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REVIEW

Go Green in Neuroradiology: towards reducing the environmental impact of its practice

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Abstract
Raising public awareness about the relevance of supporting sustainable practices is required owing to the phenomena of global warming caused by the rising production of greenhouse gases. The healthcare sector generates a relevant proportion of the total carbon emissions in developed countries, and radiology is estimated to be a major contributor to this carbon footprint. Neuroradiology markedly contributes to this negative environmental effect, as this radiological subspecialty generates a high proportion of diagnostic and interventional imaging procedures, the majority of them requiring high energy-intensive equipment. Therefore, neuroradiologists and neuroradiological departments are especially responsible for implementing decisions and initiatives able to reduce the unfavourable environmental effects of their activities, by focusing on four strategic pillars—reducing energy, water, and helium use; properly recycling and/or disposing of waste and residues (including contrast media); encouraging environmentally friendly behaviour; and reducing the effects of ionizing radiation on the environment. The purpose of this article is to alert neuroradiologists about their environmental responsibilities and to analyse the most productive strategic axes, goals, and lines of action that contribute to reducing the environmental impact associated with their professional activities.

Keywords Neuroradiology · Green radiology · Climate change · Carbon footprint · Recycling

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Introduction

In the last few years, there is an increasing interest from radiological departments and scientific societies in reducing the environmental impact of diagnostic and interventional radiological procedures, and related activities.

The global healthcare sector generates between 5 and 10% of global greenhouse gas (GHG) emissions in developed countries, making it a major contributor to the climate crisis. In an effort to decrease GHG emissions associated with healthcare, the US Department of Health and Human Services has proposed a call-to-action initiative, designed to reduce emissions across the healthcare sector. Following this pledge, 61 of the largest US hospital and health sector companies committed to reducing greenhouse gas emissions by 50% by 2030.

Radiological activity is estimated to be a relevant contributor to this carbon footprint (representing 1% of the world's total GHG emissions), mostly due to the use of energy-intensive equipment [1–3].

Considering the continuous growth of neuroradiological procedures, which represents around 20% of all radiological examinations performed in academic and non-academic institutions, most of them using high energy-intensive equipment, neuroradiologists and neuroradiological departments have a special responsibility in establishing initiatives and innovative approaches that minimizes the negative environmental impact of their activities.

The European Society of Neuroradiology (ESNR) has taken the initiative trough the "ESNR Green Committee" to educate neuroradiologists about their responsibilities for creating a greener world, and to propose some actions and policies that reduce the generated carbon footprint by reducing energy, water, and chemical consumption (including helium and contrast media), increasing the use of biodegradable materials, and improving the proper disposal of the generated waste, with the final objective of creating neuroradiological departments more environmentally friendly.

The purpose of this article is to raise the awareness of neuroradiologists towards their environmental responsibilities and to analyse the most productive strategic axes, goals, and lines of action that contribute to reducing the environmental impact associated with their professional activities.

Concepts and basic principles of "Green Neuroradiology"

A "green neuroradiology" department is a healthcare setting that, in carrying out its mission (offer state-of-the-art imaging for paediatric and adult patients to diagnose and treat disorders of the central nervous system, of the spine and of the head and neck), has as its strategic goal the ongoing reduction of its environmental impact. It complies with relevant environmental regulations and establishes clear lines of action to lessen its negative environmental impact.

The focus of the practice of green neuroradiology is based on four principles and operational axes aimed to reduce energy consumption and environmental impact [4]:

- Reducing the consumption of energy as well as other resources like water and chemicals.
- Recycling and/or properly disposing of waste material.
- Promotion of ecological neuroradiology practices.
- Reducing the effects of ionizing radiation on the environment (not covered in this article).

The implementation of environmental policies in the health sector, including neuroradiology, strikes a steadily improving balance between voluntary nature, necessity, and legal requirement. However, it is crucial to acknowledge certain barriers and challenges associated with the implementation of these policies (Table 1). To address these challenges effectively, a comprehensive approach is required, necessitating collaboration among healthcare professionals, policymakers, and technology providers.

Reducing the consumption of energy as well as other resources like water and chemicals/ recycling and/or properly disposing of waste material.

1. Equipment: Purchase and life cycle

An important issue to consider is managing the life cycle of the radiology equipment with a green approach. This management includes different phases (Figure 1 and Table 2) [4]:

- Phase 1: Purchase planning. It should be done with "green purchase" specifications, incorporating sustainability requirements in the contract. In this regard, the European Commission has published a manual on how to buy goods and services with a lower environmental impact [5].
- Phase 2: Acquisition. Priority should be given to the purchase of energy-efficient radiology equipment that meets sustainability criteria, considering the clinical needs. The European Commission and the Canadian Government have published requirements and checklists for sustainable procurement [6, 7].

