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Original Research Article

SUSTAINABLE MEDICINES IN AUSTRALIA: A SCOPING REVIEW OF GREEN PHARMACY PRACTICES AND DRUG DISPOSAL ACROSS HEALTHCARE SETTINGS

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Abstract:

The pharmaceutical waste and environmentally unsustainable practices in medicine pose increasingly challenging problems to health systems worldwide; however, Australia does not offer a unified national structure that can regulate sustainable practices in pharmacy. This scoping review aims to examine current practices, gaps, and challenges related to sustainable medicines, green pharmacy initiatives, and drug disposal systems within Australian healthcare contexts. The search was performed in PubMed, Scopus, Web of Science, CINAHL, and Google Scholar using keywords associated with green pharmacy, sustainable medicine, and pharmaceutical waste. The period of publication included studies published between 2000 and 2025 which dealt with the Australian contexts. Thematic synthesis was applied to fifteen relevant studies and reports.

The results indicate that there is a daily low level of awareness among citizens, students, and healthcare providers regarding the environmentally responsible disposal of medicine, and significant knowledge gaps exist in terms of education and training. Hospital evidence, radiology departments, and community-based scenarios highlight the common mis-segregation of pharmaceutical waste, the paucity of recycling facilities, and a misunderstanding of proper waste disposal. Although the Return Unwanted Medicines (RUM) program offers a national disposal scheme, its use is moderate. Pharmaceutical pollution of the environment continues to occur, with researchers having reported the identification of residues in wastewater and soil habitats. These obstacles to sustainable practice include inadequate translation of policies, lack of organizational prioritization, limited resources, and structural barriers. Based on the synthesized evidence, this review proposes a conceptual Australian Green Pharmacy Framework to support sustainable medicine use, environmentally responsible disposal practices, and system-wide integration across the medicines lifecycle. Nevertheless, there are areas of innovation, such as green chemistry, hospital sustainability programs, and eco-pharmaco-stewardship models, which indicate possible directions of movement. More empirical studies and policy formulation are desperately required to facilitate institutional-wide implementation.

Keywords: Green Pharmacy, Sustainable Medicines, Pharmaceutical Waste Management, Australian Healthcare System, Environmental Sustainability

1. Introduction

The recent focus on the environmental impact of pharmaceuticals has brought sustainable medicines and green pharmacy to the modern health policy discussions. Sustainable medicines refer to the pharmaceutical products that are developed, produced, prescribed, used, and disposed of in a manner that causes minimal ecological harm through reduced toxicity, resource conservation, and minimization of downstream ecological contamination (Adeyeye et al., 2022). The broader systems-focused concept is green pharmacy, which encompasses green chemistry, eco-design of pharmaceutical formulations, sustainable manufacturing, rational prescribing, and efficient waste-management infrastructure, among others, to mitigate the environmental impact of pharmaceuticals throughout their lifecycle (Zimmermann, 2022). Pharmaceutical waste: a constant factor in global environmental pollution, is generated in households, pharmacies, hospitals, and other health facilities and is characterized by expiration, non-use, contamination, and improper disposal of unused and expired goods (Janik-Karpinska et al., 2023). Taken together, these elements provide a theoretical and practical framework for addressing environmental issues arising from the use of modern medicine.

Worldwide, the disposal of unwanted medicines is poorly regulated and unevenly practiced. In most countries, there is no standardized take-back system, and instead, household waste is typically disposed of, or drugs are flushed down sinks and toilets (Rogowska & Zimmermann, 2022). This is a tendency that is commonly cited as a lack of health literacy, low levels of awareness about the effects of the environment and high accessibility of over-the-counter (OTC) drugs, which leads to hoarding and disproportionate buying. The same can be seen in Australia, where research shows that households store a high level of expired or unused medications, which poses challenges not only in disposal but also in prescribing and consumer behavior (Kelly et al., 2018). Though the pharmaceutical system in Australia is more organized than in many other countries, the country still reflects global trends: unused drugs are often stored on shelves, take-back options are underused, and the population is not well informed. These similarities may indicate that inappropriate disposal is not a regulatory or structural issue, but a behavioral and cultural issue ingrained across various health systems.

These effects on the environment and people's overall health are strong, both globally and in Australia. On the global front, levels of analgesics, antibiotics, antidepressants, and endocrine-disrupting compounds were generally found in surface water, ground water, agricultural soils, and effluent water (Abosse et al., 2024; Miettinen and Khan, 2022). These pollutants pose risks such as aquatic toxicity, reproductive abnormalities in wildlife, disruption of microbial ecosystems, and bioaccumulation in food chains over the long term. Australia is not an exception, as traces of pharmaceuticals have also been observed in sewage and biosolids, but the ecological persistence and accumulation of their residual effects are not well-researched problems (Murdoch, 2015). In addition to environmental degradation, mismanaged disposal is a major cause of health risk to the population, especially antimicrobial resistance (AMR). The presence of antibiotic residues in waterways exerts selective pressure on microorganisms, leading to the development of resistant strains and undermining the efficacy of critical treatments (Ajekiigbe et al., 2025). Although efforts are underway to emphasize AMR as a worldwide epidemic, Australian healthcare institutions also report misuse of antibiotics, contrast agents, and other pharmaceuticals due to improper disposal practices, highlighting systemic failures in clinical waste separation and environmental management. These intersecting global and national trends demonstrate that poor medicinal disposal poses a threat to the environment and a social health risk, and should be addressed through interdisciplinary, evidence-based responses.

