do not entail the same level of statistical synthesis as systematic reviews, the use of a systematic search framework may lend some methodological credibility, perhaps reduce selection bias and aiding in guaranteeing that the conceptual synthesis is reflective of current scholarly consensus.

Literature Identification and Database Selection

The primary search was executed exclusively within the Scopus database. Scopus was selected as the sole bibliographical index due to its comprehensive coverage of peer-reviewed literature across interdisciplinary domains, specifically spanning operations management, health informatics, environmental science, and healthcare administration. The search protocol targeted peer-reviewed journal articles and reviews published over a ten-year timeframe, from January 1, 2016, to January 31, 2026. This timeframe was chosen to capture the foundational integration of Lean methodologies in healthcare alongside the rapid advancement of Industry 4.0 predictive analytics and machine learning tools over the preceding decade.

The literature retrieval process utilized a comprehensive keyword search string combining four main conceptual blocks joined by Boolean operators:

("lean healthcare" OR "lean management" OR "lean principles" OR "waste reduction") AND ("predictive analytics" OR "predictive modeling" OR "data analysis" OR "forecasting") AND ("hospital" OR "healthcare facility" OR "medical center" OR "clinic") AND ("sustainability" OR "sustainable practices" OR "environmental impact" OR "resource management")

Screening Strategy and Selection Approach

The initial database search yielded 134 records. Two reviewers independently screened the titles and abstracts against predefined inclusion and exclusion criteria. The retrieved records were screened using a multi-step selection process. The initial screening examined titles and abstracts for their general fit with the review's core thematic axes: operational efficiency through Lean methodologies, predictive data techniques, and environmental sustainability within the hospital setting. All records that passed the initial screening were fully text reviewed against pre-specified inclusion and exclusion criteria.

Studies were required to satisfy three primary criteria to be included in the review:

1. Direct application or theoretical extension to health care settings (e.g., hospitals, clinics, or health system supply chains).
2. Substantive focus on Lean thinking, predictive analytics or their integrated application.
3. Clear link to environmental sustainability, resource allocation, carbon reduction or waste management outcomes.

Studies that discussed only clinical treatment outcomes without operational metrics; were not peer-reviewed (e.g. conference abstracts, editorial notes, or trade publications); were published outside of the 2016–2026 timeframe; or were published in a language other than English were excluded. Following abstract screening, 42 full text articles were assessed and 26 core studies were included in thematic synthesis. Manual backward citation searching was also performed to capture the foundational literature. The parameters for identification, screening and selection of literature for this narrative review are summarised in **Table 1**.

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The search was restricted to English-language, peer-reviewed journal publications (including original research, review articles, and early-access articles) within the title, abstract, and keyword fields.

Table: Search Strategy

Strategy Dimension	Parameter / Specification
Database	Scopus (Exclusive)
Timeframe	January 1, 2016 – January 31, 2026
Search String	("lean healthcare" OR "lean management" OR "lean principles" OR "waste reduction") AND ("predictive analytics" OR "predictive modeling" OR "data analysis" OR "forecasting") AND ("hospital" OR "healthcare facility" OR "medical center" OR "clinic") AND ("sustainability" OR "sustainable practices" OR "environmental impact" OR "resource management")
Inclusion Criteria	• Peer-reviewed journal articles and reviews published in English. • Direct focus on healthcare environments or health system operations. • Conceptual or empirical examination of Lean Healthcare, predictive analytics, or their combination. • Evaluation of waste reduction, operational efficiency, or environmental sustainability outcomes.
Exclusion Criteria	• Non-peer-reviewed items (editorials, letters to editors, trade publications, conference abstracts). • Purely clinical studies lacking operational, supply chain, or environmental waste implications. • Articles published outside the 2016–2026 timeframe or in languages other than English.
Selection Approach	Multi-stage thematic selection: Title and abstract screening, followed by full-text critical appraisal against inclusion/exclusion criteria, supplemented by backward citation tracking of key foundational articles.

Conceptual Background

Conceptualization of "Blue-Green Economic Synergy"

A formal conceptualisation of "Blue-Green Economic Synergy" is a core prerequisite for progressing sustainable hospital operations. For this review, Blue-Green Economic Synergy is an integrative operation model that dynamically adds process-based eco-efficiency ("green") with data-driven digital foresight ("blue") for circular resource management.

The "Green" Component (Process Discipline) is ecological conservation, resource conservation and physical waste reduction at the source. In healthcare settings, green capabilities are deployed through Lean Healthcare (LH) tools, for example, Value Stream Mapping, 5S workplace organization, and Kaizen continuous improvement, to remove non-value-added activities (muda) and standardise operational workflows (Marjane et al., 2026; Ong et al., 2023).

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The “Blue” Component (Digital Foresight) is the technological innovation, digital data capabilities and predictive intelligence. Blue capabilities are operationalised through predictive analytics, machine learning, and Internet of Things (IoT) sensors that analyse retrospective and real-time data to forecast patient volumes and anticipate supply obsolescence and predict waste generation streams (Ahtasham Mushtaq et al., 2025; Uysal et al., 2026). The conceptualization of Blue-Green Economic Synergy is shown in Figure 1 below.

