Water implications in dialysis therapy, threats and opportunities to reduce water consumption: a call for the planet

Mohamed Ben Hmida[1,2], Tahar Mechichi[3], Giorgina Barbara Piccoli[4] and Mohamed Ksibi[5]

[1]Department of Nephrology, Hédi Chaker University Hospital, Sfax, Tunisia; [2]Research Laboratory of Renal Pathology LR19ES11, Faculty of Medicine, University of Sfax, Sfax, Tunisia; [3]Laboratory of Biochemistry and Enzymatic Engineering of Lipases, National Engineering School of Sfax, University of Sfax, Sfax, Tunisia; [4]Department of Nephrology, Centre Hospitalier Le Mans, Le Mans, France; and [5]Laboratory of Environmental Engineering and Eco-technology, National Engineering School of Sfax (LGEET-ENIS), University of Sfax, Sfax, Tunisia

Water is a dwindling natural resource, and potable water is wrongly considered an unlimited resource. Dialysis, particularly hemodialysis, is a water-hungry treatment that impacts the environment. The global annual water use of hemodialysis is approximately 265 million m^3/yr. In this reference estimate, two-thirds of this water is represented by reverse osmosis reject water discharged into the drain. In this review, we would like to draw attention to the complexity and importance of water saving in hemodialysis. We propose that circular water management may comply with the "3R" concept: reduce (reduce dialysis need, reduce dialysate flow, and optimize reverse osmosis performance), reuse (reuse wastewater as potable water), and recycle (dialysis effluents for agriculture and aquaponic use). Awareness and sustainability should be integrated to create positive behaviors. Effective communication is crucial for water savings because local perspectives may lead to global opportunities. Besides the positive environmental impacts, planet-friendly alternatives may have significant financial returns. Innovative policies based on the transition from linear to circular water management may lead to a paradigm shift and establish a sustainable water management model. This review seeks to support policymakers in making informed decisions about water use, avoiding wasting, and finding solutions that may be planet friendly and patient friendly in dialysis, especially in hemodialysis treatments.

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Correspondence: *Mohamed Ben Hmida, Department of Nephrology, Hédi Chaker University Hospital, El Ain Boulevard, Sfax 3029, Tunisia. E-mail: mohamedbenhmida148@gmail.com*

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Because of climate change, access to potable water is, and will be, a big challenge,[1] posing unprecedented threats to human health.[2] Traditionally, humans use water linearly: extract, use, and dispose. Our planet is witnessing a critical water crisis, and if we persist in our current practices, we are headed toward serious future hazards.[3] We have all learned in school about the importance of the cycle of water:

Editor's Note

Climate change has emerged as one of the biggest challenges facing the global community to date. The health care system, though dedicated to supporting and improving human health, carries a significant environmental burden. In striving to become more sustainable while continuing to provide quality health care services, the global health care community must reduce unnecessary consumption of resources, including water. Water scarcity is an urgent matter, particularly in low- and middle-income countries, often caused by or associated with climate change–driven extreme weather conditions. Building on these considerations, this first review devoted to Green Nephrology addresses the implications of water consumption in dialysis. Although a critical lifesaving therapy, dialysis is an extremely resource-intensive therapy requiring large volumes of water. Ben Hmida *et al.* describe potential strategies to preserve water based on the "3R" concept—reduce, reuse, and recycle. The authors further highlight the importance of awareness of responsible water use to promote planet-friendly and patient-friendly solutions in dialysis.

water covers more than half of the planet, flows, evaporates, and comes back in the form of rain. However, things are not quite so simple: the distribution of water is uneven; rain does not always fall where it is most needed, and, above all, only a small part of the water covering the planet is potable. Hence, there is a need to preserve it.[1] A global water agenda focusing on securing water resources, nature-based solutions, and corporate water management is highly warranted.[1,4,5]

The environmental impact of care is an ever-growing problem, too often neglected by policymakers, health care providers, and industries, as well as by physicians, who lack training in this field, even though there is potential for significant environmental and financial benefits for all parties.[6–8]

The environmental impact of dialysis is particularly high; dialysis is water- and energy-hungry and produces an extremely high amount of waste, most of which is not recycled. Although hemodialysis may be seen as an example of the high price to pay in terms of water consumption for sustaining health, actions taken in this field may also be seen as an example of what can be done to support planet-friendly, health-related choices.[5,6]

