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Systematic Review

A scoping review of sustainable strategies adopted in nuclear medicine

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A B S T R A C T

Introduction: Sustainable development is an approach that must be applied to all areas within healthcare, especially those in constant technological development, such as nuclear medicine. The aim of this study was to scope the literature to identify knowledge gaps in the sustainable development of the nuclear medicine field.
Methods: The Joanna Briggs Institute methodology for scoping reviews was employed. A search strategy was conducted in PubMed, Embase, CINAHL and Web of Science in December 2024 using Mesh terms and keywords related to sustainability development and nuclear medicine. Three independent reviewers screened titles, abstracts, and full text. Four authors performed the data extraction and analysis.
Results: A total of 36 studies met the inclusion criteria. The majority originated from Spain, and most were published in 2022 and 2023. Studies were categorised by procedure type: 33.3 % focused on therapy, 9.7 % on PET imaging, 33.3 % on diagnostic and therapeutic procedures, and 18.1 % on SPECT imaging. They were also categorised by location to include research conducted in hospital settings (n = 23), non-hospital settings (n = 8), both (n = 4) or none (n = 1). Reviewed studies implemented sustainability measures across the sustainability pillars: environmental (n = 30), economic (n = 12), and social (n = 9) pillars.
Conclusion: This scoping review has highlighted the growing interest in sustainability, within the nuclear medicine field. Findings indicate that there is a strong emphasis on reducing environmental impact, with efforts such as waste minimisation, implementation of alternative discharge methods, and radionuclide extraction systems gaining popularity; however, further evidence is needed to understand the economic and social impact of nuclear medicine procedures.
Implications for practice: The scoping review identified a range of strategies focused on mitigating the adverse impact on the environment and working towards efficient economic and social resources, to foster sustainable practices in nuclear medicine.

Introduction

Sustainable development, a paradigm that harmonises economic growth, environmental impact, and social inclusion, has

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become a fundamental goal across diverse sectors. In nuclear medicine departments, where advanced technology intersects with critical healthcare services, the application of sustainable practices is both challenging and imperative.[1] This review explores the integration of sustainable development principles within nuclear medicine, emphasising the triadic pillars of environmental, economic, and social sustainability.

The environmental pillar of sustainability in nuclear medicine involves minimising the ecological footprint of diagnostic and therapeutic procedures.[2] This includes the responsible management of radioactive materials, reduction of energy consumption, and implementation of green practices in radiopharmacy and in clinical nuclear medicine settings.[3] With the inherent potential for environmental impact through radioactive waste and energy–intensive processes, nuclear medicine departments are tasked with innovating towards eco-friendly solutions without compromising patient care quality.[1]

Additionally, economic sustainability in the field of medical imaging seeks to balance cost-efficiency with high standards of healthcare delivery. It requires the optimisation of resource use, investment in durable and efficient medical technologies, and the development of cost-effective treatment protocols.[3] Economic sustainability also extends to the long-term financial viability of nuclear medicine departments, ensuring that they can continue to innovate and provide essential services amidst fluctuating healthcare budgets and economic pressures.[1]

The third pillar, involving social sustainability in nuclear medicine, focuses on ensuring equitable access to advanced medical technologies to promote a safe, healthy workplace. This pillar emphasises the importance of training and protecting healthcare workers who handle radioactive substances, and the ethical obligation to provide state-of-the-art medical care to diverse population groups.[3] It also involves community engagement and public education on the benefits and risks of nuclear medicine, addressing both patient concerns and societal perceptions.

Globally, sustainability efforts in radiology-related disciplines have primarily focused on reducing energy consumption in imaging facilities, optimising digital workflows to minimise waste, and enhancing the lifecycle management of radiological equipment.[4] In diagnostic radiology, strategies such as dose optimisation and digital archiving have gained momentum, while interventional radiology has seen initiatives aimed at reducing single-use plastics and improving procedural efficiency.[5] Despite these advances, sustainability in nuclear medicine remains relatively underexplored, highlighting a critical and timely need to address its unique environmental challenges related to radiopharmaceutical production, radioactive waste management, and energy-intensive imaging technologies. Nuclear Medicine procedures often involve a higher expenditure compared to other Radiology-related modalities, because of the added cost of manufacturing and transporting radiopharmaceuticals. In addition to this, these procedures are likely to have a more significant impact on the environment due to the potential discharge of radionuclides into the water systems.

Through a comprehensive review of published literature, this article aims to provide an overview of the available research evidence on sustainable practices currently adopted in nuclear medicine. Therefore, this scoping review is not intended to produce a summary of existing sustainable practices with the intent of changing clinical work, but rather its objective is to inform practice in order to direct future research studies. By analysing the intersection of the three main pillars of sustainability involving environmental, economic and social factors, the authors seek to present a holistic framework with all the available data on this topic, providing a map of possible sustainable operations that can be adopted in nuclear medicine and that can ultimately pave the groundwork for more in-depth research.