Table 1 Barriers and challenges to the implementation of green neuroradiology

- Imaging equipment: The upgrade of imaging equipment to more energy-efficient and environmentally friendly models can be a costly endeavour, demanding substantial technological investments.
- Resistance to change: Healthcare professionals, including neuroradiologists, may exhibit reluctance towards adopting new practices or technologies, particularly if these innovations disrupt established routines or workflows.
- Lack of awareness: Limited awareness or understanding of the environmental impact of neuoradiological practices among healthcare professionals may impede the adoption of green radiology initiatives.
- Regulatory compliance: Meeting environmental regulations and standards in the healthcare sector can present challenges, and navigating these requirements can be complex.
- Financial constraints: Healthcare institutions may encounter budgetary constraints that hinder their capacity to invest in eco-friendly technologies or practices.
- Patient expectations: Balancing the implementation of green neuroradiology with patient expectations for high-quality and timely healthcare services can prove to be challenging.
- Data security concerns: The transition to electronic records and the suppression/reduction of paper usage may raise concerns regarding data security and privacy, necessitating robust measures to address these issues.
- Supply chain challenges: Ensuring a sustainable supply chain for neuroradiological materials and equipment can be challenging, particularly if eco-friendly options are limited or more expensive.

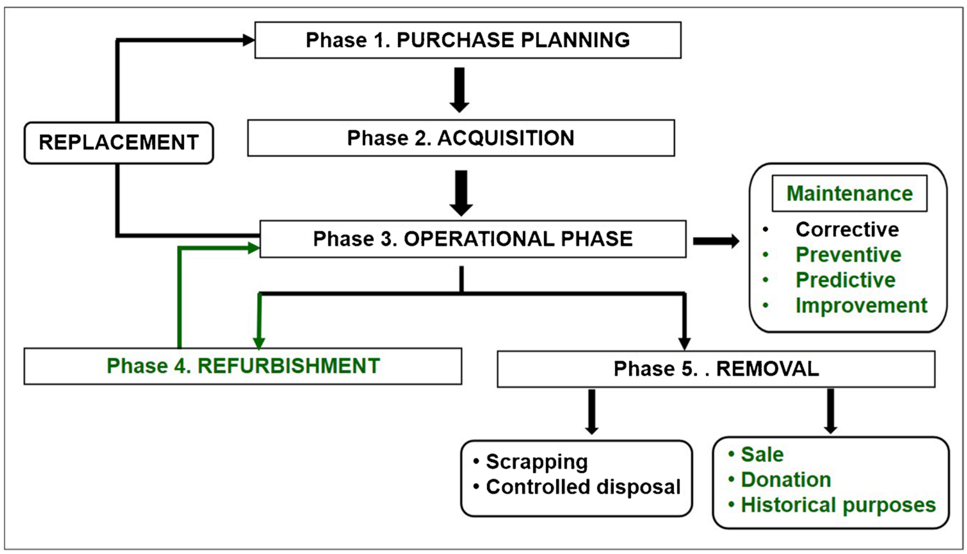

Fig. 1 Life cycle phases of radiological equipment using a green approach

- Phase 3: Operational. Regular maintenance of the equipment reduces the need for costly parts replacement, extends the lifespan of the devices, and improves energy efficiency [8].
- Phase 4: Refurbishment. The option of refurbishing the equipment can be chosen for its utilization as it extends their life cycle within the philosophy of circular economy [9].
- Phase 5: Equipment removal. Regarding equipment that uses ionizing radiations, it should be carried out in accordance with the current national legislation and within the European Union, complying with the mandate of DIRECTIVE 2013/59/EURATOM [10]. After equipment removal, one option always worth considering is donation to low-resource settings, a strategy that can improve access to medical imaging in low-and middle-income countries. The World Health Organization (WHO) has published guidelines on the subject [11].

2. Electricity and water savings

The electricity sector is considered the major source of healthcare-related GHG emissions worldwide, and radiology departments claim a large proportion of energy consumption within most healthcare facilities [12]. Indeed, energy consumption is essential for operation of both image acquisition equipment (including associates climate control systems whenever appropriate) and reporting workstations (usually composed of monitors, computers, phone chargers, and reading room lights). Among the imaging modalities, magnetic resonance imaging (MRI) and ultrasound (US) represent the most and the least energy-intensive techniques, respectively,

Table 2 Checklist of sustainability criteria purchase of radiological equipment (Adapted from references 6 and 7)

