Environmental Impact Assessment: Transition from Film-Based Radiology to Digital PACS System

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Abstract- **Aim: To assess the environmental impact and operational efficiency resulting from the transition from traditional film-based radiology systems to digital Picture Archiving and Communication Systems (PACS).**

Objectives: To quantify and compare the usage of consumables (films, chemicals) and utilities (electricity, water) between film-based and PACS-based systems. To analyze the amount of hazardous waste generated before and after PACS adoption. To evaluate the carbon footprint reduction due to PACS implementation. To conduct a cost-benefit analysis of PACS versus film-based radiology. To assess radiology staff perception regarding the shift to sustainable radiology practices.

Materials and Methods: A retrospective, comparative, observational study was conducted at the Department of Radiodiagnosis, Mewar University, over a 5-year period (2.5 years pre-PACS and 2.5 years post-PACS). Data collected included monthly film consumption, chemical usage, water consumption, hazardous waste generation, electricity usage, and financial records. A structured questionnaire was distributed among radiology staff to gather perceptions of environmental sustainability. Data analysis included paired t-tests, carbon footprint calculations, and descriptive survey analysis using SPSS.

Results: Transitioning to PACS led to a complete elimination of film and chemical usage, a 95% reduction in hazardous waste, and an 80% decrease in water consumption. Although PACS increased electricity usage slightly, the overall environmental impact was significantly reduced. The carbon footprint decreased from 3.5 tons CO_2 /year to 0.8 tons CO_2 /year, achieving a net reduction of approximately 2.7 tons annually. Cost analysis revealed 30–40% monthly operational savings. Staff surveys indicated 85% support for PACS adoption, with 70% noting improved workflow and 60% reporting better patient data management.

Conclusion: The adoption of PACS markedly improves environmental sustainability by reducing chemical waste, water usage, and carbon emissions, while simultaneously enhancing operational efficiency and achieving substantial cost savings. Digital radiology is a crucial step toward green healthcare practices and sustainable hospital management.

Keywords- **PACS, Environmental Impact, Green Radiology, Digital Imaging, Carbon Footprint, Sustainability in Healthcare, Radiology Workflow, Waste Reduction, Radiology Technology**

I. INTRODUCTION

Radiology is a crucial component of modern medical diagnostics and plays a pivotal role in disease detection, treatment planning, and patient monitoring. As the healthcare industry becomes more conscious of its environmental footprint, there is growing scrutiny on the sustainability of radiological practices. Traditional film-based radiology systems rely heavily on consumable resources such as X-ray films, chemical developers, and fixers, in addition to darkroom infrastructure and water usage. These processes generate hazardous chemical waste, contribute to environmental degradation, and require ongoing expenditure and labor.

Fig: Darkroom Setup

In contrast, the introduction of Picture Archiving and Communication Systems (PACS) represents a paradigm shift in how radiological data is handled. PACS enables the digitization of image acquisition,

storage, retrieval, and sharing, thereby eliminating the need for physical films and associated chemicals. This digital transformation not only enhances diagnostic efficiency and accessibility through integration with Radiology Information Systems (RIS) and Hospital Information Systems (HIS) but also significantly reduces the environmental burden.
The transition from film-based radiology to PACS is thus not only a technological innovation but also a step toward environmental sustainability. This thesis aims to systematically assess the environmental impact of this transition. Key areas of investigation include reductions in chemical usage and waste, energy consumption patterns, carbon footprint, cost-effectiveness, and the perceptions of healthcare professionals regarding the shift. By doing so, this study contributes to the broader discourse on green healthcare initiatives and provides actionable insights for radiology departments seeking to minimize their ecological footprint while enhancing clinical outcomes.. With increasing emphasis on sustainable healthcare, the environmental implications of radiological practices have come under scrutiny. Traditional film-based radiology involves the use of X-ray films, chemical developers, and fixers that generate considerable waste and consume significant resources. PACS eliminates the need for physical films by digitizing image acquisition, storage, and communication.

Fig: PACS server room

The transition to PACS represents not just a technological upgrade but an ecological step forward. This thesis aims to systematically analyze the environmental impact of this transition in terms of waste reduction, resource savings, and cost-effectiveness. It also evaluates the broader implications of digitalization on radiology department operations and sustainability.

II. LITERATURE REVIEW

2.1 Film-Based Radiology

Film-based radiology relies on analog imaging techniques that use X-ray films to capture diagnostic images. These films must be processed using chemical developers and fixers, typically involving substances like hydroquinone, glutaraldehyde, and acetic acid. The process also requires a water supply for rinsing and a darkroom equipped with safelights, film processors, and proper ventilation. Studies have shown that film-based radiology contributes significantly to hospital waste and environmental pollution, with silver residues and developer effluents being particularly harmful if not properly disposed of. Furthermore, storage of films demands significant physical space, climate control, and manual indexing systems, often leading to inefficiencies and increased carbon footprint through paper-based patient records and frequent duplication.

