Journal of Healthcare Leadership

Dovepress
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REVIEW

Energy Conservation and Emission Reduction in Central Sterile Supply Department Under High-Quality Development of Public Hospitals: A Narrative Review

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Abstract: This review focuses on energy conservation and emission reduction in the Central Sterile Supply Department (CSSD) of public hospitals. Based on policy frameworks including the Outline of the Healthy China 2030 Plan, the high-quality development initiative for public hospitals, and the "Three Transformations" strategy, and integrating the critical role of CSSD as the "master valve" for hospital infection control, this review systematically outlines the three-stage evolution of CSSD energy conservation and emission reduction: the passive energy-saving stage, the equipment and technology improvement stage, and the systematic management stage. Evidence was synthesized narratively from English- and Chinese-language literature published from inception to June 2025. By comprehensively analyzing existing literature, this review identifies the current bottlenecks faced by CSSDs, including challenges in technology adaptation, cross-departmental collaboration, intelligent system development, and cost-benefit balance. We propose three interrelated optimization pathways: precision technology, refined management, and integrated intelligence, and further discuss the challenges of transformation and future development directions toward a "safety-efficiency-low carbon" model. This review aims to provide theoretical support and practical guidance for energy conservation and emission reduction in CSSDs of public hospitals, assist hospitals in meeting the assessment target of "reducing energy consumption per 10,000 yuan of revenue", and promote the green and sustainable development of the medical industry.

Keywords: Central Sterile Supply Department, CSSD, energy conservation, emission reduction, high-quality development, public hospital, public hospital reform

Introduction

As the core of China's medical service system, the high-quality development of public hospitals is pivotal to enhancing national health. In the pursuit of high-quality development of public hospitals, the Central Sterile Supply Department (CSSD) serves as a "hub department" for hospital infection control and sterile supply assurance, and its management directly impacts the effectiveness of medical infection prevention and control. Meanwhile, CSSD processes such as cleaning, drying, and sterilization rely heavily on energy sources like high-temperature steam and electricity, making it one of the most energy-intensive departments in hospitals. Controlling CSSD energy consumption not only affects hospital operating costs but also aligns closely with the implementation of China's national "Dual Carbon" Strategy. Currently, as CSSDs transition from a "background cleaning and disinfection units" to "green hubs", they face challenges such as balancing new technologies with safety requirements and addressing inadequate cross-departmental collaboration. Against this backdrop, this review synthesizes the historical evolution, current issues, and optimization strategies of CSSD energy conservation and emission reduction, providing references for the green and sustainable development of public hospitals.

https://doi.org/10.2147/JHL.S588532
Received: 12 December 2025
Accepted: 15 February 2026
Published: 20 February 2026

This narrative review aims to map energy-saving practices in hospital CSSD and to identify implementation determinants under China's high-quality development policy and Dual Carbon Strategy. We framed the review question using the PICO: Population = public hospital CSSD; Intervention = any energy-saving or carbon-reduction technology or management program; Comparison = conventional practice; Outcomes = energy consumption, carbon emissions, sterilization quality, and cost.

Methods

We performed a literature search in the following databases: PubMed, Web of Science, CNKI and Wanfang without language restriction from inception to June 2025. Search terms were ("CSSD" OR "sterile supply" OR "sterilization department") AND ("energy" OR "carbon" OR "steam" OR "electricity" OR "water consumption") AND ("hospital" OR "healthcare"). Additional records were identified through reference lists and policy documents. Studies were eligible if they reported energy-saving technologies, management interventions, or carbon-emission data in hospital CSSD. Formal quality appraisal was not performed; instead, we synthesized findings narratively under three pre-defined themes: precision technology, refined management, and integrated intelligence. This approach allows rapid mapping of evidence while acknowledging the heterogeneity of designs and metrics in the included literature.

Results

Main Tasks and Key Roles of CSSD

The core functions of CSSD include the collection and sorting of medical devices, cleaning, disinfection, inspection, packaging, sterilization, storage, distribution, and traceability documentation. Its primary task is to disinfect and sterilize reusable medical devices, textiles, and surgical instruments using physical or chemical methods, thereby providing safe and sterile medical supplies for clinical departments and preventing the spread of infections.[1] Within medical institutions, the CSSD plays an indispensable role as the "master valve" for hospital infection control.

