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Review article

Promoting sustainability activities in clinical radiography practice and education in resource-limited countries: A discussion paper

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ABSTRACT

Objective: Urgent global action is required to combat climate change, with radiographers poised to play a significant role in reducing healthcare's environmental impact. This paper explores radiography-related activities and factors in resource-limited departments contributing to the carbon footprint and proposes strategies for mitigation. The rationale is to discuss the literature regarding these contributing factors and to raise awareness about how to promote sustainability activities in clinical radiography practice and education in resource-limited countries.

Key findings: The radiography-related activities and factors contributing to the carbon footprint in resource-limited countries include the use of old equipment and energy inefficiency, insufficient clean energy to power equipment, long-distance commuting for radiological examinations, high film usage and waste, inadequate training and research on sustainable practices, as well as limited policies to drive support for sustainability. Addressing these issues requires a multifaceted approach. Firstly, financial assistance and partnerships are needed to adopt eco-friendly technologies and clean energy sources to power equipment, thus tackling issues related to old equipment and energy inefficiency. Transitioning to digital radiography can mitigate the environmental impact of high film usage and waste, while collaboration between governments, healthcare organisations, and international stakeholders can improve access to radiological services, reducing long-distance commuting. Additionally, promoting education programmes and research efforts in sustainability will empower radiographers with the knowledge to practice sustainably, complemented by clear policies such as green imaging practices to guide and incentivise the adoption of sustainable practices. These integrated solutions can significantly reduce the carbon footprint of radiography activities in resource-limited settings while enhancing healthcare delivery.

Conclusion: Radiography-related activities and factors in resource-limited departments contributing to the carbon footprint are multifaceted but can be addressed through concerted efforts.

Implications for practice: Addressing the challenges posed by old equipment, energy inefficiency, high film usage, and inadequate training through collaborative efforts and robust policy implementation is essential for promoting sustainable radiography practices in resource-limited countries. Radiographers in these countries need to be aware of these factors contributing to the carbon footprint and begin to work with the relevant stakeholders to mitigate them. Furthermore, there is a need for them to engage in

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education programmes and research efforts in sustainability to empower them with the right knowledge and understanding to practice sustainably.

Introduction

The world must remain a safe place for humanity, necessitating the promotion of pro-sustainable activities while advocating against and preventing actions that negatively impact the ecosystem. In 1987, the United Nations Brundtland Commission (UNBC) defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." It involves social, economic, and environmental activities essential for ensuring a prosperous, safe, and equitable world.[1]

Among the critical areas of sustainability, addressing climate change is imperative, given that human activities have increased atmospheric carbon dioxide (CO_2) levels by 50% in under 200 years and 10% in the last 15 years.[2] These elevated carbon levels directly impact temperature, leading to global warming. The Sixth Assessment Report from the Intergovernmental Panel on Climate Change has warned that global temperature increases of 1.5 °C and 2 °C would significantly, catastrophically, and perhaps irreversibly affect life on Earth.[3] However, the current temperature is already 1 °C higher than that of the pre-industrial era, with the most substantial rise observed in the last four decades.[3] This suggests that if the current warming trend persists, it is projected that the temperature will surpass 1.5 °C above pre-industrial levels sometime between 2030 and 2052, leading to significant impacts on life.[4–6] Already, there has been a notable rise of 53.7% in heat-related deaths among the elderly population over the past 20 years.[7]

Unfortunately, healthcare is a major contributor to climate change due to its highly energy-intensive nature, vast resource consumption, and large amounts of waste production.[8,9] It accounts for 4–5% of global greenhouse gas emissions,[7] while approximately 10% of it is due to clinical radiology and radiotherapy waste.[10] These wastes are associated with radiography-related practices, as radiographers' activities and the use of equipment in radiology and radiotherapy departments play a significant role. These issues of waste arise due to the substantial energy consumption of energy-intensive equipment systems, large-scale generation and storage of data, activities related to radiotherapy treatment, travel by service providers and users, and the disposal of waste from clinical consumables like gloves, single-use gowns, and radiopharmaceuticals.[11–15] The primary contributors to waste and energy consumption in the radiology department are the large and advanced diagnostic imaging devices, specifically those associated with Magnetic Resonance Imaging (MRI), Computed Tomography (CT), and Single Photon Emission Computed Tomography (SPECT), with interventional procedures creating the most waste.[10,16] However, when considering both production and in-use phases, MRI accounts for the highest energy usage. The energy expended for each examination conducted with an MRI scanner is comparable to that needed to cool a three-bedroom house with central air conditioning for a day or desalinate 7000 gallons of fresh water.[17] It is noteworthy that such imaging equipment, even when not actively in use or in a nonproductive idle state, still requires a continuous supply of energy.[16]

