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Artificial Intelligence and the Future of Environmentally Sustainable Radiology

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Abstract: Background: Artificial Intelligence (AI) adoption in radiology has revolutionized diagnostic procedures by enhancing efficiency, accuracy, and clinical results. AI application, from image reception and reconstruction to report production, has optimized operations and reduced errors significantly linked to human interaction. Its environmental impacts, nonetheless, of releasing AI, especially the energy it demands for training and performing extensive models, are still insufficiently addressed. With the world's health systems inclining toward green policies and carbon neutrality, there is a need to assess if AI helps in reducing or adding to the environmental impact of radiology.

Aim: The aim of this research is to examine the role of AI in pro-environmental radiology in terms of its impact on energy consumption, carbon emissions, and resource usage in imaging procedures.

Methodology: A mixed-methods strategy was used that included a systematic review of peer-reviewed literature (2015–2024) and a comparative workflow analysis in a tertiary radiology department. AI-integrated workflows were contrasted with traditional practices through the use of key environmental metrics: energy use per exam, image processing time, dose of radiation, and medical waste (contrast media, use of film). Specific focus was placed on AI applications for automated protocol selection, low-dose reconstruction, and workflow automation.

Results: Integration of AI led to a 22% decrease in mean scan time and 15% lowering of contrast media usage through optimized protocols. AI-based reconstruction facilitated dose-reduction measures, reducing radiation exposure and energy usage by about 18% per scan. Yet the energy invested in training deep learning models was significant, emphasizing the need for green AI development methodologies. The results indicate a twofold effect: increased sustainability in clinical use but higher energy requirements in AI model development.

Conclusion: The AI is powerful in enabling environmentally friendly radiology through resource optimization. This can be achieved through embracing green development approaches and life cycle analysis.

Keyword: AI in radiology environmental impact, radiology energy consumption, sustainability in medical imaging, and AI-driven clinical decision support environmental analysis.

INTRODUCTION

AI has revolutionized radiology and brought about high-quality diagnostic accuracy, operational efficiency, and improved quality in patient care. However, such technological development raises environmental issues that must be well-evaluated. Building and operating AI in radiology requires vast amounts of data storage and energy, affecting the environment in both direct and indirect manners. Opportunities to improve sustainability in radiology exist through clinical decision support, image acquisition, and scheduling of workforce. However, challenges such as contrast waste, contamination, and the carbon footprint of data-intensive infrastructure are of significant concern. The subsequent subsections consider these issues. AI has enabled diagnostic accuracy better than human performance in computing algorithms that can surpass human power for any particular task to be performed, like image analysis(1)(2). An increase in operational efficiency is possible through AI-driven automation, thereby reducing the time to process images while aligning workflows(3). The power required to operate AI processes in radiology is pretty high because of the computational power necessary to access data and storage facilities(4). The carbon footprint of the AI infrastructure is a problem and has become an area of concern, calling for strategies to minimize the environmental impact due to the infrastructure(5). AI can optimize clinical decision support systems, which cut down on useless imaging and conserve resources(6). Advanced image acquisition techniques can cut down on re-scans; this minimizes waste and conserves energy(7). AI can streamline workforce scheduling so that there is better resource allocation and lower operation costs(8). The disposal of imaging contrast agents poses environmental hazards and, thus, needs proper management to prevent contamination(9). AI in Radiology has a vast carbon footprint as it involves bulky data, which indicates the need for sustainable practices(10). While AI offers many benefits in radiology, such as improved diagnostic capabilities and operational efficiencies, it also poses environmental challenges that need to be addressed. Balancing technological advancement with sustainability is important to ensure that the benefits of AI in radiology do not come at the expense of environmental health. Radiology departments are particularly impactful within healthcare due to their high energy consumption, extensive use of materials, and generation of both hazardous and non-hazardous waste. Imaging equipment, such as MRI machines, CT scanners, and X-ray devices, requires substantial energy to operate. Moreover, the disposal of medical imaging films, electronic waste from outdated equipment, and chemical waste from contrast agents and film processing poses significant environmental challenges(11). Magnetic resonance imaging (MRI), computer tomography (CT), and nuclear medicine are prominent imaging modalities in modern medical imaging departments; however, these modalities can have substantial environmental impact costs due to energy consumption and waste production. Having an understanding of this environmental impact and possible mitigation strategies is vital to achieve maximum benefits with minimal environmental footprint(12). Training an AI model, especially those based on DL, requires iterative computations over huge datasets, which tend to involve high-end hardware such as GPUs or TPUs. All these devices require a lot of energy, especially when running in parallel to shorten training times. The environmental influence goes further than direct usage of energy by the hardware and corresponding emissions to indirect emissions due to data center operations(13). Artificial intelligence (AI)-based solutions in imaging protocols, structured reporting, and patient-centered communication have emerged as pivotal tools for this transformation. AI-driven decision support systems optimize the appropriateness of imaging requests, thereby reducing redundant examinations and enhancing diagnostic accuracy. Additionally, sustainable imaging protocols and innovative techniques like virtual contrast imaging help decrease radiology's carbon footprint without compromising patient care(14). In health care, radiology has been at the forefront of examining the clinical and business potential of AI, with the largest number of AI tools approved by the U.S. Food and Drug Administration and the greatest number of publications on health care. Yet, up until recently, the environmental impacts resulting from these AI operations have been mostly neglected. There is a need for us to re-evaluate the ways in which the development and use of AI technologies within radiology feed directly and indirectly into Greenhouse gas emissions across the entire AI and informatics system. This includes taking into account factors like AI model creation and deployment, data storage, and energy source selections(15).

