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NEPHROLOGY – ORIGINAL PAPER

Advancing green nephrology: a scoping review of sustainability interventions in kidney care

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Abstract

Objective To map and synthesise existing interventions aimed at improving environmental sustainability in kidney care and to identify challenges and opportunities for implementation across treatment modalities.

Design Scoping review following PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) methodology. The study merged two existing frameworks to form appropriate review questions.

Data sources Embase, MEDLINE, Scopus, and CINAHL alongside relevant grey literature, searched in September 2024.

Eligibility criteria for selecting studies The review included studies from 1 January 2005 to 30 September 2024 that reported on environmental sustainability interventions in kidney care, including chronic kidney disease, haemodialysis, peritoneal dialysis, kidney transplantation, and conservative management and that provided measurable or descriptive information about the intervention. Conference abstracts and opinion pieces without intervention data were excluded.

Results Out of 2,512 records screened, 95 studies were included. Environmental interventions were most commonly implemented in haemodialysis ($n=58$), followed by chronic kidney disease ($n=19$), transplantation ($n=6$), peritoneal dialysis ($n=5$), and conservative management ($n=1$). Some studies addressed multiple modalities; therefore, categories are not mutually exclusive. The most frequent sustainability categories were water use, waste management, procurement optimisation, energy efficiency, and travel reduction. Interventions ranged from dialysate flow reduction and RO water reuse to telemedicine and supply chain redesign. While many demonstrated environmental and economic benefits, reporting was heterogeneous, and studies were concentrated in high-resource settings.

Conclusions There is growing interest in sustainability within kidney care, particularly in haemodialysis. However, adoption across other modalities remains limited. Future work should prioritise underrepresented areas, standardise metrics, and ensure inclusion of low-resource contexts. Co-design of interventions with patients and staff, combined with consistent reporting using frameworks such as SQUIRE 2.0, is essential. Integration of sustainability into clinical practice and policy is urgently needed to align kidney care with global climate and health goals.

keywords Advancing green nephrology · Sustainability interventions · Kidney care · Environmental sustainability · Chronic kidney disease · End-stage kidney disease · Haemodialysis · Peritoneal dialysis · Kidney transplantation · Conservative management

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Introduction

Chronic Kidney Disease (CKD) is a growing global health concern, affecting around 10% of the European population [1]. It is projected to increase to 18% of the population in some countries by 2040 and 28% by 2100 [2, 3]. Sustainability in nephrology matters not only due to the high environmental intensity of treatment modalities such as haemodialysis (HD), but also because kidney care is a growing global health burden. Green nephrology can reduce healthcare emissions, preserve resources, and improve health equity by ensuring resilient, low-carbon models of care [1, 4]. As patients progress to end-stage kidney disease (ESKD), treatment choices differ in environmental impact. In-centre haemodialysis has the highest documented life-cycle emissions and resource use per patient year. Kidney transplantation has substantially lower long-term emissions than in-centre haemodialysis, though peri-operative and pharmaceutical stages contribute to its footprint. Peritoneal dialysis typically falls between home and centre-based options depending on context. The annual carbon footprint for a patient receiving thrice-weekly HD is estimated at 3.8–10 tonnes of Carbon Dioxide Equivalent (CO_2e), which is substantially higher than the per capita healthcare emissions in many countries [5, 6]. This is mostly due to high energy consumption and substantial waste generation. Studies have shown that patient and staff transportation also contributes significantly to the carbon footprint of dialysis units, adding up to 25–30% to the total carbon footprint of HD, particularly in in-centre models with long travel distances [5, 7]. High volume of water use for dialysis presents an additional environmental impact [8].

With over 2.6 million people receiving dialysis globally as of 2020 and projections suggesting this may rise to 7 million by 2030, the environmental footprint of kidney care is expected to grow significantly [9, 10]. As of December 2022, 56% of prevalent kidney replacement therapy patients in Europe were receiving HD and 5% receiving peritoneal dialysis (PD), representing over 346,000 individuals on dialysis in total, a figure driven by ageing populations and rising rates of diabetes and hypertension [11]. Although technological advances have led to more efficient and home-based therapies, these have not consistently translated into lower environmental impact. The implementation of green nephrology initiatives remains limited, largely due to economic and regulatory barriers such as high upfront costs, lack of financial incentives, and the absence of specific guidelines or mandates for environmental performance [12].

With kidney care contributing a substantial amount of healthcare-based greenhouse gas (GHG) emissions, interventions reducing kidney care's carbon footprint would positively impact overall healthcare emissions. Modelling from England indicated measurable reductions in emissions following sustainability interventions at renal centres [13]. While this analysis was specific to England, similar opportunities are likely across Europe: applying comparable process optimisations across EU kidney centres would be expected to yield substantially larger absolute carbon savings, given the higher number of patients treated and dialysis facilities in operation. In practice, sustainable kidney care interventions have already been documented in multiple European countries, targeting clinical transformation, procurement, waste management, water use, and energy efficiency. This scoping review explores sustainable process optimisations and technological interventions implemented globally in kidney care to reduce its environmental impact alongside identifying key challenges and opportunities.

Materials and methods

Search strategy

A scoping review was performed to identify literature exploring environmentally sustainable interventions in kidney care. This scoping review followed the PRISMA-ScR methodology that systematically searches and reports on scoping reviews [14]. The search was conducted in September 2024 using the databases of Embase, MEDLINE, Scopus, CINAHL alongside grey literature aligning with the search terms, such as case studies on sustainable kidney care interventions. Keywords and phrases that were used in the search included: chronic kidney disease, end-stage kidney disease, renal care, kidney care, environmental impact, dialysis, carbon footprint, environmental sustainability, optimisations, systematic review, hospitals, dialysis units, greenhouse gas emissions, life cycle assessment. The exact search strategy can be found in Appendix 1.

This study is focussed on the overall environmental impacts of kidney care and has reviewed initiatives that reduce the environmental impact of ESKD and its pathways, including HD, PD, transplant, and conservative care. The settings considered were hospitals, dialysis units or renal centres and home in the case of home-based dialysis treatments.

We searched grey literature through the Centre for Sustainable Healthcare, NHS sustainability pages, and professional repositories. We did not employ CADTH 'Grey Matters' due to the domain-specific nature of renal sustainability sources. Search terms and procedures are detailed in Appendix 1.