An increasing number of nephrology societies have recently started implementing "green nephrology" action.[9–11] Water use is central in this setting, but barriers are often encountered. The aim of this review is to highlight the importance and feasibility of water conservation initiatives and propose solutions based on circular water management and "3R" (reduce, reuse, and recycle) approaches (see Supplementary Graphical Abstract).[6,8,10–18]

Water consumption in dialysis

Hemodialysis water consumption. Hemodialysis is the most widely used treatment for end-stage kidney disease,[19] chosen by approximately 90% of all dialysis patients; approximately 3.4 million patients are estimated to be on hemodialysis at the time of the current report, according to the 2022 Global Renal Replacement Therapy Annual Report.[20] As the dialysis population grows by at least 7%/yr,[19,20] both the water used and the wastewater generated by dialysis units increase accordingly.

The quantity of water consumed for hemodialysis depends on several factors, the most important of which is water treatment. The reference calculation of the water consumption in hemodialysis is approximately 0.5 m^3/session based on the assumption that two-thirds of this water is reverse osmosis (RO) reject water discharged into the drain.[11,21] Hence, the calculation is approximately 80 million m^3/million hemodialyzed patients/yr.

Water consumption is even higher in hemodiafiltration, with at least 22 L of sterile solutions added for each dialysis session.[22] These fluids are either the product of an industrial procedure (reinfusion bags) that requires a high (and undisclosed) quantity of water or are produced on-line, adding the same amount of wastewater per liter of final solution that is needed to produce the dialysate.

These volumes are modulated by the performance of the RO system, with new models allowing lower water waste, and by dialysis prescriptions, including wise prescription of dialysate flow (Qd) and modulation of treatment duration and frequency, as will be further discussed.

Peritoneal dialysis water consumption. At full schedule, a peritoneal dialysis (PD) patient uses 4 dialysate bags/d (2.5 L bag), but the production of this 10 L of dialysis fluid consumes a much higher amount of water. Also, dialysate for PD is packaged in plastic. Even though the fact that the water footprint of plastic varies by kind and manufacturing technique, creating 1 kg of plastic typically requires around 180 L of water. Considering that an unfilled 2 L bag of PD dialysate weighs approximately 0.155 kg, the amount of water required for its manufacture is approximately 28 L.[7] Although the exact amount of water needed is currently undisclosed by the medical industry, this is likely also linked to the fact that no company manages all production steps (from the making of the bags to the purification of the dialysate).[11]

This volume would be even higher in the case of automated PD, where, typically, more than 12 L are used per patient every day, whereas it may be obviously lower in incremental PD schedules.[11,23]

Policies to reduce water waste

Reducing dialysis needs: optimization of dialysis start and dialysis prescription—the "intent-to-delay policy". Delaying the start of dialysis is an example of how a win-win policy may also be planet friendly. The concept that early dialysis start does not increase patient survival and may, on the contrary, increase morbidity and impair quality of life while increasing costs is not new. However, the "intent-to-defer" policy has only recently been integrated into nephrology guidelines, mainly following the pivotal IDEAL (Initiating Dialysis Early And Late) study, that, thanks to its robust methodology, clearly demonstrated that starting dialysis at a much lower estimated glomerular filtration rate than that usually retained in western countries was not associated with an increase in mortality.[24]

As a consequence of the IDEAL study and of a series of large observational studies, most of the current guidelines advocate delaying the start of dialysis in asymptomatic patients with end-stage kidney disease until their estimated glomerular filtration rate reaches 6 ml/min per 1.73 m^2 or the appearance of clinical indications.[25,26]

Moreover, Ku *et al.*[27] in the Chronic Renal Insufficiency Cohort study found that dialysis initiation could be delayed by a median of 8 months if patients were managed medically until an estimated glomerular filtration rate of 5 ml/min per 1.73 m^2. Similar results have been reported in large Italian observational studies.[28]

Delaying dialysis initiation obviously saves water. For every patient-month of dialysis delay, the amount of water spared is approximately 6000 L (12 sessions × 500 L).