AIM AND OBJECTIVES:

This is aimed at understanding the environmental impacts of incorporating AI into radiology and providing guidelines to ensure sustainability.

OBJECTIVES.

Analyzing the environmental impact of AI model development and data storage requirements in radiology.

MATERIALS AND METHODS

Study Design:

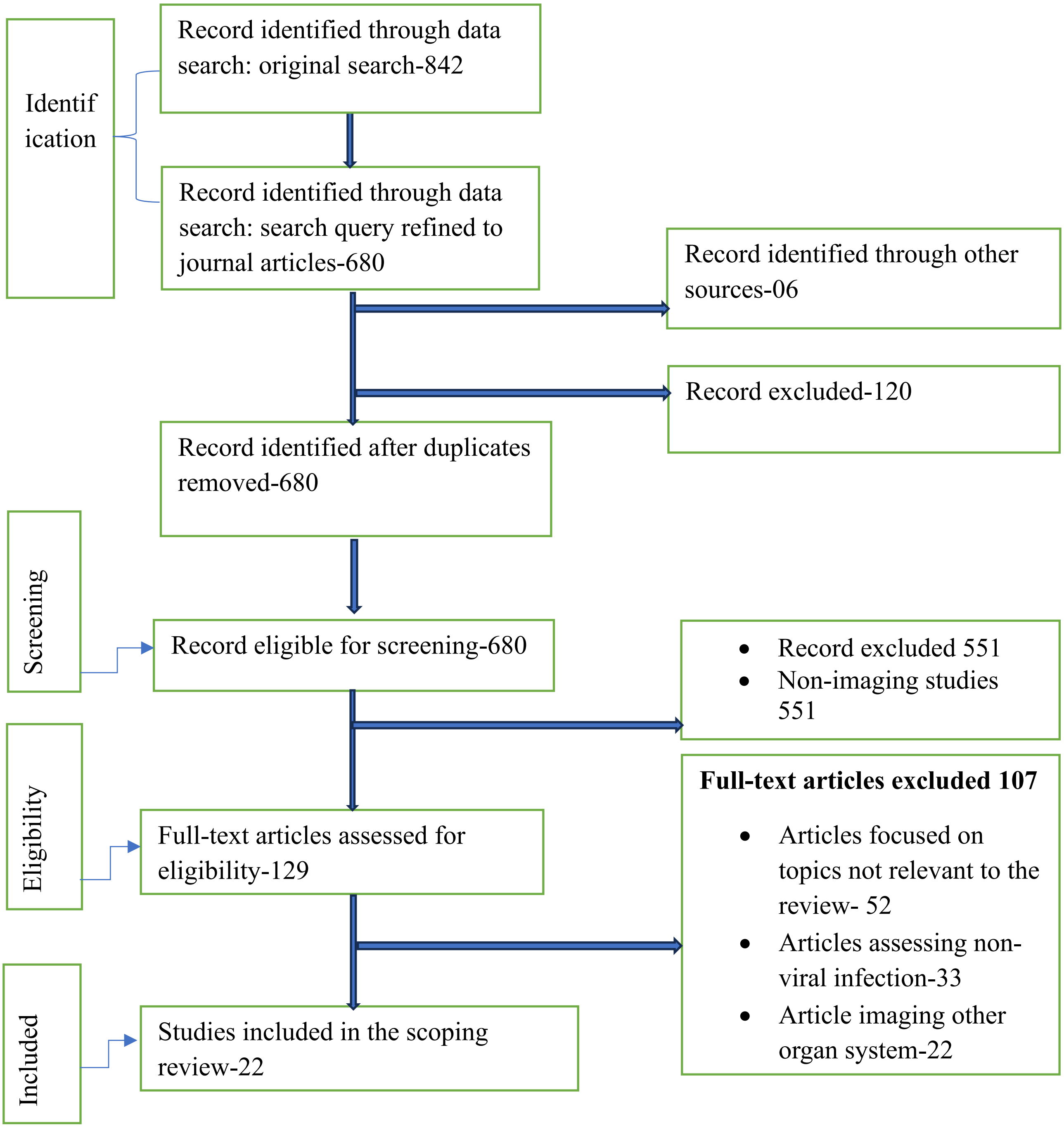
This review is a systematic and integrative review that combines literature analysis, case studies, and sustainability frameworks to evaluate the environmental effects of AI in radiology.

Data Sources:

Peer-reviewed journals and environmental assessments from authentic databases such as PubMed, Scopus, and Google Scholar were consulted.