Study selection

The screening of all abstracts identified in the search was done independently by two reviewers (A.Y and J.L) from September to November 2024. Both reviewers met to resolve any discrepancies and confirmed the list of papers to be included in the full paper review stage. The same two reviewers then conducted full text screening of the papers that were included in this stage. A third reviewer (M.A) was asked to resolve any discrepancies.

Data extraction

Covidence was used as the online software tool for managing the scoping review process. Data extraction was conducted by the same two reviewers. Covidence was used for reference import, automatic deduplication, blinded dual screening, and consensus management. The platform facilitated title and abstract screening, full-text review, and data extraction. Data fields were pre-defined within Covidence, allowing export to Excel for charting and synthesis. Reviewer decisions and exclusion reasons were recorded directly in the system to maintain an audit trail.

Reviewers used standardised questions to extract information from the papers. General information on the paper such as the title and authors was noted, alongside a description of the intervention, the sustainability category the intervention fit into and the modality of kidney disease it aligned with. Data on the environmental impact (e.g. CO_2e reductions) and reported outcomes were also extracted. Economic and social aspects were also considered.

Two existing frameworks were used as a guide to shape the review questions: the Non-adoption, Abandonment, and challenges to Scale-up, Spread, and Sustainability (NASSS) framework alongside The Centre for Sustainable Healthcare's (CSH) Green Team Competition Success Factors criteria.

The NASSS is a framework developed to systematically evaluate the outcomes of complex innovation projects in health and social care [15]. The framework specifically analyses non-adoption, abandonment, scale-up, spread, and sustainability. It includes seven domains: the technology, the adopters, the wider system, the condition, the value proposition, the organisation(s) embedding and adaption over time. The NASSS allows domains to be graded from complex to simple where more complex projects can be deemed as more likely to fail and provides a guide for implementing useful strategies. Figure 1 displays a visual of the NASSS framework.

The CSH's Green Team Competition Success Factors include 4 categories: people, process, resources and context. For people, it evaluates the involvement of patients, engagement of staff, cross-departmental communication, and support of senior leadership. For process, it analyses the level of guidance, strategy incentives, measurable targets, long-term strategy, and integrations into natural workflow. For resource, it evaluates the dedicated time, the degree of quality improvement training, infrastructure and equipment availability, evidence of implementation success elsewhere, and financial investment. Lastly for context, it looks at whether the aims align with the wider service, if it links to patient and staff benefits, and the organisational permissions, capacities and culture [16].

With the integration of the two frameworks, the reviewers came up with the following questions to assess the process optimisations and technological interventions:

- Does the paper discuss the optimisation/ technology and have information on the level of certainty by staff on what the optimisation is, where it comes from, its performance, usability, acceptability, any required adjustments to routine, and research evidence of change successfully implemented elsewhere?
- Does the paper discuss the organisation's capacity and permissions, readiness for the change, ability to finance the investment, whether it is easy to embed the change to normal routine and workflow, the team functions, the IT and infrastructure to provide teams with data, equipment and dedicated time, the training and support process for the quality improvement, incentivisation of strategies, and clear guidance and evidence?
- Does the paper have information on the value proposition including its commercial value, the benefit to staff, patients and the healthcare system, whether there are any links to clinical outcomes, whether the aims aligned with wider service, organisational or system goals?
- Does the paper mention who the intended adopters are and the certainty level about how staff and patients will adopt the optimisation, any long-term strategies for embedding change at outset, measurable targets, systematic and coordinated approaches, support from senior leaders, team agreement on the changes being suitable, skills/capability of staff, MDT/cross-departmental communication, staff and patient engagement?
- Does the paper talk about the external context including adversity/conduciveness: political, professional bodies, patient groups, regulatory, commercial context, limited learning from others?

Furthermore, the inclusion criteria followed in this review were:

- Studies assessing environmental interventions in kidney care around the world.

