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Advancing climate-resilient health: radiology's role in mitigating climate-related health risks

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Global warming poses significant challenges to healthcare systems, with radiology playing a pivotal role in addressing the health impacts of climate change. Rising global temperatures and worsening air pollution are increasing the prevalence of cardiovascular and pulmonary diseases, necessitating targeted radiological interventions. Extreme heat events elevate the risks of thromboembolic conditions, myocardial infarctions, and strokes, while air pollution exacerbates chronic respiratory diseases like COPD and asthma. Advanced imaging technologies, including photon-counting CT, spectral imaging, and automated analysis tools, are crucial for early detection, timely intervention, and monitoring of these conditions, reducing morbidity and mortality rates. Simultaneously, radiology must adopt sustainable practices to minimize its ecological footprint, as the healthcare sector significantly contributes to global energy consumption. Radiological subspecialties, particularly cardiovascular, pulmonary, and neuroradiology, must expand to meet the growing demand for climate-related care. Innovations in imaging techniques, combined with interdisciplinary collaboration, can enhance diagnostic accuracy and efficiency while reducing resource consumption. These advancements not only strengthen the healthcare system's resilience but also improve population health outcomes. By integrating preventive strategies, optimizing resources, and advancing technologies, radiology can address the health challenges posed by climate change, contributing to a sustainable healthcare system and fostering Climate Resilient Health.

KEYWORDS

climate resilient health, radiology, sustainable imaging practices, climate-related health risks, preventive medicine

Introduction to climate resilient health

Global warming has emerged as one of the most significant challenges of the 21st century. In 2022, Greenland experienced the melting of 30 million tons of ice per hour, which is 20% more than previously estimated (Greene et al., 2024). This is primarily driven by an excess of CO_2 and similar emissions—commonly referred to as greenhouse gases—that result from technological advancements and rapid industrialization, ultimately leading to a global thermal imbalance (U.S. Global Change Research Program et al., 2017). Current scientific evidence indicates an exponential increase of this problem, suggesting that the goal of limiting global warming to 1.5°C, as outlined in the Paris Agreement, is now beyond reach (Greene et al., 2024; von Paris, 2024). At the same time, the healthcare sector, including radiology, contributes considerably to the worldwide energy consumption (Palm et al., 2023; Heye et al., 2020; Palm et al., 2023). In Germany, although 74.3% of radiology professionals regard sustainability as important or very important, a nationwide survey revealed that only 38% of participants could identify implemented sustainability measures in radiology (Palm et al., 2024).

The increase in global average temperatures is not only contributing to a higher frequency of natural disasters, but it also has pervasive effects on all ecosystems, significantly exacerbating climate-related health impacts for both wildlife and humans. Immediate health consequences arise from exposure to extreme temperatures—both cold and heat—as well as from deteriorating air quality, which imposes substantial stress on cardiovascular and respiratory systems. In Europe, 2023 was recorded as the hottest year since the beginning of systematic weather monitoring, which was associated with an estimated 47,690 heat-related fatalities (Studie zählt mehr als 47.000 Hitzetote in Europa im Jahr, 2023). Current studies demonstrate a worldwide rise in heat-related mortality rates during the 2018–2022 period compared to the baseline years of 2000–2004 (Romanello et al., 2023). In Germany, the heat-related mortality rate for individuals over the age of 65 increased by 64.87%, situating the country in the mid-range of observed trends (Romanello et al., 2023). The United States exhibited an 88.29% increase in heat-related deaths, whereas leading countries such as Chile, Algeria, and the Democratic Republic of Congo experienced significantly higher increases, ranging from 210 to 250% (Romanello et al., 2023).The complex interplay between changing weather patterns and ecosystems results in numerous indirect health consequences of climate change. Among these impacts are the increased spread of infectious diseases such as malaria, dengue fever, and cholera, driven by profound disruptions to ecosystems and the hydrological cycle. Additionally, a rise in global average temperature by 2°C is expected to significantly reduce agricultural yields, leading to increased food insecurity and related malnutrition affecting an estimated half a billion people worldwide (Climate Explainer, 2024; Chapter 5: Food Security—Special Report on Climate Change and Land, 2024). The compounded direct and indirect health impacts of climate change disproportionately affect individuals with pre-existing health conditions, whose physiological resilience to changing climatic conditions is further compromised, particularly in those suffering from chronic diseases. As an example, a case-crossover study from China involving 5,746 patients demonstrated that high levels of particulate matter (PM2.5) were associated with acute exacerbations of chronic obstructive pulmonary disease (COPD) (Niu et al., 2024). Consequently, vulnerable populations, such as individuals with pre-existing health conditions and those facing socioeconomic disadvantages, are particularly at risk from the adverse effects of climate change (Romanello et al., 2023; IJERPH, Free Full-Text, Making the Environmental Justice Grade, 2024).