Because a healthy diet, protein-restricted and plant-based whenever possible, is one of the basic tools for safely delaying dialysis start, the ecologic advantages of reducing dialysis need are further associated with the reduction of red meat consumption, which has an incredibly high carbon footprint.[29,30]

Incremental dialysis. The concept of incremental dialysis is likewise not new but has been only relatively recently rediscovered, first of all in PD, in which acknowledging better preservation of residual kidney function went hand in hand with the demonstration of its importance on survival. The standard of care in PD is incremental, and this patient-friendly, resource-wise, and planet-friendly approach is acknowledged in the recent guidelines of the International Society for Peritoneal Dialysis.[23,31] Only recently, however, has this policy been "translated" into the concept of incremental hemodialysis. The issue is increasingly receiving attention, especially because, in experienced centers, up to two-thirds of the patients may benefit from a smoother dialysis start.[31]

Considering the high mortality rates during the first months of dialysis and the survival benefits in patients with preserved residual kidney function, an incremental hemodialysis start may provide an opportunity to optimize patient survival. Even at equivalent survival, preservation of the residual kidney function may reduce waste and water consumption[31,32] and improve the quality of life.[33,34] For every patient-month dialysis increment, the water amount spared is 2000 L (4 omitted sessions × 500 L).

Optimization of the reverse osmosis system in hemodialysis. During hemodialysis, 2 distinct reject fluids are produced. The first one is RO reject water, and the second is reject water coming from the dialysis machine, which has been in contact with patients' blood and contains uremic waste.[35]

Purification of the water needed to produce the dialysate involves a series of steps, including sand or charcoal filtering, softening, and deionization via RO. Whereas first-generation RO systems discharged a large quantity (50%–70%) of water at each step, new-generation RO systems recycle at least part of the wastewater; the amount of water actually discharged may be as low as 20%.[13,36] Along this line, Bendine *et al.*[13] reported that replacing old-generation water treatment systems with new-generation ones led to a 52% reduction of water consumption per session (on average from 701 to 382 L/session) in the treatment centers of a large dialysis corporation. The water-saving initiative was part of a broader green dialysis initiative, involving not only monitoring and optimization of water consumption but also of energy and waste management, as well as sustainable choices when replacing obsolete dialysis units.[13]

Technical aspects in hemodialysis. While in PD the dialysis schedule (number and type of exchanges) is the only determinant of water consumption, some further technical issues may be considered in the optimization of water consumption in hemodialysis.

In particular, in some European countries where hemodiafiltration was highly developed and the quest for efficiency primed the dialysis community, Qd was increased up to 700 to 800 ml/min to improve dialysis efficiency by 5% to 10%.[37,38]

Although this policy made sense in a young patient population, with high dialysis needs and low access to kidney transplantation, the clinical differences in an older dialysis population are probably negligible. A well-balanced Qd may be financially and ecologically profitable. Reducing, at least in some cases, Qd from the current standard of 500 ml/min to 400 ml/min could save around 100 L of water per 4-hour session.[39]

Hardware innovation in hemodialysis. Innovative technologies may further help in water management in hemodialysis.[36] Changing priming and flushing policies may allow for substantial water savings.[6,36] Many of the new-generation dialysis machines are intended to be more eco-friendly.[36] They can match the Qd to the blood flow (Qb), thus saving significant amounts of dialysate, while maintaining high dialysis performance.[36] The potential is impressive, with a reduction of water use by almost 66%.[13,36]

Reuse-recycle of dialysis wastewater

Reuse of water discharged from the reverse osmosis. RO reject water is suitable for many uses.[6,7,35,40] Indeed, the water discharged from the RO has no contact with the patients' blood and therefore presents no infectious danger. This water is rich in salts, as it is the result of the deionization process, but overall, it complies with the quality parameters for drinking water. However, because rules are not always defined or may vary from country to country, we propose in Table 1 a nonexhaustive panel of physicochemical and bacteriological data on water quality, retrieved from the literature.[12,16,18,35,41–43] Australia is the leader in this regard, with several reference studies.[6,7,21,22,43]

Although an analysis of wastewater is needed to further plan its use, there is no theoretical limitation to the reuse of RO reject water, for instance, for in-hospital services, including rehabilitation hospital pools,[40] sterilization facilities, or laundries, for which an added environmental benefit is that softened water allows for less detergent use.[6]

This type of wastewater may be used in agriculture, aquaponics, and horticulture,[14] and recent experiences reported the results of recycling approximately 12,000 L of water, leading not only to relevant savings but also sparking the interest of patients and dialysis teams in planet-friendly, sustainable approaches.[14]

No legislation requires that dialysis services reuse RO reject water; however, no law bans this procedure, thus leaving space for different initiatives according to the local policies and needs.

