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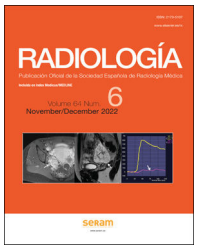

UPDATE IN RADIOLOGY

Green radiology: How to develop sustainable radiology

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Abstract The phenomenon of global warming due to the increased emission of greenhouse gases makes it necessary to raise public awareness about the importance of promoting sustainable practices. The field of radiology is not an exception, as it consumes a large amount of energy and resources to operate equipment and generate images. Green radiology is a sustainable, innovative, and responsible approach in radiology practice that focuses on minimizing the negative environmental effects of the technologies and procedures used in radiology. Its primary goal is to reduce the carbon, water and ecological footprint in our services based on four strategic pillars: decreasing energy, water, and helium usage; properly recycling and/or disposing of waste and residues (including contrast media); minimizing the environmental impact of ionizing radiation; and promoting eco-friendly radiology practices.

PALABRAS CLAVE
Radiología;
Desarrollo sostenible;
Eliminación de residuos médicos;
Cambio climático;
Ecología;
Huella de carbono;
Reciclaje;
Calentamiento global

Green radiology: cómo desarrollar una radiología sostenible

Resumen El fenómeno del calentamiento global debido al aumento de emisión de gases de efecto invernadero, hace necesario concienciar a la población sobre la importancia de fomentar prácticas sostenibles. El ámbito de la radiología no es una excepción, ya que utiliza gran cantidad de energía y recursos para poner en funcionamiento los equipos y generar imágenes. La radiología verde es un enfoque sostenible, innovador y responsable en la práctica radiológica que se centra en minimizar el impacto ambiental de las tecnologías y procesos utilizados en la radiología. Su objetivo primario es reducir la huella de carbono, hídrica y ecológica en nuestros servicios en base a cuatro ejes estratégicos: disminuir el uso de energía, agua y helio;

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reciclar y/o eliminar adecuadamente los desechos y residuos (incluidos los medios de contraste); reducir el impacto ambiental de las radiaciones ionizantes y promocionar prácticas de radiología ecológicas.

Introduction

Human activity is the principle driver of greenhouse gases (GHGs) emitted into the atmosphere. The progressive increase of these gases as a result of activities such as electricity use, deforestation, fossil fuel consumption and the destruction of ecosystems has contributed to the increase in global temperature, which in 2022 was 0.89 centigrade higher than average for the NASA reference period. The last nine years have been the hottest since records began in 1880, and this trend seems set to continue.[1]

The United Nations first reported on the adverse effects caused by climate change in 1992[2] and there is scientific evidence as to the impact it has on public health.[3] It is estimated that GHG emissions originating from the health service constituted 8% of the United States's total emissions in 2007.[4] Healthcare emissions in the United States increased 6% between 2010 and 2018 and the country is the largest contributor of healthcare emissions among industrialised nations.[5] Of these emissions, those derived from hospital care, medical and clinical services and medical prescriptions are the greatest contributors.[6]

Since the concept of 'think globally, act locally', attributed to Patrick Geddes, was conceived in the early 20th century,[7] people have been urged to consider the health of the planet by taking small actions in their own communities that have a global impact. More and more health professionals are adopting greener practices, and radiology is no exception. The change in mindset is slow, but there are now a multitude of initiatives promoting sustainable practices and hospitals seeking certification for leadership in energy savings, renewable energy use and environmental design.

Green radiology refers to the practice of radiology with a focus on environmental sustainability and the reduction of waste derived from our daily activities. Radiology uses a great deal of energy and resources to operate equipment and produce images. The equipment itself and the chemicals and drugs involved in the production of radiological studies are harmful to the environment and need to be managed properly and safely, to minimise the pollution they cause.[8] Green radiology is not only necessary to preserve the environment, but can also reduce costs in health services.[9]

This article aims to raise radiologists' awareness of their responsibilities in creating a greener world and to analyse the most effective strategic pillars, objectives and lines of action that contribute to reducing the environmental impact of radiology departments.