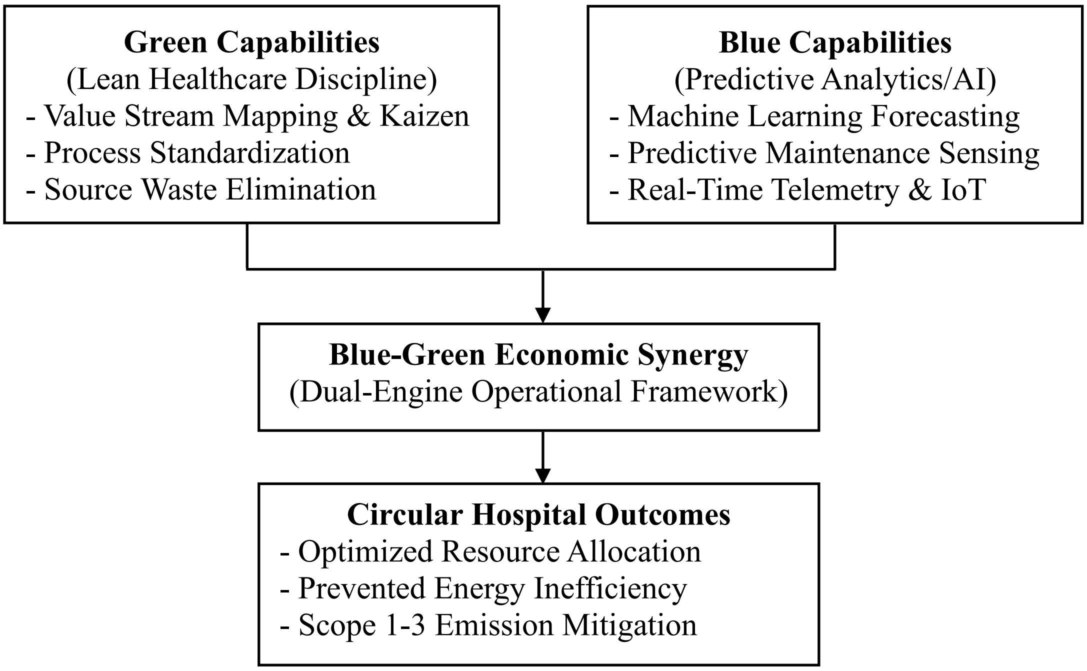

Figure: Conceptualization of Blue-Green Economic Synergy

Lean Healthcare (LH) represents the adaptation of socio-technical principles derived from the Toyota Production System to clinical and administrative healthcare operations (Tretiak, 2024). It is defined as a continuous improvement philosophy and operational methodology that systematically seeks to identify and eliminate non-value-added activities termed operational waste, or muda, while maximizing value for patients (Marjane et al., 2026; Ong et al., 2023). Within hospital systems, operational waste may encompass overproduction, motion, transportation, waiting, inventory, overprocessing, and defects (Sêneda Filho et al., 2025). When applied to environmental management, LH targets physical resource streams, minimizing unnecessary material procurement, energy expenditure, and solid waste generation at the source (Adnan et al., 2023; Veres et al., 2026).

Predictive Analytics (PA) refers to an advanced subset of business intelligence and health informatics that utilizes historical data, statistical algorithms, data mining, and machine learning (ML) models to forecast future events, patterns, and resource demands (Allahham et al., 2023; Goel et al., 2025). In hospital waste management contexts, predictive analytics may process real-time and retrospective operational data such as patient admission rates, surgical schedules, and supply chain flow to project medical waste volume, anticipate supply obsolescence, and schedule proactive maintenance for high-energy clinical equipment (Leong & Leong, 2026; Uysal et al., 2026; William et al., 2025).

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In healthcare settings, this synergy manifests when data-driven predictive technologies (blue/digital capabilities) are embedded within process-optimization frameworks (green/lean workflows), potentially transforming static hospital waste management into an adaptive, circular ecosystem that could yield simultaneous economic cost reductions and environmental decarbonization (Goh et al., 2026; Iskandar Shah et al., 2026).

Key Theories or Frameworks

The theoretical architecture underpinning the integration of Lean Healthcare (LH) and predictive analytics within a blue-green economic framework appears to draw upon three complementary organisational theories: Natural Resource-Based View (NRBV), Dynamic Capabilities Theory (DCT), and Circular Economy (CE) Frameworks.

Natural Resource-Based View (NRBV)

Classical resource-based view of the firm. Hart's Natural Resource-Based View argues that a firm's competitive advantage and operational resilience may be derived from its capabilities to deal with interactions with the natural environment (Allahham et al., 2023; Marfu et al., 2026). NRBV identifies three inter-related strategic phases: pollution prevention (minimising waste at source in operational processes), product stewardship (minimising the environmental impact of products and materials over the life cycle) and sustainable development (decoupling organisational growth from environmental degradation). Lean healthcare is the primary force behind pollution prevention as it minimises physical waste from workflows. Predictive analytics may enhance product stewardship by providing better predictions of material lifecycles and inventory consumption (Ahtasham Mushtaq et al., 2025; Oktaviza et al., 2025)

Dynamic Capabilities Theory (DCT)

NRBV highlights the strategic importance of the environmental management, and Dynamic Capabilities Theory provides an explanation of how healthcare organisations change their operational routines in turbulent environments. DCT is defined as the capacity of an enterprise to "sense, seize and transform" opportunities. In this context, predictive analytics is considered an advanced sensing capability, which senses the dynamic changes in hospital patient volume, supply consumption and waste generation (Goel et al., 2025; William et al., 2025). Lean Healthcare is the mechanism of seizing and transforming that provides the structured, continuous improvement routines for changing operational workflows based on algorithmic insights (Marjane et al., 2026; Veres et al., 2026). Together, they may constitute an organisational dynamic capability that enables hospitals to modify supply chains and waste-disposal protocols proactively, before inefficiencies materialise.

DCT prevents NRBV's resource strategies from becoming static, ensuring that environmental routines continuously evolve alongside changing technological and operational environments.

Sensing - Product Stewardship: DCT's sensing capabilities (e.g., predictive analytics, digital IoT monitoring, external data collection) allow a firm to anticipate material degradation, supply chain bottlenecks, and waste stream surges. This sensing directly enables NRBV's product stewardship by accurately forecasting inventory consumption and preventing material obsolescence before it occurs.

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Seizing - Pollution Prevention: Sensing an environmental issue is useless without the ability to act. DCT's seizing capability provides the structured routines (e.g., Lean process standardization, Kaizen workflows) necessary to mobilize resources and adjust physical operational routines. This fulfils NRBV's pollution prevention stage by eliminating waste directly at the point of origin.

Transforming to Sustainable Development and Circularity: Over the long term, DCT's transforming capability allows an organization to reconfigure its overall business architecture. Combining continuous digital sensing with continuous process improvement empowers the organization to shift from linear "take-make-dispose" models toward circular resource dynamics, realizing NRBV's ultimate goal of sustainable development. The conceptual alignment between Dynamic Capabilities Theory (DCT) and Natural Resource-Based View (NRBV) Stages is shown in **Figure 2** below.