Reuse-recycle of dialysate. Although the spent dialysate is considered at high microbiological risk, Australian studies[43] showed that these effluents may meet Food and Agriculture Organization/United Nations/World Health Organization recommendations.[44,45]

Tarrass *et al.*[17] explored the possibility of recycling spent dialysate for landscaping, watering, and agriculture. They

Table 1 | Comparison of reverse osmosis reject water composition at several dialysis centers worldwide with the US EPA standards for potable water[41]

Analyte	Units	Iran, Ali-Taleshi and Nejadkoorki[12] Sat 1	Iran, Ali-Taleshi and Nejadkoorki[12] Sat 2	France, Ponson *et al.*[16]	Morocco, Berrada *et al.*[42]	Australia, Agar[43] Sat 1	Australia, Agar[43] Sat 2	US EPA standards[41]
Aluminum	mg/l	–	–	–	–	0.01	0.01	0.2
Arsenic	mg/l	–	–	–	–	0.001	0.001	0.01
Cadmium	mg/l	–	–	–	–	0.002	0.0002	0.005
Copper	mg/l	–	–	–	–	0.009	0.01	1.3
Iron	mg/l	–	–	0.3	–	0.02	0.002	0.3
Lead	mg/l	–	–	–	–	0.001	0.002	0.015
Manganese	mg/l	–	–	–	–	0.01	0.002	0.05
Mercury	mg/l	–	–	–	–	0.0001	0.0001	0.002
Zinc	mg/l	0.0667	0.0867	–	–	0.002	0.008	5
Calcium	mg/l	–	–	–	–	0.1	0.1	No standard
Magnesium	mg/l	–	–	–	–	0.1	0.1	No standard
Sodium	mg/l	–	–	–	–	140	68	200
Total hardness	mg/l	–	–	–	–	0.1	0.1	No standard
Chloride	mg/l	25.93	27.39	45.7	542.96	150	74	250
Nitrate	mg/l	–	–	16.8	27.80	0.01	0.01	10
Nitrite	mg/l	–	–	–	0.014	0.01	–	1
Sulfate	mg/l	133.86	108.88	102.1	203.27	23	–	250
Dichloramine	mg/l	–	–	–	–	0.1	0.1	08
Conductivity	μS/cm	854.25	774.92	–	3460	680	340	2500
Fluoride	mg/l	–	–	–	–	0.15	0.06	2
Free chlorine	mg/l	–	–	–	–	0.1	0.1	4
Monochloramine	mg/l	–	–	–	–	0.1	0.1	4
pH	pH units	7.84	7.93	8	7.85	7.5	7.5	7.5 ± 1.0
Dissolved solids	mg/l	–	–	–	–	320	200	500
Trichloramine	mg/l	–	–	–	–	0.1	0.1	Uncertain
Turbidity	NTU	–	–	–	–	0.1	0.1	2

NTU, nephelometric turbidity unit; Sat, satellite; US EPA, United States Environmental Protection Agency.

collected and mixed the spent dialysate with RO reject water.[17] Biological and microbiological tests showed that organic matter and bacterial count values were within Food and Agriculture Organization/United Nations/World Health Organization standards for water for agricultural purposes, as reported in Table 2.[12,17,18,44–46] Another approach to recycling for garden watering was mixing spent dialysate with well water to lower conductivity and meet microbiological standards.[42] A further suggested option was to mix dialysis effluents with rainwater, depending on the intended use.[6,7] Rainwater harvesting is an ecological alternative that provides free and safe water; no approval is required.[47] These solutions have to be tailored to local needs and rules but exemplify how a creative approach may allow water savings in nephrology.