Concept and basic principles of green radiology

A green radiology department is a healthcare facility for which a central part of its mission (Fig. 1) is to continuously reduce its environmental impact, comply with applicable environmental regulations and establish concrete lines of action to reduce its environmental, carbon and water footprint (Fig. 2).[10]

The green radiology approach is based on four principles and strategic pillars:

- Reduce the use of energy and other resources such as water and chemicals.
- Recycle and/or properly dispose of waste.
- Reduce the environmental impact of ionising radiation.
- Promote environmentally friendly radiology practices.

Strategic pillars

Reduce the use of energy and other resources (water and chemicals)

We have limited resources available and energy efficiency, the optimisation of water consumption and reduction of chemical product usage should be central to all activities.

Reduce energy consumption

The objective of energy efficiency is to use less energy to provide the same service.

Radiological images represent 4% of a hospital's total energy consumption.[11] Over the course of one year four MRI and three CT scanners consume enough energy to power a village of 852 people in Switzerland.[12]

The following measures should be taken:

a. Manage the life cycle of radiology equipment from a green radiology perspective in all phases (Fig. 3).
   - *In phase one: definition of need.* Here we should introduce the concept of 'green purchasing'[13] based on incorporating environmental requirements and specifications into the supply, works and service contract decision-making process. Energy efficiency optimisation, reusable product and renewable energy use, emission minimisation and proper waste management are all factors to consider.
   - *In phase two: acquisition.* Prioritise the use of energy efficient radiology equipment. New equipment is designed to use less energy and to be more efficient.[14]

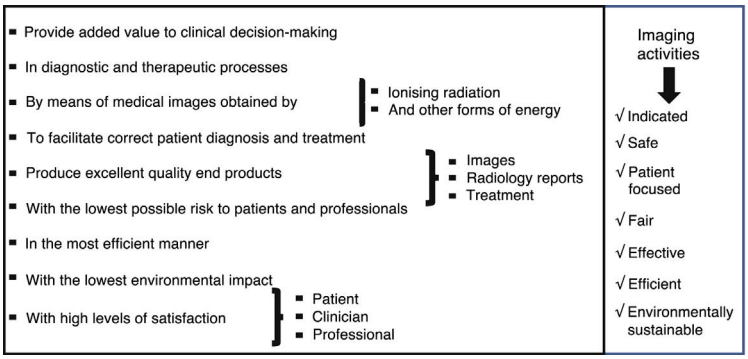

Figure 1 Outline of a radiology department mission.

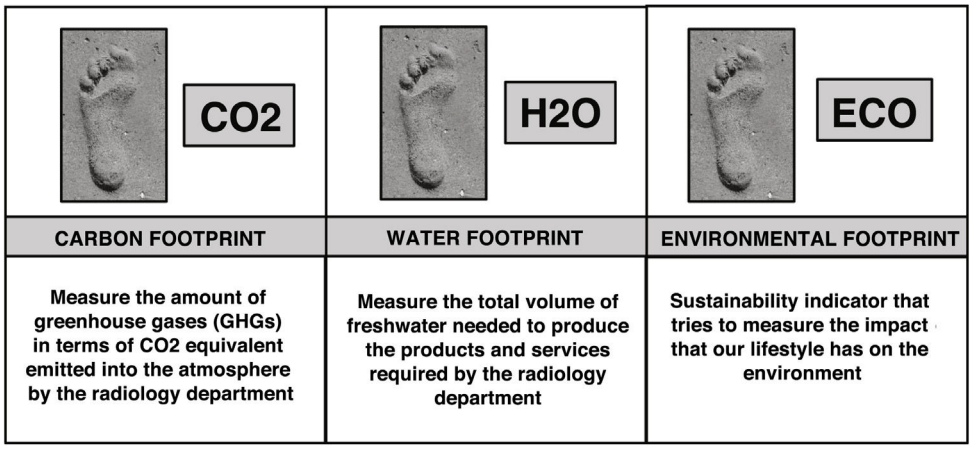

Figure 2 A radiology department's carbon, water and environmental footprint.