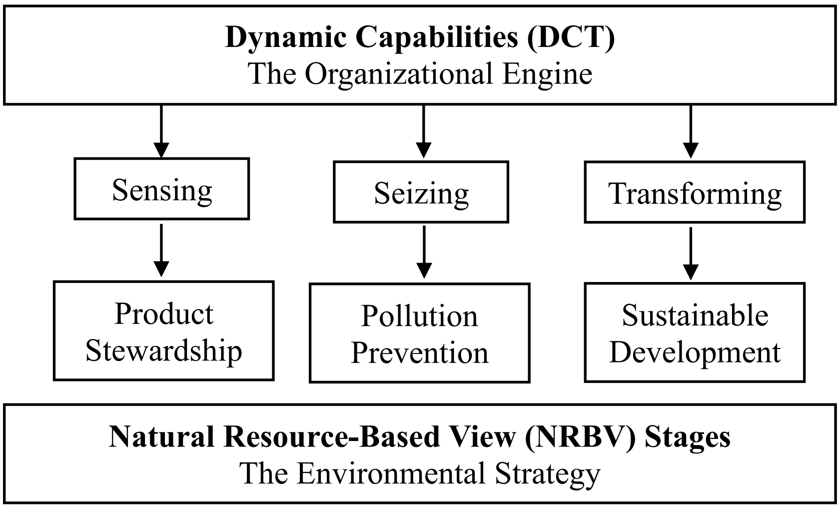

Figure: Conceptual Alignment Between Dynamic Capabilities Theory (DCT) and Natural Resource-Based View (NRBV) Stages

Circular Economy (CE) Frameworks in Healthcare

The Circular Economy frameworks offer the structural basis for Blue-Green Economic Synergy by replacing the traditional linear model ("take-make-dispose") with a closed-loop system aiming to preserve material value and prevent waste (Iskandar Shah et al., 2026; Marfu et al., 2026). For hospital waste management, CE principles are limited to the reduction of materials, refurbishment and valorisation of energy/materials (Chabouh et al., 2026; Goh et al., 2026). CE frameworks are operationalised through the conceptual integration of LH and predictive analytics: process discipline enforced through LH promotes waste segregation and waste reduction at the point of origin, while predictive analytics allows for high-precision demand forecasting and circular supply routing, directly linking hospital operations with global decarbonisation and zero-waste targets (Leong & Leong, 2026; Uysal et al., 2026).

Thematic Review of Literature

Instead of evaluating the studies selected for review sequentially by study, they are organised into four separates but interrelated thematic areas in an effort to create thematic coherence and synthesise the scholarly consensus across the retrieved literature. Such a thematic structure allows a critical assessment of the interaction of operational approaches, advanced digital instruments, economic structures and institutional components in shaping the sustainability of hospitals. The literature is synthesised along four major themes. Theme 1 concerns operational waste reduction and Lean Healthcare implementation in the clinical setting. Theme 2: Predictive analytics and artificial intelligence in proactive hospital waste management Theme 3: Integrating Blue-Green Economic Synergy and Circular Economy principles in the operations of health system. Theme 4 critically assesses the organisational, technical and policy factors that may condition successful system-wide implementation.

Theme One: Operational Waste Reduction and Lean Implementation in Healthcare Facilities

The operational architecture of modern healthcare facilities produces large amounts of physical, financial, and procedural waste. This has led to the widespread adoption of Lean Healthcare (LH) frameworks to streamline clinical workflows and resource utilisation. Lean thinking, which is based on continuous-improvement models, aims to eliminate non-value-added activities, such as unnecessary transportation, over-processing, waiting times, and excessive inventory that directly contribute to institutional inefficiency and environmental overhead (Ong et al., 2023; Sêneda Filho et al., 2025). Within hospital settings, LH may contribute to waste reduction through principal interventions, including Kaizen events, Value Stream Mapping (VSM), and 5S workplace organisation systems to address process inefficiencies in clinical units, operating theatres, and support services (Marjane et al., 2026; Veres et al., 2026). When systematically integrated into the structure of organisational routines, these methodologies establish structured operational baselines to systematically reduce material consumption, energy requirements, and medical-waste generation at the point of care, before such waste arises (Adnan et al., 2023; Oktaviza et al., 2025).

Striking patterns as well as key disagreements exist across the empirical literature concerning the specific operational mechanisms that drive successful Lean deployment and sustainable waste reduction in healthcare. A broad consensus exists across studies that leadership commitment, staff engagement and a supportive organisational culture are indispensable determinants of Lean success as process improvements rapidly deteriorate without them (Ong et al., 2023; Veres et al., 2026). However, the literature still presents considerable debate about the standalone efficacy of traditional Lean tools in high-variability clinical environments. Several studies show that the use of traditional Lean tools such as VSM can provide immediate and local efficiencies in organised settings such as operating rooms and diagnostic laboratories (Sêneda Filho et al., 2025). On the other hand, detractors argue that traditional Lean frameworks are inherently static and fail to incorporate non-linear variations in patient admissions and unexpected surges in medical waste (Marjane et al., 2026; Oktaviza et al., 2025). Furthermore, the literature remains inconclusive as to whether Lean implementation, in itself, can provide environmental sustainability. Some scholars suggest that the speed of processes and cost-cutting are often more important than ecological and waste management outcomes (Adnan et al., 2023).

A critical reading of this literature suggests a fundamental limitation to the current conceptualisation of Lean Healthcare: LH is very effective at removing deterministic operational waste in stable workflows but lacks the dynamic forecasting capacity required to manage modern, complex hospital waste streams. Empirical studies on Lean implementation appear to remain within a limited, operational, short-term perspective. Few studies have examined long-term environmental indicators such as Scope 1-3 emissions, landfill diversion rates, or life-cycle waste impacts. This conceptual limitation points toward the need for systemic sustainability in healthcare, which cannot be achieved by optimising processes alone. To move away from a reactive waste reduction approach to a more proactive environmental responsibility approach, lean methodologies must be structurally integrated with advanced predictive data tools. With physical workflow discipline and algorithmic foresight, healthcare organisations can escape the static boundaries of traditional Lean implementation and move into an integrated blue-green economic alignment.

Theme Two: Predictive Analytics and AI Applications for Proactive Hospital Waste Management

The adoption of Industry 4.0 technologies, specifically predictive analytics, artificial intelligence (AI), machine learning (ML) and Internet of Things (IoT), is a paradigm shift from reactive to proactive hospital waste management. Predictive modelling allows healthcare administrators to analyse complex historical data, patient census patterns, and operational factors to accurately forecast future waste generation, medical supply consumption, and facility utility needs (Ahtasham Mushtaq et al., 2025; Uysal et al., 2026). Facilities employ sophisticated algorithms, such as explainable artificial intelligence (XAI) models and machine learning regressions, to predict the generation patterns of hazardous and non-hazardous waste at granular, department-specific levels (Uysal et al., 2026; William et al., 2025). Simultaneously, AI-based predictive maintenance systems track high-energy medical devices and building systems in real-time, predicting mechanical failures before they happen, thereby potentially optimising energy consumption, extending equipment life, and avoiding unnecessary electronic and material waste (Leong & Leong, 2026).