A study demonstrated that monitoring the cleanliness of medical devices, work surfaces, and staff hands, identifying potential pollution sources and correcting them by optimizing cleaning/disinfection protocols effectively prevents healthcare-associated infections and ensures patient safety.[2] A systematic review and meta-analysis further confirmed that CSSD management is significantly associated with the incidence of hospital-associated infections and adverse events, highlighting that effective CSSD management is critical for improving clinical outcomes.[3]

CSSD work records also hold great value for hospital management. Electronic CSSD records can be used for auditing, legal purposes, and incident tracing, providing a basis for hospitals to develop standard guidelines for retaining disinfection records.[4] In addition, electronic record systems can be integrated with the hospital information system, anesthesia information management system, and financial system to achieve "end-to-end documentation", forming a full-cycle database. This database provides quantitative support for hospitals to dynamically adjust strategies for instrument procurement, usage, turnover, and management.

Three Stages of Energy Conservation and Emission Reduction in CSSD

Cleaning and disinfection processes are the primary sources of energy consumption in CSSDs. Energy conservation and emission reduction in CSSDs not only involve direct energy consumption management of equipment but also encompass broader measures such as optimizing resource allocation, improving equipment efficiency, and refining work processes. Analyzing the three stages of CSSD energy conservation and emission reduction enables a more comprehensive understanding and application of energy-saving strategies to achieve the goal of sustainable development. These stages are as follows.

(1) Passive energy-saving stage: In this stage, CSSDs primarily achieve energy-saving goals through the rational use and maintenance of existing equipment. While short-term energy-saving effects can be achieved (eg, through behavioral norms such as "turning off lights when leaving" and "reducing standby time"), its effectiveness is often

limited. This is due to the lack of targeted measures for high-energy-consuming equipment (eg, sterilizers and cleaning-disinfecting machines) and the absence of systematic management and technical support.

(2) Equipment and technology improvement stage: During this stage, CSSDs introduce advanced equipment and technologies, such as pulsating vacuum sterilizers, energy-efficient cleaning-disinfecting machines, digital traceability systems, energy-saving drying cabinets, and pure water systems. Technical upgrades such as waste heat recovery and variable-frequency water supply are also implemented. The combination of these improvements enables CSSDs to enhance disinfection and supply efficiency, reduce overall energy consumption, while meeting sterilization quality standards, and lay the foundation for building green hospitals.

(3) Systematic management stage: The systematic management stage is critical for CSSD energy conservation and emission reduction. At this stage, CSSDs adopt comprehensive management systems and technical tools to implement refined management throughout the entire disinfection and supply process. These systematic management measures not only improve CSSD operating efficiency but also effectively reduce energy consumption. Specific systematic management approaches and technologies for CSSDs are detailed in the following section.

Optimization Strategies for Energy Conservation and Emission Reduction in CSSD

Driven by the high-quality development of public hospitals and the "Dual Carbon" Strategy, CSSDs are transitioning from "background cleaning and disinfection units" to "green hubs", directly supporting the high-quality assessment target of reducing energy consumption in public hospitals. Current research converges on a core question: how to minimize energy consumption, costs, and carbon emissions while ensuring sterile safety. Based on existing evidence, three interrelated practical pathways have been identified: precision technology, refined management, and integrated intelligence. Together, they form the primary optimization strategies for energy conservation and emission reduction in modern CSSDs (Table 1).

Precision Technology

(1) Cleaning method upgrades: A study showed that using adenosine triphosphate (ATP) bioluminescence is a rapid and feasible method for monitoring the cleanliness of reusable surgical instruments. Additionally, cleaning-disinfecting machines exhibit higher cleaning efficiency than manual cleaning.[5] This approach not only improves cleaning qualification rates but also reduces the need for re-cleaning, thereby lowering energy consumption.

(2) Triple optimization of packaging, loading, and energy: A British study found that processing instruments in kits reduces unit carbon emission from 189 g to 66–77 g CO_2e.[6] For surgeries requiring $\leq$ 10 instruments, prioritizing single-instrument packaging is more environmentally friendly than opening a new kit. High-temperature incineration increases carbon emissions from disposable packaging by 33–55%, whereas recycling reduces emissions by 6–10%.[6] Therefore, carbon emissions and costs can be reduced through kit-based processing, integrating single instruments into kits, improving loading rates, adopting low-carbon energy sources, and implementing recycling programs.