2.2 PACS (Picture Archiving and Communication System)

PACS revolutionizes the management of medical imaging by enabling digital acquisition, storage, transmission, and retrieval of radiological data. It eliminates the need for physical films and reduces dependency on chemical processing. PACS integrates seamlessly with Radiology Information Systems (RIS), Hospital Information Systems (HIS), and Electronic Medical Records (EMR), allowing for efficient data sharing, teleconsultation, and remote reporting. The digital format not only enhances image accessibility and diagnostic speed but also minimizes logistical barriers and storage constraints. PACS systems have demonstrated improvements in departmental workflow, reduction in turnaround time, and long-term cost savings. While PACS requires electricity to power servers and workstations, its overall environmental load is significantly lower when compared to the chemical and resource burden of film-based systems.

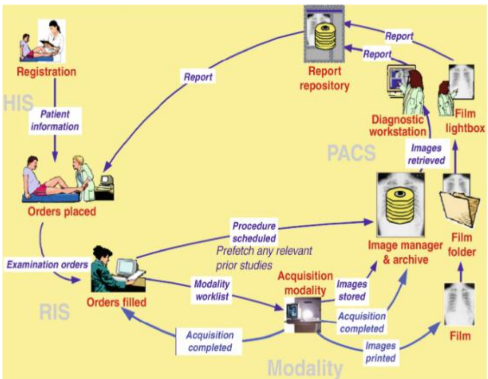


Fig. Flowchart showing Film-Based vs. PACS Radiology Workflow

2.3 Environmental Impact of Radiology

The environmental impact of medical imaging is increasingly under scrutiny, particularly in light of global sustainability efforts. Film-based radiology is associated with considerable resource consumption and environmental hazards. According to several studies, processing chemicals used in film development are toxic and require specialized disposal procedures to prevent groundwater contamination. The production of films also involves energy-intensive manufacturing and transportation processes, adding to the carbon footprint. Transitioning to digital platforms such as PACS can substantially mitigate these environmental risks. Literature reviews have documented up to a 90% reduction in chemical waste and notable declines in water and energy usage following PACS adoption. Life cycle analyses comparing the two systems consistently favor PACS from an ecological standpoint.

2.4 Global Green Radiology Practices

Green radiology is a rapidly growing domain that emphasizes reducing the ecological impact of radiology departments without compromising diagnostic quality. Around the world, healthcare institutions are adopting best practices that include minimizing radiation doses, using reusable protective equipment, digital documentation, and optimizing equipment lifecycle management. PACS is central to these efforts. For example, institutions in the European Union have adopted paperless workflows and digital teaching archives, saving substantial amounts of paper and physical storage space. Similarly, the American College of Radiology's "Imaging 3.0" initiative promotes smart imaging practices that align with environmental responsibility. Emerging technologies such as cloud-based PACS and AI-integrated diagnostic tools further contribute to efficiency and eco-friendliness.

In summary, existing literature underscores the profound environmental benefits of digital radiology systems. PACS serves as a cornerstone for sustainable imaging practices, offering reductions in waste, chemical hazards, and energy consumption while supporting improved diagnostic and operational outcomes.. The process generates hazardous chemical waste, consumes water, and poses challenges in physical storage and disposal.

2.2 PACS (Picture Archiving and Communication System)

PACS enables digital acquisition, storage, and sharing of medical images. It reduces reliance on physical infrastructure, enables remote access through teleradiology, and integrates with RIS and HIS systems for seamless patient care.

2.3 Environmental Impact of Radiology

Numerous studies indicate that medical imaging departments are significant sources of waste and energy consumption. Chemicals such as hydroquinone, glutaraldehyde, and silver nitrate used in film development are toxic to the environment. Transitioning to digital solutions like PACS can mitigate these risks.

2.4 Global Green Radiology Practices

Institutions across the globe have adopted green radiology initiatives that emphasize low-dose imaging, reduction of printed films, paperless workflows, and digital teaching files. PACS plays a central role in achieving these goals.

III. AIMS AND OBJECTIVES

Aim: To assess the environmental impact of transitioning from film-based radiology to PACS.

Objectives:

- To quantify and compare the usage of consumables (films, chemicals) and utilities (electricity, water) in both systems.
- To analyze the hazardous waste generated by film-based radiology.
- To evaluate digital storage energy consumption in PACS.
- To estimate the reduction in carbon emissions.
- To conduct a cost-benefit analysis over a defined time period.
- To understand the perception and adaptability of radiology staff towards sustainable practices.