To address these fears, some nations have adopted take-back programs, albeit in limited numbers, and have not put up countrywide programs. The Return Unwanted Medicines (RUM) program is among the oldest and most extensive national programs, which offers free disposal of unwanted medicines in a community pharmacy. RUM is a major competitive advantage in the Australian pharmaceutical stewardship environment, and international benevolent programs should be modelled after it. Nevertheless, utilization is still not balanced, as it is not promoted regardless, as well as because of the different degrees of awareness among patients and interstate and even inter-healthcare differences (Singleton et al., 2023). Such restrictions can be compared to findings in other parts of the world, where, despite the availability of disposal programs,

their effectiveness is largely related to the level of awareness, access to and combination with routine care. The presence of RUM demonstrates that Australia has a relatively leading position in the field of pharmaceutical waste management, but its uneven adoption is an indication that there is a larger system-wide problem that has hindered the effective adoption of sustainable medicine practices.

There are still considerable research gaps that limit the efforts of the world and Australia towards sustainable management of medicine. Most research around the world is done on individual parts of the pharmaceutical life cycle, thus manufacturing innovations or domestic disposal, as opposed to a systems approach. In the same way, the Australian evidence base remains rather disjointed and lacks national data on consumer disposal behaviours, inconsistent research in clinical settings, and sufficient research studying the environmental monitoring of pharmaceutical residues (Singleton et al., 2018; Singh and Gurudiwan, 2024). Empirical studies on the value of educational programs to enhance medicine disposal are limited, and little is known about cultural, linguistic and socioeconomic factors of medicine disposal behaviours. More so, the current models in sustainability tend to focus on green chemistry and design solutions without considering end-of-life issues, including take-back initiatives, waste sorting, and educating the population (Mehdi et al., 2024). Such gaps demonstrate the lack of relationship between the upstream sustainability efforts and the downstream realities of pharmaceutical waste production.

Considering such enduring issues, the scoping review will be used to map the available evidence on sustainable medicine use, disposal of pharmaceutical waste practices and green-pharmacy programs in the Australian healthcare setting. The review attempts to find out trends, gaps and opportunities to enhance the role of Australia towards global pharmaceutical sustainability by synthesizing research conducted in the household, community pharmacy and clinical settings. Through this, it will offer a basis for policy formulation, specific interventions and subsequent studies that can bring healthcare delivery to the same level with environmental responsibility.

2. Aim and Objective

The primary aim of this scoping review is to map and synthesise existing evidence on sustainable medicine use, green pharmacy practices, and pharmaceutical waste disposal systems within Australian healthcare settings, in order to identify current practices, gaps, challenges, and opportunities for improving environmental sustainability across the medicines lifecycle.

The specific objectives of this review are to:

- Identify and summarise existing research on sustainable medicine use, green pharmacy initiatives, and drug disposal practices in Australian healthcare contexts, including households, community pharmacies, hospitals, and specialised clinical settings
- Examine levels of awareness, knowledge, and attitudes among healthcare professionals, students, and the general public regarding environmentally responsible medicine use and disposal
- Explore current policies, regulatory frameworks, and national programs (such as the Return Unwanted Medicines program) related to pharmaceutical sustainability and waste management in Australia, and assess their implementation and uptake
- Assess reported environmental and public health impacts associated with improper pharmaceutical disposal, including contamination of water systems, soil, and risks such as antimicrobial resistance.

3. Matrial and Methods

The scoping review adhered to the methodological framework used by Arksey and O'Malley (2005) and was supplemented with the refinements that were suggested by Levac et al. (2010), to be used in order to make the evidence mapping systematic, transparent, and reproducible. The PRISMA-ScR checklist was used to guide the reporting, allowing for all methodological decisions to be made expressly. This review had the aim of delving into the depth of evidence on the subject of sustainable practices in medicine, green pharmacy programs, and medicine disposal methods in Australian health facilities. The study was used as a scoping review because it focused on scoping the breadth of existing literature and not necessarily determining the quality of the studies and producing meta-analytic results. This method suitably fits in as some research on this area is scattered, methodologically diverse and mostly exploratory even in nature.

3.1 Research Question

The research question that informed this review was as follows: What is the evidence of sustainable medicine practice, green pharmacy programs and drug disposal

systems in healthcare institutions in Australia? The question was made broad to consider the multi-dimensional aspect of pharmaceutical sustainability, which includes the environmental, behavioral, regulatory, clinical and waste-management aspects. It would seek to have evidence on a variety of healthcare environments, such as community pharmacies, hospitals, aged care facilities, and the wider public health sectors.

3.2 Relevant Studies identification

An extensive search plan was created and used in the large multidisciplinary databases and health-related databases, which comprise PubMed, Scopus, Web of Science, CINAHL and Google Scholar. The search in the databases was conducted from 2000 to 2025 for relevancy. The search strategy was the use of controlled vocabulary (i.e. MeSH terms) and free-text terms, including pharmaceutical sustainability, drug disposal practices and the Australian environment. The last Boolean search query that was applied in all the databases was: (green pharmacy/sustainable medicine) and (drug disposal/pharmaceutical waste) and (Australia). Other keywords that were used were required to maximize the sensitivity to retrieval, e.g., medicine waste, healthcare settings, and sustainability. Publications as old as 2000 were included in the search, as the subject matter of the study is topical and thus relevant to the conditions of the environmental and policy situation in Australia in 2000. Studies written in English were used only to ensure a consistent screening and interpretation.