To combat the direct and indirect impacts of climate change, it is critical to consider how to best prepare both the health system and individual. The comprehensive enhancement of health resilience in the face of climate change can be encapsulated by the concept of "Climate Resilient Health." It is important to distinguish this from the "Climate Resilient Health System," which focuses not directly on individual health, but on how altered environmental conditions impact the overall healthcare system, necessitating associated infrastructural adjustments. Key elements of a climate-resilient health system include architectural measures, early warning systems for natural disasters, air pollution, and disease outbreaks, as well as the optimization of medical resources and the provision of a holistically sustainable healthcare framework. Further air conditioning is an essential component of the Climate Resilient Health System, as it ensures not just stable room temperatures necessary for the operation of medical equipment but can be also used as supportive element in medical treatment strategies (Lenzer et al., 2020). Studies have shown that hospitals without adequate air conditioning can face serious operational challenges, particularly during extreme heatwaves, which can lead to a significant reduction in operational capacity. While air conditioning and ventilation, contribute to about 9–19% of overall energy consumption in public buildings, specifically in hospitals this infrastructure is vital for critically ill patients (Lenzer et al., 2020; CBECS, 2012). The absence or inadequate functioning of air conditioning systems can lead to severe disruptions, especially during extreme heat periods, highlighting their critical importance in sustaining uninterrupted healthcare services (Lenzer et al., 2020). There is, therefore, a natural overlap with Climate Resilient Health, which aims to promote resilient health outcomes and enhance population wellbeing in response to climate-related stressors.

In this context, what role can radiology play in fostering a sustainable healthcare system, and how can it contribute to addressing the health challenges arising from global warming? How can innovative imaging technologies be leveraged to enhance physical resilience and ensure adequate care for patients affected by climate-induced health conditions?

Radiology in context of climate resilient health

To effectively promote Climate Resilient Health, it is crucial not only to emphasize prevention and mitigate health risks but also to optimize radiological resources, focusing particularly on climate-related health impacts. Two systems within the human body are of particular interest when it comes to health consequences of climate change – the cardiovascular and the pulmonary system.

Associated with these two central organ systems, climate-related stressors show further significantly impact fetal development, with maternal heat exposure increasing preterm birth risk and low birthweight (Masters et al., 2025; Dastoorpoor et al., 2021). Additionally, the risk of stillbirth increases by 12–15% for each 1°C rise in temperature (Dastoorpoor et al., 2021; Asamoah et al., 2018). Given these trends, maternal-fetal monitoring must be considered in climate health strategies. Specifically, ultrasound-based monitoring enables early detection of placenta perfusion, intrauterine growth restriction (IUGR) and preterm birth risks, supporting timely interventions. In addition, awareness by preventive patient education, and individualized protection from environmental hazards are crucial to minimizing risks for both mother and child.

Cardiovascular radiology

Mortality rates are significantly higher during periods of extreme heat (Basu and Samet, 2002; Wolf et al., 2023; Liu et al., 2022). The adaptation to external temperatures and the maintenance of human thermoregulation place considerable stress on the cardiovascular system. Diaphoresis, vasodilation, and an elevated heart rate are critical physiological responses that increase blood flow to facilitate heat dissipation and thereby lower body temperature. Extreme heat, particularly in elderly populations, further elevates the risk of thromboembolic events due to dehydration and increased blood viscosity, which contribute to conditions such as deep vein thrombosis (DVT) and pulmonary embolism (PE). Both heat and cold can lead to haemoconcentration and hypercoagulability, potentially explaining seasonal differences in thromboembolic events (Khraishah et al., 2022; Deşer and Arapi, 2023; Damnjanović et al., 2013). Moreover, previous studies indicate a potential link between particulate matter exposure and venous thromboembolism (Franchini et al., 2016). Exposure to pollutants like PM2.5, PM10, and gases such as CO, O3, NO2, and SO2 also correlates with increased PE hospitalizations (Li et al., 2022).