Concept—need
• Is this purchase necessary?
Equipment certification
• Has the equipment been certified by an independent organization that
• guarantees its sustainability?
• Have unbiased studies of environmental attributes been conducted?
• Are the pre-set environmental standards available?
Manufacturer certification
• Is the manufacturer certified or registered (e.g., ISO 14001)?
• Does the manufacturer have an Environmental Management System (EMS) or Environmental Policy?
• Do they comply with environmental laws and regulations?
Energy efficiency
• Does the equipment make efficient use of resources and energy throughout its life cycle?
• What are the costs associated with the energy consumed during its useful life?
• Does it have any power-saving features like a “sleep mode”?
• Are there clear instructions on how to use the equipment for maximum efficiency?
• How does it compare to similar equipment in terms of energy efficiency?
• How much heat does the equipment produce?
Refurbishment
• Can the equipment be reused at the end of its useful life?
• Does the equipment contain refurbished parts?
• Does the equipment contain reusable parts?
Hazardous materials: MRI—helium
• Does the manufacturer offer a solution that reduces helium usage?
Renewable resources
• What type and percentage of recycled materials does the equipment contain?
Maintenance
• Is the equipment designed for easy maintenance and repair?
• Is preventive, predictive, and improvement maintenance offered?
Packaging
• Is the packaging reusable or does it contain reusable parts?
• Is it recyclable?
• Does the packaging material contain post-consumer recycled materials?
Durability
• What is the expected lifespan of the equipment?
Warranty
• How long is the warranty?
• Should an extended warranty be purchased to increase lifespan?

while computed tomography (CT) shows an intermediate consumption [13–16]. A recent study performed in a tertiary academic centre demonstrated that mean energy consumption over one year was equal to 19.9 kW/h per MRI examination (16.2 kWh for 1.5 T systems and 22.9 kWh for 3.0 T systems), and this value was near 20 times less per CT examination (corresponding to an average of 0.99 kWh of all examination regions) [16].

The use of low-field MRI systems magnets (ranging from ~0.1 to 0.55 T) significantly reduces the cost, maintenance, and energy consumption that is estimated to be 45% lower than those for a 1.5 T system [17]. Their low signal-to-noise ratio has been improved by image reconstruction methods using deep learning and denoising techniques, resulting in high image quality that is sufficient for clinical applications [18]. Considering these factors, low-field MRI systems can be expected to become very popular tools in regions of the world where MRI is difficult to install or access owing to cost (low- and middle-income countries, rural areas), especially in terms of maintenance [19].

It has been shown that the annual energy consumption of 32 reporting stations in a radiology department is not negligeable, being equivalent to 12 family households in Switzerland in 2014 [20]. Importantly, non-productive power consumption of medical imaging equipment and devices (including during standby and idle modes) is consistently reported as being very high [16, 20, 21]. It has been calculated that approximately two thirds of CT energy consumption take place during the nonproductive idle system state. In the case of MRI scanners, one third of energy consumption is attributable to the system-off state due to constant helium cooling and operation of the cooling head [16, 20]. The MRI vendors introduction of low–energy consumption at system idle and system-off states (an energy-conserving mode designed to cycle the operation of the cold head compressor) reduce energy consumption [16, 21, 22]. Definitions of CT and MRI activity system states are described in Table 3.

Table 4 suggests measures for energy efficiency in the field of medical imaging, which should be complemented by progressive hospital switch to renewable/decarbonized energy sources.

Besides energy optimization, water-saving strategies should also be implemented in neuroradiological departments, including replacement of hand wash with

Table 3 Definition of MRI/CT activity system states (modified from reference [16]

System state or mode	Definition
Net scan	The productive phase in which images are acquired
Active	The time period during which a scanner is used to examine a patient, which includes preparation for and planning of scan, the actual net scan, and reconstruction of raw data into image data (patient room time)
Idle	The time interval between "active" time periods within system-on time period Idle state may consume more power than the standby state
System-on (standby)	The time in which the equipment is powered on and immediate scanning is possible; net scan, active, and idle are system-state events occurring during system-on state Standby mode allows the system to consume less power while still being able to quickly resume its normal function
System-off	The time in which a scanner is powered down. In case of MRIs, this state still consumes energy owing to ancillary systems required to maintain a stable power system; immediate scanning is not possible, and a power-up sequence of several minutes is needed before scanning

Table 4 Individual and institutional actions that can reduce the energy utilization in the neuroradiological activity

1. Application of the American College of Radiology (ACR) appropriateness criteria in order to avoid unnecessary medical examinations [23]
2. In case of similar diagnostic accuracy, selection of the imaging modality with the lower environmental footprint
3. Utilization of abbreviated imaging protocols, whenever clinically appropriate
4. Implementation of automated energy saving plans/changes in device configuration and promotion of energy wise habits