Methods

The methodology adopted for this review followed the Joanna Briggs Institute (JBI) criteria.[6] Structured scoping reviews effectively synthesise findings from various studies, helping to answer research questions and identify gaps in the literature.[7] The scoping review did not use any existing published research protocol, instead it followed the Population, Context and Concept (PCC) framework based on the JBI Scoping review manual.[6] By using the PCC framework there is no need to state the explicit outcomes or phenomena under investigation, however the concept being examined, which in this case is sustainable strategies adopted in nuclear medicine, needs to be well evidenced through literature. In this regard, the authors acknowledge that scoping reviews lack the rigour attributed to a systematic review since they do not critically appraise individual studies or synthesize evidence from existing research. However, they still provide a relevant overview of a diverse body of literature.[6]

Information sources: search strategy

The search strategy (*see Supplementary Material*) involved four databases: PubMed, Embase, CINAHL and Web of Science. Combinations of keywords and Medical Subject Headings (MeSH) terms related to sustainability, recycling, equipment reuse, medical waste and nuclear medicine were applied. The search was conducted in December 2024, with all recent and relevant literature on the topic being included.

The adopted PCC framework - population, Context and Concept

Within the context of nuclear medicine procedures and under the concept of sustainability, relevant studies were identified through the use of eligibility criteria involving both inclusion and exclusion measures. Additionally, studies linked to the three pillars of sustainability, and carried out as part of diagnostic examinations, radionuclide therapy examinations, management strategies or involving radiotracer production and discharge, were all included in this scoping review. Primary research articles published in English were considered. Opinion articles, scientific abstracts without full-text availability, and editorials were excluded.

Study selection

All identified studies were first uploaded to Zotero (Corporation of Digital Scholarship, Fairfax, US), where duplicates were removed following Bramer's methods.[8] The references were then transferred to Rayyan (Rayyan Systems, Cambridge, US),[9] a free online tool used for article selection and for synthesising the results while summarising the data. Three independent reviewers initially assessed the titles and abstracts to identify studies that met the inclusion criteria. Full-text articles of the selected studies were subsequently retrieved and subjected to a second round of evaluation by four reviewers. Studies that did not meet the inclusion criteria were excluded, with the reasons documented in Fig. 1. Any screening disagreements among reviewers during the selection process were resolved through discussion and by seeking a consensus between the three reviewers. The same approach was used during the full text review whenever discrepancies arose; however, at this stage, consensus was sought between the four reviewers involved in this step.

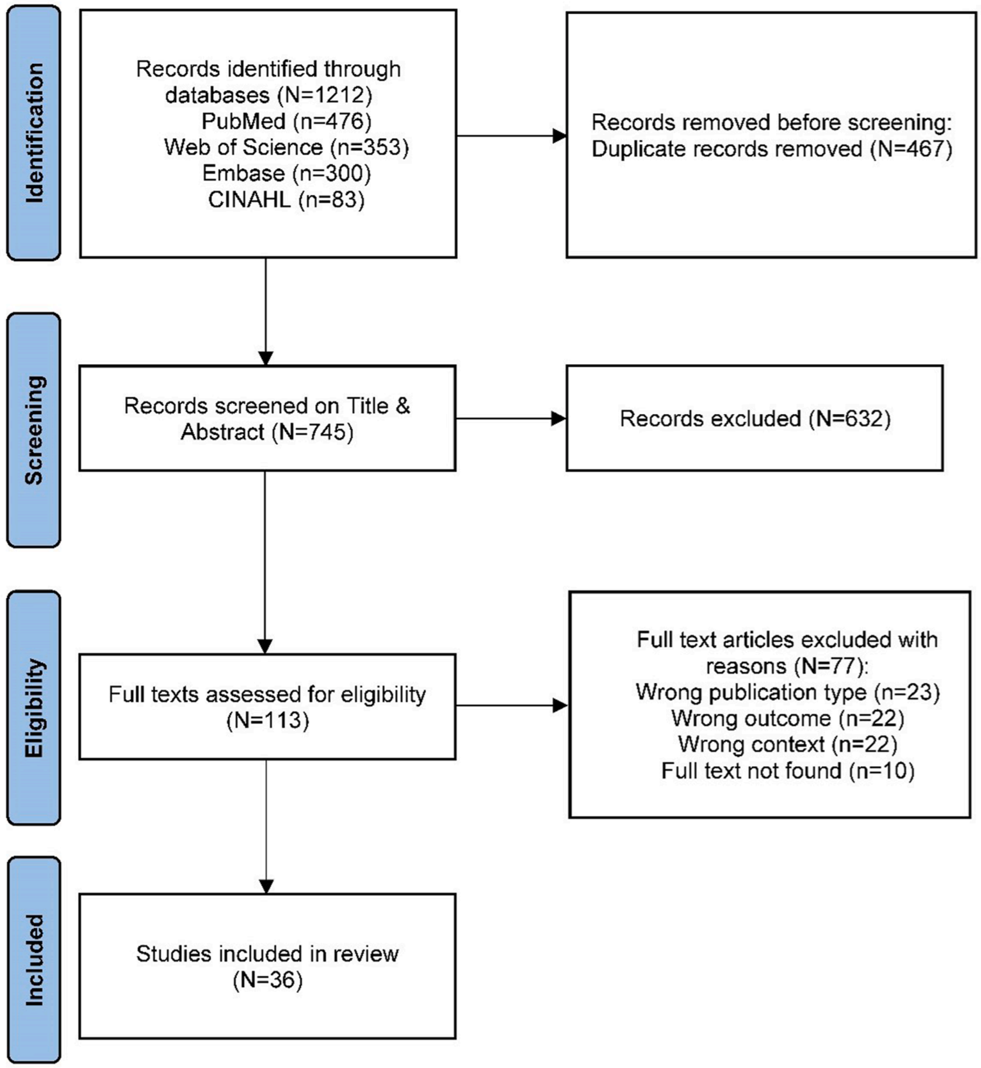

Figure 1. Search results, study selection and exclusion reason.[10]