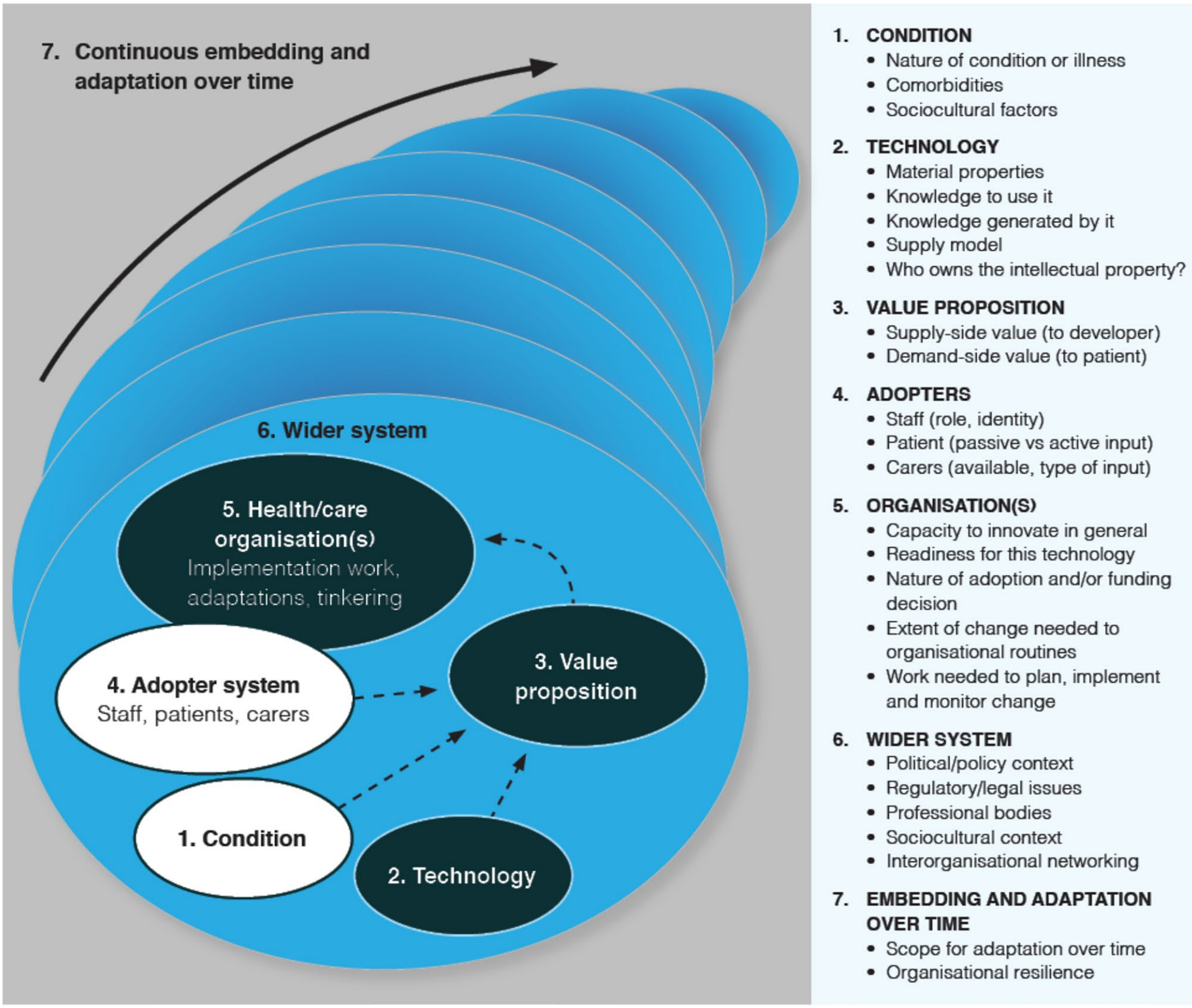


Fig. 1 NASSS Framework, from Greenhalgh T, How to improve the success of technology projects in health and social care

- Articles evaluating carbon footprint reduction strategies in kidney care and its pathways, including HD, PD, transplant, and conservative care.
- The settings considered were hospitals, dialysis units, renal centres or home settings for home based treatments.
- Papers addressing implementation challenges for sustainable kidney care practices.
- Papers published after the year 2005. This was decided as the number of papers published on the topic increased significantly from this point onwards, reflecting more focus on the area. The reviewers therefore thought that papers before this date may not align with contemporary perspectives.
- This review focussed on interventions explicitly designed or reported to improve environmental sustainability in kidney care. Broader nephrology studies addressing sustainability indirectly, such as deprescribing or laboratory stewardship, were excluded from the main dataset but are cited in the Discussion for context. Papers needed to include an identifiable intervention; purely descriptive or editorial material was excluded

The exclusion criteria followed in this review were:

- Conference abstracts
- Opinion pieces or call for action papers with no actual intervention
- Studies not explicitly related to kidney care sustainability
- Studies before the year 2005

Results

Study selection

A total of 2,512 records were identified through electronic databases including Embase ($n=867$), MEDLINE ($n=847$), Scopus ($n=685$), CINAHL ($n=51$), and grey literature ($n=62$). After the removal of 12 duplicates, 2,500 records were screened by title and abstract. Based on the inclusion criteria, 221 studies were chosen to assess for eligibility, leading to the exclusion of 2,255 articles. Upon the full paper review of the 221 studies, 95 papers were deemed suitable to include in the scoping review, further excluding 126 articles (Fig. 2).

Distribution by modality

Most studies focussed on interventions in HD ($n=58$), followed by CKD ($n=19$), transplantation ($n=6$), PD ($n=5$), haemodiafiltration (HDF) ($n=3$), and very low kidney function care (VKD)/ conservative care ($n=1$) (Fig. 3). This distribution reflects both the high environmental burden of HD and the relative availability of interventions documented in the literature. Nevertheless, several relevant initiatives were identified across all modalities.

Sustainability categories and type of interventions

The 95 included studies were mapped into 16 sustainability categories, grouped by categories (Fig. 4). The most frequently addressed categories were:

- Water use ($n=18$): including reverse osmosis (RO) water reuse for non-clinical purposes like cleaning and sanitation [8, 17–33].
- Waste management ($n=17$): such as improved clinical waste segregation, plastic reduction, and packaging redesign [34–49].
- Procurement optimisation ($n=11$): including high-ratio concentrate solutions (e.g. 44:1, central acid delivery), reusable containers, and environmentally preferable materials [50–60].
- Travel-related emissions ($n=9$): mainly tackled via telemedicine, home-based care, and virtual consultations [61–69].
- Policy ($n=8$): targeting changes in institutional governance, reporting frameworks, and integrated sustainability planning [70–77]
- Energy efficiency ($n=7$): including dialysate flow reductions, LED lighting, solar energy installations, and heat exchangers [78–84].
- Reuse ($n=6$): e.g. filters, or durable items [32, 85–89]

Other less frequent categories included treatment pathway redesign and pharmaceutical waste reduction [90–107].

No included study directly compared the scale of environmental savings between different renal replacement modalities.

Haemodialysis

HD related sustainability interventions were the most frequent and diverse, spanning all sustainability categories. Key strategies included:

- Clinical transformation through remote consultations (e.g. phone clinics, asynchronous platforms like *Patients Know Best*), reducing unnecessary travel and facilitating patient-centred care.
- Supply chain optimisation, such as:
  - Central Acid Delivery Systems to eliminate single-use containers
  - High-concentration acid solutions (e.g. 44:1), reducing packaging and shipping needs [91]
  - Packaging redesigns using low-density polyethylene (LDPE) to reduce plastic use [5]
- Water efficiency, primarily through reuse of RO reject water for non-clinical applications, avoiding potable water waste [19, 23, 25, 35].
- Energy savings, including:
  - Dialysate flow reductions from 500 to 400 mL/min [93, 94, 105, 108]
  - Solar-assisted dialysis [29, 80].
  - Heat recovery systems and efficient lighting [82].
- Waste management, with interventions in material segregation, medication waste reduction, and infrastructure changes [34, 40, 106, 107].