There is also growing evidence of contamination of aquatic environments with waste from radiological contrast media, primarily attributed to the increased utilisation of contrast-enhanced CT, CT simulation, and MRI in the past decade, as well as radiotherapy waste from the use of cobalt-60 (Co60). Although the toxicological effects of imaging contrast agents and radiopharmaceuticals from nuclear medicine and radiotherapy are not fully understood, some studies indicate that the transformed by-products of these agents persist over time and could potentially pose a threat to the ecosystem.[15,18–20]

Given the enormous onsite energy generation and supply chain emissions in clinical radiology and radiotherapy, reduction efforts in the specialty would significantly minimise the carbon footprint of the entire healthcare sector.[21] Some may argue that as individuals, they may not be able to achieve a significant impact. However, the reality is that there are numerous meaningful changes that can be made as individuals and professionals to contribute to a greener environment. Efforts collectively undertaken in respective spheres can lead to substantial positive impacts on the planet. Conversely, neglecting to promote sustainability can lead to detrimental consequences. Therefore, every action to reduce energy usage, carbon emissions, e-waste, contrast usage, image printing, and all forms of waste is crucial for human sustenance. As radiographers are directly involved in energy-intensive medical imaging procedures and have expertise in optimising imaging and treatment protocols, they are uniquely positioned to advocate, collaborate across disciplines, and spearhead eco-friendly initiatives within healthcare settings, thereby making substantial contributions to reducing healthcare's impact on climate change. This demands that the sustainability agenda in radiography, radiotherapy, and other imaging fields should not be an option but a requirement, as investing in the planet means investing in human health and life, and therefore should take an 'all-hands-on-deck' approach.

While the risks of climate change affect everyone, communities in resource-poor settings face heightened vulnerability due to inadequate infrastructure to withstand extreme heat, poor air quality, flooding, and other severe events.[5] A recent epidemiological study across 26 sub-Saharan African countries revealed that global warming could significantly amplify the burden of childhood anaemia in these regions.[22] Specifically, they found that each 1 °C rise in annual temperature correlated with a 13.8% increase in the odds of childhood anaemia. Despite contributing minimally to climate change, low-resource countries are disproportionately impacted and lack the resources to effectively cope.[23] This underscores the necessity for collaboration between the radiography workforce in resource-limited settings and their resource-rich counterparts to mitigate activities and practices, including those within resource-limited radiography settings, that contribute to or have the potential to contribute to climate change.

Radiography-related activities and factors in resource-limited departments that potentially contribute to the carbon footprint, and strategies to address them

Radiography plays a pivotal role in modern healthcare, facilitating the diagnosis and treatment of various medical conditions and injuries.[24,25] However, in resource-limited countries, the practice of radiography is often accompanied by challenges that extend beyond healthcare disparities.[26–28] One significant concern is the environmental impact, particularly the carbon footprint associated with radiography-related activities. In this section, some radiography practices in resource-limited countries that contribute to carbon footprint (albeit a small proportion compared to the amount generated in high-income countries) have been highlighted and suggestions offered with the aim that such problems could be mitigated.

Outdated equipment and energy inefficiency

The availability of state-of-the-art radiographic equipment with low carbon emissions in resource-limited countries is often limited due to financial constraints.[10] In a study in one of the countries, for example, over 25% of the CT scanners were 10 or more years old.[29] Outdated equipment tends to be energy-inefficient, consuming more of the already limited electricity for the same diagnostic output.[26] This results in higher carbon emissions per radiographic procedure, contributing to the overall carbon footprint. Older imaging equipment may also have less efficient cooling systems, requiring additional energy for cooling, further increasing their carbon footprint.[26] Frequent breakdowns of such older equipment also mean increased use of materials and energy to replace broken parts and regular disposal of the broken parts.[27,28] This has the potential to increase the use of materials and energy, contributing to emissions.[27] While some big cities in resource-limited countries have moved on to state-of-the-art equipment, most interior communities in some resource-constrained countries still use old equipment with poor energy efficiency.[28] Even though there are few significant energy-consuming equipment such as CT, SPECT, and MRI scanners, and interventional procedures in these regions,[30] their low energy efficiency due to the age of equipment does not help in decreasing the carbon footprint. For instance, the mean energy consumption of CT and MRI scanners per body region is estimated to be 1.2 kWh $\pm$0.7 and 20 kWh $\pm$5, respectively.[31]