3.3 Eligibility Criteria

The a priori procedure was to set the eligibility criteria that would help guide the screening. The inclusion criteria were that the studies had to concentrate on any aspect of pharmaceutical sustainability or disposal in the Australian healthcare context and were published between 2000 to 2025. Quality studies, qualitative studies, mixed-method research, reviews, evaluations, and reports that had empirical or descriptive data were eligible designs. The studies were filtered out as those that were not related to sustainability or disposal, not written in Australia with Australian-specific results, non-English, opinion, commentary, or purely theoretical articles without references to medicine disposal or sustainability.

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Published 2000–2025	Not related to sustainability or medicine disposal
English language	Non-English publications
Australian context or data	Conducted outside Australia without relevance
Empirical studies, reviews, evaluations	Editorials, commentaries, opinion pieces
Focus on disposal, waste, sustainability, or green pharmacy	Focus solely on manufacturing without end-of-life relevance

3.4 Study Selection

All identified records were exported for processing, and duplicates were removed both automatically and manually. The review took place after two stages of screening. Initially, two independent reviewers were tasked with screening titles and abstracts against the eligibility criteria. Articles that seemed unclear or could be of interest were taken forward for full-text analysis to minimize the chances of omitting pertinent findings. In the second phase, the reviewers received the complete texts of all eligible articles and thoroughly analyzed them. The inclusion decisions that were not similar were settled through discussion, and where a decision was not reached, we used the third reviewer. The study's selection process is reported in the PRISMA-ScR flow diagram, which outlines the records identified, screened, excluded, and ultimately included.

3.5 Data Extraction

The review team created a pre-designed charting form, which was used to extract the data. A small number of included studies were piloted in this form, which was refined to include all the relevant information. The data collected included authorship, publication year, research objective, study design, sample description, clinical environment, type of sustainability or disposal practice being studied, research results, and challenges or facilitators. There were also contextual details, e.g.,

regulatory implications or environmental impacts. To improve methodological consistency, data were independently extracted by two reviewers from an initial subset of studies, and the findings were compared. After discussion of extraction parameters, the rest of the studies were charted by one of the reviewers and re-read by the other.

Table 2. Data Extraction Fields

Field	Description
Author(s), Year	Citation details
Study Aim	Purpose and objectives
Design and Methods	Study type, data collection methods
Setting	Healthcare context (e.g., hospital, pharmacy, aged care)
Population	Participants or units of analysis
Focus	Sustainability, disposal, policy, behavior
Key Findings	Main results
Barriers/Enablers	Factors influencing practices
Implications	Policy, practice, or research relevance

3.6 Data Analysis and Synthesis

The information was synthesized through a repetitive narrative and thematic method. Since the studies included had different designs, scopes, and methodological rigour, thematic synthesis enabled the combination of qualitative and quantitative results. Data analysis involved reading the extracted data multiple times, coding it to identify emerging concepts, and clustering it to derive higher-order themes pertinent to the research question. Themes were inductively created using recurring patterns within the data and deductively using existing frames in pharmaceutical sustainability. The synthesis was focused on determining the scope of available evidence, character of interventions or practices, contextual obstacles and literature gaps. The results were finally grouped into thematic categories, which included awareness and knowledge, policy and regulatory framework, environmental effects, disposal habits and obstruction and enablers to sustainable pharmacy projects.

3.7 Ethical Considerations

Since this scoping review involved the synthesis of already written and publicly available literature, no ethical approval was necessary. No human subjects were used in the instruction of the review.

4. Results

4.1 Search Results Overview

Empirical and conceptual studies that dealt with various aspects of the medicines lifecycle were found in the scoping process, manufacturing and policy to clinical use, pharmacy practice and household disposal. Fifteen important studies were incorporated in this synthesis after the screening against the inclusion criteria. These included Australian research concerning community, hospital and radiology environments, healthcare services, national/regional surveys, international research on green pharmaceutical production, global policy research and community-level and pharmacy-level research on the disposal and retention of medicines.

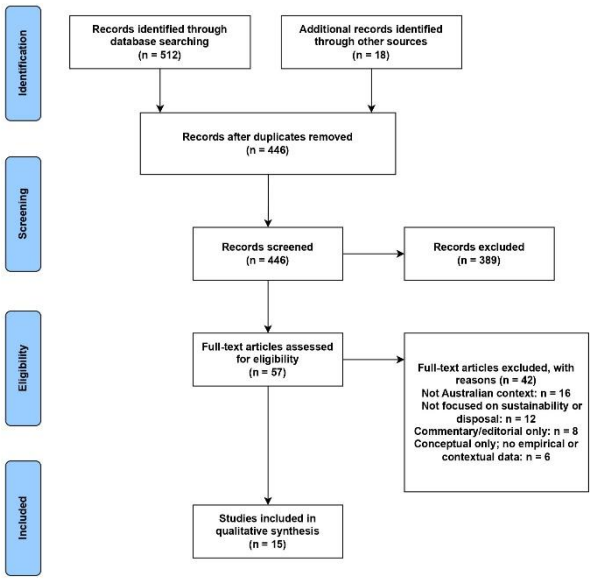

Figure 1 PRISMA Chart (Author)

Even though the background database search and screening steps are not replicated in the current work, the selection is performed by considering PRISMA-ScR principles. The relevance of titles and abstracts to sustainable medicines use, green pharmacy, or pharmaceutical waste disposal was initially filtered, and then the full-text was reviewed to ensure that it was eligible based on the context of Australian healthcare settings or conceptually relevant evidence in other countries. This process was mapped through a PRISMA-ScR flow diagram, showing a narrowing process of a wide pool of records to a narrow set of studies which, together, shed light on education, policy, practice, environmental effects, and system barriers and facilitators.