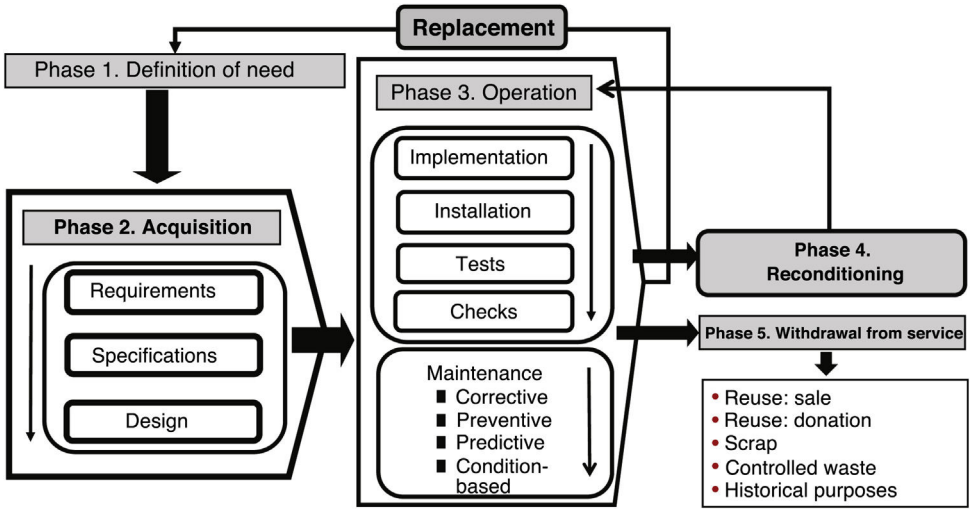

Figure 3 Life cycle of radiology equipment.

Prior consideration should be given to the way the modality will be used to adapt the equipment to the requirements of the centre, as advanced imaging technologies are more energy intensive: a 3.0 Tesla (T) MRI scanner consumes more energy than a 1.5 Tone, and a 256-cut CT scanner consumes more than a 64-cut one.[12] One study showed that, in terms of energy consumption and polluting emissions, ultrasound had a comparatively lower environmental impact to produce and use than CT and MRI.[15]

- *In phase three: operation.* Regular maintenance of equipment reduces the need to replace costly parts, prolongs the useful life of machines and improves equipment efficiency, reducing energy consumption.[16]

- *In phase four: reconditioning*. Equipment manufacturers and radiologists can explore equipment reconditioning. This is an environmentally friendly option which follows the principle of recycling and reuse.[17]
- *In phase five: equipment withdrawal from service*. When equipment can no longer be reconditioned for reuse, it should be decommissioned according to current legislation, particularly in relation to ionising radiation.[18] The World Health Organisation has published guidelines on equipment donation.[19]

b. Turn off radiological equipment, computers and workstations that are not being used.[20–26]

It is estimated that in Europe in 2020 49 terawatt hours (TWh) were lost by failing to turn radiology equipment off. Over the course of a year, thirty-two workstations consume 53,000 kilowatt hours (kWh): the equivalent of 100 barrels of oil. It is calculated that turning computers off after use could save 45% of this energy.[11] Two thirds of the energy used by a CT scanner is consumed while the system is idle. For MRI, one third of the energy consumption is attributed to machines not being turned off.[12]

It is vital to check that equipment is completely turned off at the end of the working day and not left on standby or idle.[21,23,24] This measure applies to computers and workstations used by health and administrative personnel as well as imaging modalities (CT, MRI, ultrasound).

c. Use of motion sensor lights and light emitting diode (LED) bulbs.

Hospital lighting design needs to find a balance between performance, comfort and energy efficiency.[27] Motion sensor lighting and LED bulbs can significantly reduce energy consumption.[28,29]

d. Heating, ventilation and air conditioning systems control.

Heating, ventilation and air conditioning (HVAC) in radiology departments are a significant source of energy consumption. To remain in working order, the majority of radiology equipment must be kept at a constant temperature maintained by HVAC systems. Cooling systems are responsible for nearly 50% of total energy consumption, and approximately two thirds of energy is consumed while the system is inactive.[20] Interventional radiology generates substantial volumes of GHGs, the majority of which originate from energy used to maintain climate control.[30] Leaving workstations on standby produces excess heat that can increase HVAC use and therefore energy consumption as the system attempts to maintain working temperatures.[8]

Reducing water use

Water resources are becoming increasingly scarce.