This climatic stress on the cardiovascular system is intensified by global warming and associated with adverse cardiovascular outcomes (Gunasekaran et al., 2024). Hence, the increasing frequency and duration of extreme temperature events contribute to a rise in cardiovascular decompensation, with a notable increase in incidences of stroke and myocardial infarction (Basu and Samet, 2002; Liu et al., 2022).

Radiology plays a pivotal role in the early detection and diagnosis of these conditions. Modalities such as ultrasound for DVT or computed tomography (CT) angiography are critical for timely cardiovascular intervention, which is essential to mitigate severe outcomes and reduce mortality rates. As the number of patients experiencing adverse cardiovascular outcome rises, the importance of radiological subspecialties such as neuroradiology and cardiovascular imaging will grow significantly. The safe execution and interpretation of unenhanced cranial computed tomography, CT angiography, and perfusion imaging should not be limited solely to neuroradiologists. Cardiac CT imaging is also expected to gain greater relevance in the future. It is essential to ensure not only the technical availability and equipment capacity to meet the growing patient demand, but also the provision of specific training for radiologic technologists (MTR) and certification of radiologists for accurate performance and interpretation of these imaging modalities.

Image post-processing has the potential to reduce energy consumption through shortened MRI sequences while additionally minimizing image artifacts. In computed tomography, advancements such as multidetector CT, spectral imaging, and photon-counting CT have demonstrated benefits, including enhanced contrast for qualitative plaque decomposition, improved evaluation of in-stent stenosis, and the detection of microcirculatory changes in asymptomatic cerebral infarctions. These developments have ultimately enabled better detection of myocardial infarction and intracranial ischemia (Radiology: Cardiothoracic Imaging Highlights, 2022; Evaluation of Microcirculation in Asymptomatic Cerebral Infarction With Multi-Parameter Imaging of Spectral CT - ScienceDirect, 2022; Rodriguez-Granillo et al., 2024; Tian et al., 2024; Bratke et al., 2020). Additionally, virtual non-contrast (VNC) reconstructions can replace separate unenhanced imaging, thereby reducing both radiation exposure and power consumption. Algorithms that opportunistically detect incidental cardiac findings and automatically quantify coronary artery calcium and Agatston scores can further aid in identifying undiagnosed cardiovascular conditions during routine chest CTs conducted for non-cardiac indications (Palm et al., 2022).

Pulmonary imaging

Pulmonary diseases, such as chronic obstructive pulmonary disease (COPD) and asthma, represent a significant burden on healthcare systems worldwide. In 2017, chronic respiratory diseases accounted for approximately 3.9 million deaths globally, reflecting an 18% increase since 1990, making it currently the third leading cause of mortality worldwide (Prevalence and Attributable Health Burden of Chronic Respiratory Diseases, 1990–2017: A Systematic Analysis for the Global Burden of Disease Study 2017 - The Lancet Respiratory Medicine, 2024). Air pollution is a major risk factor in both the development and exacerbation of pulmonary conditions. Fine particulate matter (PM2.5), nitrogen oxides (NO_x), and ozone (O_3) are particularly prevalent in urban areas, substantially contributing to the incidence and prevalence of COPD and asthma (Niu et al., 2024; Prevalence and Attributable Health Burden of Chronic Respiratory Diseases, 1990–2017: A Systematic Analysis for the Global Burden of Disease Study 2017 - The Lancet Respiratory Medicine, 2024; Air Pollution, 2024; Orru et al., 2017). According to the World Health Organization, an estimated 4.2 million people die each year from causes linked to air pollution, with about 40% of these deaths attributed to respiratory diseases such as COPD and asthma (Air Pollution, 2024). In Europe, air pollution significantly shortens life expectancy. For instance, an increase in NO_x levels by just 1% results in a reduction in life expectancy by approximately 6.7 months (Rodriguez-Alvarez, 2021). Climate change further exacerbates these issues as particulate matter exposure increases due to more frequent wildfires, prolonged droughts, altered weather patterns, reliance on fossil fuels, and increased ozone formation. These factors collectively degrade air quality, raising the risk of respiratory diseases.

