Radiology Environmental Impact: What Is Known and How Can We Improve?

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The healthcare sector generates approximately 10% of the total carbon emissions in the United States. Radiology is thought to be a top contributor to the healthcare carbon footprint due to high energy-consuming devices and waste from interventional procedures. In this article, we provide a background on Radiology's environmental impact, describe why hospitals should add sustainability as a quality measure, and give a framework for radiologists to reduce the carbon footprint through quality improvement and collaboration.

Key Words: Green radiology; Sustainability; Climate change; Quality improvement.

Abbreviations: ACR American College of Radiology, **CT** Computed tomography, **EPA** Environmental Protective Agency, **EPD** Environmental product declaration, **HVAC** Heating, ventilation, and air conditioning, **IOM** Institute of Medicine, **LCA** Life cycle analysis, **MRI** Magnetic resonance imaging, **QI** Quality improvement

INTRODUCTION

Global warming from greenhouse gas emissions is one of the great public health concerns of our time. The Intergovernmental Panel on Climate Change issued its Sixth Assessment Report, predicting that increases in ambient temperatures at 1.5°C and 2°C would profoundly, catastrophically, and potentially irreversibly impact life on Earth (1). The temperature is already 1°C higher than the pre-industrial era temperature with the greatest increase over the past 40 years (1,2). If the current rate of warming continues, the temperature is expected to reach 1.5°C above pre-industrial levels between 2030 and 2052 causing an impact on life (3−5).

The changing environment causes a substantial impact on health. Disruption of ecosystems can threaten food and water supply as well as introduce new opportunities for infection transmission (5,6). Extreme weather events and pollutants can also create health hazards from direct exposures, changing population movements, and increasing healthcare disparities for vulnerable groups (5,6). The World Health Organization estimates that between 2030 and 2050, at least 250,000 additional deaths will occur per year, from malnutrition, malaria, diarrhea, and heat (7). Although all individuals are at risk of climate change effects, disadvantaged communities, with insufficient infrastructure to protect against extreme heat, poor air quality, flooding, and extreme events are most vulnerable (5,6,8).

As evidence of the relationship between human activity, climate change, and health continues to accumulate, the urgency for all sectors, including healthcare, to curb emissions has become clear. The United States health system was responsible for 10% of the United States' total greenhouse gas emissions in 2013 (9) and is currently the highest contributor to the global healthcare carbon footprint accounting for 27% of the total healthcare emissions (10). If the United States healthcare system were ranked as an independent nation, its greenhouse gas emissions would rank 13th in the world (9). Given these major health implications and healthcare's contribution, healthcare professionals must take the lead in lowering the healthcare carbon footprint.

Diagnostic and interventional radiologists are uniquely positioned to lead efforts and make major contributions to reducing healthcare's contribution to climate change. This

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Acad Radiol 2023; 30:625–630

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https://doi.org/10.1016/j.acra.2022.10.021

review summarizes radiology's environmental impact, details why sustainability should be added as a quality measure, and gives a framework for radiologists to reduce the carbon footprint through quality improvement and collaboration.

RADIOLOGY ENVIRONMENTAL IMPACT

Research on the environmental impact of radiology has been slow to start but increasing in recent years. The literature in this space can be categorized by the waste in interventional radiology, diagnostic imaging, and conferences. This information has also been incorporated into life cycle analysis (LCA) and environmental product declarations (EPDs) by industry. The sections below summarize the current knowledge of radiology's contribution to the healthcare carbon footprint.

Interventional Radiology Waste

Health care facilities in the United States produce more than 5.9 million tons of waste annually, and radiology is not an exception to waste production (11). Solid waste generation is greatest in interventional procedures due to a high volume of short cases and use of primarily single-use products (catheters, sheaths, wires, devices, coils, sterile drapes, and sterile towels). An audit of 17 procedures in an interventional radiology suite found an average of 8 kg of waste per case with the greatest waste burden coming from coiling (13.1 kg) and embolization (10.3 kg) cases (12). Chua et al calculated the greenhouse gases emitted in an interventional radiology department over 5 days from 7:00 AM to 7:00 PM, and found the sources of CO2 emissions in descending order were indoor climate control (11,600 kg CO2eq), production and transportation of disposable surgical items (9,640 kg CO2eq), electricity plug load for equipment and lighting (1,600 kg CO2eq), staff transportation (524 kg CO2eq), waste disposal (426 kg CO2eq), production/laundering/disposal of linens (279 kg CO2eq), and gas anesthetics (19.3 kg CO2eq) (13). Interestingly, a large proportion of solid waste can be recycled. Clements et al weighed 72 different interventional radiology products from 26 manufacturers finding the proportion of waste from primarily excessive packaging was 54.8% of the total product weight (14). Of this waste, 76% was potentially recyclable due to packaging with hard plastic, paper, and cardboard (14). These foundational studies summarize the current knowledge of waste production in interventional radiology and identify areas for potential improvement.