In the context of predictive analytics in healthcare operations, various methodologies and implementation priorities are discussed through a comparative analysis of the literature. A consensus exists that data-driven forecasting performs significantly better than traditional historical-average estimation methods in predicting material requirements and waste generation (Ahtasham Mushtaq et al., 2025; Uysal et al., 2026). However, there are clear methodological divisions between academics who advocate deep learning and complexity-based AI models and those who favour interpretable, lower-complexity statistical methods. Proponents of advanced AI claim that it is more accurate in predicting in highly erratic, multi-variable hospital environments (William et al., 2025). Opponents point out that “black-box” ML architectures suffer from poor clinician trust, high computational costs, and implementation friction in resource-constrained facilities (Uysal et al., 2026). Additionally, some studies are conducted on the macro-level forecasting of hospital supply chains (Ahtasham Mushtaq et al., 2025; Allahham et al., 2023), whereas others address micro-level facility management, such as equipment energy optimisation and local waste sorting (Leong & Leong, 2026).

A critical review of this literature suggests a substantial divergence between algorithmic potential and operational application. Most research on predictive analytics remains largely centred on algorithmic validation and technical feasibility, with limited empirical evidence of how these predictive insights are operationalised in routine hospital functions (Leong & Leong, 2026; William et al., 2025). The high-accuracy forecasting models are fundamentally underutilised in rigid, unoptimised administrative environments that lack the operational agility

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to act on data-driven projections (Goel et al., 2025; Uysal et al., 2026). This gap supports the central premise of this narrative review: predictive analytics alone may not drive waste reduction. The environmental and financial benefits of predictive tools will only be realised in volume when the data outputs of these tools are directly connected to adaptive, continuous-improvement workflows such as those offered by Lean Healthcare that transform predictive foresight into real-time operational adjustments.

Theme Three: Blue-Green Economic Synergy and Circular Economy Integration

The concept of convergence of process efficiency with digital intelligence is directly aligned with the emerging framework of Blue-Green Economic Synergy, which seeks to bridge environmental sustainability and data-driven economic innovation in healthcare operations. "Green" principles in healthcare settings are related to ecological preservation, decarbonisation, resource efficiency, zero-waste initiatives, while "blue" capabilities are related to digital technology, artificial intelligence, data analytics, and value creation (Allahham et al., 2023; Marfu et al., 2026). This dual-engine approach provides the theoretical bridge toward operationalising Circular Economy (CE) models within hospitals that are shifting the sector away from the traditional, highly polluting "take-make-dispose" linear model toward the closed-loop resource management (Goh et al., 2026; Iskandar Shah et al., 2026). Within a circular framework, hospital waste streams may be systematically reduced, segregated, remanufactured, or valorised into energy and secondary raw materials rather than simply discarded; these practices could lower institutionally costs and contribute to national and global carbon-neutrality goals (Chabouh et al., 2026; Marfu et al., 2026).

A recent literature review highlights the divergent thematic orientations and conceptual applications of circular economic models in the different healthcare jurisdictions. Blue-green and circular economy models are broadly accepted as critical for healthcare systems to achieve carbon neutrality by mid-century (Goh et al., 2026; Iskandar Shah et al., 2026). However, disagreement still seems to exist on the key drivers and barriers of circular transition. A second stream of literature identifies regulatory mandates, macro-level policy enforcement and regional waste infrastructure as the main drivers of hospital circularity (Goh et al., 2026; Milić et al., 2026). Conversely, a counter-stream argues that internal organisational factors such as corporate culture, leadership priorities and digital capabilities may have a larger impact on the implementation of circular waste practices (Allahham et al., 2023; Marfu et al., 2026). Moreover, some studies report advanced circular practices, such as the valorisation of organic waste to energy (Chabouh et al., 2026), while others indicate that many health systems are still struggling with basic waste segregation and single-use plastics (Iskandar Shah et al., 2026).

However, the literature review also shows a crucial gap between theory and practice. "Blue-green synergy" and "circular economy" are often used as abstract high-level concepts but there are no practical guides on how to make them work on the ground. Much of the current research is still conceptual or limited to macro-level policy reviews with little practical guidance for hospital managers on how to embed circular principles into daily operations (Goh et al., 2026; Iskandar Shah et al., 2026). Moreover, the literature considers green operational practices and blue digital instruments as parallel strategies rather than as synergistic drivers (Allahham et al., 2023; Marfu et al., 2026). This review addresses this gap by demonstrating how Lean Healthcare could enable the operational standardisation that is necessary for green waste reduction and predictive analytics provides the blue digital intelligence that is needed to control circular material flows. This review is a practical mechanism to operationalise blue-green economic synergy in hospitals.

Theme Four: Organisational, Technical, and Policy Implementation Dynamics

Complex organisational, technical, and policy dynamics determine the successful combination of Lean Healthcare and predictive analytics for sustainable waste management. From an organisational perspective, integrated operational-digital frameworks require transformational leadership, cross-functional collaboration, and continuous employee development to overcome institutional inertia and resistance to change (Ong et al., 2023; Veres et al., 2026). Technically, the synthesis of process workflows with predictive analytics requires a robust digital infrastructure, high-quality data governance, and interoperability between legacy hospital information systems, electronic health records, and Internet of Things (IoT)-enabled waste monitoring hardware (Allahham et al., 2023; William et al., 2025). In addition, internal capabilities may be constrained by the external policy environment, such as national environmental policies, healthcare accreditation standards, hospital waste disposal requirements, and public funding schemes for green infrastructure (Adnan et al., 2023; Goh et al., 2026).

In a comparative analysis of studies, we find contrary empirical evidence on the main barriers to institutionalising sustainable operational models. Evidence broadly suggests that all healthcare facilities experience continuous resource constraints and change fatigue challenges (Adnan et al., 2023; Ong et al., 2023). However, research on high-income health systems tends to focus on technical and data-driven obstacles, such as data privacy regulations, legacy system incompatibility, and AI model interpretability (Leong & Leong, 2026; Uysal et al., 2026). Conversely, research on low- and middle-income healthcare settings suggests that the principal barriers may comprise basic organisational and policy issues such as lack of leadership support, lack of capital for green technologies, and poor enforcement of waste disposal policies (Adnan et al., 2023; Iskandar Shah et al., 2026). There are also differences of opinion as to the most effective catalyst for sustainable operational transformation, whether it is top-down regulatory enforcement or bottom-up voluntary staff initiatives (Goh et al., 2026; Veres et al., 2026).