- minimize the time equipment remains idle (e.g., increment of the degree of utilization of the imaging modalities per time period through improved workflow and optimized patient throughput)
- programming the equipment to turn on and off automatically in specific hours/days of the week (e.g., during overnight and weekends in outpatients' scanners)
- implementation of power-save mode instead of system-off mode on MRIs systems
- activate auto-shut down/power-save mode functions in computers, projectors and monitors
- turning off lights/use motion-sensitive lights and turning down heat in areas not in use
- operate air conditioning on a schedule
- use green computing services
- switch to energy-efficient light bulbs
- be mindful of greener transport options
- minimize the amount of waste that cause emissions

5. Active measurement, reporting, and performance-tracking over time of department-specific energy consumptions (facility-level data)
6. Educational efforts and awareness campaigns targeting the medical team and other healthcare professionals regarding energy-consumption
7. Promotion of sustainability research and quality improvement projects within the field of radiology-related energy use
8. Appropriate planning of new installations or expansions of radiology departments

- facilitating synergetic use of cooling systems and/or scanning architecture
- adding alternative methods of counteracting waste heat (waste heat recovering methods/heat storing technologies)

9. introduction of system-off, system-on, and standby modes

- utilization of lower and greener energy sources to manufacture, distribute, and install radiological equipment and devices

10. Formation of a green team of neuroradiologists, nomination of a green officer, and collaboration with joint committees

alcohol-based hand rubs to reduce water usage, utilization of water-sparing cleaning products, total switch to digital imaging (film-based equipment consumes large quantities of water), and implementation of water conservation technologies and practices, such as greywater (water from showers, bathtubs, sinks, kitchen, dishwashers, laundry tubs, and washing machines) and rainwater reuse for non-drinking purposes, upgrading faucets, and toilet technology (including low-flow systems) as well as prevention/fast elimination of plumbing and pipe system leaks [24, 25].

3. Climate control: heating, ventilation, and air conditioning

Along with lighting, heating, ventilation, and air conditioning (HVAC) systems represent a significant contributor to total energy consumption. In healthcare structures, HVAC systems are utilized to improve the quality of the environment occupied by health workers, patients, and visitors, and play a crucial role in maintaining the functionality of radiology equipment. Indeed, CT and MRI scanners are energy intensive in their operation, with peak consumption exceeding 100 kW [16], which also generate heat when acquiring images. The implementation of waste heat recovery methods to recycle excess heat, instead of using more energy to get rid of it, provides valuable energy sources and reduces energy consumption [26].

Among all the equipment of a Radiology Department, the most crucial portion of temperature control is required to maintain the MRI scanner, given that gradient coils can reach more than 60 °C when used [27]. For this reason, MRI scanners usually have dedicated heat exchange pump systems that reduce the coil temperature by circulating deionized water or ethylene glycol solution through tubes or channels near the gradient coil.

4. Waste disposal and biodegradables

Healthcare facilities are the second largest waste producers, after the food industry [28]. The 5 Rs of waste management (Reduce, Reuse, Recycle, Rethink, Research) are the fundamental principles of decreasing waste (Table 5) [29].

First, proper waste segregation plays a crucial role to reuse and recycle materials. A distinction should be made between food waste, solid waste, and regulated medical waste, with the latter requiring a higher energy cost until final breakdown [30]. Clearly labelled waste bins/containers and recycling containers are essential, in/outside examination rooms, staff areas, and at meeting events. Second, minor adjustments can be made in terms of using biodegradable materials. Drinking cups, for oral contrast administration, made of corn starch can be used instead of the conventional Styrofoam, plastic, or paper cups. Scan table coach rolls can also be manufactured from bioplastics [31]. Additionally, transition from a single-use linear to a multi-use circular economy is necessary to contribute to a greener planet [32]. And most importantly, we should create awareness, inform ourselves, and lobby for sustainable waste management programs.

One of the relevant negative effects in the environment is the excessive use of paper, as its production includes deforestation, the use of enormous amounts of energy and water as well as air pollution, and waste problems. Consequently, it is crucial to implement policies promoting the transition of neuroradiological departments to a paperless system by utilizing electronic records and avoiding the printing of electronic materials such as scientific articles, radiological requests and reports, and emails. In instances where paper usage is unavoidable, it is recommended to employ 100% postconsumer recycled paper, opt for double-sided copies to reduce paper consumption, and facilitate the recycling of used paper through selective segregation.