4.2 Study Characteristics

Although many studies were reviewed from 2000 to 2025, few of them related to the research focus were selected. The majority of the selected studies were published in 2015-2025 (2000–2014 yielded no eligible studies), and the output evidently increased during the past decade, which can be explained by the rise in the awareness of the environmental and population health impacts of pharmaceuticals. Some of the studies were Australian and directly involved the investigation of practice in hospitals, radiology units, community pharmacies and households (Singleton et al., 2018, 2021, 2023; Kelly et al., 2018; Barraclough et al., 2019; Taylor et al., 2025). Others were international outlooks on green manufacturing and regulatory frameworks (Gauci, 2024; Jairoun et al., 2025; Adeyeye et al., 2022; PIEKARA, 2025; Murdoch, 2015), and Singh and Gurudiwan (2024) reported on green manufacturing education among the Australian pharmaceutical students.

The research methodologies include mixed-methods (e.g. Singleton et al., 2018, 2021, 2023), cross-sectional survey (Singh and Gurudiwan, 2024; Kelly et al., 2018; Taylor et al., 2025; MacDonald et al., 2024; Barraclough et al., 2019), qualitative interview (Kelly et al., 2018; McMillan et al., 2021). The setting was varied and included hospital pharmacies and radiology departments, dialysis units, rural hospitals, community pharmacies, households, and pharmaceutical manufacturing sites.

Table 3: Overview of included studies

Study	Setting / Country	Focus	Design
Singh & Gurudiwan (2024)	Australian pharmacy schools	ES and ESPP awareness among undergraduates	Cross-sectional survey
Jairoun et al. (2025)	Global (Scopus-based)	Regulatory and policy approaches to sustainable medicines use	Bibliometric and policy analysis
Gauci (2024)	Pharmaceutical manufacturing, Malta	Green pharmaceutical processes and greenness assessment tool	Qualitative + pilot tool validation
Adeyeye et al. (2022)	UK and global	Eco-pharmaco-stewardship in clinical practice	Narrative review
Singleton et al. (2023)	Australian public hospital pharmacy	Pharmaceutical waste bin audits and disposal practices	Sequential mixed methods
Taylor et al. (2025)	Australian radiology departments	Radiographers' attitudes, knowledge and disposal practices	Cross-sectional survey
MacDonald et al. (2024)	Australian medical imaging (hospital vs community)	Comparison of disposal practices and attitudes	Cross-sectional survey

Singleton et al. (2021)	Hospital pharmacies, Australia and UK	Pro-environmental behaviours and carbon targets	Mixed methods
Kelly et al. (2018)	Australian households	Medicine retention, storage and disposal	Qualitative interviews with descriptive counts
PIEKARA (2025)	Community pharmacy, Poland	Returned medicines and disposal patterns	Pilot mixed analysis
Singleton & Letts (2025)	Rural hospital, Queensland	Hospital-wide recycling and carbon reduction initiative	Behavior changes case study
McMillan et al. (2021)	Australian community pharmacies	Harm-minimization service roles	Qualitative interviews
Singleton et al. (2018)	Australian hospital pharmacies	Knowledge, understanding and antecedents to PEBs	Mixed methods, text analytics
Barraclough et al. (2019)	Dialysis units, Victoria	Environmental sustainability practices	State-wide survey
Murdoch (2015)	Australia, NZ, Pacific	Pharmaceutical pollution pathways	Technical review and situation analysis

4.3 Thematic Findings

The synthesis of the included studies yielded four overarching themes: (1) awareness and knowledge of medicine disposal and sustainability; (2) policy and regulation; (3) environmental and health impacts; and (4) barriers and facilitators shaping sustainable pharmaceutical practices across healthcare, community, and manufacturing contexts in Australia. These themes provide a comprehensive overview of the current state of knowledge and practice, as well as the structural and educational gaps that impede sustainable medicine management.

4.3.1 Knowledge and Education of Medicine Disposal and Sustainability

In professional, student, and popular communities, information on sustainable medicine usage and disposal was observed to be uneven, superficial, and usually disjointed. Singh and Gurudiwan (2024) highlighted that, although 98 per cent of Australian pharmacy undergraduates were exposed to general environmental sustainability concepts, less than 12 per cent of the same group reported having been exposed to Environmental Sustainability in Pharmacy Practice (ESPP), and only 7.9 per cent of the group had been exposed to ESPP content in their curricula. Nonetheless, students were highly motivated with only limited exposure: 65 per cent of them thought that ESPP was applicable to their practice in the future, and 89 per cent of students felt that proactive sustainability actions should be taken by the profession. This lack of correlation between motivation and formal training highlights a great curricular gap.