Chronic kidney disease

In CKD settings, interventions targeted upstream practices, often involving paper use reduction, pharmaceutical waste management, and remote monitoring. Key findings include:

- Paperless systems and automation of lab results, reducing material use and clerical errors [47]
- Medication optimisation: better prescribing, stock management, and deprescription practices aimed at reducing unused drugs [106, 107]

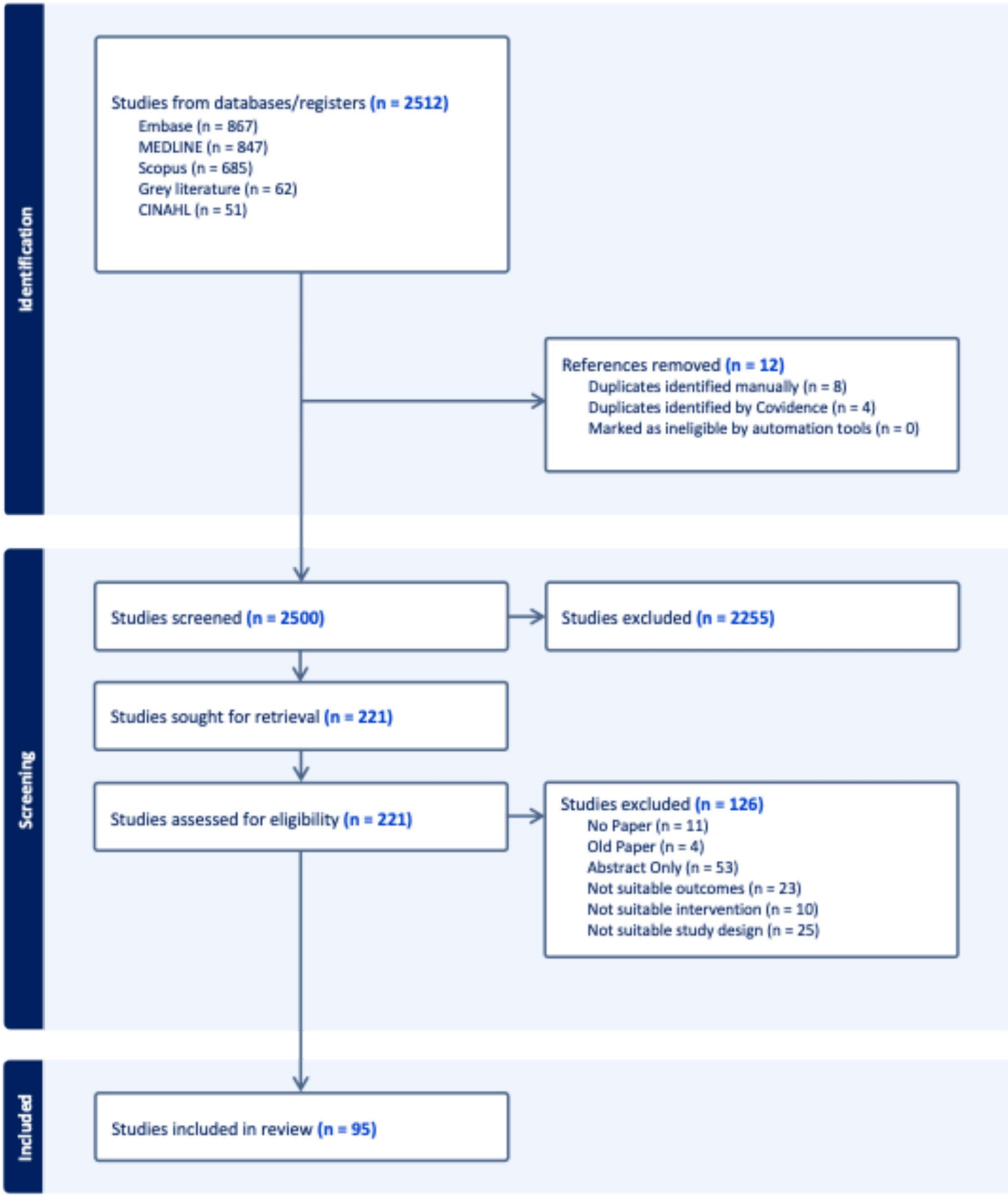


Fig. 2 PRISMA Flow Diagram

- Travel reduction strategies such as remote care pathways (e.g. home BP monitoring, digital records), virtual check-ins or community-based services were also observed in some nephrology clinics resulting in improved access while reducing emissions associated with it [67, 68, 109, 110]

Fig. 3 Number of optimisations by modality

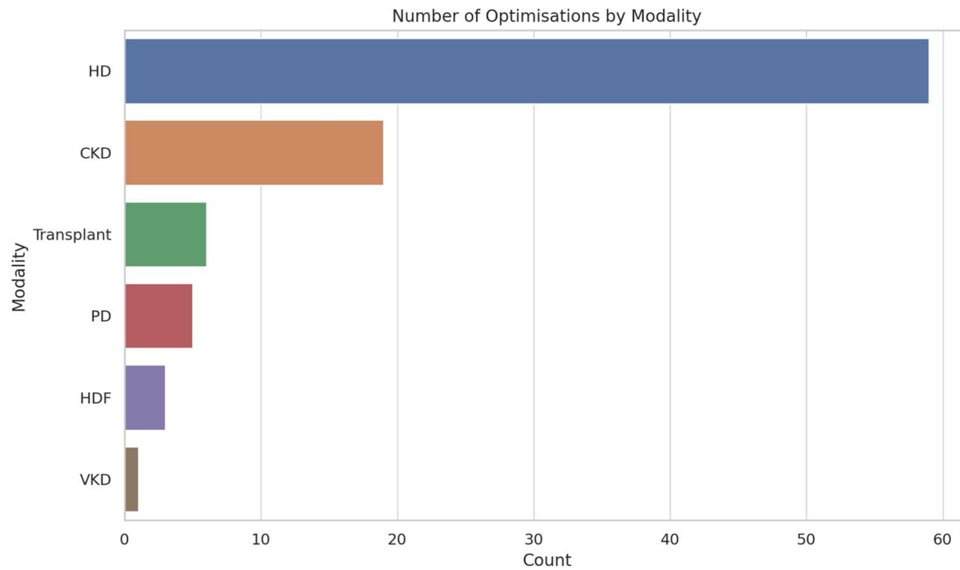
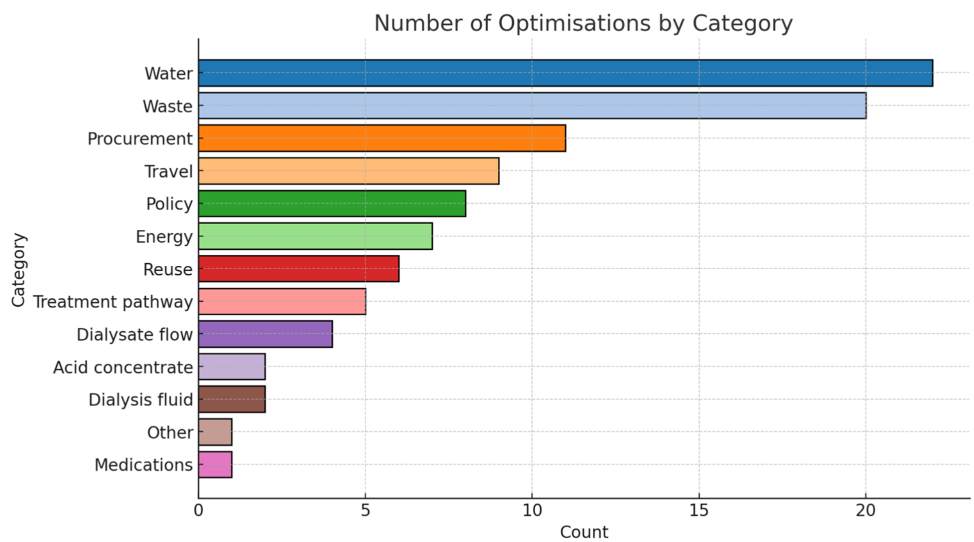