IV. METHODOLOGY

Study Design: Comparative, observational, retrospective study.

Study Site: Department of Radiodiagnosis, mewar university.

Study Period: 5 years (2.5 years before PACS implementation and 2.5 years after).

Data Collection:

- Monthly data on film rolls used, volume of developer/fixer chemicals, and water used in darkroom processing.

- Electricity usage in the radiology department pre- and post-PACS.
- Monthly records of hazardous waste generation.
- PACS-related electricity usage (server load, workstation power).
- Financial records of film procurement, chemical purchase, waste disposal, and digital system maintenance.
- A structured questionnaire distributed to radiology staff evaluating awareness, attitudes, and experiences related to environmental sustainability.

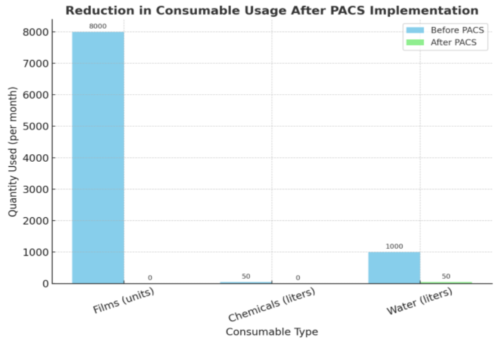
Data Analysis:
- Descriptive and inferential statistics using SPSS
- Paired t-test or Wilcoxon signed-rank test for pre- and post-PACS comparisons
- Carbon footprint calculations using standard emission factors
- Qualitative analysis of survey responses

V. RESULTS

5.1 Film-Based Radiology
In this section, you outline the baseline data for the traditional film-based radiology system before the transition to PACS. For example:
- Film Usage: The number of films used per month is tracked. For example, 8,000 films/month indicates how much material is being consumed.
- Chemical Usage: Developers and fixers are used in the film processing. This would include the volume of chemicals used, which would likely be measured in liters (e.g., 50L/month).
- Water Consumption: Processing films uses a significant amount of water (e.g., 1000 liters/month), which is a concern from both an environmental and operational perspective.
- Electricity Consumption: While film processing requires electrical equipment for the darkroom, the total consumption is tracked (e.g., 120 kWh/month).
- Hazardous Waste: The amount of waste generated by the film-based system is another critical factor, such as 25 kg/month of hazardous chemical waste. These need proper disposal, and their environmental impact is considerable.

5.2 Post-PACS
This section compares the data from after PACS implementation to show the improvements made in terms of resource use, waste reduction, and overall efficiency:
- Film and Chemical Usage: After the switch, film and chemical usage becomes null, as PACS eliminates the need for physical films and the associated chemicals.
- Water Consumption: Water usage drastically reduces, from 1,000 liters/month to under 50 liters, as no longer needed for processing films.
- PACS Electricity Usage: Although PACS systems require electricity to power servers and workstations, the usage is optimized, with a typical consumption range between 60 and 80 kWh/month.
- Reduction in Hazardous Waste: The waste generated by PACS is negligible, with a 95% reduction in hazardous waste compared to the film-based system.
- Cost Savings: One of the most important results is the significant reduction in operating costs, estimated at 30–40% savings per month due to lower costs for film, chemicals, water, and waste disposal.

Chart: Reduction in consumable after PACS implantation



5.3 Carbon Footprint
The carbon footprint of the two systems is measured to assess the environmental impact:
- Pre-PACS: The carbon emissions of the film-based system are higher (3.5 tons CO_2/year) due to the energy used in film production, processing, and disposal.
- Post-PACS: The carbon footprint is reduced to 0.8 tons CO_2/year, primarily from the electricity used to power PACS servers and workstations.
- Net Reduction: The study found a net reduction of approximately 2.7 tons of CO_2 per year, a significant environmental benefit of adopting PACS.

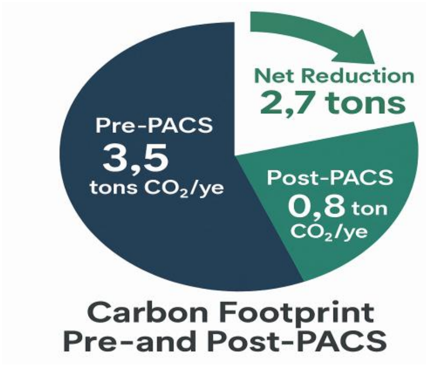


Chart: Carbon Footprint Pre- and Post-PACS

5.4 Staff Survey

A survey of radiology staff is included to gauge their perceptions of the PACS transition. Results from the survey highlight:

- 85% Support: Most staff members agree that PACS is environmentally beneficial.
- Efficiency and Workflow: 70% of staff report that PACS improves workflow and diagnostic efficiency.
- Data Management: 60% of staff feel that patient data management has improved with PACS, which can be linked to the ease of access, reduced errors, and better integration with hospital systems.