5. Helium consumption

Helium (He) is a rare and strategic material, used as a cooling agent in aerospace industries and in various scientific and medical applications, including cooling of superconductive MRI magnets, which represents 20% of total helium consumption [33, 34]. Currently, the main source of He is the exploitation of natural gas. The USA has historically been the world's largest producer of helium, although other countries with large natural gas fields, such as Qatar, Algeria, and Russia, have significant helium reserves.

This element is a non-renewable, strategic resource that is becoming more expensive and scarcer, and its use and extraction have raised environmental concerns [35]. All these facts have prompted the need to explore ways to improve conservation practices and achieve a more efficient utilization of He, particularly as a cooling agent required to maintain the superconducting state of MRI systems.

Several strategies should be considered to reduce He usage in MRI systems:

- Regular maintenance and inspections: Implementation of strict regular inspections and preventive maintenance can help identify and fix any potential He leaks promptly. The use of specialized software with alarms that monitors and manages the He levels and consumption in real time can help in the prompt identification of He leaks.
- Educate and train staff: It is important to train MRI technicians about the importance of He conservation and the proper procedures to follow. This can include guidelines on reporting anomalies and handling emergency situations.
- Reduced active MRI scans time periods: Optimizing scanning protocols and procedures can help reduce the

Table 5 Waste management; action to reduce its environmental impact in medical practice (Adapted from reference 26)

Reduce
• Paperless practice: avoid printing of scientific articles, radiological reports, and e-mails
• Purchase durable, upgradable equipment where possible
• Buy equipment and drugs in bulk
• Adequate stock management
• Use rechargeable batteries and refillable ink cartridges
• Fill sharps bins full before disposal
• Use small aperture sharps bins
• Use large waste receptacles
• Unpack equipment only when it is needed
• Consider whether equipment is actually needed
• Keep ward and theatre temperature to a safe minimum
• Turn off electronic equipment that is not being used
• Avoid the use of nitrous oxide
• Avoid plastic bags for collecting dry waste
Reuse
• Use postconsumer recycled paper and paper products
• Use unpackaged but unused equipment if it is safe to do so
• Consider reusing devices with low risk of passing infection (e.g., calf compressors)
• Drink from China cups not plastic disposable cups
• Consider using washable sharps bins and waste containers, emptied into a central hospital collection point
• Consider schemes where companies collect and refill used receptacles
Recycle
• Segregate potential recyclable material—cardboard, paper, plastic, glass
• Consult waste recycling firms about recycling waste, identifying hospital areas for compaction and collection
Rethink
• Redesign the ergonomics in clinical areas so that it is easier to recycle than to dispose
• Ask supply managers to preferentially tender drug and equipment contracts based on companies' environmental credentials
• Engage with hospital managers to develop greener waste management policies
• Organise staff training on waste management
• Take responsibility for the contents of recyclable waste

time MRI machines are in operation, thereby reducing He consumption.

- Incorporation of advanced cryogen technologies:

  Improved cryogenic systems: Use more efficient and optimized cryogenic systems that require a minimum amount (few litres as opposed to 900–1500 for a standard MRI system) of He for cooling (cryogen-free systems) while maintaining optimal performance. This technology eliminates He refills costs, reduces the risk of He loss due to leaks, and reduces potential long interruptions to MR services due to He issues. As no liquid helium can escape, these magnets do not need a vent pipe, significantly reducing construction costs. However, there are still few commercialized He-free systems on the market and limited to field strengths up to 1.5 T, and they cost more than traditional systems, which limits their full potential for adoption. When adopting He-free MRI technology, it is crucial to provide training to technicians and operators on the new system's operation, maintenance, and safety protocols.

  Quench Recovery Systems: Implement quench recovery systems that recapture and recondense the He for its reuse.

  Closed-Cycle Systems: Closed-cycle cryogenic systems aim to minimize the loss of He gas by recirculating and reusing the He gas within the system making it available for reuse in the MRI machine's cooling system.

It is important to check the utilization of this advanced cryogen technologies when acquiring new MRI systems, which eliminate the need for frequent He refills and minimize He-related maintenance, and to evaluate different manufacturers and models to find the system that best fits your facility's needs in terms of image quality, performance, and cost-effectiveness.

By implementing these strategies, healthcare facilities and MRI centres can significantly contribute in significant cost savings over the lifetime of the equipment, and in reduction of He environmental impact.

6. Contrast media footprint/saving in neuroradiology

Gadolinium-based contrast agents (GBCA) and iodine-based contrast media (IBCM) are broadly used for contrast resolution of MRI signal and CT attenuation, respectively, and their use is leading to widespread contamination of freshwater and drinking water systems [36, 37].