Diagnostic Imaging Waste

Diagnostic imaging relies heavily on medical technology making radiology a major consumer of electricity in the healthcare system. The literature details the energy consumption of magnetic resonance imaging (MRI) (15−18), computed tomography (CT) (17−20), x-ray (18,21), ultrasound (18), heating ventilation and air conditioning (HVAC) (13,19), and workstations (22−25). A report to Natural Resources Canada by the Canadian Coalition for Green Health details the annual consumption of different imaging devices: MRI 111,000 kWh/yr, CT 41,000 kWh/yr, x-ray 9,500 kWh/yr, and ultrasound 760 kWh/yr (18). Given the high energy consumption of CT and MRIs, energy inefficiency can result in a large amount of waste and demand on the electrical grid. Heye et al investigated the energy consumption of three CT and four MRI scanners in Switzerland and found the total annual energy consumption of the imaging devices was 614,825 kWh/yr (17). Additionally, the study identified energy waste including two-thirds of the CT energy consumption during the nonproductive idle system state and one-third of MRI energy consumption during the system-off state due to the need for constant cooling (17). Although much less energy is consumed by monitors and workstations, there is energy consumption waste after hours and on weekends with unused stations (22−25). Prasana et al found that the total energy consumption of monitors and workstations was 137,760 kWh/yr with 76% of the energy accounting for waste (24). Finally, an area of limited research is ordering imaging exams to decrease energy use. Alshqaqeeq et al examined six different imaging indication examples and found that if the lower energy exam were selected for similar American College of Radiology (ACR) appropriateness recommendations in 1%−10% of patient cases, it would lead to an annual energy savings of 24−240 million kWh/yr in the United States (26). An unexplored area is energy waste related to unnecessary exams being ordered.

Diagnostic imaging also has environmental repercussions beyond those related to energy consumption. Iodinated-based contrast media for CT and gadolinium-based contrast media for MRI are leading to widespread contamination of drinking water systems due to patient voiding after exams (27−29). There is specific concern regarding ultraviolet water treatments, which may degrade gadolinium-based contrast media resulting in an increased risk of adverse health effects (27). There are also several gaps in the literature on areas that contribute to the environmental footprint. The impact of manufacturing, installing, and decommissioning imaging equipment, monitors, and workstations are not well studied outside of the industry estimations. Establishing the baseline carbon footprint of all diagnostic imaging processes will be an important first step toward forming strategies to reduce healthcare carbon emissions.

Radiology Conferences

A relevant and growing focus is the carbon footprint of radiology conferences. In the field of radiology, the largest annual meeting is the Radiological Society of North America (RSNA), which provides a platform for collaboration, exchange, and dissemination of knowledge. A study by Yakar et al found that the total airplane travel-related CO2-equivalent emissions were 39,506,038 kg CO2eq (30,31). Additionally, the study found that even though international participants were slightly less than half (49%, 10,684 international participants/21,907 total participants), the group accounted for the most travel-related carbon emissions (82%, 32,438420 kg CO2eq/39,506,038 kg CO2eq) (30,31). The study offers data that can help meeting organizers incorporate sustainability into the planning of these important events. More studies still need to determine how other factors of conferences, themselves, impact the environment beyond travel requirements. Additionally, more investigations are needed to determine the total carbon footprint of all radiology conferences.

Life Cycle Analysis

LCA has been defined by the environmental protection agency as a "comprehensive method for assessing a range of environmental impacts across the full life cycle of a product system"(32). This analysis accounts for the resources, material processing, product manufacturing, distribution, use, and end-of-life of a product and is a primary tool used to support decision-making for sustainable development. A few life cycle analyses have been performed in radiology (13,33,34). The LCAs performed for abdominal imaging exams and cardiac imaging tests found ultrasound has the lowest and MRI has the highest environmental impact (33,34). More LCAs are needed to compare the environmental impacts of different processes in radiology.