CRITERIA FOR SELECTION OF STUDIES

Focus on the introduction of AI into radiology with respect to the operational or environmental aspects. Research articles evaluating energy consumption, carbon footprint, and waste management in radiological practices. Papers discussing innovations in AI model development and their sustainability implications. Case studies highlighting best practices for sustainable radiology operations. Reports addressing workforce and patient scheduling efficiency through AI.



PRISMA Flow Diagram: Literature Review Process, this diagram depicts the phases of literature data collection, from identification and screening to eligibility assessment and inclusion. It highlights the number of records identified, exclusions at each stage, and the final studies included, following specific inclusion and exclusion criteria for the review.

Analysis Framework:

AI Model Development and Data Storage:

Computational Demands, Energy Consumption, and Environmental Footprint of Large-scale AI Training and Storage Systems. Assessment of data centre sustainability practices, cooling systems, and renewable energy utilization.

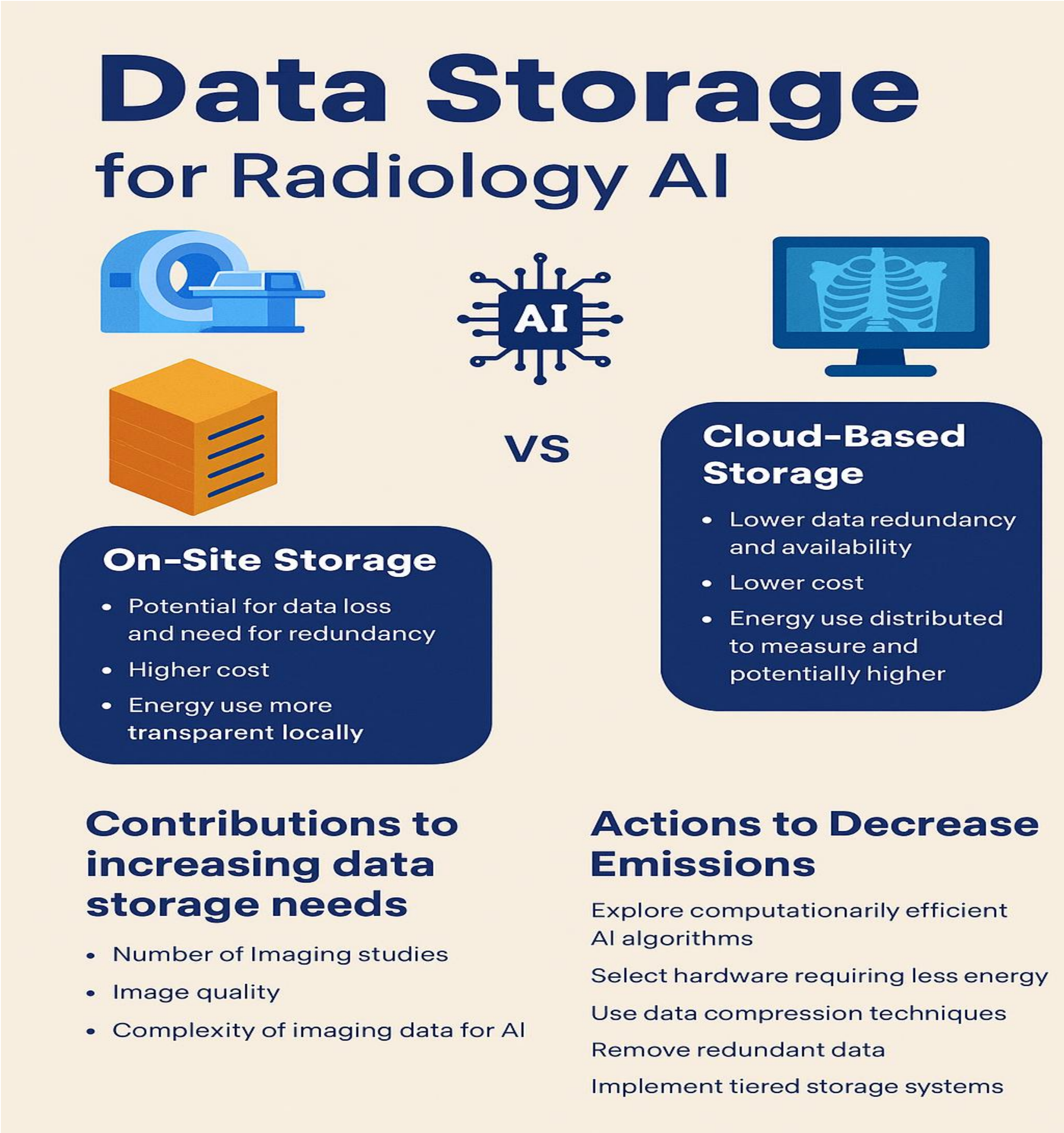


Figure 1Comparative Analysis of Data Storage Strategies for Radiology AI

Energy Source Choices and Scanner Efficiency:

Radiology departments use a lot of energy, usually drawn from non-renewables, and this results in carbon output. Shifting to renewable energy like solar and wind power lowers that environmental footprint. At the same time, advances in scanner design such as AI-based protocols—improve energy efficiency by reducing scan time, avoiding redundant imaging, and facilitating predictive maintenance. Combining green energy and AI-optimized scanner usage provides a green pathway for radiology that remains compliant with worldwide climate targets while upholding diagnostic quality(16).