Moreover, the authors acknowledge the exclusion of grey literature and non-English studies from this scoping review, which may have introduced a regional representation bias. This was done in order to ensure methodological consistency. Grey literature often lacks peer review, which may compromise the reliability and comparability of findings across diverse sources. Similarly, restricting the review to English-language studies ensured accurate interpretation and minimised the risk of translation bias, though it is recognised that this may have limited the inclusion of relevant practices and innovations reported in non-English-speaking regions. Nonetheless, this exclusion may have also led to an over or under-representation of geographical areas.

Data extraction and analysis

Data was collected using an extraction table, jointly designed by the four reviewers after performing a preliminary test on two articles. The four reviewers met three times to discuss the feasibility of the extraction table and the findings from each of the articles. The extraction table included the following information: authors, year, country, study aim, type of radioisotope or procedure name/type, categories of data collected, sustainable pillars explored, methodology type, key findings and recommended strategies. Each reviewer filled in the extraction grid independently. Once completed, the extraction grid was discussed and finalised through a consensus. The results were presented using descriptive analysis and a narrative summary, supplemented by figures and tables.

In this scoping review, data synthesis was conducted using Rayyan software in conjunction with a structured Excel spreadsheet to enhance transparency and inter-reviewer reliability. Rayyan facilitated independent screening and blinded decision-making by multiple reviewers, allowing for systematic identification of discrepancies and reducing the risk of bias during the selection phase.[9] The use of a standardised Excel template for data extraction enabled consistent categorisation of study characteristics and sustainability measures, allowing for quantitative cross-checking of inputs. This structured approach supported reliability by providing a clear audit trail of decisions while allowing for statistical comparison of agreement levels, thereby reinforcing the validity of the synthesis process beyond traditional consensus discussions.[7]

Results

Consistent with the JBI scoping review framework, the information obtained was collated, summarised and reported as shown below.

Search strategy and article selection

After removing duplicates, 745 articles were identified using the search strategy indicated previously. Thirty-six studies met all the inclusion criteria and were included in the review. The main reasons for exclusion were publication types (n = 23) in situations where the article was a review, a comment or an editorial; the outcome (n = 22) not being related to one of the three pillars of sustainability, and a wrong context when the reviewed research was not directly related to nuclear medicine (n = 22) (Fig. 1).

Characteristics of included studies

Key statistics from the dataset revealed a total of 36 articles, with publication years ranging from 1978 to 2024. Fig. 2 illustrates the number of published articles in relation to the country of publication. Geographically, Spain was the most prolific contributor with five published articles, followed by Saudi Arabia and Brazil, each contributing two articles. The most frequent years of publication were 2022 and 2023, suggesting a recent peak in interest in the topic of sustainability within the field of nuclear medicine.

For ease of data analysis, the articles have been grouped into three publication periods: before 2000, from 2000 to 2019, and from 2020 onwards as shown in Fig. 3. This analysis showed that 16 articles were published between 2000 and 2019, potentially indicating the years during which the topic of sustainability started gaining momentum. In line with this, the period before 2000 had fewer publications, with only 6 articles falling into this selection.

Methodologies employed in the reviewed studies were diverse, demonstrating a broad range of approaches. The most common methodologies included proof of concept and experimental studies,[11–21] and also retrospective studies.[22–27] Various prospective observational studies focused on measurements, audits, models and real-time data collection, highlighting the methodological diversity employed. Unique data collection methods such as radiation measurements, descriptive studies, surveys, and telephone interviews with patients were also noted. Studies were additionally categorised based on the location where they were conducted whether inside the hospital, outside the hospital, both[18,23,33,42] or none[43] (Fig. 4); Results indicated that 23 studies were conducted in hospital environments while eight articles discussed research performed in non-hospital settings.

To facilitate analysis, articles were further categorised by the type of nuclear medicine procedure: ten focused solely on therapy,[11,14,15,17,19,24–27,44] eight (33.3 %) addressed both diagnostic and therapeutic procedures,[12,13,16,20,35,36,38,40] five (18.1 %) focused on SPECT imaging[18,30–32,43] and two (9.7 %) on PET/CT applications.[22,28] Other categories, specifically the *pre-test* and *not specified* groups, accounted for the smallest shares, each having 2.8 %. Out of the studies conducted in non-hospital settings, three focused on therapeutic procedures[19,34,44]; four addressed both diagnostic and therapeutic procedures[13,16,36,39] while one study was classified as a pre-test.[41] As can be seen from Fig. 5, the distribution of articles by field shows a predominance of therapeutic studies, however, the data obtained from PET/CT articles highlighted this latter category as being a more focused but important area of research.