ICM represent up to 80% of the total pharmaceutical effluent of a hospital [38] and, due to their high ionic strength and osmolality, are highly resistant to biodegradation [39]. IBCM themselves are not lethal, as iodine is naturally present in the sea or in drinking water, but when they react with common disinfectants used in water treatment plants, they inadvertently generate harmful byproducts that contaminate sources of drinking water with toxic and mutagenic effects [40].

GBCAs are also not eliminated by wastewater treatment processes due to their high stability and are released into hydrosystems, where they do not seem to be altered by environmental processes (e.g., degradation, sorption) [41, 42]. Since these contrast agents demonstrate conservative behavior in estuaries [43] they can be transported to the ocean without being degraded. In Europe, a flux model study of the anthropogenic gadolinium for the four European seaboards estimated 12.2 tons per year in 2015 [44]. Nowadays, this figure is likely to be substantially higher, given that total GBCA consumption has increased by approximately 80% in the last 8 years, as a consequence of a progressive increase of the number of MRIs performed [45]. Gadolinium can accumulate in living organisms, particularly in aquatic environments, where it can impair the normal functioning of organisms and ecosystems [45]. It can also enter the food chain and potentially affect higher-level predators, including humans. The long-term effects of gadolinium in the environment are still a subject of ongoing research and are therefore crucial to monitor and assess its impact as more data becomes available.

Neuroradiology currently is the medical field with the highest impact on the production and use of GBCA, covering an estimated 40% of the about 750 million doses intravenously administered worldwide since 1988 [46]. According to these estimates, more than 20 million doses are prescribed every year for brain and spine enhanced MRI globally. These numbers are even expected to increase based on the expansion of the MRI scanners market and the facilitated access of patients to MRI [45].

The above-mentioned environmental impact of contrast media requires the implementation of strategies to reduce it. Industry and academy are working together to achieve this goal. In a vision of greening neuroradiology for decreasing contrast media footprint, the best approaches for sustainability are: (A) increase in appropriateness of contrast media use [23, 47]; (B) reduction of administered contrast media with the support of deep-learning algorithms [48] and/or dose optimization of high-relaxivity and high stability GBCA compounds [49, 50]; and (C) implementing recovery circuits of used/unused GBCA and IBCM (collection of post-examination patients' urine to recover rapidly eliminated contrast media fractions and recycling contrast media leftovers found at the bottom of used bottles) [40, 51–54].

It must be acknowledged that the biological fate of contrast media is not completely explored and there is absence of clinical consequences of bio-accumulation in human tissues. Nevertheless, the trend towards an increase of environmental contamination with anthropogenic contrast media paves the way to downstream approaches beyond neuroradiology practice such as specific removal from sewage waters and/or phytoremediation.

Promotion of ecological neuroradiology practices

The objective of ecologic practice is to reduce the environmental impact that the lifestyle of staff and patients has on the practice of neuroradiology and, by applying the adage "think globally act locally", carry out small-scale actions that have a global impact. The following actions may impact in a better ecologic practice of neuroradiology:

- Implement teleradiology—teleworking. It is the most widely used service in telemedicine, and if it respects the guidelines of good practice codes it is an excellent tool [55], which has demonstrated to reduce the carbon footprint of healthcare, primarily by reducing emissions related to transportation [56].

However, these advantages must be weighed against significant disadvantages, such as the potential for reduced visibility of radiologists to referring physicians, diminished engagement, feelings of inequity, and negative impacts on education and mentorships [57].

- Organize scientific meetings that include an "online" format. In-person events have a significant environmental impact due to participant travel, accommodation, and meals. As an example, organizing the annual Radiological Society of North America (RSNA) Congress is equivalent to the average annual carbon footprint of 1308 US households [58, 59]. Holding virtual events significantly reduces the environmental impact, and it is advisable to use a green meeting checklist (Table 6) [60].

- Promote sustainable mobility and use alternative modes of transportation. The daily transportation of professionals has a significant impact on GHG emissions. A recent study has shown that staff transportation accounted for 2.23% of the volume of GHG generated by a hospital-based interventional radiology department [61]. The use of public transport, less polluting shared vehicles, bicycles, and walking should be promoted [32] and generate a collective awareness about having cleaner air and less congested roads/streets.