Radiology companies have also started creating EPDs for their equipment using LCA. The EPD details the life cycle and environmental impact of a product in a single report. It is way for companies to create transparency to the consumer regarding the environmental impact. An example is the EPD for Siemens Healthineers Magnetom Vida (35). EPDs provide important information for hospital leadership to consider when incorporating sustainability into healthcare.

PERFORMING SUSTAINING IMPROVEMENT

Radiology literature primarily focuses on characterizing the carbon footprint. A few studies evaluated strategies to reduce the carbon footprint including decreasing energy consumption by turning off lights, workstations, and monitors during non-work hours (22−25) and cutting waste by recycling packaging material (14). However, as sustainability initiatives increase, it is important to establish a framework for radiologists to measure and improve resource use and carbon emissions. A proven way to do this is to approach sustainability as a quality measure. The next sections detail why sustainability should be a quality measure, project improvement methods, and unique concepts to consider when leading sustainability projects.

Establishing Sustainability as a Quality Measure

The Institute of Medicine (IOM) defines six aims of quality, which have become the standard domains for quality measures and improvement in the healthcare setting: safe, efficient, effective, timely, equitable, and patient-centered (36). The American Board of Radiology and the ACR define quality based on the IOM aims, which provide the current framework for radiologists to measure and evaluate the quality of medical care. However, sustainable healthcare is not included in these key documents and educational material to drive measurement.

National and international medical organizations should acknowledge the importance of sustainability and include it as a seventh quality aim. The value of healthcare needs to evolve from the traditional definition of outcomes per dollar (37) to a more holistic definition including financial, environmental, and social considerations as the bottom line (38). This new bottom-line including sustainability brings benefits to the healthcare system in three main ways: An everyday consideration includes resource stewardship as supply chains struggle to meet the growing healthcare demand and cost increases; A public health consideration includes protecting health by slowing climate change and decreasing environmental pollutants; A policy consideration is to prepare healthcare systems to meet local, state, or federal carbon emission goals.

Given the many benefits, radiology organizations would greatly benefit by adding sustainability to the healthcare quality construct. The addition would provide radiologists with a practical way to approach sustainability through quality improvement. It will also reenergize quality improvement by establishing a new area to assess quality in the hospital and be inclusive of the growing interest in the radiology community.

Quality Improvement Methods

The sustainability initiative will benefit from using well-established project improvement methodologies. Among the most popular methods are Six Sigma (define, measure, analyze, improve, control) (39), Lean (define value, map the value streams, create flow, establish pull, and seek perfection) (40), and the improvement model supported by the Institute for Healthcare Improvement (plan-do-study-act cycles)(41). A relevant and new model incorporates sustainability into an improvement model (SusQI: setting goals, studying the system, designing improvement efforts, measuring impact/return on investment) (38). A consistent theme among different models includes a common goal definition, data acquisition and analysis, implementation of process change, and review of results (42).

Sustainability projects will be enriched by using a quality improvement model. The literature is abundant with educational reviews detailing information for project evaluation and selection, role assignment, planning, improvement methods, and sustaining improvement in radiology (42−44). These methods apply to performing projects with sustainability. However, given the broadened focus from the current quality paradigm, sustainability projects come with new challenges. Two big challenges are identifying a standard measure to compare different forms of waste and leading large teams of diverse stakeholders.

Establishing a Standard Sustainability Measure

A standard measure for quality improvement in sustainability initiatives is important to compare different types of resources, energy expenditure, and waste across the healthcare system. Individually, solid waste and electricity can be tracked as kg of waste and kWh of electricity usage. However, it is difficult to compare waste with different units. A standard measure between the different types of waste has several advantages: It would allow hospitals to evaluate the total amount of waste used for different hospital operations, diagnosis codes, and procedures; It would enable comparison of different waste streams to prioritize interventions that will make the largest impact; finally, it would enable establishing standards for high quality resource usage and low waste production for different hospital services.

Given that climate change is one of the largest public health problems of our time, carbon emission equivalents are a good standard measure for sustainability. The EPA has online calculators to convert several forms of waste such as energy and weight of different types of solid waste to CO2eq (45,46). This will lower the upfront work to establishing conversions to CO2eq. Once a continuous baseline measurement for a hospital service or process is established, QI methods can be used to perform continuous QI towards the established goal.