A critical synthesis of implementation dynamics shows that the current literature remains highly compartmentalised, with technical, organisational, and policy factors generally examined separately rather than as an interrelated ecosystem. Researchers study predictive AI models without considering organisational culture (Uysal et al., 2026) or Lean transformations without considering larger regulatory and digital constraints (Veres et al., 2026). This disjointed analytical approach may obscure the socio-technical realities of healthcare administration. The purpose of this review is to synthesise these implementation dynamics. Blue-green economic synergy may not be attainable through technological or procedural interventions in isolation. A comprehensive approach involving organisational readiness, digital-process alignment, and enabling policy frameworks may be necessary for resilient zero-waste hospital operations to establish an integrated roadmap for sustainable healthcare delivery. The structural relationship between these themes is shown in **Figure 3**.

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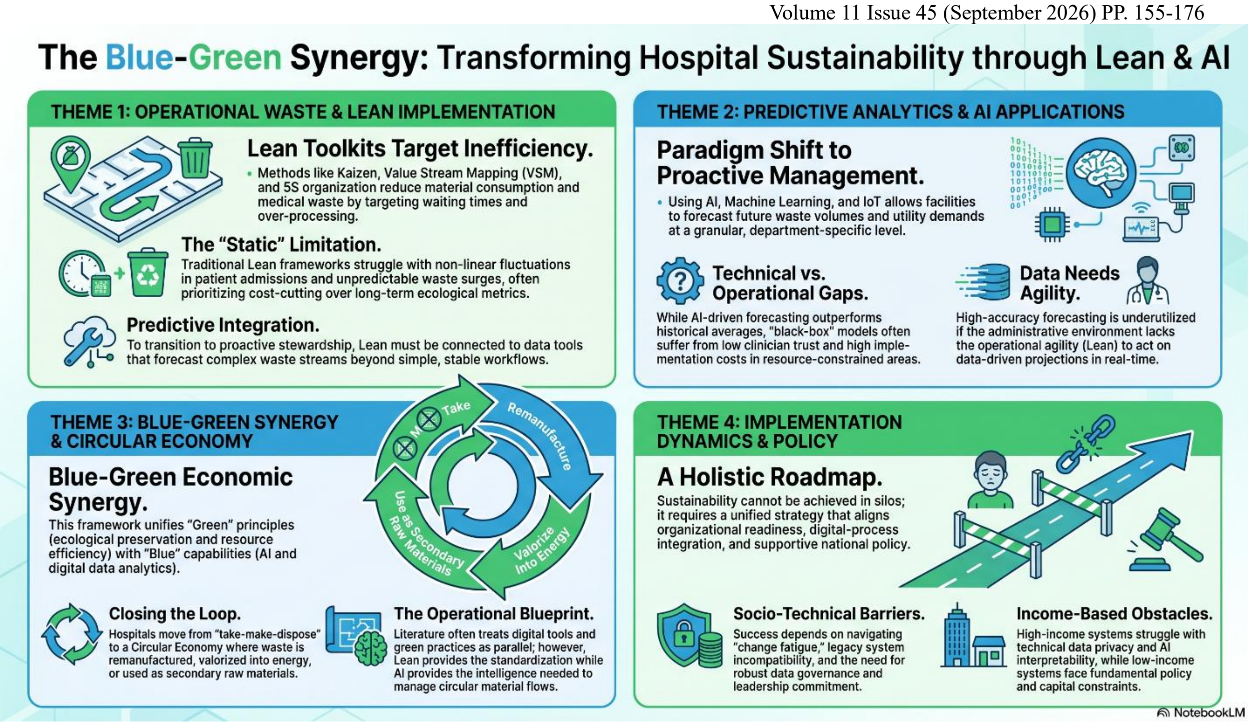

Figure: Thematic Review of Literature

Critical Discussion

To transition from thematic synthesis to high-level conceptual appraisal, this section critically evaluates the body of literature through four interrelated analytical dimensions. Moving beyond descriptive summaries, the discussion synthesizes the overarching agreements that form current scholarly consensus, critically interrogates key methodological and conceptual disagreements across the literature, identifies persistent empirical and theoretical gaps, and outlines practical and strategic implications for healthcare administrators, policymakers, and operational managers striving to realise blue-green economic synergy.

Agreements in the Literature

The existing literature review shows a strong academic consensus that operational discipline and technological integration are critical to hospital sustainability. Across geographical and organisational contexts, researchers uniformly agree that traditional, unoptimised healthcare workflows produce unsustainable volumes of physical and financial waste that cannot be remediated through incremental policy changes alone (Adnan et al., 2023; Goh et al., 2026; Ong et al., 2023). There is a broad consensus that Lean Healthcare (LH) methodologies such as Value Stream Mapping and Kaizen continuous improvement routines are a necessary operational basis for identifying non-value-added activities and minimising material waste at the point of clinical delivery (Marjane et al., 2026; Sêneda Filho et al., 2025; Veres et al., 2026). Simultaneously, scholars concur that Industry 4.0 technologies, especially artificial intelligence (AI) and predictive analytics, considerably improve operational foresight through facilitating dynamic demand forecasting, predictive equipment maintenance, and precise medical waste stream projection (Ahtasham Mushtaq et al., 2025; Leong & Leong, 2026; Uysal et al., 2026). The literature appears to support aligning these operational and technological interventions with circular-economy and green-economy principles to promote resource efficiency, carbon-footprint reduction, and resilient healthcare systems (Soares et al., 2023; Tomaselli et al., 2026).

The importance of this consensus, beyond these individual domains, lies in the collective acknowledgement that, for complex hospital systems, single-domain solutions implemented in isolation are inherently inadequate. There is consensus on LH that process optimisation is required as a prerequisite for digital transformation and consensus on predictive analytics that physical process discipline needs to be supplemented with algorithmic sensing to adapt to dynamic clinical environments (Goel et al., 2025; Oktaviza et al., 2025). Theoretically, this alignment may contribute to the Natural Resource-Based View (NRBV) and Dynamic Capabilities Theory (DCT) by suggesting that environmental performance may be contingent on the strategic combination of process-oriented pollution prevention capabilities with advanced data-driven sensing mechanisms (Allahham et al., 2023; William et al., 2025). Regarding health system governance, this literature appears to support moving beyond fragmented departmental efforts and considering integrated approaches that combine operational improvement with digital intelligence (Tomaselli et al., 2026).