Fig. 4 Number of optimisations by sustainability category



Transplantation

Few studies focussed specifically on transplant settings, but those included:

- Digital tools to coordinate pre- and post-transplant care [61, 63]
- Efforts to optimise medication use and delivery logistics [65]
- Education platforms and teleconsultation services that allowed stable patients to be managed closer to home [62, 69]

In the UK, the number of transplant recipients exceeds that of patients receiving in-centre HD.

Peritoneal dialysis

PD was underrepresented despite being a home-based and potentially lower-impact modality. Notable examples included:

- Delivery optimisation to reduce packaging and shipment frequency [64]
- Local storage and reuse of packaging materials [43, 44]
- Training adaptations to encourage environmentally conscious practices (e.g. appropriate disposal of dialysate bags and medication vials) [38]

One study addressed energy savings in PD cyclers, although data were limited [42].

Haemodiafiltration and conservative management

HDF is a refinement of HD, and most process-based interventions described for HD are also applicable to HDF, though water use is typically higher.

Only a few studies were explicitly focussed on HDF, with interventions similar to those in HD regarding flow rates, energy usage, and waste minimisation [103, 111]. VKD patients (very low kidney function opting for conservative management) were the least represented, with only one mention related to telemedicine and home monitoring [68].

Settings

Most HD studies were conducted in tertiary and satellite hospital units in high-income countries, with a minority involving home therapies. PD studies were mainly home-based. Transplantation interventions occurred in tertiary centres and telehealth-supported follow-up programmes. Chronic kidney disease studies focussed on outpatient or community nephrology services.

Distribution by review questions

When analysed in light of the review questions derived from the integrated frameworks (NASSS and CSH's Green Team Success Factors), a clear pattern emerges (Fig. 5). Each study was assessed against five domains—*Technology*, *Organisation*, *Value Proposition*, *Intended Adopters*, and *External Context*. For each domain, we recorded a "yes" if the paper provided information relevant to that domain (e.g. describing a technological optimisation, organisational readiness, value for patients or health systems, intended adopters, or contextual enablers/barriers). Figure 5 therefore illustrates the number of studies that addressed each domain ("yes counts") across different kidney care modalities, showing where evidence is more concentrated and where it is comparatively lacking. The majority of interventions were mapped under the Technology and Value Proposition domains, particularly in haemodialysis, reflecting the strong emphasis on equipment-level optimisations, process efficiencies, and demonstrable environmental and economic gains. Organisation and External Context followed a similar trend, again with haemodialysis predominating but also notable contributions from CKD-focussed interventions, which often addressed broader systemic or upstream factors such as policy alignment, resource use, and digital care models. By contrast, Intended Adopters was consistently the least represented category across modalities, indicating that staff engagement, patient perspectives, and long-term embedding strategies were less frequently considered or reported.

Taken together, this distribution highlights how most published interventions were designed and reported primarily through a technological and value-for-money lens, with relatively less explicit attention given to organisational readiness, contextual enablers, and especially adopter engagement—dimensions emphasised by the NASSS and Green Team Competition frameworks. This suggests that while many interventions demonstrate environmental and economic benefits, further research should more systematically assess how such initiatives perform in terms of stakeholder engagement, equity, and alignment with system-wide sustainability goals.

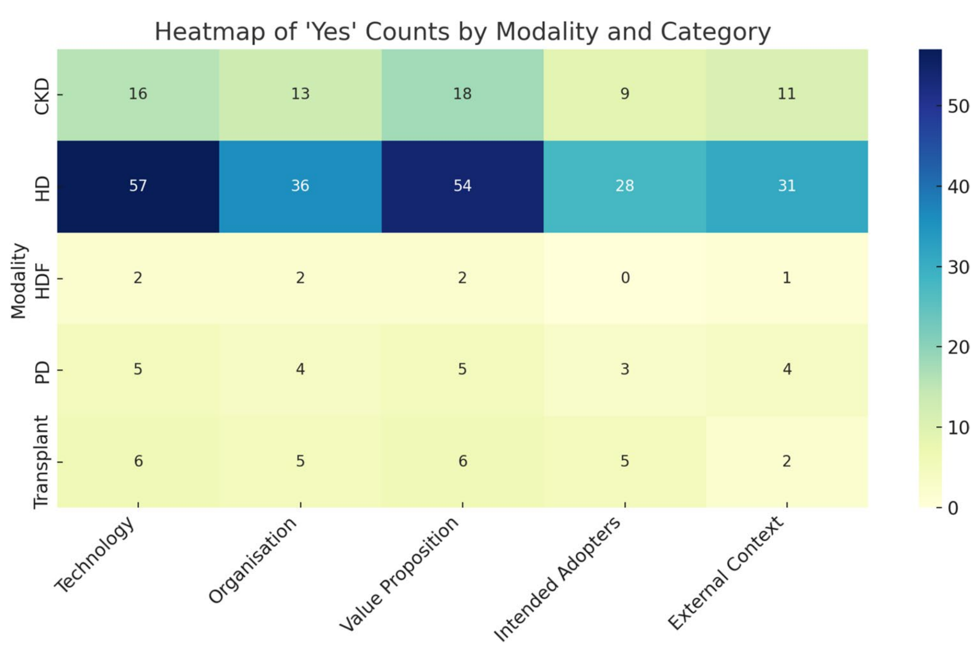


Fig. 5 Heatmap of 'Yes' counts by kidney care modality and the review questions based on the NASSS and CSH's Green Team Competition Success Factors (Categorised by: Technology, Organisation, Value Proposition, Intended Adopters, External Context)

Interventions with impacts on carbon emissions

Table 1 shows the interventions' impacts on actual carbon emissions, categorised by intervention type and treatment modality. Waste management strategies together with water reduction and travel minimisation prove to have a great impact on sustainability.