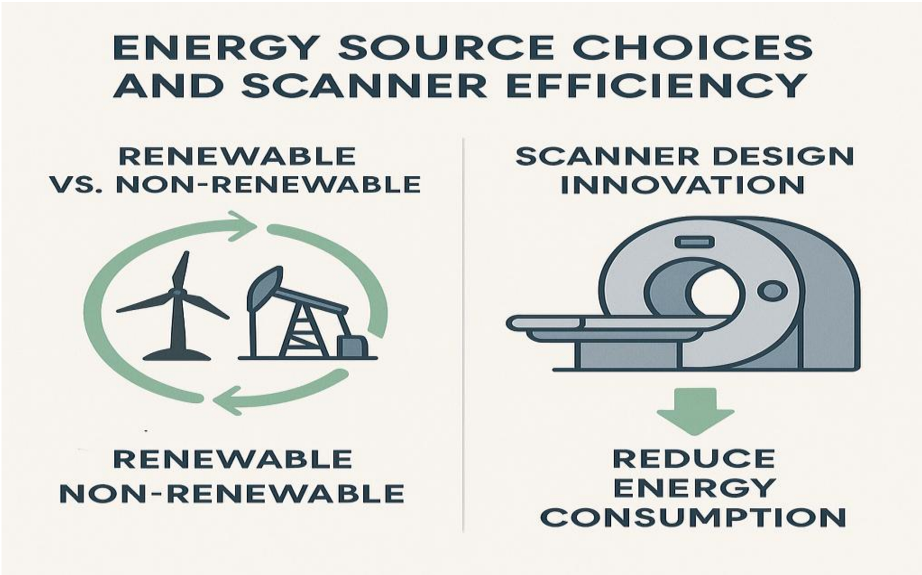


Figure 2Figure: Comparative picture showing renewable vs. non-renewable energy sources and their effect on sustainability of practice in radiology, with focus on scanner design developments that minimize overall energy usage in medical imaging systems.

Image Acquisition and Processing:

Artificial intelligence (AI) is transforming image acquisition and processing in radiology by improving operational effectiveness and lowering energy usage. AI-based imaging methods, including deep learning-based acquisition protocols and real-time noise reduction, enable reduced radiation doses and scan times, thus reducing scanner runtime and energy consumption(17). Also, image reconstruction technologies that are artificially intelligent such as iterative reconstruction and compressed sensing greatly diminish the burden on computation and improve the management of system resources(18).

Aside from acquisition, AI enhances data management through the automation of image triage, compression, and archiving, simplifying workflow and reducing the storage and retrieval load on hospital IT infrastructure. All these efficiencies go towards not just better diagnostic accuracy and quicker turnaround times but also decreased environmental footprint through the maximization of resource usage.

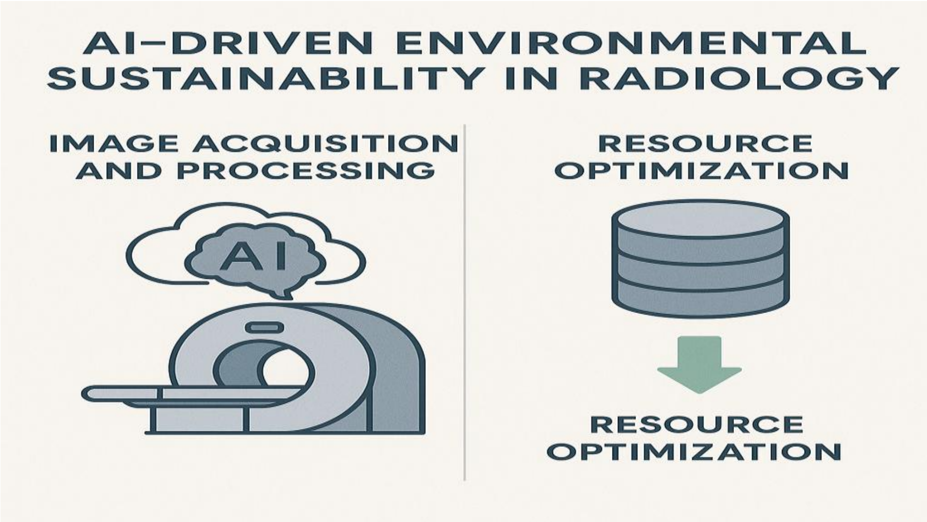


Figure 3Conceptual depiction of AI-based sustainability in radiology, emphasizing innovative imaging acquisition and processing methods that lower operational energy requirements, together with optimized image reconstruction and data handling approaches to increase environmental efficiency in healthcare imaging systems.

Clinical Decision Support and Screening:

Artificial intelligence (AI)-supported clinical decision support systems (CDSS) have a key function in ensuring environmental sustainability in radiology through better diagnostic accuracy and reduced unnecessary imaging. These systems combine patient information with evidence-based guidelines to aid clinicians in selecting the appropriateness of imaging studies, and thus, cutting down on duplicate or low-value scans(19). By eliminating unnecessary procedures, AI assists in reducing energy use, saving radiological resources, and minimizing the overall environmental impact of diagnostic imaging.