Refined Management

(1) Sub-specialty management model: CSSDs adopting the sub-specialty management demonstrate significant advantages in quality control. Research indicates that this management model improves medical staff satisfaction, reduces equipment damage rates, and enhances the theoretical knowledge and practical skills of CSSD professionals.[7]

(2) Plan-Do-Check-Act (PDCA) cycle management: The PDCA cycle, consisting of "4 stages + 12 steps", uses refined management to effectively improve the qualification rates of cleaning, disinfection, and sterilization, enhance medical staff satisfaction, and elevate the overall CSSD management levels.[8]

(3) 6S management model: Implementing the 6S management model (sort, set in order, shine, standardize, sustain, and safety) improves the cleaning and disinfection quality of CSSD equipment, reduces instrument processing errors, enhances the management quality and work efficiency of surgical instruments, and minimizes energy and resource waste.[9]

(4) Defect management improvement model: Adopting a defect management improvement model enhances cleaning and disinfection effects, reduces adverse events, and helps reduce energy consumption.[10]

Table 1 Key Measures for Energy Conservation and Emission Reduction in CSSD

Optimization Pathway	Key Measures	Implementation Dimension	Core Role	Application Scenario
Precision technology	ATP monitoring + cleaning-disinfecting machine	Cleaning process	Improve cleaning qualification rate, reduce re-cleaning	Processing of reusable surgical instruments
	Kit processing + packaging recycling	Packaging/energy process	Reduce carbon emissions	Batch processing of instruments, disposable packaging
Refined Management	Sub-specialty management model	Staff/quality control	Improve medical staff satisfaction, reduce equipment damage rate	Classified processing of instruments in multiple departments
	PDCA cycle	Full-process management optimization	Improve cleaning, disinfection, and satisfaction	Daily improvement of cleaning, disinfection, and sterilization
	6S management model	Equipment/ environment/ operation standards	Improve efficiency, reduce error rate, reduce resource waste	Equipment storage in CSSD, instrument processing operations
	Defect management improvement model	Problem identification and improvement	Reduce adverse events, reduce energy waste caused by errors	Rectification of cleaning and disinfection problems, quality improvement
Integrated intelligence	Intelligent energy control system	Energy/equipment monitoring and control	Cut non-working-hour energy waste; enable data-based cost analysis	Monitoring of industrial steam, purified water, and high-energy equipment
	Systematic analysis	Process problem diagnosis and optimization	Identify causes and propose improvement measures for efficiency	Analysis of equipment-operation and energy-supply coupling relationships
	Emergency capacity optimization	Resource control in emergency scenarios	Utilize resources in emergencies, reduce energy waste	Emergencies such as epidemics and equipment failures

Abbreviations: ATP, adenosine triphosphate; CSSD, Central Sterile Supply Department; PDCA, Plan-Do-Check-Act.

Integrated Intelligence

(1) Intelligent energy control system: An intelligent energy control system (integrating sensors, PC/mobile clients, and cloud servers) enables automated monitoring/control of CSSD energy (industrial steam, pure water, etc.) and high-energy equipment (sterilizers, pure steam generators). It realizes automatic equipment startup, preheating/self-test, and scheduled energy supply (eg, 5:00 startup, 19:30 shutdown) to cut non-working-hour waste. Post-application data showed per-sterilization reductions of 55.7 kg purified water, 52.2 kg industrial steam, and 0.12 kWh electricity; it also supports abnormal alarms and cloud data storage for cost accounting.[11]

(2) Systematic analysis: By conducting a systematic analysis of the multi-level dependencies in the disinfection and supply process, the causes of performance fluctuations can be identified and targeted improvement measures can be proposed.[12] This data-driven analysis not only improves the operational efficiency of CSSD but also helps reduce energy waste.

(3) Emergency capacity optimization: Although most medical institutions in China have established emergency management systems, they often lack regional specificity and require further refinement.[13] Optimizing emergency plans and enhancing staff emergency response capabilities can ensure efficient resource utilization during emergencies and minimize unnecessary energy consumption.

Discussion

Policy Background and Current Status of High-Quality Development of Public Hospitals in China

In 2016, the Healthy China 2030 Plan issued by the Central Committee of the Communist Party of China and the State Council set the overarching goal of building a healthy nation. In 2021, the General Office of the State Council released the Opinions on Promoting the High-Quality Development of Public Hospitals (Guobanfa [2021] No.18), which established the "Three Transformations": shifting from scale expansion to quality and efficiency, from extensive management to refined management, and from material inputs to talent and technology. To facilitate the implementation of these guidelines, the National Health Commission and the National Administration of Traditional Chinese Medicine issued the High-Quality Development Promotion Action for Public Hospitals (2021–2025) (Guoweiyi Fa [2021] No.27), detailing key construction actions (building high-level hospital networks, developing clinical specialty clusters, cultivating talent teams, and creating "trinity" smart hospitals), and capacity enhancement actions (improving medical quality, patient experience, hospital management, and clinical research). The hospital management upgrade section explicitly calls for greater efficiency, lower costs, and a reduction in energy consumption per 10,000 yuan of revenue.