Water consumption can be reduced by replacing surgical handwashing with alcohol-based hand disinfectants and using water-saving tap designs (pedal operated, motion sensor, high flow elbow-operated lever taps, etc.).[31]

Reducing chemical product use: helium usage

In MRI, reducing or eliminating cryogenic liquid helium as a non-renewable resource can have a positive impact.[32] New MRI scanners now use practically no helium or at least have minimal need for refills.[33]

Recycle and/or properly dispose of waste

The terms 'residuals' or 'residual waste' are used to describe residual materials that are deemed to have no further use. These are differentiated from 'reusable or recyclable waste' identified as materials that may be reused or recycled. Following the rule of the three 'R's (reduce, reuse, recycle), it is possible to make small local changes which have a global impact.

Recommended courses of action:

Encourage the use of reusable materials

Encourage the use of reusable materials, such as lead shields or aprons. Single-use products are much more polluting (use of petrochemicals and GHG global emissions).[34]

Reduce or eliminate materials

Reduce or eliminate non-reusable materials, such as plastic bags. In the case of Spain, there is a legal requirement to do so as regards plastic bags.[35]

Use biodegradable materials

A radiology department can get through hundreds of cups a day and it is recommended that departments use ones made of a bioplastic (cornstarch) instead of conventional cups made of polystyrene foam, plastic or even paper.[36]

Reduce paper use

The use and consumption of paper and cardboard have continued to increase in recent years. In Spain, the average use of paper has gone from 116 kg annually per inhabitant at the beginning of the nineties to 175 kg per inhabitant now.[37] In the digital world, all health centres and departments must work towards replacing paper requests and reports with purely digital communication.[8]

Appropriate waste separation

This means appropriately labelled recycling bins must be placed outside every radiology room and all staff areas so that biodegradable waste can be collected separately. Currently 14 autonomous regions in Spain have implemented the appropriate legislation to regulate this.[38] Eliminating vascular and interventional radiology-related waste is critical because it constitutes a significant proportion of the waste produced.[31] This is worthy of a detailed study beyond the scope of this publication.

Waste derived from the dismantling of ionising radiation-emitting modalities should be managed safely and appropriately, in adherence to all current standards and regulations.[18]

Table 1 Radiation protection standards for green radiology: environmental factors.

Standards	Environmental Factors
Royal Decree 1085/2009, of 3 July, which **regulates the installation and use of X-ray** machines for medical purposes.[18]	It regulates: - Radiation protection programme (PPR) - Legal aspects of the lifecycle of imaging equipment
Real Decreto 1976/1999, of 23 December, which establishes **quality criteria in diagnostic radiology**.[48]	It regulates: - Quality control programme (PGC) - Patient dose indicator - Repeat rate indicator
Real Decreto 601/2019, of 18 October, on the **justification and optimisation of the use of ionising radiation** for the protection of people exposed to radiation in medical settings.[49] This is the partial transposition of Council Directive 2013/59/EURATOM.[50]	It regulates the principles of: - Justification - Optimisation - Dose control: diagnostic reference levels (DRL) - Dose limitation
Real Decreto 1029/2022, of 20 December, which establishes regulation to protect patient health against the dangers arising from exposure to ionising radiation.[51] This is the partial transposition of Council Directive 2013/59/EURATOM.[50]	It regulates: - Patient dose indicator - Exposed professionals dose indicator

Reduction and management of pharmaceutical products: contrast media (particularly compounds containing gadolinium)

The aim is to reduce the contamination of water sources and soils with trace gadolinium and iodinated contrast media.

- Gadolinium

The use of gadolinium-based contrast agents causes the pollution of freshwater, drinking and irrigation water systems.[39] In a study conducted across six German cities, traces of this element were found in Coca-Cola soft drinks bought in well-known fast-food chains.[40] Gadolinium pollution is directly linked to increases in the numbers of MRI performed. It is estimated that each MRI scanner uses 2.7 kg of gadolinium per year.[41]

Fifteen per cent of gadolinium-based contrast agents (by volume) contained in syringes are not used and end up being thrown away. This is the equivalent of two tanker trucks per year. Additionally, 85% of the gadolinium present in contrast media, which is excreted in urine, ends up in the environment (rivers, groundwater, oceans).[11,42,43]

Recommended courses of action are: limit its prescription, limit the volume of contrast used, recycle unused doses, replace prefilled syringes with bulk containers (respecting hygiene protocols) and implement systems to collect patient urine.[11,41]