The above results emphasised a focus on integrated diagnostic and therapeutic studies within hospital-based settings, with substantial efforts being directed towards understanding the environmental impacts of medical practices. The varied methodologies

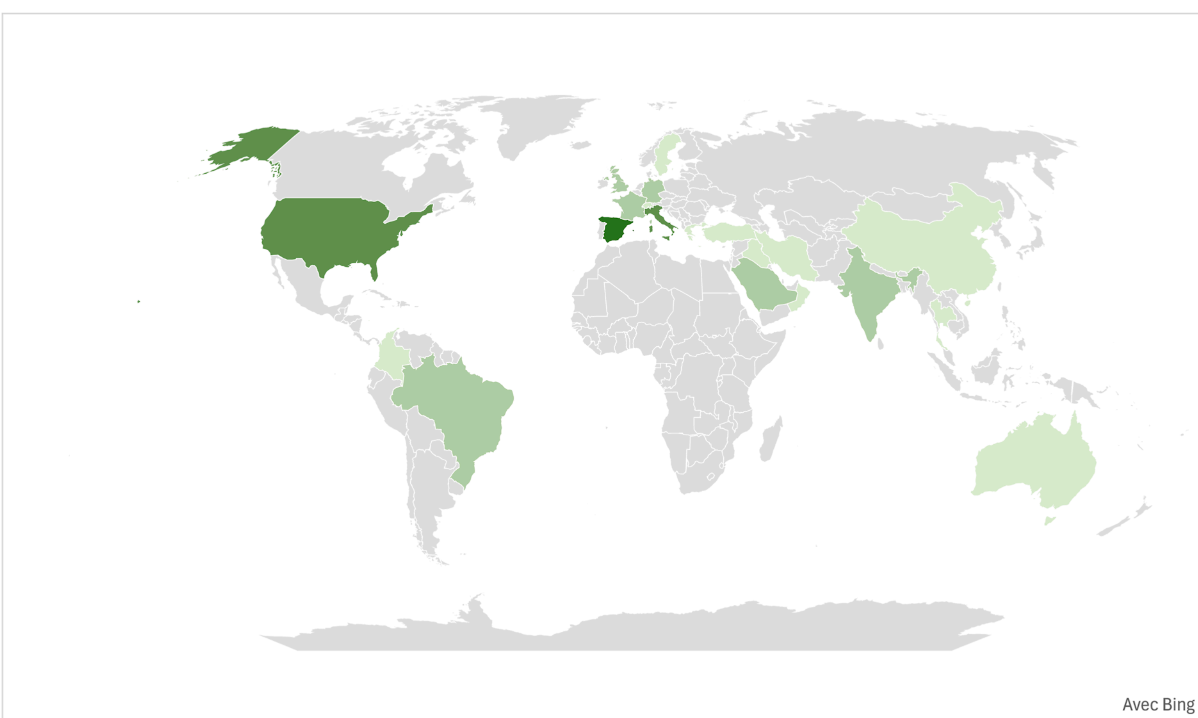

Figure 2. Visual representation of the countries where the studies included in this review were conducted.

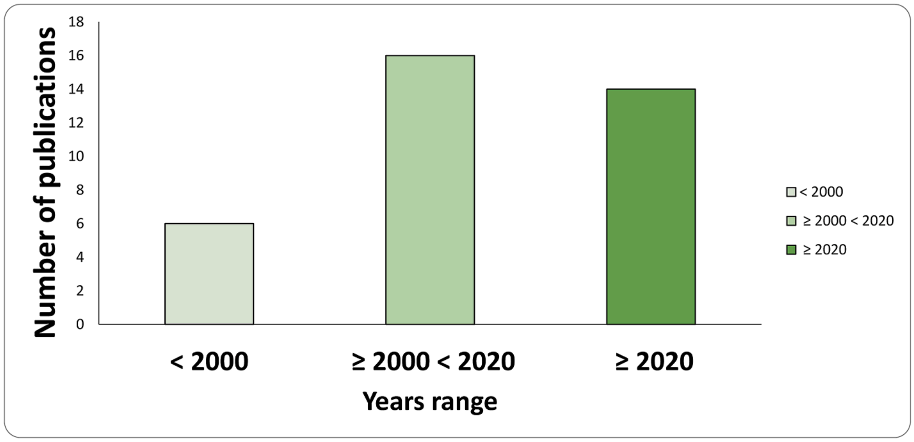

Figure 3. Graphical representation of the number of publications on sustainability, over the years.