Interventional neuroradiology

In addition to the high use of HVAC systems in the interventional neuroradiology (INR) suites, which represent a major contributor to total energy consumption in radiological departments, improper management of waste products generated in INR suites is a major issue. Operating theatres (OT), in general, contributes disproportionately to total hospital waste (representing up to 20%), and INR suites are not an exception [62]. As the volume and complexity of interventional procedures increase, waste increases exponentially with an average of 8 kg of waste per case [63]. Although waste can be sorted into different categories based

Table 6 Checklist for a sustainable and carbon–neutral event

Planning
• Appoint a person in charge to plan and ensure the ecological compliance of the event
• Establish a green purchasing policy in compliance with ecological requirements
• Use signs that can be reused in future events
• Provide reusable name badges and collect them after the event
• Use promotional items made of recycled material that are durable and reusable
• Paperless event. Provide only documents online—email
• Plastic-free event
Accommodation and venue selection
• Give preference to hotels and venues with a Green Key certificate*
• Carry out a visit to the hotel and venue to verify that the criteria are met
Transportation
• Choose a hotel/venue that is within walking distance or at least accessible by public transportation
• Provide information about public transport
• Provide attendees with public transportation passes
• If bus transportation is needed, use vehicles that consume less energy and have a reduced emission of greenhouse gases (CO_2)
• Provide bicycles for short-distance transportation
• Provide shuttle service from hotels to the event site
• Establish a carbon neutral initiative to offset the CO_2 emissions derived from the event
Catering
• Minimize the use of disposable products
• Prioritize organic meals and snacks that are seasonal and locally available
• Offer tap water instead of bottled water
• Require attendees to register for meals (reduces food waste and costs)
• Manage recycling and waste management. Donate excess food to charitable organizations
Information and participation
• Make informative brochures showing attendees the green meeting policy
Participation
• Allow attendees to promote their own green initiatives

*The Green Key certificate is the leading standard of excellence in the field of environmental responsibility and sustainable management within the tourism industry

Table prepared based on information from: Sustainable meeting checklist de EUROSAI, Website https://www.eurosai.org/handle404?exporturi=/export/sites/eurosai/.content/documents/Sustainable-meeting-checklist.pdf */ United Nations sustainability, website* www.greeningtheblue.org */ United States Environmental Protection. Agency It's Easy Being Green! A Guide to Planning and Conducting Environmentally Aware Meetings and Events, Web site 10000MUU.PDF (epa.gov)* on its segregation management (general, clinical, sharps, cytotoxic, and radioactive waste), it has been shown that most hospitals do not segregate waste properly at the point of generation (high proportion of general waste, which is potentially recyclable, is incorrectly disposed of as clinical waste) [64–66]. This improper waste segregation markedly raises the cost, as it increases the amount of waste wrongly classified as clinical that requires expensive high energy processing [62, 67].

Lack of awareness and expertise about waste management and sorting complacency and the pace of work are some of the factors that lead to poor waste management.

In addition to providing physicians, radiographers, and nurses with the required education regarding the significance of effective waste management, professionals can benefit from waste management guidelines to assist them towards more sustainable interventions [68, 69]. Other strategies address suboptimal waste practices, such as increasing the number of bins for both clinical and general waste, and separating waste in the suite itself produced prior to a patient entering the INR suite, from waste produced during the procedure, as this reduces medical waste by 50% [57, 69]. Containers should be located close to the place where waste is generated and labelled with the different types of waste to be deposited in them [70].

Excessive plastic packaging, the opening of unnecessary material that is ultimately not used, and the amount of single-use material that needs to be disposed after the intervention is over are other factors that must be considered to reduce waste generation.

To accommodate the diversity of procedures carried out daily in an INR suite, a broad range of inventory is required. Even while certain inventory may only be utilized once a year or less, it must still be available in case it is needed for a procedure, especially if it might be needed in the emergency setting. The "first in, first out" strategy, consignment schemes, or agreements with vendors to rotate out items before expiration are a few examples of programs that can be used to mitigate losses connected with outdated inventory [71].

Other actions, such as reducing water consumption by using hydroalcoholic gel between interventions, using LED lights, turning off systems when not in use and during scheduled rest periods, and using recyclable material, contribute to the maintenance of green radiology in INR suites.

European and world initiatives for Green Radiology

Some of the existing initiatives are described below, without intending to be exhaustive. It is important to highlight that more and more institutions and professionals are becoming aware of this issue and are implementing sustainable practices in their daily work. These initiatives have the following goals: create collaborative structures and support networks, share and disseminate best practices, raise awareness, and educate.