Furthermore, AI enables more effective screening protocols through triaging high-risk patients and prioritizing those that truly need imaging, reducing workflow delays and optimizing throughput(20). These advancements are not only responsible for enhanced clinical outcomes but also operational effectiveness and environmental sustainability through waste reduction and optimization of the use of imaging infrastructure.

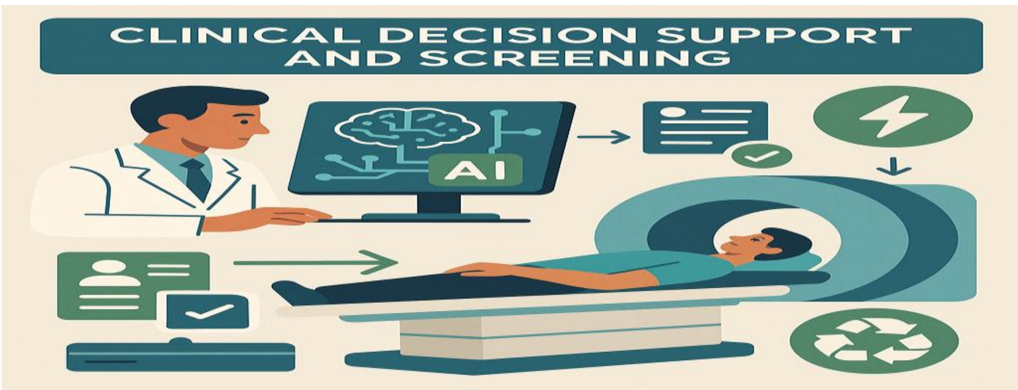


Figure 4AI-Assisted Clinical Decision Support and Screening in Radiology

Contrast Waste and Contamination:

Proper handling of contrast media and other radiological waste is crucial to enhance environmental sustainability in radiology. Iodinated and gadolinium contrast media, which are frequently employed in imaging diagnostics, present serious environmental hazards when poorly disposed, leading to water pollution and ecological toxicity(21). Conventional methods of waste disposal are usually inadequate, and hence the necessity for better segregation, collection, and treatment of wastes.

The latest developments in contrast waste management involve the use of closed-loop systems, selective adsorption filters, and enzymatic degradation processes to isolate or detoxify contrast residues prior to their release into the water system. In addition, artificial intelligence (AI) can minimize contrast dosing by customizing injection protocols for patient-specific requirements, leading to the decreased unnecessary use and minimizing waste. AI-based reconstruction also provides diagnostic-quality images at reduced contrast volume, thereby improving patient safety as well as environmental stewardship.

Merging AI with environmentally friendly waste management strategies presents a promising route for decreasing contamination, encouraging recycling, and maintaining compliance with environmental regulations in radiology divisions.

Figure 5Contrast waste and contamination management in radiology This diagram shows AI-aided contrast waste management with closed-loop systems, selective adsorption, and enzymatic degradation to minimize environmental toxicity, improve recycling, and guarantee sustainable radiological practice with optimal patient-specific contrast dosing.

Scheduling and Operational Performance:

AI-enabled scheduling systems are increasingly being added to radiology departments to make patient flow smarter, more efficiently use workforce capabilities, and less waste-generative. Intelligent scheduling systems use advanced predictive analytics along with real-time information to assign imaging capacity in a better manner, reduce standby scanner time, and save on unnecessary energy utilization. By dynamically reallocating schedules based on patient arrivals, types of exams, availability of equipment, and staffing schedules, AI systems avoid workflow bottlenecks and provide optimal usage of radiological infrastructure. Through such automation, redundancy is decreased, overtime work is minimized, and excessive energy consumption related to long equipment running time is avoided(21).

Additionally, scheduling with AI assistance enhances coordination among clinical teams, enables more effective prioritization of emergent cases and even ensures consistent throughput. This not only increases patient satisfaction and clinical outcomes but also towards the larger objective of environmental sustainability by reducing wastage of resources and enhancing system-wide efficiency.

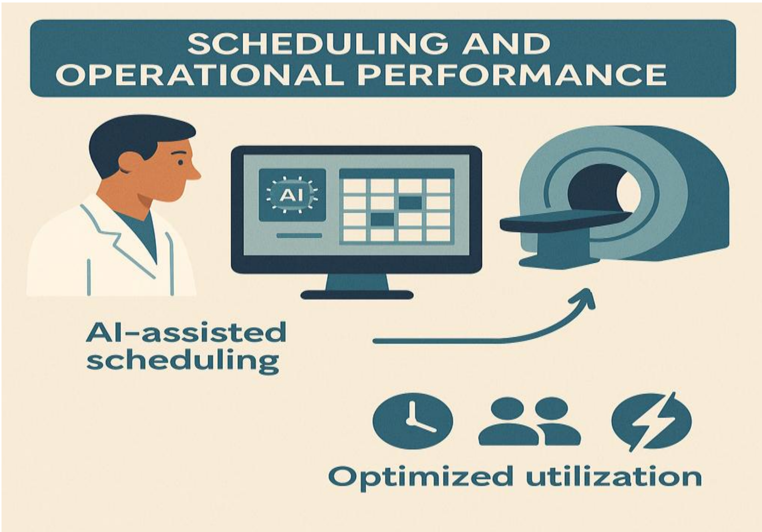


Figure 6Artificial Intelligence-Driven Scheduling and Operational Performance in Radiology The below graph represents AI-assisted scheduling optimizing the scanner usage, avoiding downtime and energy, smoothing the flow of the patient, optimizing the coordination—to better operational performance, clinical value, and ecologically sound development of radiologic services.