Such gaps were also observed in practicing professionals. Singleton et al. (2018) discovered that hospital pharmacists and pharmacy technicians of Queensland had no systems-thinking attitudes and were unaware of the environmental effects of pharmaceuticals. Most of them used the assumption that using hospital policy meant automatically having an environmentally responsible disposal, regardless of the fact that they were not familiar with the best-practice disposal. Comparing pharmacists in the UK and Australia, Singleton et al. (2021) additionally noted that the state of environmental concern and environmental knowledge were low in both nations, that were reflected in poor interest in pro-environmental behaviours.

Similar gaps in knowledge were established among radiographers. In Taylor et al. (2025), one-third of the respondents were interested in the pharmaceuticals

getting into the environment through excretion, but over 70% were anxious about inappropriate disposal when it was in their immediate presence. MacDonald et al. (2024) also discovered that a large proportion of radiographers did not know how pharmaceuticals get into the ecological environment and their impact on human and ecosystem health. Nearly one-fifth of them had never been trained on how to dispose of pharmaceutical waste.

The lack of knowledge at the community level led to unsafe storage and disposal. According to Kelly et al. (2018), 166 households in Australia reported a massive amount of unused, expired, or just-in-case medicines and 2,301 individual items were recorded, including 1,424 unused. Necessary disposal behaviours were not always affected by the risks that were identified by the participants, including accidental ingestion or loss of efficacy. Instead, people were likely to make personal judgments of risk-benefit instead of taking professional advice. Similar results were highlighted in the Polish pilot study by PIEKARA (2025), who found large quantities of unexpired drugs in garbage containers in their study- international trends include over-purchasing and lack of literacy in disposing of those drugs.

Taken together, these papers prove the existence of knowledge gaps throughout the gap between undergraduate education and professional practice, as well as between professional practice and household behaviours. The issue of environmental sustainability is marginalized in health training curricula and is inadequately covered in workplace training.

Based on this, there is a need to explain the geographical area of studies that are used in this review. Some of them were Australian-hospital pharmacy practices (Singleton et al., 2018; 2021; 2023), household medicine disposal (Kelly et al., 2018), radiography waste practices (Taylor et al., 2025; MacDonald et al., 2024), and community pharmacy services (McMillan et al., 2021). There were also a number of international yet conceptually related sources, such as green manufacturing studies in Malta (Gauci, 2024), domestic disposal wisdom in Poland (PIEKARA, 2025), and international policy studies (Jairoun et al., 2025). These non-Australian research studies are very critical in offering comparative and theoretical frameworks, which underscore gaps in the system in Australia.

4.3.2 Policy and Regulation

At the policy level, sustainability frameworks are neither uniform nor coherent, nor are they properly integrated. Jairoun et al. (2025) identified comparable fragmentation in the world system of sustainable-medicine governance, and such gaps exist in Australia, especially in the execution of the national Return Unwanted Medicines (RUM) program. Indicatively, Singleton et al. (2023) conducted their investigation in a tertiary hospital pharmacy in a metropolitan area in Queensland. In contrast, previous research by Singleton et al. (2018, 2021) was conducted in five public and one private hospital located in Queensland and, comparatively, in the UK. The problem with RUM is low public awareness, uneven adoption, and limited promotion, particularly in rural and culturally diverse communities (Chen et al., 2023; Gabriela et al., 2022). Such gaps are caused by structural barriers like low pharmacy throughput, limited disposal messaging, and the lack of regulatory standards that can be enforced.

Integration is also lacking in regulatory oversight of clinical practice. Adeyeye et al. (2022) emphasizes that eco-pharmaco-stewardship is an aspect of prescribing, monitoring, and deprescribing, rather than a waste-management practice at the end of the chain. Murdoch (2015) also stated that the Australian, New Zealand, and Pacific wastewater systems are not configured to eliminate the residues of pharmaceuticals, and currently, there are no binding environmental standards.

In healthcare organizations, policy penetration is a go-through. Barraclough et al. (2019) found that, despite most Victorian dialysis units having an environmental sustainability policy, not all had active green groups or systematic sustainability programs. Comparably, although there are carbon-reduction targets established in the UK, Singleton et al. (2021) carried out research that did not find significant evidence of pro-environmental behaviours in pharmacy departments, which might be caused by policy directives alone, without workplace culture and compliance tools.

All of these studies reveal a lack of cohesion between policy purpose and practice, and suggest that more regulation, distinct guidelines and coordinated action across health sectors are required.

4.3.3 Impact on the environment and health

Poor disposal of medicines has negative environmental effects. Murdoch (2015) reported the presence of over 200 pharmaceutical compounds in Australian and New Zealand water bodies, marine sediments, and biosolids. Pharmaceuticals persisted despite mature wastewater treatment, and antibiotics in effluents induced antimicrobial resistance in environmental bacteria.

Contamination of the healthcare facilities was also a major issue. Singleton et al. (2023) reported the mis-segregation of recyclable waste into recycled clinical-waste streams in Queensland, resulting in unnecessary incineration and carbon emissions. Taylor et al. (2025) and MacDonald et al. (2024) found that between 9.7 and 17.1 per cent of radiographers disposed of contrast agents via drains, posing a significant long-term risk of waterway contamination.

Similar challenges were experienced in households. That report by Kelly et al. (2018) identified unsafe disposal practices through the dumping of medicines in domestic waste or sewers. PIEKARA (2025) found that these behaviours incur ecological and economic costs.

On the whole, the results reveal that inadequate disposal leads to environmental deterioration, antimicrobial resistance, wastage, and carbon emission.