Discussion

This scoping review mapped 95 sustainability interventions across all major areas of kidney care. While HD dominated both the number and diversity of interventions—reflecting its resource-intensive nature—important and novel strategies were also identified in CKD, transplantation, PD, HDF, and conservative care/ VKD. Some general nephrology initiatives not labelled as environmental, such as deprescribing, test stewardship, and patient-led improvement work, also support sustainable practice and merit integration into future sustainability analyses.

The interventions covered a wide spectrum of sustainability categories, with water efficiency, waste reduction, procurement, and travel-related emissions emerging as the most common targets. Across modalities, the reviewed interventions included both structural and behavioural approaches, from telemedicine and digital health platforms to supply chain redesign, packaging improvements, and equipment-level optimisation.

Haemodialysis: high impact, high innovation

HD interventions were the most extensively documented, likely due to the modality's disproportionate contribution to healthcare-related environmental impacts, particularly greenhouse gas emissions, water use, energy consumption, and plastic waste, as well as its higher global prevalence compared to PD, which positions it as a natural focal point for sustainability efforts. Studies targeting dialysate flow reductions, acid concentrate packaging, central acid delivery systems, and heat exchangers offer replicable solutions with demonstrable environmental and economic benefits.

Clinical transformation initiatives—such as remote consultations and asynchronous care via platforms like *Patients Know Best*—reflect a growing move toward low-carbon models of care delivery that enhance patient autonomy while reducing emissions from patient and staff travel [112].

Some clinical transformations focus on reducing travel to the hospital. For example, through setting up telephone clinics and virtual consultations, patients can access appointments without the need of going into hospital, hence reducing GHG emissions associated with travel and the outpatient appointment itself. Developing a system where the hospital schedules appointments over the phone, and blood tests, blood pressure and weight readings are taken prior to the phone appointment will facilitate virtual appointments [61]. Establishing phone tariffs to cover the calls might be required if not in place already [69]. Other methods to carry out virtual consultations include the use of software or apps which have two-way messaging features and accessible patient care plans [63, 67].

Switching to central acid delivery is another optimisation where acid is delivered to dialysis units in bulk load, pumped into holding tanks and then distributed to dialysis machines via a piped loop system [90]. This initiative helps to make HD more sustainable as it reduces both acid waste and packaging waste. Other options for more sustainable acid solutions include working with manufacturers to change acid concentration levels. For example, the development of 44:1 concentrate solutions has reduced container size and helped lower transport-related emissions by decreasing road freight volume [91, 113]. Additionally, manufacturers using low density polyethylene (LDPE) lightweight packaging to replace the rigid high density polyethylene plastic packaging also help to significantly reduce the plastic waste of a kidney unit [92].

Other changes implemented to reduce the carbon footprint of ESKD can involve infrastructure- and estates-level changes. Installing solar panels to dialysis units can allow dialysis sessions to be powered with renewable energy [29, 78]. This could help to reduce the environmental burden of dialysis sessions and lead to energy cost savings.

Water use is one of the most wasteful components of dialysis with around 500 l used per treatment [114]. This is assuming that the dialysate flow is 500 ml per minute requiring 125 l of water for a patient where two thirds of the water is rejected in reverse osmosis [92]. Therefore, initiatives to reduce water use and reuse reject water are also impactful in reducing the environmental impact of dialysis. Reducing water use could be done through initiatives such as reducing dialysis fluid flow rate to 400 ml per minute where water will be saved without compromising clinical outcomes [94, 102]. Also, as the rejected water does not encounter the patient and does not carry any infection risks, it could be reused in activities such as toilet flushing or laundry, through the installation of a reverse osmosis plant [23, 26, 27].

Other hotspots that could be targeted to reduce the environmental impact of ESKD are reducing paper use in clinical practices, for example by automating blood test results [47], and introducing waste segregation systems to improve waste management at the hospital [40, 106, 107].

CKD, PD, and transplantation: emerging opportunities

CKD-focussed interventions were generally broader in scope and upstream in nature, addressing prescription practices,

Table 1 Table of interventions with carbon emission savings, categorised by intervention type and treatment modality