While climate change exacerbates pre-existing health conditions and worsen outcomes, it may also be linked to cause onset of diseases. Besides worsening existing respiratory conditions, rising air pollution levels have been also linked to the onset of childhood asthma (Wang et al., 2016; Rorie and Poole, 2021; Agache et al., 2025). Studies show that prenatal exposure to fine particulate matter ($PM_{2.5}$, PM_{10}, SO_2) increases the risk of childhood asthma (Bao et al., 2025). Additionally, ozone exposure and wildfire-related air pollution are emerging as major contributors to new respiratory and allergic diseases.

Recognizing climate change as a primary factor in disease emergence is essential for developing preventive strategies, improving early diagnosis through imaging, and integrating radiology into broader public health efforts. Clinical parameters, radiological imaging techniques—particularly chest radiographs and computed tomography (CT)—are crucial for the diagnosis and monitoring of COPD and asthma. Studies indicate that early detection of bronchiectasis is possible in approximately 30% of COPD patients using CT, which correlates with the frequency of exacerbations and mortality rates (Martínez-García et al., 2021; Hata et al., 2022). Imaging analysis tools, such as YACTA, can automatically quantify the emphysema index, thereby not only complementing clinical diagnostics but also serving as a preventative screening method during opportunistic CT examinations (Weinheimer et al., 2017). This allows for early intervention, even when the disease is still in an asymptomatic stage (Weinheimer et al., 2017; Heussel et al., 2006; Lim et al., 2016). When COPD is detected early and optimally treated, the frequency of exacerbations can be reduced by up to 50% (Wedzicha et al., 2016). This is particularly relevant given that the frequency of exacerbations is positively correlated with the GOLD stage, and timely intervention can significantly mitigate their occurrence.

These findings underscore the necessity of further developing and specializing radiological procedures to address the growing challenges posed by climate change and air pollution. Such methods are particularly crucial in regions with high air pollution levels, where continuous monitoring of structural changes in the lungs can facilitate the early detection of pulmonary diseases. Therefore, targeted optimization of radiological resources and specialization in climate-related health impacts are of paramount importance.

Outlook

The Organization for Economic Co-operation and Development (OECD) estimates that by 2060, global healthcare costs associated with air pollution-related diseases will rise to approximately 2–3% of the global gross domestic product (GDP), equating to about 3.3 trillion US dollars annually (OECD, 2016). Radiology has a critical role to play in addressing the health challenges posed by global warming. Innovative imaging techniques can support the development of a sustainable healthcare system while enhancing the resilience of the population. To promote Climate Resilient Health, prevention and the optimization of radiological resources, especially those specialized in climate-related health impacts, work synergistically.

Advanced technologies will not only facilitate the precise diagnosis and treatment of climate-related health conditions but also enhance the overall understanding of patients' health status through the identification of comorbidities during opportunistic CT screenings. Early targeted therapeutic interventions can be initiated, thereby increasing treatment efficiency and strengthening the resilience of the healthcare system against climatic challenges. These advancements, particularly those based on artificial intelligence, can enhance the efficiency and accuracy of radiological procedures, which is crucial to ensuring reliable medical care under extreme climatic conditions.

However, significant challenges may occur when implementing advanced imaging technologies specifically in low-resource settings, including high equipment costs, energy demands, limited infrastructure, and a shortage of trained personnel. Scalable innovations—such as mobile imaging units, solar-powered digital radiography, and AI-assisted diagnostics—can help bridge access gaps.