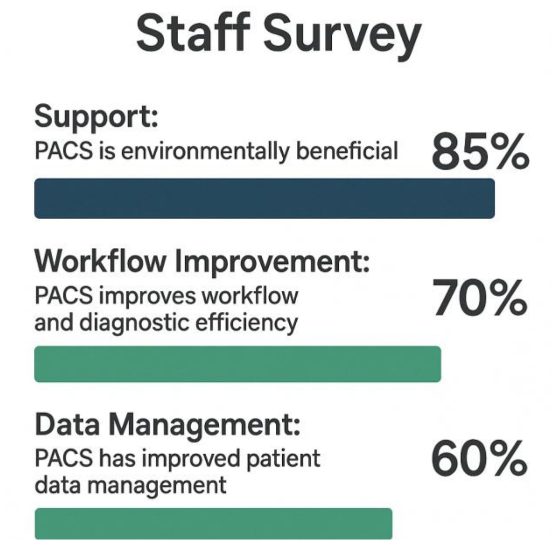


Fig. Staff Survey

VI. DISCUSSION

The study demonstrates the considerable ecological and operational benefits of PACS implementation. A marked reduction in chemical use, water consumption, and waste generation underscores its environmental significance. Although digital systems consume electricity, the overall carbon footprint is significantly reduced.

Environmental Benefits of PACS:

- You can emphasize that the significant reduction in chemical use, water consumption, and hazardous waste aligns with global environmental initiatives and healthcare sustainability efforts. This reduction supports the claim that PACS is an environmentally friendlier alternative compared to traditional film-based systems.
- The carbon footprint reduction, from 3.5 tons to 0.8 tons of CO2 per year, is a crucial point to discuss, as it demonstrates PACS's potential in achieving more sustainable healthcare practices.

Operational and Economic Efficiency:

- The operational efficiency is another critical aspect to discuss. The reduction in waste, chemicals, and film procurement costs results in long-term savings. PACS helps reduce storage space and improves workflow efficiency, which contributes to better healthcare delivery and resource management.
- From an economic perspective, the 30–40% savings in operational costs post-PACS is significant, demonstrating a clear financial benefit to hospitals that adopt digital radiology systems.

Staff Perception and Adaptability:

- The staff survey results are an essential part of the discussion. You can elaborate on how most healthcare professionals positively perceive PACS's environmental and operational benefits. However, it's also crucial to discuss any concerns or barriers to adoption (e.g., the initial costs, the need for staff training, or technical challenges).
- The 60% who believe PACS improves data management is worth exploring further, as it reflects how digitalization enhances accuracy, accessibility, and patient care.

Implications for Healthcare Sustainability:

- This section could also discuss broader implications for healthcare systems adopting sustainable imaging practices. Given the increasing emphasis on green healthcare, PACS represents a step forward in reducing the healthcare sector's ecological footprint.

- You could also mention how this research supports international standards promoting sustainable practices and how hospitals can further optimize PACS to reduce energy consumption (e.g., by leveraging cloud-based services or energy-efficient data centers).

Limitations:

- Discuss any limitations encountered during your study. For example, the data collected from only one institution might limit the generalizability of the findings. Similarly, the study may not have captured the long-term environmental impact of PACS systems after several years of use.
- Other limitations might include variations in electricity consumption due to different geographical locations or the specific technology used in each institution.

Suggestions for Future Research:

- Given the promising results, future studies could include a larger sample of hospitals to strengthen the generalizability of your findings.
- Research could also focus on the environmental impact of cloud-based PACS systems versus on-premises servers, as cloud technology is evolving and could further reduce environmental burdens.
- Another area of future study could be the long-term lifecycle of PACS infrastructure, including the environmental impact of data storage, server disposal, and system upgrades.

VII. CONCLUSION AND RECOMMENDATIONS

Conclusion:

The Conclusion section provides a concise summary of the main findings from your research, emphasizing the impact of the transition from film-based radiology to PACS in terms of environmental sustainability and operational efficiency.