Disagreements

Although there appears to be broad agreement on the overarching goals of hospital sustainability, there is significant disagreement on the best methodological pathways and implementation hierarchies for integrating Lean principles with predictive analytics. One major area of contention is the debate between researchers who prefer complex, high-parameter deep learning and ML models and those who favour interpretable, lower-complexity statistical algorithms for waste prediction (Uysal et al., 2026; William et al., 2025). Advocates of advanced neural networks claim that non-linear clinical and waste data require complex black-box architectures for actionable accuracy (William et al., 2025). In contrast, critics argue that complex models suffer from algorithmic opacity, which significantly decreases clinical trust, increases computational energy consumption, and poses serious barriers to adoption in resource-limited settings (Leong & Leong, 2026; Uysal et al., 2026). Moreover, a substantial conceptual uncertainty concerns whether Lean implementation inherently supports environmental sustainability or primarily promotes cost containment and operational speed, potentially at the expense of ecological outcomes (Adnan et al., 2023; Sêneda Filho et al., 2025).

A critical examination of these disagreements suggests a tension between technical optimisation and socio-technical feasibility in the administration of healthcare. The tension around model complexity points to a fundamental trade-off between predictive accuracy and operational utility: models with high accuracy are often underutilised if hospital staff cannot interpret their outputs or operationalise them into daily workflows (Goel et al., 2025; Uysal et al., 2026). Similarly, the debate on the environmental efficacy of Lean is reflected in the historical focus on economic and operational metrics, with limited attention to ecological indicators (Adnan et al., 2023; Veres et al., 2026) (Morell-Santandreu et al., 2020). Accordingly, a paradigm shift in the evaluation of technologies and process improvements may be warranted. Research and practice could prioritise balanced, “explainable” digital-Lean frameworks that explicitly quantify environmental decarbonisation and the ease of human adoption, as well as conventional financial metrics, rather than algorithmic sophistication or operational velocity per se.

Gaps

A rigorous appraisal of the literature identifies critical theoretical, empirical and practical gaps inhibiting the widespread realisation of blue-green economic synergy in healthcare. From a theoretical perspective, no validated unified framework exists in the current literature that conceptualises the dynamic interaction of Lean Healthcare workflows and predictive analytics algorithms to facilitate circular waste management (Marjane et al., 2026; Oktaviza et al., 2025). Empirically, the studies appear to be methodologically siloed, either studying the human and organisational determinants of Lean transformations (Ong et al., 2023; Veres et al., 2026), or the technical validation of the predictive algorithms in isolated settings (Ahtasham Mushtaq et al., 2025; Uysal et al., 2026), rarely performing integrated empirical evaluations of both systems deployed concurrently. Moreover, sectoral evidence is uneven. Empirical data are available for high-income health systems and specialised clinical units such as operating rooms but facility-wide waste streams and resource-constrained health systems in developing countries appear to be severely under-researched (Adnan et al., 2023; Goh et al., 2026; Iskandar Shah et al., 2026).

These gaps have important consequences for both academia and the world of practice. Without an integrated conceptual model, hospital leaders lack an operational blueprint to guide these efforts, and institutions have adopted digital instruments and Lean initiatives as isolated and competing priorities rather than as synergistic drivers (Allahham et al., 2023; Marfu et al., 2026). The lack of long-term environmental measurements, such as Scope 1–3 greenhouse gas emissions, landfill diversion rates and life-cycle material impacts, in practice, means that the actual ecological benefit of integrated operations is not fully quantified (Adnan et al., 2023; Goh et al., 2026) (SueChueLam et al., 2025). Future research could progress the field by moving beyond localised pilot studies to multicentre longitudinal empirical studies that quantify the combined effect of digital-lean integration on environmental decarbonisation and financial performance in diverse global healthcare settings.

Implications

Implications of convergence of findings across this narrative review are important to healthcare practice, institutional policy and theoretical advancement. The main practical implication for healthcare administrators and operational managers is that digital technology investments need to be preceded or implemented jointly with process standardisation as the deployment of predictive analytics on chaotic, unstandardised workflows will only automate operational waste rather than remove it (Marjane et al., 2026; Oktaviza et al., 2025). Facility leaders need to invest in dual-capability teams with skills in Lean process optimisation and data literacy to bridge the gap between algorithmic forecasts and frontline execution (Goel et al., 2025; Veres et al., 2026) Through changes in healthcare accreditation and funding standards to mandate the incorporation of waste tracking, circular procurement policies and carbon accounting, regulatory bodies and health authorities could encourage institutions to move toward blue-green operational models (Goh et al., 2026; Iskandar Shah et al., 2026).

This review demonstrates, from a theoretical perspective, that Blue-Green Economic Synergy provides a robust conceptual link between process engineering, digital informatics and environmental responsibility in healthcare. This synthesis contributes to the advancement of Dynamic Capabilities Theory and the Natural Resource-Based View in contemporary Industry 4.0 healthcare settings (Allahham et al., 2023; Leong & Leong, 2026; Marfu et al., 2026), conceptualising Lean Healthcare as the operational engine for process discipline ("green") and predictive analytics as the technological engine for digital foresight ("blue"). In practice, this two-engine strategy allows hospitals to shift to a proactive circular operational ecosystem from a reactive, compliance-based waste management system. Ultimately, this synergy may enable healthcare institutions to fulfil their core healing mission, while reducing their environmental footprint, protecting public health and ensuring long-term financial security.

Recommendations and Future Directions

Recommendations for Practice

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Recommendations for Policy or Organizational Use

Health authorities, regulatory bodies, and hospital boards need to create structural incentives and regulatory frameworks at the policy and governance level to institutionalise circular economy principles. Policy makers should require that Scope 1, 2, and 3 carbon accounting be incorporated into regular hospital performance reviews, shifting beyond basic operational cost savings to assess environmental performance indicators such as landfill diversion rates and life-cycle material impacts (Adnan et al., 2023; Goh et al., 2026). National health authorities and accreditation agencies could revise quality standards to explicitly embed sustainable waste management criteria, penalising linear "take-make-dispose" practices and rewarding closed-loop circular models (Goh et al., 2026; Iskandar Shah et al., 2026). In addition, public healthcare systems could establish dedicated innovation funds to subsidise the upfront capital expenditure for smart waste-monitoring IoT infrastructure, clean technology upgrades and

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advanced predictive analytics platforms in public and resource-constrained health facilities (Adnan et al., 2023; William et al., 2025).