4.3.4 Barriers and Facilitators

Structural, educational, financial, and cultural barriers to sustainable practice existed. Basic waste-segregation facilities, such as recycling bins in dispensing areas, were often lacking in hospitals (Singleton et al., 2023). Radiographers lacked training and were not confident in proper disposal practices (Taylor et al., 2025; MacDonald et al., 2024). ESPP material was still largely absent from pharmacy education (Singh & Gurudiwan, 2024), and waste management was not considered relevant to pharmacists' profession (Singleton et al., 2021). Another obstacle to manufacturing sustainability was financial barriers; small companies were unable to adopt green chemistry due to high costs and regulations (Gauci, 2024).

Despite these obstacles, facilitators point to concrete ways of improvement. Singleton and Letts (2025) demonstrated that a co-designed behavioral intervention at a rural Queensland hospital led to a decrease of 2 tons of CO2 being straightforwardly sent to landfill in 3 months, and to thousands of containers being removed from waste streams. Recycling was already practiced in Victorian dialysis units (Barraclough et al., 2019), and community pharmacies in Queensland and Western Australia were placed to increase their sustainability-related functions (McMillan et al., 2021). The greenness-assessment tool provided by Gauci (2024) provides a transferable framework of sustainable pharmaceutical production.

Table 4: Thematic summary of findings

Theme	Key Findings	Supporting Studies	Australian Context (State/Setting)
1. Awareness and Knowledge of Medicine Disposal	• Low awareness of correct disposal methods among healthcare professionals and students. • Confusion about waste segregation and environmental impacts. • Public accumulation of unused/expired medicines common.	Singh & Gurudiwan (2024); Singleton et al. (2018); Kelly et al. (2018); Taylor et al. (2025); MacDonald et al. (2024)	• Pharmacy undergraduates nationwide (Australia). • Hospital pharmacies in Queensland. • Australian households (national study). • Radiology departments (public & private nationwide).

2. Policy and Regulation	• Lack of consistent uptake of sustainability policies despite frameworks. • Limited staff awareness of state-based waste rules. • Need for stronger national regulation on pharmaceutical pollution.	Singleton et al. (2021); Jairoun et al. (2025); Murdoch (2015)	• Hospital pharmacies in Queensland; UK–Australia comparison. • Australian wastewater and biosolid contamination documented.
3. Environmental and Health Impacts	• Pharmaceuticals detected in waterways, soil, and wastewater systems. • Radiological and contrast agents improperly discarded into drains. • Risk of antimicrobial resistance and ecosystem disruption.	Murdoch (2015); Taylor et al. (2025); MacDonald et al. (2024); Adeyeye et al. (2022)	• Environmental sampling in Australia and New Zealand. • Radiology departments across Australia. • Climate-health impact applicable to Australian health sector.
4. Barriers to Sustainable Practices	• Lack of recycling bins, unclear guidelines, poor environmental knowledge. • Limited resourcing, financing, and organizational prioritization. • Limited curriculum inclusion of sustainability topics.	Singleton et al. (2023); Gauci (2024); Singh & Gurudiwan (2024)	• Queensland hospital pharmacy department. • Pharmacy undergraduates across Australia. • API manufacturers (Malta—model relevant for Australia).
5. Facilitators and Enablers	• Existing recycling systems in dialysis units. • Community pharmacies positioned to expand sustainable services. • Tools such as greenness assessment frameworks for greener manufacturing. • Multi-disciplinary engagement improves hospital sustainability performance.	Barraclough et al. (2019); McMillan et al. (2021); Gauci (2024); Singleton & Letts (2025)	• Dialysis units in Victoria. • Community pharmacies in Queensland & Western Australia. • Rural hospital in Queensland demonstrating CO_2 reduction through recycling initiatives.

5. Discussion

This scoping review identifies a shocking mismatch between the recognized environmental impact of medicines and the maturity of systems that can manage them in a sustainable way. In education, clinical practice, policy, and manufacturing, these indications are patchy and ad hoc in nature, instead of a concerted strategy on sustainable management of medicine. Meanwhile, the papers consulted also present clear opportunities and practicable levers that can be used to support a Green Medicines Framework adapted to the Australian environment.

One of the points that can be identified is the widespread lack of environmental literacy among future and present health professionals. In the Australian pharmacy student population, nearly all participants in the study by Singh and Gurudiwan (2024) had experienced the general understanding of environmental sustainability, although fewer than 12% had heard of environmental sustainability in pharmacy and the pharmaceutical

practice, and fewer than 8% had read related materials in their course. The same trend is reflected in hospital pharmacy and radiology workplaces. Singleton et al. (2018, 2021) demonstrated that pharmacists and technicians did not have skills of systems-thinking or a clear understanding of the impact of pharmaceuticals on the environment, whereas many radiographers in MacDonald et al. (2024) and Taylor et al. (2025) were unaware of the environmental impact of contrast media and the most effective disposal practices. Comparing it to the international views, such as the eco-pharmaco-stewardship framework developed by Adeyeye et al. (2022) in the UK, it becomes clear that the Australian practice has not yet implemented the eco-reflective approach to prescribing, dispensing, and daily clinical decision-making.