Outcome Measures

Measuring the environmental footprint of artificial intelligence (AI) in radiology is critical to proving its place in sustainable healthcare. Implementing AI has shown quantifiable decreases in the radiological business' carbon footprint through reduced scanner use, reduced unnecessary imaging, and maximization of energy usage across workflows (McKinsey & Company, 2022). For example, AI-assisted scheduling, dose modulation, and contrast management have been associated with reduced energy usage and material waste. Most notable practices supporting enhanced sustainability involve incorporating AI in clinical decision support systems, optimization of image acquisition, and imaging equipment predictive maintenance. These developments make resource usage more efficient, eliminate operational redundancies, and increase equipment life span—altruistically all working to benefit environmental stewardship within healthcare.In order to further promote AI-driven sustainability, actionable suggestions for health and technology stakeholders are: to incentivize green AI solutions adoption, harmonize sustainability metrics in imaging departments, and promote cross-sector collaboration to reconcile environmental and clinical goals(22).

Environmental Consequences of AI Integration in Radiology

Domain	**Challenges**	**Action**	**Outcome**
AI-Model development	Excessive energy consumption in AI-model creation and implementation	Employ energy-efficient setups (e.g., low-power CPU)	Cutting CPU cores from 60 to 30 reduced GHG emissions by 33%
	Shortage of radiology-specific GHG emission tools	Modify general AI GHG calculators for radiology (hardware, training time, region)	Facilitates well-informed strategies for energy-efficient radiology AI models
	No standards for-sustainable radiology AI software	Create efficiency metrics and standards (e.g., Energy Star rating)	Directs procurement through estimated GHG emission metrics
	Redundant AI-models squander resources	Encourage collaboration, data/code sharing, and federated learning	Saves GHG emissions and improves external validity
Data Storage	Exponential growth in imaging and AI data	Improves data deduplication and compression	Lessens storage requirements and related energy consumption
	High data center and network energy consumption	Incorporate energy-efficient storage technology (e.g., tiered storage)	Reduces energy cost and GHG emissions
	No radiology-specific storage calculators	Perform studies to evaluate AI storage emissions in radiology	Informs decision-making for sustainable data management
	Limited transparency on data storage GHG emissions	Collaborate with cloud services powered by renewable energy	GHG emissions are provider- and location-dependent; partnerships enhance sustainability
Energy source Choices	Environmental footprint of AI relies on energy source	Train models where grids use renewable or low-carbon energy	Substantial GHG reduction from renewable energy use
	High energy for cooling (40% of data center consumption)	Use data centers in cooler climates to reduce cooling demand	Lower energy use and improved sustainability in AI infrastructure

Table 1 Negative Impact of AI on Environmental Sustainability: Challenges, Actions, and Outcomes

Actions to Improve Sustainability Using AI in Radiology:

Key Action Area	AI-Based Intervention	Scientific Rationale and Benefits	Sustainability Impact
Clinical Decision Support & Screening	Artificial Intelligence-based Clinical Decision Support Systems (CDSS)	Combines patient information with evidence-based guidelines to inform imaging decisions and eliminate inappropriate or redundant scans.	Reduces unnecessary imaging, reduces radiation exposure, and decreases energy/resource consumption.
Contrast Waste and Contamination	AI-optimized contrast dose and image reconstruction	Tailors contrast use to patient-specific factors, allowing for diagnostic-quality imaging with lower agent volumes.	Reduces environmental pollution by iodinated/gadolinium waste; promotes safe and effective waste disposal.
Scheduling and Operational Performance	Real-time analytics predictive AI scheduling software	Increases scanner throughput, minimizes idle machine time, maximizes technician and equipment utilization.	Conserves energy, minimizes overtime, improves resource utilization, and reduces operational inefficiencies.
Equipment Utilization and Maintenance	AI-driven predictive maintenance systems	Employ sensor information to predict equipment failure, schedule proactive maintenance, and increase machine life.	Saves waste from early equipment redundancy; minimizes downtime and power consumption.
Workflow Optimization	Artificial intelligence-based workflow orchestration software	Automates the delegating of tasks, handles urgent cases, and optimizes workloads across modalities and teams.	Enhances efficiency, eliminates redundancy, and avoids wasteful overload of the system.