Moreover, in Africa, there is significant utilisation of Co60 machines, in radiotherapy practice. A publication in 2019 estimated the number of machines to be 60.[32] While resource constraints are the main reason for the lack of advanced equipment in certain areas, power surges do not support the operation of high-energy linear accelerator machines.[32] These Co60 machines rely on radioactive sources, emitting radiation continuously regardless of whether they are switched on or off.[32] Considering, the environmental effects of the use of these modalities, the radiology and radiotherapy departments should be encouraged to adopt modern suites with automatic energy-saving capabilities. By receiving financial assistance and incentives, such as grants, subsidies, or partnerships with manufacturers, and adopting green procurement equipment and accessories, these countries can overcome barriers to adopting eco-friendly technologies.[30]

Energy-efficient equipment not only lowers energy consumption during operation but also minimises associated greenhouse gas emissions. Exploring eco-friendly practices to reduce energy consumption is a positive step. A good case example is the University of Michigan, where engineers attached communication cards to MRI and CT machines to monitor energy usage, including idle time.[33] Similarly, the University of California, San Francisco (UCSF) successfully reduced energy consumption by putting MRI and CT machines in standby, idle, or sleep modes when not in use. This simple measure decreased energy usage by 15–20%, positively impacting climate change.[33]

Additionally, investing in modern equipment enhances diagnostic and therapeutic capabilities and workflow efficiency,[32] improving overall healthcare quality. By prioritising the acquisition of energy-efficient radiographic equipment and also having one-stop-shop healthcare centres, resource-limited countries can achieve dual benefits of environmental sustainability and improved healthcare delivery. Besides these, the use of remote patient management, where, for example, a dosimetrist conducts treatment planning remotely, not only saves on travel to and from work but also reduces the carbon footprint.[34] In all, collaborative efforts between governments, healthcare organisations, and international stakeholders are essential in facilitating the transition to energy-efficient technologies and ensuring equitable access to sustainable healthcare solutions.

Insufficient clean energy to power equipment

There are also issues with insufficient clean energy to power imaging equipment in some countries. In some cases, the national grid power is inadequate to meet the needs of the population,[35] leading to a high dependency on private electricity generation via diesel and petrol power generators to operate imaging equipment. This dependency significantly increases the carbon footprint due to the continuous release of carbon monoxide in the fumes from these generators.[36] Additionally, there is the issue of noise pollution from the power generators, which exacerbates the existing noise and fume pollution from numerous non-Ultra Low Emission Zone (ULEZ) compliant vehicles on the roads.[36] For instance, in one African country, only 60% of the population has access to electricity,[37] which is not always reliable and consistent. Consequently, millions of people rely on generators powered by diesel, petrol, and gas to produce electricity.[37] Therefore, addressing these concerns and investing in renewable energy sources presents a viable solution for resource-limited countries to mitigate the environmental impact of radiography facilities. By exploring opportunities to adopt solar or wind-powered energy systems, these countries can reduce reliance on conventional energy sources to power radiology and radiotherapy equipment and lower operational costs.[36] Renewable energy offers a sustainable alternative that aligns with global efforts to combat climate change and reduce carbon emissions.[38]

Commuting long distances for radiological examinations

Anecdotal evidence suggests that many patients travel long distances for cross-sectional examinations and treatments, thereby increasing the carbon footprint. This is often due to the limited availability of such machines in certain communities, with most located in urban areas or neighbouring countries. For instance, few African countries have radiotherapy centres, compelling patients to travel long distances by air or road to access these services in nearby countries. Using brachytherapy, for instance, a 2019 report indicated that only 20 out of 52 African countries had this facility.[32] They further noted that while Austria, for example, has one radiotherapy machine for every 200,000 people or fewer, many low-resource countries like Tanzania have only one machine for up to ten million people and some nations have no radiotherapy facilities at all.[32] In terms of CT scanners, Nigatu et al.[27] reported in 2023 that only 14% of low-income countries have at least one computed tomography (CT) scanner per one million people, compared to 100% of high-income countries.

Additionally, breakdowns in communication channels, often stemming from communication infrastructure challenges or technical issues, seem to contribute to heightened patient traffic in some African hospitals. For instance, it has been noted by some of the authors of this paper that certain patients occasionally travel solely to some radiology departments to inquire about basic matters such as appointment bookings or equipment functionality. This practice further contributes to carbon emissions. Therefore, any effort to minimise such travel can significantly help mitigate environmental impact. For example, hospitals, particularly their radiology and radiotherapy departments, can upgrade communication with improved internet and digital platforms, as well as online resources to inform service users. However, a major challenge to this suggestion is that service users without access to the internet may not be able to access online information.