Organisational leaders must also enforce circular supply chain contracts to align procurement policies with blue-green economic strategies. Hospital procurement departments should move towards sustainable vendor partnerships, where vendors are required to take back packaging, remanufacture medical devices, and provide full life-cycle transparency for clinical consumables (Chabouh et al., 2026; Iskandar Shah et al., 2026; Marfu et al., 2026). To do this, health system executive boards must establish formal corporate sustainability governance bodies that link executive performance indicators directly to environmental decarbonisation goals (Ong et al., 2023; Veres et al., 2026). Governance bodies could create policy environments that incentivise sustainable operational choices and require data-driven environmental reporting to support resilient healthcare systems that can achieve long-term carbon neutrality (Goh et al., 2026; Marfu et al., 2026).

Future Research Directions

Future research needs to move from small pilots to larger multi-centre longitudinal studies to advance academic knowledge and address longstanding empirical gaps. First, empirical studies should be conducted to evaluate the joint implementation of Lean Healthcare and predictive analytics across diverse health-facility networks, with explicit measurement of their joint effects on financial performance, operational throughput, and environmental metrics over long time periods (Ahtasham Mushtaq et al., 2025; Marjane et al., 2026; Uysal et al., 2026). Scholars may therefore need to develop and validate standardised, multidimensional performance frameworks that measure the precise economic and ecological return on investment (ROI) generated by blue-green economic synergy (Adnan et al., 2023; Marfu et al., 2026). Second, future research should examine the geographical and sectoral extension of this research beyond developed countries and speciality hospital departments, including comparative analyses in low- and middle-income health systems, where operational challenges, digital infrastructure, and policy environments may differ substantially (Adnan et al., 2023; Iskandar Shah et al., 2026).

Finally, there is an urgent need for methodological research to address the technical and socio-technical integration challenges in digital health care operations. Information systems researchers should investigate the design of low-cost edge computing IoT architectures and lightweight machine learning algorithms that can operate effectively in the legacy hospital information systems with no compromise on data privacy or energy efficiency [Leong & Leong, 2026; William et al., 2025]. Simultaneously, organisational behaviour scholars should examine the human and cultural drivers of digital-Lean transformations with particular attention to strategies for managing change fatigue, fostering algorithmic trust among clinicians, and cultivating sustainable cultures of ongoing environmental improvement (Ong et al., 2023; Veres et al., 2026). Addressing these empirical, geographic, and methodological pathways could provide the evidence base required to support the scaling of sustainable, zero-waste operations across health systems around the world.

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Conclusion and Limitations

Conclusion

The narrative review shows that the synergy between Lean Healthcare methodologies and predictive analytics provides a solid operational-digital framework to implement the Blue-Green Economic Synergy in hospital waste management. This review, by way of systematic synthesis of the existing literature across the domains of operations research, health informatics, and environmental management, explains that Lean process discipline offers the needed baseline for the elimination of physical waste, whereas predictive analytics and machine learning offer the dynamic forecasting capabilities that are necessary to navigate volatile clinical environments (Allahham et al., 2023; Marjane et al., 2026; Uysal et al., 2026). The primary contribution of this paper may be to delineate the conceptual relationship between process-oriented "green" efficiency and technology-driven "blue" intelligence, providing a common pathway to healthcare administrators to move from linear "take-make-dispose" operational models to closed-loop circular systems (Goh et al., 2026; Iskandar Shah et al., 2026; Marfu et al., 2026). As health systems worldwide seek to reconcile increasing clinical demand with stringent carbon neutrality requirements, adopting this dual-engine strategy may be critical to transforming hospitals into resilient, green institutions that protect public health and environmental sustainability.

Limitations

The review provides an in-depth conceptual synthesis, but it is necessary to recognise several methodological and structural limitations. The literature identification was limited to the database Scopus, within a ten-year window (2016–2026), excluding relevant studies indexed only in other databases such as PubMed, Web of Science or IEEE Xplore, as well as grey literature and non-English publications. Secondly, a clear sectoral and geographic bias exists in the literature reviewed, with the empirical evidence being concentrated on high-income healthcare systems and specialised hospital departments (e.g. operating rooms), limiting the immediate generalisability of the findings to resource-constrained settings in low- and middle-income countries (Adnan et al., 2023; Iskandar Shah et al., 2026). Third, there was significant conceptual overlap and inconsistent terminology in the literature, with terms such as "digital lean", "smart sustainability" and "blue-green synergy" being used interchangeably, blurring clear theoretical boundaries (Allahham et al., 2023; Marfu et al., 2026). Finally, as this is a narrative review, the synthesis and interpretation of the literature may be largely qualitative, without the statistical aggregation and formal meta-analytic pooling that are typical of systematic reviews.

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References

Adnan, A. N., Ma'aram, A., Sirat, R. M., Taib, M. F. M., Ismail, A., & Libasin, Z. (2023). Preliminary framework of lean healthcare sustainability performance measurement for health sector. *Malaysian Journal of Medicine and Health Sciences*, 19(5), 145–151. https://doi.org/10.47836/MJMHS.19.5.21

Ahtasham Mushtaq, M., Anis Noor, M., Santillo, L. C., & Verde, R. (2025). Implementing AI for dynamic demand forecasting in lean healthcare logistics: A case study approach. *Lecture Notes in Bioengineering*, 269–282. https://doi.org/10.1007/978-3-031-82923-9_26

Allahham, M., Sharabati, A.-A. A., Hatamlah, H., Ahmad, A. Y. B., Sabra, S., & Daoud, M. K. (2023). Big data analytics and AI for green supply chain integration and sustainability in hospitals. *WSEAS Transactions on Environment and Development*, 19, 1218–1230. https://doi.org/10.37394/232015.2023.19.111

Bharsakade, R. S., Acharya, P., Ganapathy, L., & Tiwari, M. K. (2021). A lean approach to healthcare management using multi criteria decision making. *OPSEARCH*, 58(3), 610–635. https://doi.org/10.1007/s12597-020-00490-5

Chabouh, S., Bouajila, I., Abid, G., Amara, H. B., & Hammami, S. (2026). Design of a sustainable food waste management system for collaborative healthcare facilities. *IFIP Advances in Information and Communication Technology*, 770, 394–410. https://doi.org/10.1007/978-3-032-05673-3_24

D'Andreamatteo, A., Ianni, L., Lega, F., & Sargiacomo, M. (2015). Lean in healthcare: A comprehensive review. *Health Policy*, 119(9), 1197–1209. https://doi.org/10.1016/j.healthpol.2015.02.002

Dion, H., Evans, M., & Farrell, P. (2023). Hospitals management transformative initiatives; towards energy efficiency and environmental sustainability in healthcare facilities. *Journal of Engineering, Design and Technology*, 21(2), 552–584. https://doi.org/10.1108/JEDT-04-2022-0200