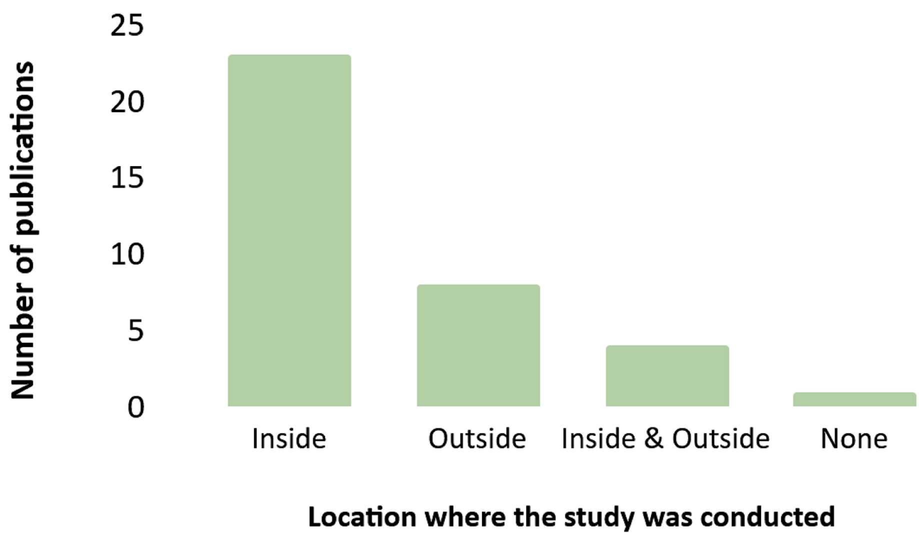

Figure 4. Graphical representation of the distribution of studies, per location.

and broad distribution of reviewed studies underscore the extensive research efforts aimed at improving the sustainability and the environmental footprint of radioisotope use in healthcare.

Study categories relating to the 3 pillars

In literature the concept of sustainability is debated in terms of three main pillars, often referred to as the triple bottom line, which encompass environmental, economic and social dimensions. Each of these 3 pillars is essential for achieving a sustainable level. Whilst the authors of this scoping review strived to categorise articles in the environmental, economic and social sustainability fields, some of the reviewed studies contained a crossover between the different pillars in terms of their findings and discussions.

The majority of studies emphasised environmental sustainability, with 20 articles focusing exclusively on this aspect.[12–16,19,21,23–25,32–36,38–40,42,44] There was also significant attention being given to economic sustainability within the reviewed literature, with three articles addressing this pillar,[29,31,45] and four others exploring the intersection between environmental and economic sustainability.[11,18,22,37] Other studies focused on the combination of economic and social sustainability[28,30,41] as well as on the environmental and social aspects in relation to each other.[17,20,26,46] The last two articles discussed the three pillars together.[27,43]

Environmental

The environmental pillar was the most dominant with 30 of the 36 articles addressing this aspect. Key environmental concerns included the disposal of radiopharmaceuticals, particularly I-131 and Lu-177, into sewage and water systems following therapeutic use.[24,44] Several studies emphasised the importance of adhering to national discharge regulations, estimating radioactivity levels in patient excreta, and considering the environmental impact of such effluents. Solutions such as the installation of **s**torage tanks, abatement systems, and waste segregation protocols were discussed.[24,33,35] Additionally, some articles highlighted the significant volume of low- and high-level radioactive waste generated by facilities operating cyclotrons or providing advanced oncology services.[23] Strategies such as waste segregation, minimisation plans, and facility upgrades to align with International Atomic Energy Agency (IAEA) recommendations were discussed as means to improve waste management and environmental stewardship[36] Another issue raised was the wastage of radiopharmaceuticals due

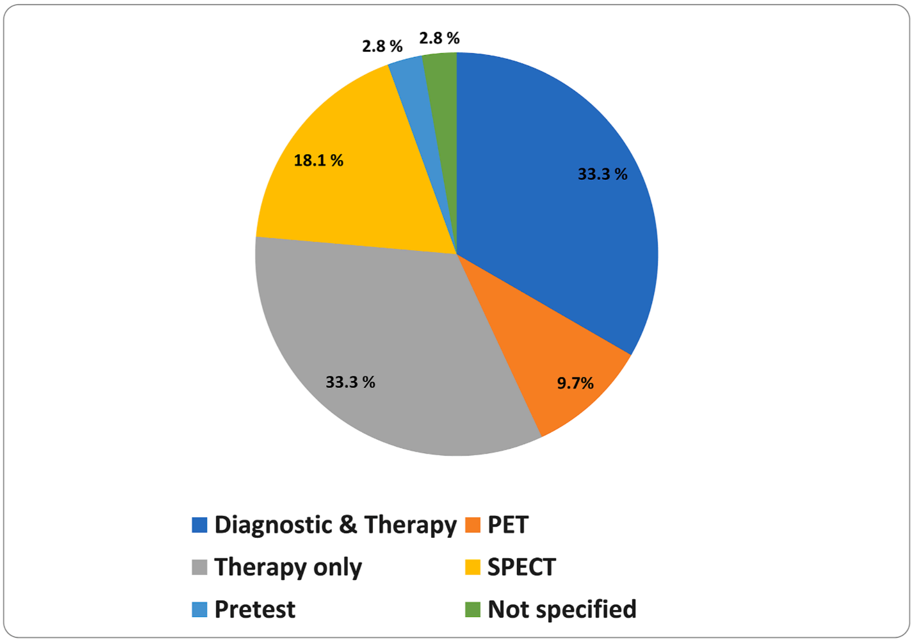

Figure 5. Graphical representation of the distribution of studies, per area.

to cancelled or rescheduled patient appointments, with one study estimating that this accounted for up to 16 % of utilised materials.22 Improved resource planning was suggested to address this inefficiency.