Another implication of the findings is that the policy frameworks, though more visible at the high level, are yet to be translated into consistent practice. Jairoun et al. (2025) show that the world of sustainable medicines usage is developing, and both green chemistry and regulatory strategies are being considered; however, at the same time, disintegration and the necessity to have a more integrated approach to governance are noted. The analysis of the pharmaceutical pollution in Australia, New Zealand and the Pacific by Murdoch (2015) also supports this issue as the author records the detection of pharmaceutical pollution in the treated wastewater, rivers and biosolids, without any special environmental standards regarding pharmaceutical residues. The disparity between policy purpose and practice is quite clear within facilities. Barraclough et al. (2019) discovered that not all Victorian dialysis units had an environmental sustainability policy, and only a small number of units practiced a structured green project. Even where mandatory, Singleton et al. (2023) demonstrated that in hospital pharmacy departments, despite the presence of a waste reduction and recycling plan, large portions of recyclable or non-contaminated material still find their way into clinical and confidential waste streams, which are related to gaps in infrastructure and misunderstandings.

International comparison postulates that high-level policy by itself is inadequate. Singleton et al. (2021) found no significant difference in the pro-environmental behaviours of the Australian hospitals and the UK hospitals that were working on the basis of the legislated carbon reduction targets. Workplace norms, perceived role boundaries, and auditor-driven compliance had a greater effect than carbon policy and not all UK pharmacists even considered waste management as part of their professional responsibility. The result is in line with international appeals, including that by Adeyeye et al. (2022), to shift beyond symbolic sustainability rhetoric to operational eco-pharmaco-stewardship as the work of clinical roles, incentives and organizational culture.

The available evidence related to environmental and health effects highlights the need to have such reform. Murdoch (2015) reports over 200 of these pharmaceutical compounds in the environmental media, including in Australian wastewater that would be recycled, and their impact on aquatic environments, soil, and antimicrobial resistance. On the practice level, draining radiopharmaceuticals and contrast agents through the drains, like the case reported by Taylor et al. (2025) and MacDonald et al. (2024), is a direct and avoidable source of contamination. Both massive amounts of unutilized or expired medicines and dependence on individual risk-benefit analysis, as opposed to the advice of a professional or take-back program, are demonstrated in the homes of Kelly et al. (2018). When the PIEKARA (2025) pilot in Poland discovered that there were huge amounts of unexpired medicines in the disposal bins, it was proposed that it is not a solely Australian trend but rather a global one. Combined, these results join the rest of the international literature that has found excretion, poor disposal, and lack of treatment capacity to be major contributors to pharmaceutical pollution.

Although these challenges have been found in the literature, a number of facilitators show how significant improvements can be made concerning the sustainable management of medicine. Gauci (2024) shows that a few active-pharmaceutical-ingredient (API) and finished-dosage-form manufacturers already have implemented green pharmaceutical practices, including green solvents, solvent-recovery systems, wastewater-treatment technologies, and one-pot synthesis, and have a proven greenness-assessment tool to benchmark synthesis pathways. On the organizational level, Singleton and Letts (2025) explain the formation of environmental benefits by co-designed behavioral interventions, which consequently resulted in the achievement of significant carbon and landfill avoidance of thousands of containers in their rural Queensland hospital project; they did it with the Behavior Change Wheel and the Theoretical Domains Framework in mind. Equally, McMillan et al. (2021)

demonstrate community pharmacies are in a position to increase their harm-minimization functions, which implies their viability as community-based sources of sustainable medicine programs like consumer education and return programs. These instances can be associated with the global trends of green chemistry, regulation innovation and cross-sectoral cooperation outlined by Jairoun et al. (2025) that demonstrate that successful change is possible even in the context of resource constraints when interventions are localized and led by local actors.

There are, however, limitations with the current evidence base. A large part of the literature is localized, one-site or one-discipline research, which limits generalization and does not allow for accurate estimation of pharmaceutical waste or contamination nationally. Outstandingly, the environments that are under-researched are aged-care, primary care, and rural community settings, which are high-consumption environments. High dependence on self-reported attitudes leads to recall and social-desirability bias, and the amount of research on intervention is minimal; most researches pinpoint problems and does not assess solutions. The contribution of Gauci (2024) enhances the current knowledge on manufacturing sustainability, but it is geographically limited, and how the principles of green chemistry can be applied to the Australian industry is under-researched. Despite these limitations, the literature provides guidance for a sustainable medicines model. It highlights the necessity to integrate environmental sustainability and ESPP content into health curricula; national policy into organizational policy, e.g., consistent waste-segregation infrastructure, and a lifecycle-based Green Medicines Framework, i.e. the connection between green manufacturing, eco-pharmaco-stewardship, the use of stronger take-back systems and behavior-change interventions through local champions.

6. Framework Development implications

The results of the scoping review indicate that sustainable management of medicine in Australia should be addressed system-wide and in a structured manner. Despite some individual projects proving to be effective, the facts show that there is a significant lack of cohesion in education, practice, regulation and general behavior. Using the literature mapped, it is possible to suggest a conceptual Australian Green Pharmacy Framework that will bring together key elements required to improve environmental sustainability throughout the medicine's lifecycle.

Notably, the framework below is conceptual and developed out of a synthesis of other studies as opposed to empirical validation. It is to inform policy-making in the future, conduct pilot interventions and cross-sector implementation.