1. Coalitions of institutions and hospitals.
    - Sustainable Radiology from the University of California [72]. Formed by six hospital systems. Areas of improvement include clean electricity, energy efficiency, waste reduction, water conservation, and sustainable food procurement.
    - Global Green and Healthy Hospitals (GGHH) [73]. An association that connects professionals worldwide, offering its members programs in the field.
2. Certification of green hospitals, such as the "World Health Organization (WHO) Green Health Partnerships program", which includes criteria such as radiation dose reduction and proper management of radioactive waste [74].
3. Operational framework for building climate resilient and low carbon health systems (World Health Organization 2023). This document presents an operational framework for building climate resilient and low carbon health systems, and provides guidance on how the health sector can systematically and effectively address the challenges increasingly presented by climate change, while reducing its own contribution to climate change [75].
4. Radiologist networks. They are raising awareness about the environmental impact of radiology and promoting a more sustainable future.
    - Radiologists for a Sustainable Future (R4SF). An active social network on X (@Rads4SF).
    - University of California Sustainable Radiology Collaborative group [22]. The mission of this group formed by five University of California (UC) hospital systems 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.
5. International and national radiological societies.
    - European Society of Radiology (ESR) [76]. It launched its Green Radiology Program in 2014, with the aim of promoting sustainability in radiological practice by creating guidelines and recommendations, promoting research and developing assessment tools.
    - International Society of Radiology (ISR) [77]. In 2019, it launched a commitment to sustainability in radiological practice, including the promotion of

education, research, and collaboration, as well as the implementation of practices that reduce the environmental impact of radiology.
- French Society of Radiology (SFR). It has published a white paper Radiology and Eco-responsibility. On the way to Green Radiology [78].
- European Society of Neuroradiology (ESNR) (www.esnr.org) has recently created a "Green Committee" with the objective to inform and educate neuroradiologists about their responsibilities for creating a greener world, and to propose some actions that reduce the generated carbon footprint, with the final objective of creating neuroradiological departments more environmentally friendly.

6. European initiatives to recycle used/non used contrast media

- MEGADORE (Medical Gadolinium Recycling): The aim of this industrial university chair, supported since 2021 by the UBO Foundation (Université de Bretagne Occidentale) with partnership of Guerbet, Bracco, Imadis and Crédit Mutuel Arkea, is to recover the funds from syringes of GBCA not injected into the patient and introduce them into a recycling process [79].
- Re-Contrast: This is a contrast recycling program from Bayer that allows to recover and recycle the client's leftover IBCM and GBCA [80].
- Iodine-recycling program: This is a contrast recycling program, sponsored by General Electric, running in Europe and North America that allows to recover and recycle the client's leftover IBCM [81]
- Guerbet has a contrast recycling program that allows to recover and recycle in France the client's leftover IBCM [82].
- GREENWATER (reducinG contRast agEnts' rEsiduals iN hospital WAstewaTER): this pilot project, which had a span of one year, and received unconditional funding from Bracco, aimed to track the amount of retrievable IBCM and GBCA in urine collected within an hour of their intravenous administration from outpatients who received a contrast-enhanced CT or MRI [54].
- German project to discharge ICM into the environment: this pilot project established a set of measures (installation of specific separation toilets, establishment of feedback systems, interviews, questionnaires, and observation) implemented to sensitize outpatients and staff to the environmental impact of IBCM and evaluated the acceptance of retention and recovery systems [83]. These measures had a high acceptance among staff and patients, but are likely to be of high value only if patients stay on site for a correspondingly long time, after contrast-enhanced CT examination.

Conclusion

The healthcare sector is a resource-intensive industry, consuming significant amounts of water and energy, and producing a lot of waste. All radiological specialities need to be aware of the fact that radiology practice is estimated to be a major contributor to this unfavourable environmental effect. Neuroradiology is probably the radiological subspecialty with the greatest environmental impact, as it accounts for a significant proportion of all diagnostic and interventional radiological procedures performed, most of them using high energy-intensive equipment. Because of this, neuroradiologists and neuroradiological departments have a special responsibility in implement decisions and initiatives that lessen the unfavourable environmental effects directly or indirectly related with their practice. These actions are required to maintain the environment's health and ensure a sustainable future for generations to come.

Declarations

Conflict of interest • Àlex Rovira has received speaker honoraria from Bayer and Bracco. He is member of the ESMRMB-GREC Working Group whose yearly meetings have received unconditional support from Bayer Healthcare, Bracco Imaging, GE HealthCare, and Guerbet.

• Douraied Ben Salem is chief editor of Journal of Neuroradiology and head of the industrial* university** chair "MEGADORE" (MEdical GADOlinium REcycling).* Guerbet, Bracco, Imadis, Crédit Mutuel Arkea;**UBO Foundation (Université de Bretagne Occidentale)
• Carlo Cosimo Quattrocchi has signed speaker contracts with Bayer Healthcare, Bracco Imaging, and Guerbet. He is co-chair of the ESMRMB-GREC Working Group whose yearly meetings have received unconditional support from Bayer Healthcare, Bracco Imaging, GE HealthCare, and Guerbet. He is member of the ESUR-CMSC whose 2-yearly meetings have received support from Bayer Healthcare, Bracco Imaging, GE HealthCare, and Guerbet.
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