In recent years, the reform of public hospitals has steadily advanced, focusing on improving quality and efficiency. However, rising hospital operating costs have made sustainable development through refined management and energy conservation imperative. The metric "energy consumption per 10,000 yuan of revenue" has thus become a core performance indicator, reflecting a hospital's modern management capacity and green-development potential. The reform is now entering a deep phase centered on public welfare and high-quality development, with future efforts prioritizing refined management, smart hospital construction, and talent development under the overarching theme of "improving quality and efficiency while promoting green operations."

Challenges of Energy Conservation and Emission Reduction in CSSD

In the current transformation of CSSD to a "green hub", it is necessary to balance the three goals of "sterile safety", "energy conservation and emission reduction", and "operational efficiency". In practice, multiple bottlenecks are encountered, which can be summarized into the following four categories.

(1) Technology-safety balance dilemma: Upgrading to new technologies requires substantial investment, which burdens small and medium-sized hospitals. Additionally, the sterility of some low-carbon technologies remains unvalidated, requiring further research for practical application. CSSDs also continue to rely on traditional thermal power; clean energy (eg, solar energy, waste heat recovery) is limited by building conditions and regional factors, and pipeline modifications disrupt normal operations.

(2) Management-implementation gap: Collaboration between clinical, equipment, and logistics departments remains weak, with no effective cross-departmental coordination mechanisms. Staff often have a superficial understanding of energy-saving measures and lack operational proficiency, while reliance on experience hinders the adoption of new practices.

(3) Fragmented intelligent construction: Intelligent systems typically have single functions (eg, only instrument positioning) and lack integration with energy consumption and quality data, resulting in "data silos". Emergency management prioritizes "supply guarantee" over energy conservation, leading to inadequate energy-saving protocols and resource misallocation.

(4) Cost-benefit contradiction: Initial investments in energy-saving transformations are high, but hospital funding prioritizes clinical needs over such upgrades. Moreover, energy-saving benefits are often intangible, and the absence of a quantitative evaluation system leads to insufficient management attention.

https://doi.org/10.2147/JHL.S588532

Future Prospects

In the future, CSSD energy conservation and emission reduction will shift from “single-point optimization” to “systematic upgrading”. Through a deep integration of technology, management, and intelligence, a “safety-efficiency-low carbon” green operation model will be established. Four core development directions are outlined below.

(1) “Safety-low carbon-efficiency” technology system: Develop modular technologies compatible existing equipment and sterile-compliant degradable materials. Promote regionalized clean energy solutions (eg, solar energy + natural gas, waste heat recovery). Implement full-life-cycle instrument management (eg, procuring wash-resistant instruments, establishing shared instrument pools, and promoting recycling and remanufacturing) to achieve full-chain carbon reduction.

(2) “Collaboration-empowerment-assessment” management closed loop: Establish hospital-level special working groups, define departmental assessment indicators (eg, linking clinical waste rates to performance), and conduct regular collaborative optimization. Integrate energy-saving training (eg, hands-on exercises) and recognize “energy-saving models” to eliminate implementation barriers through mentorship programs.

(3) “Data-decision-emergency” intelligent linkage: Build an integrated platform integrating “instrument traceability + energy consumption monitoring + quality control”, and use artificial intelligence (AI) to generate optimal cleaning plans, breaking down data silos. Implement hierarchical emergency responses (eg, AI-driven demand forecasting, prioritizing emergency surgical instrument processing) and establish regional shared instrument pools to reduce waste.

(4) “Diversified investment-quantified benefit” cost model: Expand funding sources (eg, Dual Carbon subsidies, green credit, and third-party energy performance contracting) to reduce initial pressure. Develop benefit accounting standards (covering both tangible and intangible benefits), issue regular benefit reports, and promote a virtuous cycle of “investment-benefit-reinvestment”.

This review provides an evidence-based framework and quantifiable indicators for future multi-center prospective studies aiming to validate and refine green-operation models of hospital sterilization supply worldwide.