The future: zero liquid discharge policies. Zero liquid discharge is an innovative water treatment process in which all wastewater is purified and recycled. The process is complex and includes several steps: ultrafiltration, RO, evaporation, and electrodeionization.[48] Although setting up the system is

Table 2 | Comparison of hemodialysis wastewater composition at the dialysis facility in several dialysis centers worldwide with the quality standards for agriculture[44,45]

Parameters	Units	Iran, Ali-Taleshi and Nejadkoorki[12] Sat 1	Iran, Ali-Taleshi and Nejadkoorki[12] Sat 2	Morocco, Tarrass *et al.*[17]	Tunisia, Jallouli *et al.*[18]	Brazil, Machado *et al.*[46]	FAO-UN/WHO standards[44,45]
pH		7.84	7.93	7.84	7.46	7.49	6–8.5
Conductivity	μs/cm	854	774	13,200	13,530	4080	300–700
Salinity	g/l	–	–	–	9.113	9.42	–
COD	mg/l	16.10	17.73	–	262.033	832	5–45
Cl^-	mg/l	25.93	27.39	289	3976	–	30
Total nitrogen	mgN/l	–	–	–	143	126.7	–
PO_4^{3-}	mg/l	–	–	–	6.472	53.95	–
SO_4^{2-}	mg/l	133.86	108.88	80.4	110.67	23	0–20
Mg^{2+}	mg/l	–	–	–	13.88	–	–
Ca^{2+}	mg/l	–	–	–	21.091	–	–
Na^+	mg/l	–	–	–	3757	–	–
Bacterial count	CFU/ml	–	–	450	450	–	2–10 × 10^4

CFU, colony-forming unit; FAO-UN/WHO, Food and Agriculture Organization/United Nations/World Health Organization; Sat, satellite.

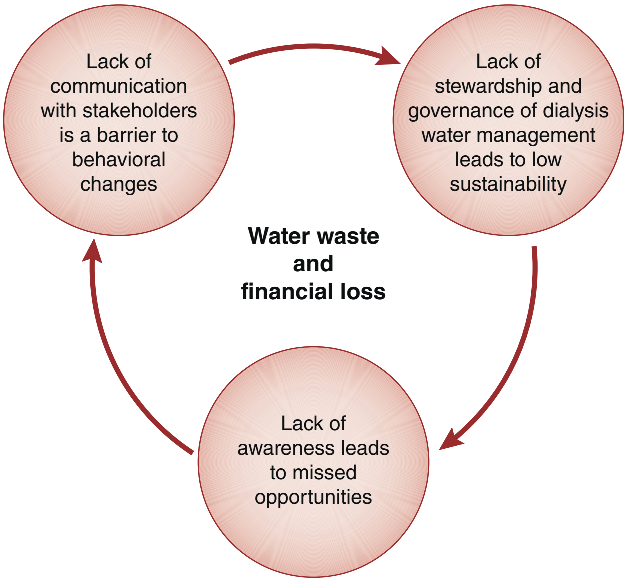

Figure 1 | The vicious circle in water management.

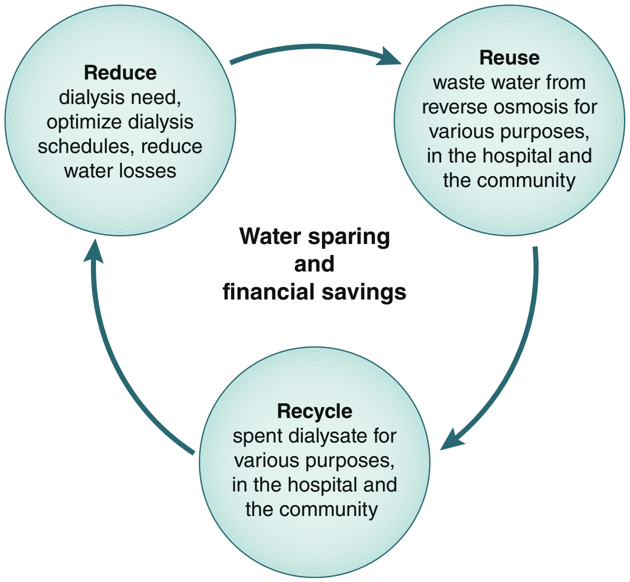

Figure 2 | The virtuous circle in water management.

complex and expensive, in the long term, the procedure should also allow for financial advantages. At the time of writing this review, this innovative water treatment procedure has not been used in dialysis; however, its feasibility has been discussed, and there is room for projects involving this advanced technology.[48] Appropriate investments are of course required.[49]

Sustainable water management

Economical and legal barriers. If the present environmental crisis has become so severe, it is also because exploiting the planet is rentable, at least in the short term,[50] hence the idea that environmentally friendly strategies are more expensive than careless ones. However, this is not necessarily true since the environmental commitment of dialysis can be viable, rational, and financially profitable.[7,8,51] Figures 1 and 2 exemplify the differences between a vicious circle of dialysis water management and a virtuous one.