Economic

The economic pillar of sustainability focuses on promoting economic growth and development that is inclusive and equitable, ensuring long-term financial viability without depleting natural resources or causing irrevocable environmental damage. Few articles addressed the economic pillar alone.[29,31,45] However, as previously mentioned, several articles integrated the economic pillar with other sustainability aspects.[11,18,22,27,28,30,37,41,43]

The studies merging the economic and social pillars,[28,30,41] primarily focused on human resources issues, emphasising strategies required to mitigate staff shortages and to optimise workforce allocation. These studies highlighted the importance of balancing cost-effectiveness with the well-being of healthcare staff, ensuring that economic decisions do not compromise the quality of care or working conditions.

Conversely, the articles integrating the economic and environmental pillars[11,18,22,37] addressed the financial impacts of implementing sustainable practices. Such articles proposed solutions to enhance the cost-efficiency of waste management, energy use, and resource allocation within healthcare settings. In addition, one study discussed the need to consider sustainability when referring patients for a NM cardiac examination or when choosing the imaging modality.[43] Overall, the articles falling under this pillar of sustainability demonstrated how environmentally sustainable practices can lead to long-term economic benefits, such as reduced operational costs and improved financial performance.

Social

The third pillar of sustainability considers the social aspect of this topic, taking in consideration the importance of social equity, health and well-being while advocating for a fair distribution of available resources and opportunities. This pillar maintains the need to foster community engagement and to enhance the quality of life for all individuals irrespective of gender, ethnicity or age. No article addressed the social pillar alone. The studies merging the social and economic pillars primarily focused on human resources issues, emphasising strategies used to mitigate staff shortages[30] and to optimise workforce allocation.[28,30,41] Conversely, those studies integrating the social and environmental pillars addressed and proposed solutions to enhance awareness among healthcare professionals about radiation protection and safety.[20,46] Such studies also addressed the concerns of patients, workers, and the general public in specific contexts,[17,26] both within hospitals[26,46] or outside hospital institutions, concerning the release of radioactive materials into the environment.[17]

Comparative summary

Whilst 30 out of the 36 included articles focused on the environmental sustainability pillar, only 12 discussed economic sustainability, while 7 articles focused on social sustainability. This demonstrates that considerable research density is currently focused on the environmental aspects of nuclear medicine, with a sparsity of articles debating the economic and social sustainability pillars.

Recommendation strategies

Thirty-three out of the 36 articles included in this review recommended strategies to improve sustainability in the field of nuclear medicine. Table 1 presents a summary of the sustainability strategies, by theme and by pillars for ease of review.

It is important to recognise that low and middle-income countries do not have the same financial privileges as high-income countries. Hence, whilst different environmental, economic and social sustainability strategies have been proposed, they need to be considered in a country and department-specific context.[29]

Table 1
Sustainability strategies identified in the reviewed articles.

Sustainability pillars	Sustainability themes	Sustainability strategies
Environmental sustainability	Adequate solid waste management plans	• Radioactive waste must be consigned and treated separately from other clinical wastes • 131I contaminated items to be bagged and stored for decay • Implementation of a designed prototype waste storage trolley for 131I contaminated items • 177Lu contaminated items to be appropriately stored for decay • Unused 125I seeds to be returned to supplier • 99mTc to be incinerated as clinical waste • Maintain adequate records of storage and disposal • Daily assessment/audit of waste management • Surface monitoring/radiation surveys to inspect for leakages or radiation pollution • Implement alternative discharge methods such as utilising outpatient care and general ward stays to maintain safe radiation levels while reducing the burden on medical facilities
	Adequate water waste management plans	• Adoption of a “collection and delayed containment” approach • Installation of storage tanks allowing for the dilution, retention, and decay of waste • Usage of hybrid membranes, composed of amyloid fibrils and activated carbon, for the efficient removal of radioactive compounds from water • Implementation of automatic system able to extract 131I from biological and hospital waste samples
	Adequate gaseous waste management plans	• Usage of activated charcoal to trap and re-use radioactive Xenon • Implementation of single-breath inhalation or rebreathing systems for ventilation studies
Economic sustainability	Optimisation of activity levels	• Ensure a high radiochemical purity is present during labelling, to reach optimal activity levels • Reduction of the administered activity for nuclear Medicine diagnostic examinations, without compromising image quality • With the exception of radiopharmaceuticals with a lipophilic nature, consider increasing the dilution volume • Establish regulatory limits on the number of Lutetium-177 treatments each hospital can administer
	Maximising vial usage	• Enhance the stability and usability of the radiopharmaceuticals by ensuring suitable storage conditions • Maintain strict aseptic conditions to ensure microbiological stability and extend shelf life • Avoid air entry during aliquot extraction • Implementation of an optimal Dual-Size vial system
Social sustainability	Staff retention	• Foster collaborative environments • Empower staff to undertake tasks previously performed by medical physicians, following appropriate training
	Cultural change	• Adopt flexible working policies • Consider staff allocation adaptation • Provide appropriate radiation protection instructions to patients upon discharge to ensure safe and sustainable treatment practices • Daily assessment of radiopharmaceutical administration
	Streamlining pathways	• Introduce a central booking system for cross-site appointments • Usage of outpatient “pretest” contacts to avoid or decrease no-shows, tardy patients, improper preparation and drug contraindications

Discussion

The findings of this scoping review cannot be generalised, as they lack the rigor attributed to a systematic review. However, this review still provides a medium for mapping the existing literature on the topic of sustainability in the field of nuclear medicine. Therefore, the objective of this scoping review was to collate and evaluate the available literature on sustainable practices in nuclear medicine, with a focus on the three pillars of sustainability.