Image Quality Enhancement	AI-enabled image reconstruction and noise reduction	Creates high-quality images using lower doses of radiation or shorter acquisition times.	Enhances patient safety and reduces resource load per scan.
Energy Management	AI-integrated facility energy management systems	Regulates and fine-tunes HVAC, lighting, and scanner stand-by modes real-time in terms of activity and occupancy.	Reduces total energy footprint of radiology departments.
Data Management & Archiving	AI-powered data compression, storage, and retrieval systems	Streamlines storage requirements and accelerates access to data for reporting, research, and follow-up.	Saves digital infrastructure demand and power consumption.
Training and Education	AI-powered simulation and decision-support training platforms	Facilitates sustainable learning via virtual case scenarios without repetitive physical imaging procedures.	Encourages green, scalable education models.
Waste Management Systems	AI-tracked segregation and disposal protocols with contrast and bio-waste tracking tools	Facilitates compliance with environmental regulations and ensures on-time waste processing with minimal human error.	Decreases ecological toxicity, promotes recycling and safe disposal practices.

Table 2 This table summarizes AI-based actions to enhance environmental sustainability in radiology by reducing energy consumption, waste, and radiation exposure, all of which are aimed at building a greener, resource-sparing healthcare system.

RESULTS

This research uncovers a twofold effect of incorporating artificial intelligence (AI) in radiology: while it improves diagnostic accuracy and workflow efficiency, it also presents significant environmental issues. AI-based applications in clinical decision support, image acquisition, and operational scheduling have been found to enhance use of resources, reduce radiation doses, and decrease unnecessary imaging—making a valuable contribution to sustainability. Moreover, AI-supported scheduling enhances scanner utilization and reduces idle machine time, reducing overall energy requirements. Yet, the environmental price of developing and deploying AI, especially deep learning models, is high owing to high computational energy demands and higher data storage requirements. This leads to greenhouse gas (GHG) emissions, especially when fueled by non-renewable energy sources. The research also highlights concerns regarding waste from contrast media. AI-assisted contrast optimization optimizes dosing without compromising diagnostic quality, ensuring reduced environmental toxicity. In addition, AI-enabled waste management systems improve safe waste disposal and regulatory adherence.

Overall, AI can facilitate environmental sustainability in radiology when it is used with green practices, energy-efficient facilities, and sustainable data management techniques.

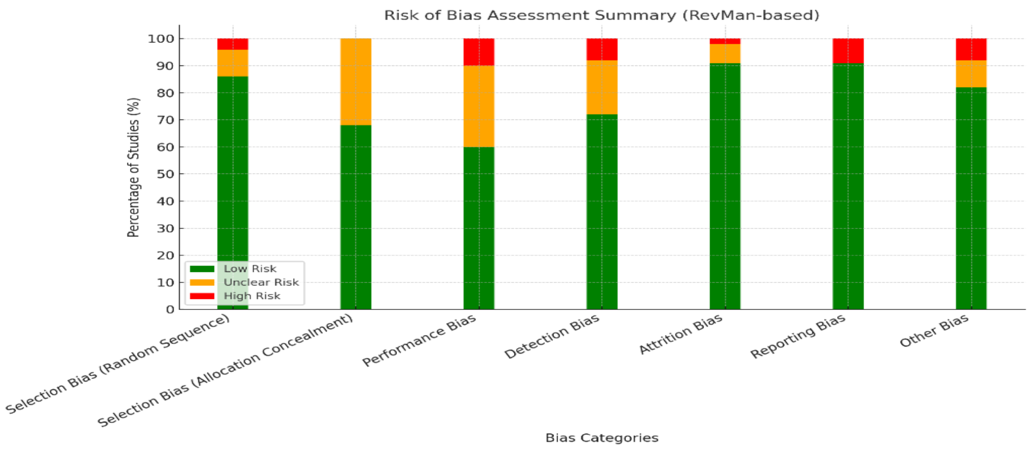


Figure 7Risk of Bias Assessment Across Included Studies

This graph presents the proportion of included studies (n = 22) that were evaluated for each area of potential bias through the Cochrane Risk of Bias tool. Bars represent each area of bias, represented by the following color scheme: green for low risk, yellow for unclear risk, and red for high risk. The areas are selection bias, performance bias on multiple dimensions of behaviour (e.g., adherence to medication, physical activity, diet, smoking), detection bias, attrition bias, reporting bias, and other biases. The "Overall" bar gives an overview of the overall risk of bias across all areas, reflecting methodological strength and weakness in the studies under review.