- Iodine

The presence of iodinated contrast media and their biotransformation products in the urban water cycle has been documented.[44] The introduction of these products into the water cycle and their transformation into toxic by-products presents a potential long-term risk to living organisms.[45] These products represent up to 80% of the total pharmaceutical waste produced by a hospital.[46] The majority of the recommendations for gadolinium also apply to iodinated contrast media.[11,47]

Reduce the environmental impact of ionising radiation

The correct application of the principles of radiation protection is not only a cornerstone of our specialty, it also undoubtedly has an environmental impact and the proper management of radiation contributes to green radiology. Radiology involving ionising radiation (alongside with radiotherapy and nuclear medicine) is subject to more regulations than any other medical procedure. Table 1 sets out the main radiation protection standards,[18,48–51] with actions and indicators that have environmental impact.

- *Principle of justification*. Only indicated procedures should be performed to help to reduce the carbon footprint (energy saving) and water footprint (iodinated contrast media). The results of a recent review article[52] show that 40% of CT and 44% of plain radiography procedures were not justified, and a national audit in Luxembourg on the appropriateness of CT testing revealed that 30% of requests were not justified.[53] CT is known to be the main artificial source of radiation to which people are exposed[54,55] and efforts to apply the justification principle should focus particularly on this type of request.
- *Principle of optimisation*.[56] The application of the ALARA (As Low As Reasonably Achievable) principle, while guaranteeing image quality, also reduces the amount of exposure (energy) necessary at the same time as avoiding repeat radiographies. It is important to note that collecting data on 'rejection rate or image repetition' and 'image quality' indicators is a legal requirement in Spain covered by Real Decreto 1976/1999 on quality.[48]

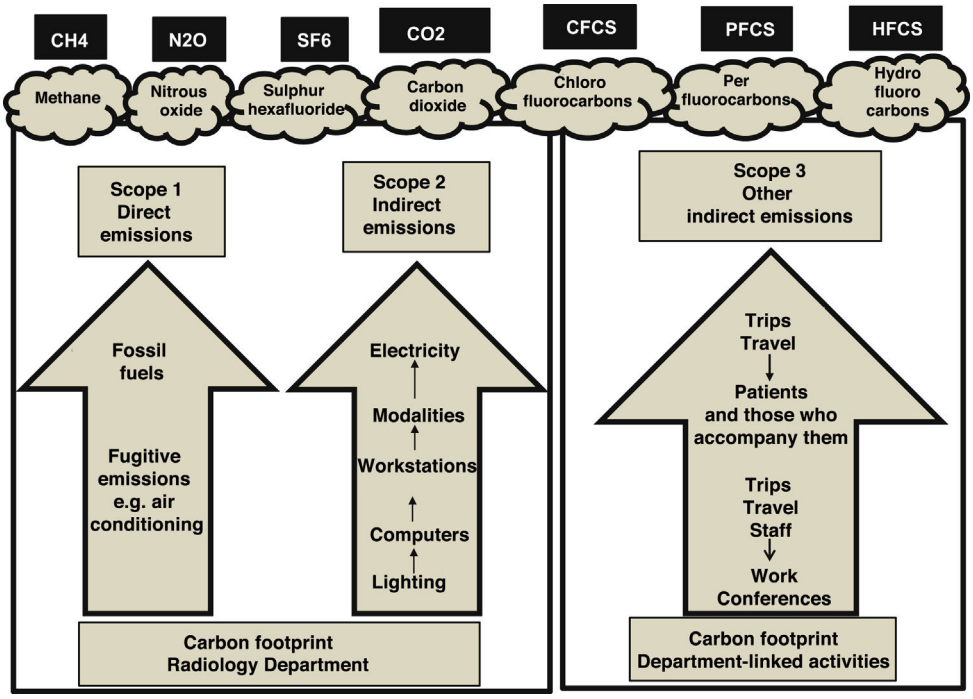

Figure 4 Calculation of the carbon footprint in a radiology department.

- *Interventions during the equipment's life cycle*. The appropriate management of equipment obsolescence and renewal[57] also contributes to equipment efficiency and reduces their carbon footprint. More modern equipment, as well as reducing energy consumption, also reduces radiation emissions.[20]
- *Staff training*. Health authorities, in particular the Autonomous Community Health Departments, should train prescribing physicians, radiologists and technicians[58] in the application of these principles and knowledge of current legislation relating to patient radiation protection.