The first fundamental aspect is community education and involvement of consumers, which the evidence has cited as a chronic weakness. Research on the retention and disposal of household medicine (Kelly et al., 2018; PIEKARA, 2025) indicates that consumers tend to stockpile large quantities of unused medications and do not know how to dispose of them correctly. It should be provided in a system of countrywide programs of education that should be conducted through pharmacies, general practice, hospitals, and online health platforms. These programs are to encourage reasonable use of medicine, create awareness of the environmental degradation caused by improper disposal and to strengthen the involvement in the available take-back programs like the Return Unwanted Medicines (RUM) program. Messaging to the public may also be reinforced through incorporating environmental stewardship in the counselling duties of pharmacists in dispensing.

The second pillar is waste separation and infrastructure enhancement in healthcare organizations, which entails hospitals, aged care, radiology, and community pharmacies. Hospital pharmacy audit (Singleton et al., 2023) and radiology department tests (MacDonald et al., 2024; Taylor et al., 2025) evidence proves that waste is often mis-segregated, no one is aware of how to dispose of it, and no relevant bins can be found in strategic locations. A Green Pharmacy Framework in Australia would harmonize pharmaceutical waste types, formulate countrywide uniform segregation guidelines and mandate healthcare institutions to install sufficient recycling, clinical and pharmaceutical waste containers in all medicine-use-points. With the infrastructure, the visual signage, and frequent staff training, it would have been good to ensure that the segregation of the waste is as intended by the policy.

The third element is associated with safe collection, transport and processing systems, and more consistent coordination is necessary. Despite the significance of the RUM program as a national initiative, the literature indicates that there is inconsistent awareness in communities and that there is little unity with other

sustainability initiatives. An enhanced system would locate collection systems into a lifecycle framework linking them to prescribing, deprescribing, stock management and pharmacy workflow. The opportunities can be the inclusion of additional drop-off points, mobile take-backs in rural populations, or an inclusion in digital platforms that will notify consumers of medication expiry.

Another focal point is the regulatory control and governance. Although research like Jairoun et al. (2025) indicates that the world is becoming more interested in sustainable pharmaceutical regulation, the Australian evidence indicates that the translation of policy into practice is minimal. A framework in Australia may suggest standards of regulation on the management of pharmaceutical residues in wastewater, the minimum sustainability standards of the hospital waste plan, and environmentally preferable procurement incentives. Also, regulatory levers can promote the implementation of green chemistry in the manufacturing process, which can be considered in line with Gauci (2024) and world trends as observed in bibliometric studies.

One more pillar that underlies is multi-sector collaboration, which is always highlighted throughout the literature examined. The sphere of sustainable medicine management is the intersection of industry, clinicians, consumers, regulators and environmental agencies. A viable framework implementation would involve collaborations among educational institutions, manufacturers, health care providers, pharmacy organizations, waste services, and community organizations. Co-designed and collaborative interventions, like the rural hospital recycling project by Singleton and Letts (2025), prove to be extremely valuable, as evidenced by their success. Pilot programs in the future might be used to determine the feasibility of integrated sustainability interventions at metropolitan and rural hospitals, community pharmacies and primary care settings.

In general, the suggested Australian Green Pharmacy Framework integrates the knowledge in the education, clinical practice, manufacturing, environmental science and organizational behavior. It gives a conceptual map to help refine policies, lead on pilot work and mobilize nationally to help lessen the environmental impact of medicines. Evidence might be continually updated to make this framework operationalized and revised to incorporate a concept of sustainability as a fundamental part of pharmaceutical care throughout Australia.

7. Conclusion

This scoping review proves that although the environmental sustainability concerns associated with the medicines are gaining awareness, there are still considerable gaps in the Australian healthcare system. The studied articles provide little information to the pharmacy students, pharmacists, radiographers and consumers regarding the environmental effects of pharmaceuticals and how they should be disposed of. Simultaneously, the lack of uniformity in waste sorting and the lack of policy translation and fragmentation in the implementation of sustainability programs are also causes of continued environmental pollution and avoidable healthcare waste. The status of international literature on the subject of pharmaceutical pollution is global and argues in favor of the necessity of urgent action.

Nevertheless, the review also highlights several positive developments that reinforce the critical importance of building environmentally responsible pharmacy systems. Innovations in green chemistry, the expansion of recycling programs within hospitals and community settings, and emerging models of eco-pharmaco-stewardship demonstrate that meaningful progress is both feasible and already underway. These initiatives show that when supported by targeted education, adequate infrastructure, and coordinated multi-sector collaboration, pharmacy services can significantly reduce their ecological footprint. Importantly, these findings emphasize that integrating environmental responsibility into routine pharmaceutical practice is no longer optional but essential for safeguarding public health, reducing waste, and ensuring long-term sustainability of the healthcare system. Building such ecologically responsible pharmacy systems is vital not only for minimizing environmental harm but also for promoting efficient resource use, reducing carbon emissions, and aligning pharmacy practice with broader national and global sustainability goals.

Not only do ecologically responsible pharmacology systems minimize ecological damages, but they also safeguard the populace and coordinate the healthcare activities with climatic and sustainability objectives. The idea of the Australian Green Pharmacy Framework developed in this review gives grounds to create more sustainable systems of medicine management. To realize this vision, it would need integrated policies, enhancement of regulatory oversight, increased education opportunities and continuous research to aid

education opportunities and continuous research to aid in evidence-based implementation. The industry, government, clinicians and consumers will be essential in continuously engaging in the quest to help create a greener, safer and more sustainable future in the use of medicines in Australia.

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