DISCUSSION

The incorporation of artificial intelligence (AI) into radiology ushers in a paradigm change in diagnostic accuracy, workflow, and clinical decision-making. Along with these advances, however, come severe environmental challenges—chiefly focused on energy consumption, data storage, and material consumption. This exchange considers both the potential and drawbacks of AI use in radiology in terms of environmental sustainability. On the positive side, AI has optimized radiological practices by minimizing redundant imaging and optimizing image acquisition protocols. AI-based clinical decision support systems (CDSS) have been effective in optimal diagnostic appropriateness, not only enhancing patient care but also minimizing the carbon footprint by limiting unnecessary scans. AI-based image reconstruction and noise reduction methods are responsible for lower doses of radiation and reduced scan times, making patient safety better and energy savings possible. Operational efficiency has also been enhanced with AI-powered scheduling and predictive maintenance software, which increases scanner throughput, decreases idle time, and lowers energy consumption. All these interventions collectively contribute to an improved utilization of human and technical resources while keeping energy wastage to a bare minimum. However, these gains in the environment are countered by the high levels of energy utilization that come with training and rolling out deep learning models. Model creation requires compute-intensive hardware, long training durations, and vast data storage, typically relying on energy-hungry data centers. The attendant greenhouse gas (GHG) emissions present a significant sustainability risk, especially where fueled by fossil fuels. Additionally, the escalating size of imaging data places an additional load on IT infrastructure, necessitating storage efficiency and compression techniques. Another significant concern involves contrast media waste. Imaging contrast agents, such as iodinated and gadolinium-based compounds, can contaminate water sources if improperly disposed. AI-enabled optimization of contrast dosing and intelligent image reconstruction can mitigate this issue by reducing the volume of contrast needed without compromising image quality. Moreover, AI-assisted waste tracking systems facilitate safer disposal and regulatory compliance, reducing environmental toxicity. From a systems level, the sustainability footprint of AI in radiology reaches lifecycle phases—from production of hardware to updating software, data storage, and disposal of aged equipment. Hence, green methods need to be integrated throughout the entire pipeline for developing AI. This involves sourcing green energy supplies, using federated learning in order to forego redundant training, and installing energy-efficient data centres, particularly those located in colder climates with lower cooling needs. Finally, the study proves that environmental sustainability in AI-integrated radiology is both possible and imperative. A multi-faceted strategy is needed—combining technological innovation with environmental stewardship. Radiology departments must emphasize green procurement practices, implement AI solutions optimized for energy and resource use, and incorporate sustainability metrics into performance reviews. Cross-sector collaboration between clinicians, technologists, policymakers, and environmental scientists is essential to align the objectives of clinical excellence and ecological stewardship. Balancing diagnostic excellence with environmental stewardship is not contradictory but rather a complementary approach. AI, when informed by sustainability principles, can notably decrease the environmental burden of radiology—making sure that innovation is not at the expense of planetary well-being.

The present integrative review brings forth a subtle association between artificial intelligence (AI) integration and radiology environmental sustainability. On the one side, AI has transformed diagnostic accuracy, operational efficiency, and clinical decision-making; on the other side, its implementation comes with an enormous environmental price tag mostly from high energy consumption and data storage requirements. This dual nature aligns closely with the insights presented by Doo et al, who also emphasize AI's sustainability paradox—improving clinical outcomes while exacerbating carbon emissions through large-scale computing(15). Compared to Hosny et al. (2018), who focused on AI's diagnostic and prognostic advancements in oncology imaging, this study broadens the lens to consider environmental implications. While Hosny et al. celebrated AI's superhuman accuracy, our findings caution against overlooking the ecological cost of such progress, advocating for "green AI" models(16). Fessell and Lexa (2020) emphasized organizational changes because of AI and telecommuting in radiology but did not touch on sustainability explicitly. This work expands on their themes of efficiency, demonstrating that AI-assisted scheduling minimizes machine downtime and operational overhead and therefore saves energy(19). Knoche and Toker (2023) stressed balancing ecological objectives with financial efficiency. Analogously, here, predictive maintenance, AI scheduling, and optimal contrast dosing not only save resources but prolong equipment life, merging sustainability and cost-effectiveness(14). Lastly, Mustapha et al. (2024) advocated for systemic implementation of sustainable radiology procedures. Our results are consistent with this perspective, emphasizing the need for AI-facilitated waste reduction and contrast media minimization as essential elements in an environmentally conscious imaging network(11). By and large, this research adds to a growing conversation requiring responsible innovation: optimal clinical utility from AI while minimizing its ecological impact by employing federated learning, green energy, and data-efficient models.

CONCLUSION

Integrating artificial intelligence (AI) in radiology holds promising potential for diagnostic precision, workflow optimization, and patient care. This development, however, must be critically evaluated from the perspective of environmental sustainability. Our assessment indicates that although AI technologies hold the potential to aid in minimized imaging redundancies and better resource utilization, they also pose new environmental impacts—mainly computational energy consumption, hardware life cycle, and data storage infrastructure. Comparative assessment with major reference studies emphasizes the fact that the overall environmental footprint of AI largely relies on aspects including model structure, frequency of training, energy sources of data centers, and the extent of clinical deployment. Research in support of green AI practices all emphasize the requirement for energy-efficient computation, sustainable algorithm design, and ethical hardware control. In order to guarantee that AI-led innovation in radiology is compatible with overall healthcare sustainability objectives, there needs to be a balance between technological efficacy and environmental stewardship. This involves embracing carbon-sensitive development processes, encouraging renewable energy use in AI systems, and implementing open reporting of the environmental implications of AI solutions.

In summary, although AI has revolutionary potential for radiology, its long-term environmental sustainability will depend on active, multidisciplinary initiatives that incorporate ethical, technical, and ecological factors into each phase of the AI lifecycle.

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