Intervention	Category	Treatment modality	Impact on carbon emissions
Central delivery of acid for haemodialysis	Acid concentrate	HD	Reduced acid wastage, saving 8,330 kgCO_2e per year. Reduced packaging waste, saving 7,699 kgCO_2e per year.
44:1 Haemodialysis concentrate solution	Acid concentrate	HD	Carbon savings estimated at 16.22 tonnes CO_2e per year from saved road freight.
Using Citrate as an alternative to Heparin in Haemodialysis	Medications	HD	Using citrate has less than 1.5% of the carbon footprint of heparin.
Waste reduction- bolus administration of intravenous antibiotics	Procurement	CKD	Carbon savings estimated at 6.73 tonnes CO_2e a year.
Telephone clinics to follow-up renal transplant recipients	Travel	Transplant	Carbon savings estimated at 2000 kgCO_2e per year.
Remote CKD monitoring as a part of a disease management programme	Travel	CKD	Carbon savings estimated at 40kg CO_2e per year.
Dialysing nearer to home	Travel	HD	Carbon savings at 6.74 tonnes of CO_2e per year.
Establishing a tele-clinic service for kidney transplant recipients through a patient-codesigned quality improvement project	Travel	Transplant	Saved 3,527 miles of motorised travel in total. This equates to a saving of 1,035 kgCO_2.
The follow-up of renal transplant recipients by telephone consultation.	Travel	Transplant	Carbon savings estimated at 2000 kgCO2e annually.
The environmental impact of dialysis vs transplantation	Treatment pathway	VKD	Transplants over a 15 year period decreases environmental impact by 95.7% compared to haemodialysis and 90.9% compared to peritoneal dialysis.
Waste reduction - stopping the unnecessary practice of hanging a saline bag for emergencies and bicarbonate bag diverted away from the clinical waste stream to domestic waste.	Waste	HD	Carbon savings estimated at 26.847 tonnes CO2e per. Reduced clinical waste, 21.5 tonnes per year.
Paperless reporting of routine dialysis haematology and biochemistry results	Waste	HD	Carbon savings estimated at 380kgCO2e per year.
Paper reduction, reuse and recycling	Waste	HD	Carbon savings estimated at 109 kg CO2e per year.
Diversion of waste to the recycling Stream through the use of baling machines	Waste	CKD	Carbon savings at 85.2 tonnes of CO_2e per year.
The carbon footprint of waste streams in a UK hospital	Waste	CKD	The carbon footprint per tonne of hospital waste was lowest when it is recycled (21-65 kgCO_2e), followed by low temperature incineration with energy from waste (172-249 kgCO_2e).
Baling and recycling of bottles and cardboard	Waste	CKD	Carbon savings estimated at 8665 kg CO_2e per year.
Managing medical waste	Waste	HD	The usage of the lighter dialysis set can create 17 million kg reduction of medical waste.
Quantification of recyclable Peritoneal Dialysis plastics in a home dialysis programme	Waste	PD	Carbon savings of 21.99 metric tons CO_2e though recycling PD PP waste.
Reuse of reject water from reverse osmosis for steam production	Water	HD	Carbon savings estimated at 764.88 kg CO_2e per year.
Recycling reject water from the dialysis unit	Water	HD	Carbon savings estimated at 764.88 kg CO_2e per year.
Renewable generation of electricity from haemodialysis effluent water	Water	HD	Cut down up to 300 kg CO_2e per year through this system. Device was able to generate up to 1.6 kWh of electricity per day and 487 kWh per year. This energy can be used to power a 100-W lightbulb for 16 h or a 50-W LED TV for 32 h.
Replacing the old water purification system with new systems that have an ECO mode to regulate output according to demand and variable speed pumps to minimise energy consumption	Water	HD	Reduced carbon emissions by 20%.

paperless administration, and patient self-monitoring [73]. These efforts align well with planetary health principles by preventing disease progression and reducing dependence on high-resource interventions [115].

PD despite its theoretical advantage as a home-based therapy with fewer infrastructural demands, was underrepresented. A handful of studies addressed waste reduction in supply deliveries, local material reuse, and training for sustainable practices, but further research is needed—especially regarding environmental trade-offs between CAPD and APD modalities [116, 117].

Transplantation-related sustainability remains a research gap. While studies highlighted remote follow-up and medication logistics, more comprehensive evaluations are needed to understand the full environmental and economic implications of transplantation compared to dialysis, particularly over the long term [118].

Underexplored areas: pharmaceuticals, reuse and conservative care/ VKD and co-benefits

Pharmaceutical waste, though a recognised issue in nephrology (particularly in CKD and post-transplant patients) [119], was infrequently addressed. Optimising medication stocks and prescribing behaviours can reduce both waste and costs, yet this area remains underdeveloped compared to others such as water or energy efficiency.

Dialyser reuse, historically associated with cost-containment in low- and middle-income countries, is now being reconsidered in high-income settings as a sustainability strategy in response to the ecological emergency [120]. When conducted under validated protocols, dialyser reprocessing has been shown to preserve clinical adequacy and safety while significantly reducing plastic and packaging waste. Nonetheless, adoption remains limited due to persistent cultural concerns, regulatory restrictions, and the absence of updated guidelines [121]. Reintroducing dialyser reuse into routine practice would require a multipronged effort: further research into safety and cost-effectiveness, regulatory reform (e.g. enabling Article 17 in EU countries), engagement of industry stakeholders in viable economic models, and a gradual shift of healthcare systems towards circular resource use. These developments reflect a growing consensus that circularity principles, long underutilised in nephrology, offer promising co-benefits for both environmental sustainability and system resilience.

The complete lack of sustainability research in patients with very low kidney function opting for conservative care is striking. As the population ages and more patients opt for conservative care, it is essential to develop low-impact, supportive models that prioritise quality of life and avoid unnecessary interventions [122–124].

Finally, the adoption of sustainable interventions such as remote consultations, home-based dialysis modalities, incremental haemodialysis, and conservative kidney management offers not only environmental benefits but also recognised health co-benefits. Remote care pathways have been associated with improved patient experience, engagement, and treatment adherence, while reducing the burden of travel without compromising care quality [125, 126]. Home-based therapies, particularly peritoneal dialysis with remote monitoring, have demonstrated improvements in quality of life, autonomy, and patient-reported outcomes [127]. Incremental haemodialysis, which individualises treatment frequency according to residual kidney function, has been associated with better preservation of residual function, fewer hospitalisations, lower symptom burden, and non-inferior survival compared to conventional thrice-weekly schedules [128]. When aligned with patient values and preferences, conservative management may further reduce unnecessary interventions and hospital admissions, facilitating more holistic, low-impact models of care that support both planetary and patient wellbeing [129].

This review highlights a need for standardised metrics to assess environmental performance in kidney care. Only a small number of interventions reported quantitative outcomes in terms of kg CO_2 equivalence, kWh, litres of water saved, or waste volumes. Adoption of LCA methodologies or alignment with ISO 14040/44 standards would significantly improve comparability and validity [130].

Additionally, the heterogeneity in study design—from audits and case reports to full implementation projects—limits generalisability [5]. Many reports lacked economic evaluation or stakeholder feedback, and few addressed unintended consequences (e.g. workload shifts, digital exclusion, or rebound effects) [15].

The analysis of the review categories, based on the NASSS framework and the CSH's Green Team Competition Success Factors (Fig. 5), reveals that sustainability interventions in kidney care are unevenly distributed across modalities and categories. Haemodialysis showed the highest number of optimisations in all domains, particularly in the *Technology* and *Value Proposition* categories, reflecting the high material and energy intensity of HD and the focus of innovation efforts on equipment, consumables, and process efficiency. Chronic kidney disease interventions, while fewer overall, were more evenly spread across categories, suggesting a broader range of intervention types at earlier stages of the patient pathway. In contrast, peritoneal dialysis, haemodiafiltration, and transplantation had fewer documented optimisations, indicating potential gaps or under-reporting of sustainability initiatives in these areas. This imbalance highlights an opportunity for future research and intervention design to extend beyond HD, ensuring that sustainability strategies are applied comprehensively across all kidney care modalities.