- Environmental Impact: You conclude that PACS significantly reduces the ecological footprint of radiology departments by eliminating the need for physical films, chemicals, and darkroom infrastructure. This reduces hazardous waste, energy consumption, and carbon emissions. The carbon footprint reduction is a particularly important outcome, with the switch to PACS resulting in an estimated reduction of 2.7 tons of CO_2 per year.
- Operational Benefits: You highlight the operational improvements resulting from PACS, including enhanced workflow efficiency, quicker diagnostic turnaround times, and better integration with hospital systems (e.g., HIS and RIS). The elimination of physical film storage also results in considerable space savings.
- Cost Efficiency: Your findings also point out the financial benefits of PACS, with 30–40% savings in operational costs due to reduced resource consumption and waste disposal costs.
- Sustainability in Healthcare: The research supports the idea that transitioning to PACS is a crucial step in promoting green healthcare and improving sustainability in medical imaging. It aligns with global sustainability goals, such as reducing waste and conserving resources.

Recommendations:

This section proposes practical steps based on your findings. Here's how it might look in more detail:

- Adopt PACS Systematically: You recommend that radiology departments transition to PACS systems as a standard practice, especially in hospitals that still rely on film-based systems. The environmental, operational, and financial benefits make it an attractive solution.
- Promote Integration with RIS/HIS: For hospitals that have already adopted PACS, you recommend further integrating PACS with Radiology Information Systems (RIS) and Hospital Information Systems (HIS) to enhance data sharing, reporting speed, and diagnostic accuracy. This will streamline the entire workflow, from patient scheduling to diagnosis and treatment.
- Conduct Regular Audits: You recommend implementing regular audits of environmental parameters (such as resource usage, waste generation, and carbon emissions) to ensure the continued sustainability of radiology practices. These audits could be part of a broader green radiology initiative, which aims to continuously improve efficiency and minimize waste.

- Training on Sustainability: You suggest that medical institutions introduce sustainability training for radiology staff. This could include educating staff about the environmental benefits of PACS, encouraging them to adopt eco-friendly practices, and raising awareness about the importance of reducing waste and conserving resources in the healthcare sector.
- Further Research on Cloud-Based PACS: You propose future studies to assess the environmental impact and cost-effectiveness of cloud-based PACS compared to on-premises systems. This would help healthcare organizations understand the full potential of cloud-based solutions, which are often more energy-efficient and scalable.
- Examine Long-Term System Impact: Since the environmental and operational impacts of PACS may evolve over time (due to factors like system upgrades or changes in energy use), further research should focus on the long-term sustainability of PACS systems. This could include lifecycle assessments of the servers, storage infrastructure, and software used in PACS.

REFERANCE

[1] Reiner BI, Siegel EL. Radiology reporting: returning to our image-centric roots. AJR Am J Roentgenol. 2006;187(5):1151-1155.

[2] Willaert R, et al. Digital radiology: A practical approach to the evaluation of PACS in a clinical environment. Journal of Digital Imaging. 2006;19(1):13–21.

[3] Ranschaert ER, et al. Radiology in the digital age: present and future. Insights into Imaging. 2016;7(6):559–576.

[4] Andriole KP. Productivity and cost assessment of filmless versus film-based radiology. Radiology. 2002;225(2):345–352.

[5] Andrew M. Hsiao, Annemarie Budau-Bymoen, Petar Seslija, Charlotte J. Yong-Hing, Yogesh Thakur. 2020. Peer Review Tool for General Radiography Technologists Improves Image Quality. Canadian Association of Radiologists Journal 71:1, 48-5

[6] Timothy P. Szczykutowicz, Christina L. Brunnquell, GregoryD. Avey, Carrie Bartels,Daryn S. Belden, Richard J. Bruce, Aaron S. Field, Walter W. Peppler, Peter Wasmund, Gary Wendt. 2018. A General Framework for Monitoring Image Acquisition Workflow in the Radiology Environment: Timeliness for Acute Stroke CT Imaging. Journal of Digital Imaging 31:2, 201-20

[7] Bahar Mansoori, Karen K. Erhard, Jeffrey L. Sunshine. 2012. Picture Archiving and Communication System (PACS) Implementation, Integration & Benefits in an Integrated Health System. Academic Radiology 19:2, 229-23

[8] Don MacDonald, Doreen Neville. 2010. Evaluating the Implementation of Picture Archiving and Communication Systems in Newfoundland and Labrador—a Cost Benefit Analysis. Journal of Digital Imaging 23:6, 721-731

[9] Ying-Chen Fang, Ming-Chin Yang, Ya-Seng Hsueh. 2006. Financial Assessment of a Picture Archiving and Communication System Implemented all at Once. Journal of Digital Imaging 19:S1, 44-51

[10] Janice Honeyman-Buck. 2003. PACS adoption. Seminars in Roentgenology 38:3,256-26