Stake Holder Engagement

Sustainable healthcare initiatives are complex and require multiple stakeholders to collaborate on investigations and solutions. Achieving successful progress will require a departure from primarily collaborating with members of the Radiology department to implement change. Instead, leaders must engage a broad network of diverse stakeholders to advance progress toward a shared vision. A way that radiology can catalyze change is through systems leadership.

System leadership requires the individual to gain insight and understanding through collaborative learning from all stakeholders involved in the process. The Harvard Kennedy School developed a system to perform systems leadership summarized as CLEAR (Convene and Commit, Look and Learn, Engage and Energize, Act with Accountability, and Review and Revise) (47). The CLEAR system emphasizes several important concepts that will facilitate a leader managing a large network of stakeholders. It encourages leaders to listen to all individuals, define shared interests, and establish ways to create change across a large system. Given stakeholders will often experience environmental initiatives from different perspectives, the system recognizes the importance of evaluating the process by system mapping and adjusting ideas based on insight and knowledge gained. It recognizes the importance of gaining trust and inspiring the group and recommends leaders find a way to equalize power among stakeholders and make sure all stakeholders feel welcome to share thoughts. Finally, it encourages leaders to prioritize the collective interest and goals for the initiative over the individual interests. Through these methods, a single individual can mobilize solutions for complex environmental challenges.

COLLABORATION TO DRIVE THE FUTURE

New networks of radiologists are raising awareness of radiology's environmental impact and promoting a more sustainable future. At an institutional level, several organizations are forming local environmental stewardship committees to raise awareness and guide departments on lowering their carbon footprint. Some locations are forming coalitions between multiple institutions. An example of one of these groups is the University of California Sustainable Radiology Collaborative formed by five University of California hospital systems with energy efficiency, reducing waste, and external outreach subgroups. All interested individuals from the participating institutions were invited to be included in the subgroups. The subgroups meet once a quarter to discuss ongoing initiatives, remove barriers to projects, and share information. The collaborative's mission is to heighten the awareness of sustainable practices, leverage buy-in and accountability for sustainable practices across UC institutes, and share and disseminate best practices for sustainability. Local engagement is important to adopt future recommendations.

Several national groups in radiology are advocating for a more sustainable future (48). The ACR voted and approved resolution 14 on environmental sustainability. The Association of the University of Radiologists formed a task force committee, started a greening radiology campaign, and had a successful 2022 annual meeting with the theme sustainability, climate change, and radiology. Radiologists for a Sustainable Future is a national network of individuals raising awareness of radiology's environmental impact. The group is affiliated with Healthcare Without Harm and advocates for a greener future. Networks of radiologists working together on a local, national, or even international level will drive the future of radiology by establishing recommendations and best practices as data are produced in this space.

However, given the nature of sustainability, radiologists must collaborate with individuals of diverse expertise to maximize change. For example, local environmental experts, energy and waste management specialists, and engineers would be valuable contributors of the investigation team. It is also important to collaborate with industry and innovate to create more sustainable imaging and interventional radiology equipment. An example of this partnership is between the University of California San Francisco and Siemens Healthineers, which aims to construct innovative and sustainable imaging by reducing energy consumption of MRI devices. Additionally, the University of California San Diego is partnered with Stryker to evaluate ways to reduce waste in interventional radiology suites. Collaboration with industry will help to develop new industrial standards for creating sustainable equipment and drive innovation for the future.

CONCLUSION

Radiology is early in the investigative journey to an environmentally sustainable future. Scientific data in this space are limited, and there are many gaps in knowledge regarding radiology's carbon footprint. However, by creating sustainability as a hospital quality measure, it will give radiologists a framework to approach the topic. It will connect sustainability to proven project improvement methods and value discussions for healthcare policies.

We all have an opportunity to promote sustainable imaging and procedures. Complex environmental topics require team science with a large network of stakeholders. An individual can catalyze change by connecting and inspiring a large group of individuals towards a common goal. Ultimately, it will take collaboration and innovation from a large group of individuals on a local, national, and international level to create a future of ecofriendly radiology and medicine.

DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Sean Woolen, Alastair Martin, and Amy Becker report a relationship with Siemens Healthineers that includes: funding grants not related to the project. Andrew Hernandez reports a relationship with Canon Medical System that includes: funding grants not related to the project. Sean Tutton reports relationships with Siemens Healthineers and Stryker that includes: paid consultant not related to the project.

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