Beyond this descriptive mapping, triangulation of the CSH's Green Team success factors with frameworks like the Sustainable Value framework [131] will provide further insights. We combined the NASSS and CSH Green Team frameworks because no single validated framework exists for assessing environmental interventions in healthcare. This highlights the need for standardisation of evaluation tools to strengthen future research.

While many interventions quantified environmental and economic benefits, relatively few addressed cross-disciplinary teamwork, staff engagement, or long-term integration into clinical workflow—dimensions emphasised by the Green Team framework [16]. Indeed, an integrative review of healthcare "Green Team" initiatives found that staff engagement, alongside policy support, external collaboration and organisational structure, was one of the four main facilitators of success in environmentally sustainable initiatives [132]. Likewise, applying the Sustainable Value lens shows that social dimensions such as patient experience, equity of access, and staff wellbeing were rarely considered. Recent evidence shows that organisational culture and job satisfaction are central to sustainable healthcare quality: by optimising processes and reducing waste, healthcare services can enhance staff wellbeing and ultimately improve patient care—underscoring the importance of embedding social value criteria into sustainability interventions [133]. Taken together, these findings suggest that the current literature has largely prioritised measurable technical and economic outcomes, while underreporting organisational, contextual, and social aspects that are equally important for long-term adoption and system-wide sustainability. Embedding Green Team and Sustainable Value criteria more explicitly in future studies would strengthen the evidence base, ensuring that sustainability interventions in kidney care are not only environmentally and economically effective but also feasible, acceptable, and equitable across diverse contexts.

While the search was comprehensive, potential limitations include publication bias toward positive or innovative results, and underrepresentation of grey literature and non-English sources [14]. Moreover, most interventions originated from high-income countries, highlighting the need for context-specific solutions in low- and middle-income settings. Also, as is consistent with scoping review methodology, no formal risk of bias or certainty assessment was performed, and no meta-analysis or synthesis of effect measures was conducted. This approach is appropriate given the exploratory nature of the review and the heterogeneity of study designs, but it should be noted as a limitation in the interpretation of results.

Our findings support the integration of sustainability principles into routine nephrology care, aligning clinical outcomes with respect for planetary boundaries. This shift can be facilitated by professional societies, regulators, and procurement agencies through the incentivisation of low-impact practices such as low-flow HD and the use of reusable consumables, the incorporation of environmental criteria into procurement tenders and clinical guidelines, and the promotion of staff education and sustainability literacy across kidney care services.

Healthcare organisations can also implement multimodal interventions that address travel, procurement, and waste simultaneously, maximising co-benefits for patients, providers, and the environment [134, 135].

Crucially, many sustainability interventions identified in this review were cost-saving or cost-neutral, offering a strong economic case for action even in resource-constrained systems.

Few studies incorporated patient or donor perspectives. One relevant report from Canada included patient-generated sustainability ideas. Greater inclusion of patient voice and co-design is needed in future sustainability work.

Environmental sustainability should be embedded within all kidney care activities rather than treated as a specialist niche. Many established practices already align with sustainability principles, including extending transplantation and peritoneal dialysis where clinically appropriate. Integrating environmental goals into everyday decision-making supports a planetary health model of kidney care.

Optimising clinical management choices has significant sustainability implications. Examples include promoting home rather than centre-based haemodialysis where safe, supporting peritoneal dialysis, using incremental starts, balancing RRT versus conservative management, and timely transition to palliative approaches. These decisions should integrate both clinical and environmental considerations.

Environmental context modifies the impact of sustainability interventions. For example, water reuse or recovery is particularly relevant in arid or semi-arid regions, while energy-related interventions yield greater benefits in areas with high grid carbon intensity.

Future research should prioritise longitudinal studies that include robust environmental and economic impact assessments [13, 50], while also ensuring the inclusion of diverse patient populations and treatment modalities such as PD, conservative kidney management, and transplantation. Co-design with patients and healthcare staff is essential to enhance the acceptability, feasibility, and equity of interventions, and consistent reporting using tools like the SQUIRE 2.0 checklist or a dedicated environmental quality framework will be key to improving transparency and comparability across studies [136].

Conclusion

This scoping review reveals a growing landscape of innovation in sustainable kidney care, yet underscores the urgent need for coordination, standardisation, and system-level thinking. Nephrology faces a pivotal moment: rising environmental challenges and growing inequities make sustainable transformation both urgent and achievable. By advancing interventions that are evidence-based, environmentally sound, and designed with attention to equity and access, the kidney community can lead by example toward a greener, healthier future.

Limitations

However, despite the maturity of this field in HD, interventions were highly variable in methodology, scope, and reporting standards. Many were pilot programmes or quality improvement projects without long-term follow-up or consistent metrics, limiting comparability and scalability.

Implementation challenges included short project timelines, limited follow-up, staff turnover, inconsistent funding, and lack of evaluation metrics. Some digital or waste interventions increased workload for staff or patients, or shifted impacts to other parts of the system. Infection control and regulatory barriers also limited scale-up. These findings highlight the need for long-term monitoring and system-level coordination.

Most included studies originated from the United Kingdom and other high-income regions, reflecting the current distribution of published work. This geographic concentration limits generalisability to low- and middle-income settings.

The review included studies published from 2005 to 2025. Earlier sustainability initiatives may have been excluded, though few pre-2005 renal publications addressed environmental topics. Future reviews could examine archival material to assess this potential gap.

Due to heterogeneity in intervention design, outcome units, and reporting standards, quantitative synthesis or meta-analysis was not feasible. Standardised reporting frameworks are required to enable future comparative analysis.

Appendix 1

Keywords and phrases used in the search strategy included the below:

1	Chronic kidney disease
2	End stage kidney disease
3	Renal care
4	Kidney care
5	Environmental impact
6	Dialysis
7	Carbon footprint
8	Environmental sustainability
9	Optimisations
10	Systematic review
11	Hospitals
12	Dialysis units
13	Greenhouse gas emissions
14	Life cycle assessment

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Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interests The authors declare no competing interests.

Ethical approval Ethical approval was not required for this study as it did not involve human participants or animal research. The study focussed solely on the analysis of papers related to kidney care sustainability.

Informed consent to participate Informed consent was not applicable to this study, as it did not involve any individual participants, patients, or human data.

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