Promoting environmentally friendly radiology practices

This involves encouraging practices in which radiologists can gain a new understanding and appreciation for the aspects of their work that could make it more sustainable.[59]

- *Staff training*. Professionals should be aware of the importance of environmental sustainability and how they can implement environmentally friendly practices in radiology.
- *Promote environmental awareness among patients*. Patients should be educated on the importance of these practices, indicating how they can collaborate to reduce waste and carbon emissions. There are education programmes for the general public about how they can collaborate to promote environmental sustainability.[60]
- *Encourage teleradiology*. Aims to reduce travel which in turn reduces the carbon footprint.[61] The COVID-19 pandemic spurred advances in teleradiology, which had a positive environmental impact during the months of lockdown.[62]
- *Organise medical courses/conferences which include an online element*. Medical courses and conferences are another source of carbon emissions because of participants' travel, accommodation and meals, making it possible for people to attend online would reduce the environmental impact of these events. The carbon footprint can be reduced by minimising the materials used and ensuring they are biodegradable (recyclable cups, reduce printed advertising).[8]
- *Encourage sustainable travel*. Promote the use of public transport, car sharing, bicycles, walking to get around, and build a collective consciousness that prioritises cleaner air, less congested roads, fewer accidents and less sedentary workers.[63]

Continual improvement and indicators

If we follow the aphorism, 'What you don't measure you can't understand, what you don't understand you can't manage, and what you don't manage you can't improve', a system of indicators and environmental management should be implemented that is capable of measuring resource management efficiency, monitor environmental indicators and evaluate the objectives proposed.

Carbon footprint

The carbon footprint is an indicator of the amount of GHGs in terms of CO_2 equivalent emitted into the atmosphere by an individual, organisation, process or event in a specific timeframe. Fig. 4 illustrates the type and scope of emissions. This calculation is used to estimate environmental impact

Table 2 Environmental indicators in Radiology I.

Indicator name	Algorithm or numerical data	Units	Sector	Source of information	Period
Pillar 1. Reduce consumption of energy and other resources					
Green purchasing criteria	(No. of dossiers with green purchasing requirements/total no. of dossiers) × 100)	%	Purchasing contracts	Tender dossiers	Annual
Preventive maintenance	(No. of contracts which include preventive maintenance/total no. of contracts for workstations and modalities) × 100	%	Purchasing contracts	Tender dossiers	Annual
Predictive or condition-based maintenance	(No. of contracts with predictive or condition-based maintenance/total no. of contracts for workstations and modalities) × 100	%	Purchasing contracts	Tender dossiers	Annual
Total electricity consumption	Megawatt-hour (MWh)	MWh	Radiology department	Hospital	Annual Quarterly analysis
Turning off equipment and workstations	(No. of machines turned off/total no of machines) × 100	%	Radiology department	Monitoring at the end of morning and afternoon shift	Once a month
Water use	Cubic metre (m^3)	m^3	Radiology department	Hospital	Annual Quarterly analysis
Pillar 2. *Minimise waste*					
Production of non-hazardous waste	Tonnes of waste	Tn	Radiology department	Hospital	Annual Quarterly analysis
Amount of recyclable material collected	(kg of recyclable waste collected/kg of total ordinary waste produced) × 100	%	Radiology department	Hospital	Annual Quarterly analysis
Production of hazardous waste	kg of waste	kg	Radiology department	Hospital	Annual Quarterly analysis
Activities from integrated waste management plan performed	Number of activities performed	Number	Radiology department	Radiology department	Annual

and to identify the most significant sources of emissions, to help to evaluate reduction, compensation and/or mitigation strategies.

The carbon footprint of an organisation (e.g. a radiology department) measures all directly or indirectly emitted GHGs expressed in kilograms of CO_2 equivalent (kg CO_2e) as a result of its activities. The Spanish Ministry for a Green Transition has published a guide on how to calculate the carbon footprint for this purpose.[64]

Other indicators

Other indicators that relate to energy efficiency, waste management and environmental impact of ionising radiation and green radiology are set out in Tables 2 and 3.

Global green radiology initiatives

These projects seek to reduce the environmental impact of radiology and promote collaboration between radiologists, equipment manufacturers and health organisations.