The classification of results revealed that therapy and combined diagnostic–therapeutic studies dominated the literature, particularly in hospital settings. SPECT-related sustainability efforts were more common than those focusing on PET/CT, likely due to the broader accessibility and routine use of SPECT in clinical practice. The relatively low representation of PET/CT studies may reflect higher costs, limited availability, or less integration into current sustainability initiatives.

Among the included articles, there was a predominant emphasis on the environmental pillar ($n = 30/36$). This focus can be attributed to several factors, primarily because environmental aspects are easier to define and address. The consumption of energy, resources, and consumables, along with waste management and the carbon footprint, are critical topics in the field of imaging, just as they are in other sectors of daily life. These aspects are tangible and measurable, making it simpler to develop and use indicators and measurement indices such as kilowatt-hours for energy consumption, kilograms for waste management, and kilograms of CO_2 equivalent for the carbon footprint. Consequently, the search equation used in this review contained more keywords and descriptors related to the environmental pillar, leading to the identification of more articles addressing this aspect (see Supplementary Material).

Given the unique characteristics of nuclear medicine practice and its use of radioactivity, particular attention was given in the reviewed articles to the management of solid and gaseous waste released in nature, and to radiopharmaceutical products disposed of in sewer and water systems. Public concerns and anxieties about the use of radioactivity in medicine and its environmental impact are substantial, necessitating strict regulations governing solid, liquid and gaseous waste management. In this context, studies measuring the quantity of radioactivity in nature are crucial to alleviate public anxiety and demonstrate compliance with radiation protection directives and guidelines.

Notably, none of the reviewed articles addressed the delivery of radionuclide therapies in an interventional imaging context. This represents a potential research gap, especially when considering existing sustainability strategies from fields such as radiotherapy and interventional radiology.[4,5] For example, life cycle assessment (LCA) studies in interventional radiology have shown that the highest contributors to carbon emissions are not necessarily imaging devices themselves, but rather operating room climate control and single-use materials. Similar findings have been reported in radiotherapy,[4] where the carbon footprint of linear accelerators is substantial but can be mitigated through optimisation of treatment protocols and energy usage. These findings suggest that interventional and therapeutic procedures carry complex environmental implications beyond imaging, which could be explored in future nuclear medicine studies, particularly in therapies guided by imaging or performed in hybrid settings. Moreover, understanding these dynamics could help address not only environmental but also economic and social sustainability pillars in a more integrated manner. Futher more, recent sustainability studies have concentrated on the environmental pillar in radiology and radiotherapy[4,5] highlighting issues such as the accumulation of plastic waste from single-use packaging and the high energy consumption of imaging equipment, workstations, lighting, and other devices. These environmental aspects were absent from the nuclear medicine literature reviewed, revealing a gap in the literature which underscores the need for a broader environmental assessment of nuclear medicine services that extends beyond radioactivity-specific concerns.

Several articles on nuclear medicine extended the scope of sustainability to include social and economic dimensions. Topics such as staff safety and well-being, equitable access to radiopharmaceuticals, supply chain resilience, and the financial sustainability of services were commonly addressed. This broader perspective highlights the multifaceted nature of sustainability in nuclear medicine and shows the importance of integrating all three pillars; environmental, social, and economic into future research and practice.

The results of this scoping review indicated that optimising the use of physical resources, such as radiopharmaceuticals, is one strategy that may allow to foster a sustainable environment. Such a strategy is also aligned with the “As Low As Reasonably Achievable” (ALARA) principle which has been adopted into radiation protection and environmental policies.[47] Additionally, radiation protection strategies required to protect both staff and the public are essential for improving practices in nuclear medicine, and it is important that such strategies inform and are aligned with current departmental policies and every day clinical practice.

Research studies on low dose administration and dose optimisation have been performed even in recent years however, their impact on sustainability has historically rarely been reported. With the development and implementation of time-of-flight (TOF) technology in the newer nuclear medicine systems, there is an opportunity to locally optimise the administered radioactivity levels without the risk of compromising image quality.[48] Such investigations will not only ensure patient safety but will also contribute to environmental, economic and social sustainability. The administration of lower/optimised radioactivity dose levels will serve to reduce radioactive waste, allowing nuclear medicine staff to draw-up doses for more patients from the same vial, whilst also addressing staff and public concerns related to radiation exposure. Initiatives such as the “Long Term Plan” for the National Health Service, in the United Kingdom, and the Health and Long-term care reform, produced by the European Commission, focus on bringing together professionals from different backgrounds to coordinate better care and enhance the resilience and sustainability of healthcare systems.[49,50]

Socially sustainable practices focused on workplace wellbeing, including the recruitment, retention, education and training of staff. Such practices have been identified as being crucial in addressing the radiography workforce shortages that are currently affecting diagnostic radiography and nuclear medicine. The present scoping review demonstrates an underrepresentation of research investigating the social sustainability pillar, indicating that future research is required to devise strategies and practices to address this.