At the same time, these technologies should be complemented by preventive and community-based strategies to maximize impact. For example, integrating basic radiological screening into primary care and leveraging tele-radiology cannot only support early disease detection and by timely therapeutic intervention improve climate resilient health but moreover extend diagnostic capacity to vulnerable populations. This dual approach can significantly strengthen the resilience and equity of healthcare systems facing climate-induced challenges.

Despite the central role of radiology in climate-resilient health strategies, access to imaging services remains uneven, with disparities between urban and rural areas. A comparative study from Munyangaju et al. (2024) comparing low- and middle-income countries to OECD countries revealed substantial geographic inequalities with disparities in radiological capacity: Mozambique had only 0.4 CT scanners per million inhabitants, compared to 5.8 in South Africa and 19.3 in Spain. A similar trend was observed for X-ray units, with a positive correlation between imaging availability and both national income and GDP per capita (Fleming et al., 2021; Munyangaju et al., 2024). This highlights how limited imaging availability in underserved communities delays diagnosis and increases morbidity, including conditions worsened by climate change such as pneumonia and heat-related stroke. Scalable models—such as mobile imaging units, teleradiology platforms, and shared radiology hubs—have shown promise in addressing these problems, enabling outreach to remote populations. Collaborative efforts with NGOs, international aid organizations, and government programs—such as RAD-AID International's initiatives in East Africa and India—can help close the socioeconomic and geographic gap by improving diagnostic imaging access, a crucial step toward building inclusive, climate-resilient healthcare systems.

To advance Climate Resilient Health, cross-sector collaboration must be strengthened through targeted initiatives and partnerships. Beyond tight interdisciplinary medical cooperations, radiologists should actively engage with public health programs—such as the WHO's Heat Health Action Plans (HHAPs)—by contributing imaging expertise to support early detection of heat-related illnesses and enhance disease surveillance efforts (Martinez et al., 2022). Real-world models like Germany's *KOPHIS* project and the *Lancet Countdown* task forces illustrate how multi-sectoral alliances can integrate environmental, clinical, and radiological data for resilience planning (Romanello et al., 2023; Kreuz, 2025). Collaboration with emergency and primary care teams, as well as civil protection and disaster relief organizations such as the Red Cross—especially during wildfires or extreme heat events—can streamline triage. Establishing formal interdisciplinary task forces that include radiology ensures imaging is embedded in preparedness frameworks, not just clinical workflows. These efforts enable more responsive and equitable healthcare systems under climate stress.

In summary, adapting radiological subspecialties in response to climate change will require an emphasis on expanding cardiovascular and neuroradiological expertise, as well as thoracic radiology focusing on pulmonary imaging, embedded within a close, interdisciplinary clinical collaboration. In addition to providing technical resources and optimizing protocols, expertise in these subspecialties is essential for effectively managing the increasing patient load associated with climate change and ensuring adequate medical care. To meet this responsibility, competencies in relevant subspecialties must be continually developed to foster Climate Resilient Health, and new technological advancements such as automated image analysis should be integrated into routine radiological practice. Simultaneously, innovative radiological solutions must be explored and promoted to reduce the ecological footprint and increase the efficiency of healthcare services to ensure a Climate Resilient Health System. Only through the responsible use of resources can the challenges of climate change be met, ensuring a high quality of healthcare to support Climate Resilient Health.

Policy recommendations

To operationalize climate-resilient radiology, healthcare policy must support both innovation and accessibility. Governments and public health agencies should integrate radiological services into climate adaptation plans, including heatwave early warning systems and vector-borne disease surveillance programs. Policymakers should invest in expanding tele-radiology infrastructure and mobile imaging units to ensure diagnostic equity in rural and climate-vulnerable populations. National health systems should mandate the integration of radiology into emergency preparedness frameworks, including heatwave response plans and vector-borne disease surveillance. Preventive imaging—such as disease screening programmes or opportunistic CT analysis—should be reimbursed within primary care frameworks to enable early detection of climate-sensitive conditions. Interdisciplinary climate-health task forces, including radiology stakeholders, should be formalized at national and regional levels to guide coordinated action. Regulatory bodies can promote sustainability by incentivizing energy-efficient imaging technologies, AI-assisted diagnostics, and low-dose protocols through procurement standards and climate-conscious accreditation systems. Lastly, establishing funding programs for preventive radiological screening in primary care settings can enable early intervention and reduce long-term healthcare costs.