- The International Society for Radiology (ISR) commitment to sustainability.[65] In 2019, the ISR committed to promote sustainability in radiology practice and reduce its environmental impact, including promoting education, research and collaboration, and implementation of sustainable practices in radiology.
- Certifications for green hospitals. At global level, there are various certifications for environmentally friendly hospitals. For example, the WHO *Green Health Partnerships*[66]

Table 3 Environmental indicators in radiology II.

Indicator name	Algorithm or numerical data	Units	Sector	Source of information	Period
Pillar 3. Reduce the environmental impact of ionising radiation.					
Image rejection rate	(No. of radiographs rejected/no. of radiographs performed) × 100	%	Rooms and shifts	Modalities register	Weekly
Image quality	(No. of imaging studies of acceptable quality/total no. of imaging studies) × 100	%	Type of imaging study	Biopsy	Annual
Doses to which patients are exposed	(No. of imaging studies that exceed the dose/total no. of imaging studies) × 100	%	Type of imaging study	Biopsy	Annual
Doses to which professionals are exposed	Radiation doses in mSv	mSv	Medical personnel	Official dosimetry	Annual
Pillar 4. Promote environmentally friendly radiology practices					
Activities to promote environmentally friendly radiology practices	Number of activities performed	Number	Radiology department	Radiology department	Annual
Teleradiology	(No. of imaging studies evaluated through teleradiology/total no. of imaging studies) × 100	%	Radiology department	RIS	Annual
Remote CPD	Number of activities performed	Number	Radiology department	Radiology department	Annual
Use of car sharing, bicycles or walking	Number of professionals who share a car or travel by bicycle or walking	Number	Radiology department	Radiology department	Annual

RIS: radiology information system.

includes criteria such as reducing radiation doses and proper management of radioactive waste.
- There are also hospital networks such as Global Green and Healthy Hospitals (GGHH)[67] that connect professionals around the world, offer programmes to their members on sustainable healthcare and drive initiatives that unite the health sector across the globe to tackle environmental issues.

European green radiology initiatives

In Europe, green radiology practices are being implemented to reduce the environmental impact of radiology and make it more sustainable. Here are some examples:

- European Society of Radiology (ESR).[68] The ESR launched its Green Radiology Programme in 2014. It aims to promote sustainability in radiology practices by issuing guidelines and recommendations and promoting research and development of evaluation tools.
- The University Hospital of Geneva (Switzerland). The hospital has implemented a programme which includes the use of digital imaging technologies, reducing radiation doses and implementing energy-saving measures.[69]
- The University Hospital of Copenhagen (Denmark). The hospital has implemented green radiology practices including recycling programmes, proper waste disposal, LED lighting and turning radiology equipment off when it is not being used.[70]

Spanish green radiology initiatives

Green radiology is gaining momentum in Spain, with a number of initiatives and practices underway. Some examples are:

- Multiple Spanish hospitals, including the Barcelona Hospital Clinic and the Hospital de la Paz in Madrid, have implemented different initiatives to reduce their environmental impact.[71,72]
- More efficient equipment. The modernisation of radiology equipment and replacement of obsolete models with more energy efficient alternatives has been included in number of innovation plans, such as the recent European-funded Invest in State-of-the-Art Technology (INVEAT) plan,[73] which ended in 2023. Adopting latest generation technology not only reduces the environmental impact, but can also improve image quality and reduce the radiation dose necessary.

Conclusion

Green radiology is an innovative approach to reducing the environmental impact of radiology practices. As health professionals adopt more sustainable practices, we will reduce waste and radiation emissions, promote energy efficiency and adopt more environmentally friendly practices are adopted in radiology. These efforts are necessary to maintain a healthy environment and guarantee a sustainable future for coming generations.

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Author contributions

1. Research coordinators: SL, AM, AR
2. Development of study concept: SL, AM, AR
3. Study design: SL, AM, AR
4. Data collection: SL, AM, AR
5. Data analysis and interpretation: SL, AM, AR
6. Statistical analysis: N/A
7. Literature search: SL, AM, AR
8. Writing of article: SL, AM, AR
9. Critical review of the manuscript with intellectually relevant contributions: SL, AM, AR
10. Approval of the final version: SL, AM, AR

Conflict of interests

The authors have no conflicts of interest to declare.

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