The European Federation of Radiographer Societies (EFRS) also emphasises the critical role of radiographers in promoting sustainability within healthcare due to the significant environmental impact of medical imaging and radiotherapy.[51] Whilst the studies included in this review are aligned with this vision, the EFRS further recommends establishing green teams led by sustainability champions, optimising transportation and energy use, reducing non-essential materials, and ensuring appropriate recycling and disposal practices.

Such practices are especially important in nuclear medicine, in this regard the results of the reviewed studies highlighted the need to mitigate any possible impacts of radioactive waste on the environment and to work towards the purchase of clinical goods that cause minimal adverse environmental impact. Clinical practices should incorporate evidence-based hypofractionation and efficient scheduling to minimise resource use. Policy decisions should favour renewable energy sources and energy-efficient designs, and sustainability education should be integrated into radiographer training. In this context, national societies are encouraged to raise awareness and to prioritise sustainability in their agendas.

The EFRS envisions radiographers as key agents in driving sustainable practices within their fields. Radiographers, through their daily interactions with patients and decision-making roles, can drive substantial environmental benefits while maintaining high standards of care, thereby contributing to the broader goal of reducing the healthcare's carbon footprint, and of promoting a sustainable future. Additionally, the EFRS emphasises the need for continued research, education, and policy development to support and enhance sustainability efforts in all sectors of diagnostic imaging, including nuclear medicine, and therapeutic procedures. Ultimately education, research, and policy development are crucial aspects required in making sustainability a standard practice within the radiography profession.

Limitations

This review has some limitations; primarily, it does not include an evaluation of the quality of the included studies since the authors' aim was to conduct a scoping review based on the JBI methodology for scoping reviews,[6] rather than a systematic review of the literature. Additionally, although the authors made substantial efforts to include all relevant articles, some studies may have been missed due to the choice of databases used and search terms applied. Specifically, the search conducted indicated a shortage of studies addressing the economic and social aspects of sustainability. Moreover, any potential publication bias or variations in regulatory practices across countries were not investigated.

Conclusion

This scoping review has explored a range of sustainable practices within nuclear medicine, highlighting key areas where advancements have been made and where challenges persist. The literature reviewed indicated a long-term interest in sustainability within the field of nuclear medicine, with a notable increase in publications occurring in recent years and focused on the environmental pillar. The findings indicated that while efforts such as waste minimisation, implementation of alternative discharge methods, improved radiopharmaceutical production, and radionuclide extraction systems are gaining popularity, there remains a substantial gap in the widespread adoption of these practices across different regions and institutions. Integrating and embedding such approaches in everyday work can help to reduce the carbon footprint of nuclear medicine services, whilst maintaining the quality of the diagnostic and therapeutic procedures delivered.

Additionally, the emphasis on environmental sustainability seen in the reviewed articles suggests a primary concern for the environmental impact of the use of radiopharmaceuticals, with particular attention to economic sustainability and the interplay between different sustainability factors. The notable sparsity of articles exploring the economic and social dimensions of sustainability, highlights an area of action where further research should take place.

Whilst local reviews of current processes are required as immediate action points, medium-term strategies focused on drafting sustainability plans and standard operating procedures are needed to improve departmental sustainability. Long term strategies should include more research related to the economic and social pillars of sustainability. Only by delving into the short and medium-term strategies that take into account local resources and departmental limitations, will it be possible to draft long term sustainable working procedures that encompass multiple realities and that can be used to inform policy and practice. This scoping review further highlighted the need to overcome barriers such as high initial costs, regulatory constraints, and the requirement for interdisciplinary collaboration. Future research should focus on developing standardised guidelines while fostering a culture of sustainability amongst nuclear medicine staff, thus ensuring that this field evolves in alignment with global environmental goals without compromising patient care or diagnostic accuracy. The continued emphasis on innovation and policy reform will be crucial to embedding sustainability as a core value within nuclear medicine.

Animal welfare

Not applicable.

Informed consent

Not applicable.

Ethics approval

This research did not require Institutional Review Board approval because *methodology of a scoping review*.

Availability of data

Data required for this study may be made available by the author(s) upon reasonable request.

Author contributions

DR: Investigation, Formal Analysis, Data Curation, Writing – Original Draft, Writing – Review & Editing.

KG: Investigation, Formal Analysis, Data Curation, Writing – Original Draft, Writing – Review & Editing.

AG: Conceptualisation, Methodology, Investigation, Formal Analysis, Writing – Original Draft, Writing – Review & Editing.

CA: Methodology, Investigation, Writing – Review & Editing.

SM: Conceptualisation, Methodology, Writing – Review & Editing.

PC: Writing – Review & Editing.

CB: Writing – Review & Editing.

AK: Writing – Review & Editing.

MC: Conceptualisation, Methodology, Investigation, Formal Analysis, Data Curation, Writing – Original Draft, Writing – Review & Editing.

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Conflicts of interest statement

The authors declare that they have no competing interests.

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Appendix A. Supplementary data

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