High film usage and waste

Many rural communities in resource-limited countries still heavily rely on conventional film-based radiography, resulting in increased consumption of films and processing chemicals.[39,40] The manufacturing and disposal of radiographic films and chemicals involve resource-intensive processes that significantly contribute to carbon emissions.[40] For example, film-based radiography and wet film image processing techniques that use processing chemicals to develop and fix the developed images are still in use in many remote places in Africa.[41] Unfortunately, both the production and the by-products add to the environmental waste. The improper disposal of soluble silver in the environment poses a serious risk, as it is a substantial solid waste produced in X-ray clinics.[42] Improper handling of X-ray waste hurts aquatic life as it includes the largest concentration of inorganic and organic contaminants as well as silver.[43] The environmental impact extends to long-term degradation, including air and water pollution, deforestation, and resource depletion. Addressing these challenges requires a holistic approach encompassing technological innovation and sustainable practices to mitigate environmental and occupational risks associated with film-based radiography. These need to include addressing the lack of awareness regarding plain film waste management[43] and the substitution of film processing systems with energy-efficient digital imaging systems to minimise energy consumption and carbon emissions.[44] However, the initial investment required for transitioning to digital radiography can be a barrier for resource-limited countries. To address this challenge, international collaborations and funding initiatives should play a vital role in supporting these countries in acquiring and implementing digital radiography technologies. By providing financial assistance, technological support, and capacity-building initiatives, such collaborations enable resource-limited countries to embrace sustainable radiography practices while improving healthcare delivery and patient outcomes.

Moreover, promoting digital radiography and advancing telemedicine and teleradiology, offer a sustainable solution to reduce the carbon footprint associated with radiography in resource-limited countries.[34] Embracing these technologies minimises the need for the physical transportation of radiographic films and medical images, thereby decreasing emissions from transportation.[2] Teleradiology in particular, reduces the need for paper-based request cards, film envelopes, consent forms, checklists, etc. whose production and use are contributors to carbon footprints and wastage respectively in low-resource settings. Moreover, telemedicine enhances accessibility to diagnostic services, particularly in remote areas where healthcare disparities are prevalent. Khodaie et al.[45] demonstrated the potential of telemedicine to bridge geographical barriers and improve healthcare access. Tshalibe et al.[46] recommended the use of a single-cloud PACS database by local hospitals to eliminate repeat examinations by patient transfers across hospitals and misplacement of clinical results. By adopting telemedicine and teleradiology, resource-limited countries can optimise resource utilisation, reduce environmental impact, and enhance healthcare equity. However, while telemedicine may help to reduce carbon emissions in low-income countries, it is also warned that the poor internet connectivity in some countries, if not fixed, will hinder the sustainable implementation of telemedicine, thus compromising efforts to reduce carbon emissions.

Radioactive waste resulting from contaminated materials used in nuclear medicine is also observed to contribute to chemical waste in this setting. Similarly, waste products like contrast agents often find their way into water bodies, posing toxicity risks to animals and humans.[47] For instance, there are concerns about the negative environmental impact of iodinated-based contrast media via their breakdown products.[47] Further, there are reports of traces of gadolinium in urine following contrast-based MRI examinations, ending up accumulating in sewage systems and, in effect, finding their way into surface water bodies.[48] Given that they do not undergo any degradation processes in waste water-treatment plants,[49] they can pose a danger to aquatic plants and living organisms which may end up reaching the human food chain.

It is recommended that such waste, especially leftover contrast media, be collected and returned to manufacturers for recycling.[10,48] Other possible solutions proffered include individualising the volume of contrast agents, that is, justifying the need for the use of contrast agents for each examination based on clinical indication, and determining weight per volume for each patient.[48] Another option is to employ available artificial intelligence-assisted software that optimises image quality to cut down the volume of contrast in use.