There is still a cruel lack of laws and regulations favoring green medicine in general and green nephrology in particular. However, large-scale initiatives are increasingly being undertaken, and among them are the Environmental Protection Agency's water management plans in the United States.[52] The Environmental Protection Agency currently has 27 signed water management plans that outline the best practices for different facilities. Some of them are easily applicable to nephrology, including the use of water-smart landscaping and irrigation, reuse of laboratory culture water, control of RO system operations, and recovery of rainwater.[52]

In Europe, the Guide to Cost-Benefit Analysis published by the European Commission in 2014 indicates that externalities (i.e., indirect costs or benefits that include an environmental impact) must be taken into account when evaluating a project. This guidance legitimizes the systematic evaluation of health care projects, including projects for new dialysis units, and may support specific choices such as centralized dialysate delivery systems.[53–55] Although local experiences showed the

Box 1 | Water and dialysis therapy: key points

- Hemodialysis is a water-intensive and water-hungry treatment that may have a negative impact on the environment.
- Presently, hemodialysis annual water consumption is estimated at approximately 265 million m^3 (resulting from 0.5 m^3 per session for almost 3.4 million patients, assuming that they are treated for 4 hours, 3 times per week).
- Up to two-thirds of this wastewater is rejected water from the reverse osmosis system (176 million m^3) plus the rejected water from the dialysis machine; this water has potential for being recycled and reused.
- The reduce, reuse, and recycle steps are the "3R" that may change dialysis water management from linear to circular.
- "Reduce" includes various steps: delaying renal replacement therapy initiation and choosing an incremental hemodialysis policy, improving technology in dialysis machines, and reverse osmosis.
- "Reuse and recycle" refer to rejected water from reverse osmosis and spent dialysate. The reverse osmosis reject water is not contaminated (it is microfiltered and softened) and meets the World Health Organization standards for drinking water. The spent dialysate, which has been in contact with patients' blood, may be used for agricultural purposes.
- Education of health care staff and stakeholders is needed to increase awareness of the environmental impact of dialysis and facilitate targeted programs.
- Systematic application of the "3R" policy may allow not only environmental but also financial savings, shifting from a vicious to a virtuous, circular water management.

feasibility of water conservation, global programs are needed to lead to systematic sustainable water management.

Dialysis wards as environmental-sustainability schools. Environmental sustainability is not taught in medical education.

The dialysis ward may become a fantastic school for promoting environmentally friendly attitudes; the potential for teaching through example is enormous, and health care teams should value this as a great honor and responsibility. The range of actions, recently illustrated in a survey involving dialysis head nurses, is wide and includes not only water but also energy and waste management.[56–60]

Conclusions

Dialysis is among the most environmentally impactful areas of medicine. Water management and wastewater recycling should become international priorities. In this review, we have attempted to summarize the problem and provide some suggestions on priorities and feasible actions. Nephrologists face the challenge of sustainability in an expanding end-stage kidney disease population with limited, if not decreasing, funding. In nephrology, like in other major public health fields, programs must be clearly defined, evidence gathered, theories developed, alliances formed, policies proposed, and action taken.

Further studies are needed to assess water and energy needs, carbon footprint, and more globally, ecological issues in dialysis, leading to shared guidelines to minimize the environmental impact. Environmental certifications, such as LEED (Leadership in Energy and Environmental Design) certification, should be required for dialysis units.

Regarding water, we should start monitoring what we are doing, following the path meter/measure/manage to compare the performance of different equipment and establish priorities, following the "3R" strategy—reduce water consumption and develop water conservation plans, reuse water, and recycle water. Transitioning from linear to circular water management requires investments, including the choice of new RO and dialysis machines and, from the side of the industry, the further development of new hardware.

We hope that our review will help policymakers make informed decisions about water use in dialysis; we need the support and commitment of all stakeholders. Only the worldwide commitment of health professionals, dialysis caregivers, industrial partners, and scientific societies will succeed in making dialysis more environmentally friendly. While waiting for global commitment, we hope this "Call for the Planet" will inspire initiatives toward planet-friendly water management in dialysis.

DISCLOSURE

All the authors declared no competing interests.

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SUPPLEMENTARY MATERIAL

Supplementary File (PDF)

Supplementary Graphical Abstract.

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