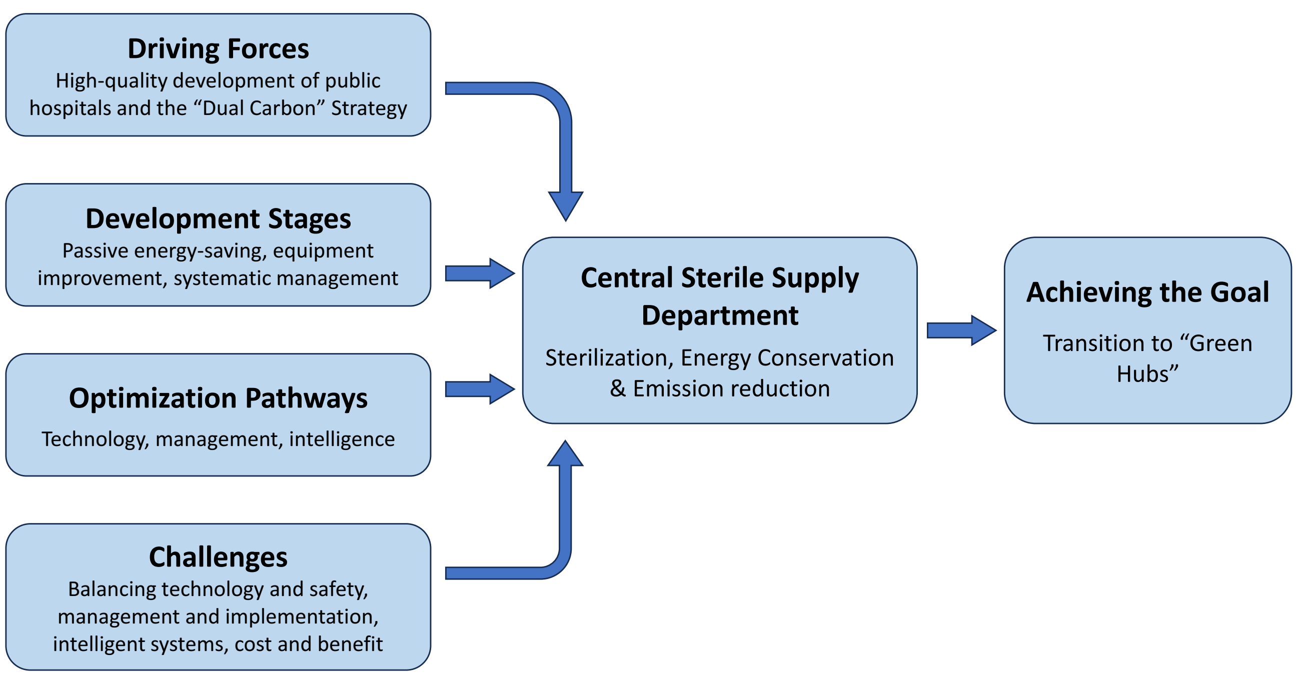

Figure 1 Relationship Diagram of Driving Forces, Development Stages, Optimization Pathways, Challenges, and Goals of Energy Conservation and Emission Reduction in Central Sterile Supply Department. Indicator key: Bold framed words “Driving Forces”, “Development Stages”, “Optimization Pathways”, “Challenges” and “Green Hubs” represent the five main content themes of the manuscript. Bold “Central Sterile Supply Department” indicates the study setting and “Achieving the Goal” indicates the desired outcome of the entire framework. Blue arrows denote the sequential flow of the framework.

Conclusion

Energy conservation and emission reduction in public hospital CSSDs not only responds to the high-quality development of public hospitals and the "Dual Carbon" Strategy but also meets the internal demand for CSSD's own high-quality development. CSSDs have undergone three development stages. Despite the current challenges in technology and management, CSSDs will eventually evolve into "green hubs" through advancing technological innovation, improved management systems, and the construction of intelligent platforms (Figure 1). These hubs will ensure the highest standards of sterile safety with minimal energy consumption and carbon emissions, providing solid support for the high-quality development of public hospitals and contributing to the low-carbon transformation of the medical industry.

Abbreviations

AI, artificial intelligence; ATP, adenosine triphosphate; CSSD, Central Sterile Supply Department; PDCA, Plan-Do-Check-Act.

Data Sharing Statement

No datasets available during the current study.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Funding

This study was supported by the National Natural Science Foundation of China (82471290 to KP), 333 High-level Talent Training Project in Jiangsu Province ((2024)3-2272 to KP) and First Affiliated Hospital of Soochow University Nursing Research Project (HLYJ-2026-04 to PC). The funders were not involved in the design or execution of the study or in the analysis and interpretation of the data.

Disclosure

The authors declare no competing interests in this work.

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