Furthermore, unused radioactive seeds from implants and sealed sources used for calibration purposes also pose potential waste management challenges.[50] To address these concerns, it is imperative to segregate radioactive waste from other materials, minimise waste generation through concerted efforts, and implement engineered encapsulation of sealed sources to prevent the release of loose material.[43]

Moreover, a report by the Basel Action Network[51] found that resource-constrained countries often struggle to manage electronic and equipment waste effectively. Notably, the waste from old lead and electronic components used in X-ray equipment,[51] as well as abandoned broken-down medical equipment units,[52] poses significant challenges. Woolen et al.[53] assert that most wastes from radiologic and radiotherapy procedures that are recyclable range from single-use products (catheters, sheaths, wires, devices, coils, sterile drapes, and sterile towels) to complex equipment and chemical waste. Therefore, establishing robust recycling initiatives not only mitigates the environmental impact of radiography-related activities but also promotes responsible management of hazardous materials.[54] Additionally, recycling contributes to the circular economy by reusing valuable materials and reducing reliance on finite resources.[54] In education, for example, the use of paper for examinations persisted for many years until the onset of COVID-19 caused a drastic shift, moving teaching activities online and introducing paperless examinations. It appears that educators have returned to paper examinations, and this trend will likely contribute to increased waste within the industry. Hence, ensuring that the papers used, if they cannot be eliminated, are recycled could help advance the sustainability agenda. By recycling these aforementioned wastes, resource-limited countries can minimise the extraction of new resources, conserve energy, and reduce greenhouse gas emissions associated with manufacturing processes. Moreover, promoting online exams and lectures in places where the internet can support them will be a good idea.

Inadequate training and research on safe sustainable practices and policy

Inadequate training and awareness among healthcare professionals, including a lack of understanding of how sustainability can be incorporated into their daily practices, present a challenge that needs addressing. For instance, fostering habits such as sustainability awareness and simple initiatives like turning off equipment during unproductive hours and utilising low-power mode during off-peak hours can significantly contribute to sustainable practices. Soares et al.[55] propose the inclusion of mandatory modules on green skills in educational curricula and specific sustainability courses during healthcare professionals' training. Thus, implementing educational programs for radiographers is crucial in resource-limited countries to promote environmentally friendly radiography practices. These programmes should emphasise optimising practices and using energy-efficient equipment.

While further research may be needed to explore how sustainability education can be integrated into radiography curricula in resource-limited settings, starting with seminars, workshops, and conferences at various professional and national organisational levels could be effective. Globally, the degree of education is a significant indicator of climate change awareness.[56] Therefore, empowering radiographers with tools and information for sustainable practices can help resource-limited countries make significant strides in reducing the negative impact of medical imaging and radiotherapy activities on the environment and improving healthcare quality.

de Reeder et al.[57] and Anudjo et al.[10] highlight a lack of research activities in sustainability within imaging and radiation-related medical professions. To address this gap, it is also crucial to increase research activities on sustainability issues in radiography and related professions in resource-limited countries. Governments and healthcare organisations should incentivise research endeavours by allocating funding and resources. This support can drive the development of innovative solutions, including alternative materials, optimised imaging techniques, and energy-efficient technologies. Collaboration between academia, industry, and government entities is essential to drive innovation and meaningful change in radiography. By prioritising research and innovation, resource-limited countries can enhance healthcare delivery sustainability, reduce environmental impact, enhance the green skills among staff and improve patient outcomes. Investing in research and innovation is key to building a resilient and sustainable future-ready healthcare system that meets the needs of both present and future generations. Currently, there are also limited policies to drive support for the sustainability agenda in low-income countries.[58] The authors believe that clear policies in radiography education and practice will provide essential guidance, accountability, and standardisation for integrating sustainable practices, ensuring compliance with regulations, fostering continuous improvement, and demonstrating organisational commitment to environmental stewardship. For example, a policy on green imaging practices can contribute to reducing carbon emissions.

Conclusions

Medical imaging and radiotherapy, along with their related activities in resource-limited settings, contribute to carbon emissions and waste production, especially in environments where outdated equipment and energy inefficiency prevail. Transitioning to modern, energy-efficient equipment and embracing renewable energy sources offer viable solutions to reduce the carbon footprint of radiography facilities. Additionally, managing waste and promoting digital radiography and telemedicine among other things can minimise transportation emissions and enhance healthcare accessibility.

It was observed that inadequate training and research on sustainable practices pose challenges that need urgent attention. As educational initiatives and research endeavours are essential to empower radiographers and drive innovation in sustainability radiographers in these countries need to be aware of these factors contributing to the carbon footprint and begin to work with the relevant stakeholders to mitigate them. Furthermore, there is a need for them to engage in education programmes and research efforts in sustainability to empower them with the right knowledge and understanding to practice sustainably.

Clear policies on green imaging are also necessary to provide guidance and standardisation for integrating sustainable practices into radiography education and practice. Overall, concerted efforts from governments, healthcare organisations, and international stakeholders are crucial to achieving sustainable radiography practices that benefit both present and future generations.

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