Conclusion

Climate change presents an unprecedented challenge to global health, with wide-ranging impacts that demand urgent and strategic adaptation across all healthcare sectors, including radiology. Radiology has a critical role in fostering Climate Resilient Health by enhancing diagnostic precision, promoting prevention, and optimizing the use of resources to address climate-related health impacts effectively. By expanding expertise in key areas such as cardiovascular, pulmonary, and neuroradiological imaging, radiology can provide targeted solutions for the increasing burden of climate-associated diseases, such as heat-related cardiovascular events and pollution-induced respiratory conditions.

Advanced imaging technologies, including photon-counting CT and artificial intelligence-driven analysis, offer immense potential to improve early detection, enhance diagnostic accuracy, and reduce the ecological footprint of radiological practices. Innovations such as opportunistic imaging, virtual non-contrast reconstructions, and automated analysis tools can help identify comorbidities early, enabling timely interventions that reduce the severity of health outcomes and enhance system efficiency.

In parallel with clinical innovation, the environmental sustainability of radiological practice must be prioritized. While technological advancements in radiology are essential for improving diagnostic accuracy and building climate-resilient health systems, they also risk increasing the ecological footprint through higher energy consumption, carbon emissions, and e-waste. To ensure that innovation does not undermine sustainability goals, radiological development must adopt a dual-focus approach: enhancing diagnostic capability while actively reducing environmental impact. This includes prioritizing low-dose imaging protocols, energy-efficient modalities, AI-based workflow optimization, and life-cycle-conscious procurement practices. Embedding sustainability metrics into radiology research, funding criteria, and regulatory approval processes can help balance precision medicine with environmental responsibility.

To ensure that radiological innovation aligns with environmental sustainability, it is essential to consider ecological impacts across the entire imaging technology lifecycle. Lifecycle assessments (LCA) should be adopted as a standard tool in procurement and development decisions, allowing emissions, energy use, and material waste to be evaluated from production through end-of-life. Extending the operational life of imaging equipment through refurbishment offers significant environmental benefits; for instance, Philips refurbished over 3,500 systems in 2022, substantially reducing electronic waste and CO_2 emissions compared to producing new devices (Philips Macht Weiterhin Deutliche Fortschritte in Richtung ESG-Ziele, 2025). At the same time, new technologies such as photon-counting CT (PCCT) provide diagnostic advantages but may also increase energy demand due to high computational load, illustrating that not all innovation inherently supports sustainability goals. To mitigate these impacts, manufacturers should prioritize eco-design principles, including modular hardware, energy-saving standby modes, and minimal helium consumption in MRI systems. Radiology departments can further reduce their environmental footprint by implementing best practices such as device shutdown protocols, smart scheduling, and digital workflows—strategies that can collectively reduce energy use and lower material waste without compromising diagnostic quality.

To meet the challenges posed by climate change, radiology must adopt sustainable practices, prioritize interdisciplinary collaboration, and integrate cutting-edge technologies. This approach not only supports the resilience of healthcare systems but also ensures equitable and high-quality care for populations disproportionately affected by climate change. Through these efforts, radiology can emerge as a pivotal contributor to a sustainable and climate-resilient healthcare future, safeguarding global health in an era of profound environmental change.

As climate change drives a growing burden of disease, the radiology community must participate in healthcare-wide and cross-sector efforts to mitigate its impacts. This includes adopting energy-efficient imaging technologies, reducing the environmental footprint of radiology departments, and integrating climate resilience into their clinical practice and addressing climate-induced illnesses.

> "*The climate crisis is not a political issue,*
> *it is a moral and spiritual challenge to all of humanity.*"
> Al Gore.

Author contributions

VP: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Writing – original draft, Writing – review & editing. EN: Conceptualization, Writing – review & editing. H-UK: Writing – original draft, Writing – review & editing. SS: Conceptualization, Data curation, Investigation, Methodology, Writing – original draft, Writing – review & editing.

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