Goel, G., Sharma, A., Sunita, Sharma, A., Singh, S., & Sharma, S. (2025). Role of sustainability and data analytics in healthcare efficiency. In *Optimized Healthcare: Leveraging Technology for Efficiency and Accessibility* (pp. 60–84). Bentham Science Publishers. https://doi.org/10.2174/9798898811563125010006

Goh, K. C., Kurniawan, T. A., Meidiana, C., Abdurakhmonov, O., Anouzla, A., Hin Yong, W., Islam, M. T., Kern, A. O., Aziz, F., Wou Onn, C., Othman, M. H. D., Zhang, D., Dai, W., Iqbal, M. A., Amjad, M., & Abass, K. S. (2026). Hospital waste management in Germany and the European Union during the Industry 5.0 era for carbon neutrality by 2050: A critical review. *Waste Management and Research*, 44(2), 116–132. https://doi.org/10.1177/0734242X251361726

Hussain, M., Malik, M., & Al Neyadi, H. S. (2016). AHP framework to assist lean deployment in Abu Dhabi public healthcare delivery system. *Business Process Management Journal*, 22(3), 546–565. https://doi.org/10.1108/BPMJ-08-2014-0074

Iskandar Shah, D. R. S., Anuar, N. F., Panizan, N. A. Z., Ibrahim, R., Ramli, R., Perai, N. A. A., & Aghamohammadi, N. (2026). Toward sustainable healthcare: Circular economy models in hospital operations and waste management. *Critical Reviews in Environmental Science and Technology*, 56(10), 530–550. https://doi.org/10.1080/10643389.2026.2641479

Leong, Y. Z., & Leong, W. Y. (2026). AI-enabled predictive maintenance of medical equipment for energy and waste reduction. *Engineering Proceedings*, 129(1), Article 10. https://doi.org/10.3390/engproc2026129010

Mahmoud, Z., Angelé-Halgand, N., Churruca, K., Ellis, L. A., & Braithwaite, J. (2021). The impact of lean management on frontline healthcare professionals: A scoping review of the literature. *BMC Health Services Research*, 21(1), Article 383. https://doi.org/10.1186/s12913-021-06344-0

Marfu, A., Purwanto, A., Atmanto, D., Rahmayanti, H., Marini, A., Safitri, D., Julia, V., Dewiyani, L., Saputro, R. H., Muharrani, N. P., Wulandari, S. S., & Atichasari, A. S. (2026). A multi-method framework for prioritizing circular economy drivers in sustainable hospitals. *Circular Economy and Sustainability*, 6(2), Article 74. https://doi.org/10.1007/s43615-026-00798-2

Marjane, C., Bajjou, M. S., & Chafi, A. (2026). Synergizing lean healthcare and Industry 4.0 technologies for sustainable healthcare transformation: A literature review. *Sustainability*, 18(5), Article 2650. https://doi.org/10.3390/su18052650

Marsilio, M., Pisarra, M., Rubio, K., & Shortell, S. (2022). Lean adoption, implementation, and outcomes in public hospitals: Benchmarking the US and Italy health systems. *BMC Health Services Research*, 22(1), Article 122. https://doi.org/10.1186/s12913-022-07473-w

Milić, M. K., Sinanović, Š., Prodović, T., & Bubanj, S. (2026). Sustainability of healthcare systems: Integration of green technology in hospital facilities. *AFMN Biomedicine*, 43(1), 15–22. https://doi.org/10.65641/afmnai-2026-026

Oktaviza, Y., Yunus, M., Ibrahim, M., & Chan, S. (2025). Integrating advanced technology and lean six sigma for enhanced hospital management and operations. *Studies in Big Data*, 158, 157–167. https://doi.org/10.1007/978-3-031-70855-8_14

Ong, K. Y., Zailani, S., Kanapathy, K., Rahman, M. K., Mamun, A. A., & Bhuiyan, M. A. (2023). Determinants of effectiveness of lean healthcare performance in Malaysian public hospitals. *The TQM Journal*, 35(7), 1815–1829. https://doi.org/10.1108/TQM-04-2022-0137

Osorio-Canchig, K. T., Reyes-Vásquez, J. P., & Aldás-Salazar, D. S. (2025). Improvement of the efficiency of hospital care: A simulation-based approach. *DYNA*, 92(239), 101–110. https://doi.org/10.15446/dyna.v92n239.120207

Sêneda Filho, E. J., Espôsto, K. F., Carpinetti, L. C. R., & Zanon, L. G. (2025). Improving operating room efficiency through lean thinking: A multi-criteria decision-making approach. *International Journal of Lean Six Sigma*, 16(1), 1–31. https://doi.org/10.1108/IJLSS-05-2025-0132

Uysal, İ., Altın, F. G., & Özcan, F. (2026). Predicting medical waste amounts and costs using machine learning and XAI for sustainable waste management in healthcare. *International Journal of Environmental Science and Technology*, 23(1), Article 21. https://doi.org/10.1007/s13762-025-06895-3

Veres, C., Stoian, M., Szabo, D.-A., & Gabor, M. R. (2026). The role of leadership in lean healthcare transformation: A mixed-methods study. *Journal of the Knowledge Economy*, 17(1), 1538–1563. https://doi.org/10.1007/s13132-025-02661-5

William, P., Ameena Banu, M., Balaji, V. S., Mamedova, G., Subramani, B., Agalya, M., & Alagarsamy, M. (2025). Machine learning applications in optimizing healthcare waste management processes. In *Hospital Waste Management and Toxicity Evaluation* (pp. 321–341). IGI Global. https://doi.org/10.4018/979-8-3693-5757-6.ch012

William, P., Vijayarajan, S. M., Balaji, V. S., Subramani, B., Manivannan, R., Hajiyeva, R. J., & Alagarsamy, M. (2025). Leveraging AI and IoT for efficient hospital waste management analysis. In *Hospital Waste Management and Toxicity Evaluation* (pp. 343–368). IGI Global. https://doi.org/10.4018/979-8-3693-5757-6.ch013

Zamparas, M., Kapsalis, V. C., Kyriakopoulos, G. L., Aravossis, K. G., Kanteraki, A. E., Vantarakis, A., & Kalavrouziotis, I. K. (2019). Medical waste management and environmental assessment in the Rio University Hospital, Western Greece. *Sustainable Chemistry and Pharmacy*, 13, Article 100163. https://doi.org/10.1016/j.scp.2019.100163