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Sources of Variation in the Carbon Footprint of Hemodialysis Treatment

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ABSTRACT

Background Greenhouse gas emissions from hemodialysis treatment in the United States have not been quantified. In addition, no previous studies have examined how much emissions vary across facilities, treatments, and emission contributors.

Methods To estimate the magnitude and sources of variation in the carbon footprint of hemodialysis treatment, we estimated life-cycle greenhouse gas emissions in carbon dioxide equivalents (CO_2-eq) associated with 209,481 hemodialysis treatments in 2020 at 15 Ohio hemodialysis facilities belonging to the same organization. We considered emissions from electricity, natural gas, water, and supply use; patient and staff travel distance; and biohazard and landfill waste.

Results Annual emissions per facility averaged 769,374 kg CO_2-eq (95% CI, 709,388 to 848,180 kg CO_2-eq). The three largest contributors to total emissions were patient and staff transportation (28.3%), electricity (27.4%), and natural gas (15.2%). Emissions per treatment were 58.9 kg CO_2-eq, with a three-fold variation across facilities. The contributors with the largest variation in emissions per treatment were transportation, natural gas, and water (coefficients of variation, 62.5%, 42.4%, and 37.7%, respectively). The annual emissions per hemodialysis facility are equivalent to emissions from the annual energy use in 93 homes; emissions per treatment are equivalent to driving an average automobile for 238 km (149 miles).

Conclusions Similar medical treatments provided in a single geographic region by facilities that are part of the same organization may be expected to have small variations in the determinants of greenhouse gas emissions. However, we found substantial variation in carbon footprints across facilities, treatments, and emission contributors. Understanding the magnitude and variation in greenhouse gas emissions may help identify measures to reduce the environmental effect of hemodialysis treatment.

JASN 33: •••–•••, 2022. doi: https://doi.org/10.1681/ASN.2022010086

About 500,000 Americans receive chronic hemodialysis treatment for kidney failure.[1] Compared with other medical treatments, hemodialysis has a high environmental effect because it requires large amounts of energy, water, and supplies and is accompanied by substantial waste production.[2] In addition, hemodialysis treatment generally involves patients and staff traveling several times a week to a dialysis facility.

Received January 19, 2022. Accepted April 16, 2022.

A.R.S. and J.E.S. contributed equally to this work.

Published online ahead of print. Publication date available at www.jasn.org.

See related editorial, "XXX," on pages XXX–XXX.

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The accelerating effects of climate change make it critical to understand and address the carbon footprint of healthcare, which is responsible for about one tenth of all greenhouse gas emissions in the United States.[3] Three previous studies from the United Kingdom, Australia, and Morocco estimated greenhouse gas emissions related to hemodialysis treatment by analyzing specific contributors such as electricity, supplies, transportation, and waste production.[4–6] However, the healthcare sectors (and accompanying emissions) are a much smaller proportion of the economies in those countries.[7] Energy sources, transportation use, and practice patterns can also be quite different across countries.

Emissions related to hemodialysis treatment in the United States have not been quantified. Moreover, no previous studies have examined how much emissions vary across facilities, treatments, and emission contributors. Understanding the magnitude and variation of emissions may help identify measures to reduce the carbon footprint of hemodialysis treatment. Reducing environmental effect is also likely to decrease both facility costs and overall healthcare expenditures. Therefore, we sought to estimate the magnitude and sources of variation in the carbon footprint of hemodialysis treatment.

Significance Statement

Studies have demonstrated that hemodialysis facilities have a high environmental effect because the treatment requires large amounts of energy, water, and supplies. However, data regarding how much greenhouse gas emissions from hemodialysis treatment vary across facilities, treatments, and emission contributors have been lacking. In this study, the authors estimated magnitude and sources of variation in the carbon footprint of hemodialysis treatment. They found that the annual emissions per hemodialysis facility are equivalent to emissions from the annual energy use of 93 homes, and emissions per treatment are equivalent to driving an average automobile for 238 km (149 miles). Carbon footprints across facilities, treatments, and emission contributors also varied substantially. Understanding the magnitude and variation in greenhouse gas emissions may help identify measures to reduce the environmental effect of hemodialysis treatment.

METHODS

Facilities

This study was conducted at 15 freestanding dialysis facilities in northeast Ohio. All facilities are part of the same nonprofit organization, have a centralized system for managing staff and supplies, and provide in-center hemodialysis treatment. The study was approved by the institutional review board of MetroHealth Medical Center (Cleveland, OH).

Data Elements

We obtained data for each facility on resource use, patient and staff travel, and waste production for the year 2020 from administrators of the dialysis organization. Electricity, natural gas, and water use data were extracted from utility bills. Actual supply usage is tracked monthly for each facility. We obtained and disassembled each supply item into components of identical composition and weighed each component (Supplemental Table 1). For example, there are six different dialyzers used at the participating facilities. Each dialyzer includes five components: fibers, potting material, housing, caps, and an outer wrap. Note that there are variations in the weight and composition of these components (*e.g.*, polycarbonate versus polypropylene for the housing material). All supplies at the participating facilities are single use. We also observed several treatments and talked to dialysis technicians to ensure no supplies were missed. Patient home addresses and modes of transportation were obtained from electronic medical records. Staff home addresses were obtained from employment records. There were no data available on staff mode of transportation. On the basis of discussions with facility head nurses, we assumed that all staff used a car for transportation. We also obtained total quantities of three types of waste produced: biohazard, landfill, and recycling.

Statistical Analyses

Carbon footprint calculations are performed on the basis of greenhouse gas emission factors, or the amount of carbon dioxide produced, on average, per unit of fuel consumed or material used. The effect of other greenhouse gases, such as methane and nitrous oxide, is included in emission factors as carbon dioxide equivalents (CO_2-eq). We used a life-cycle approach that includes emissions associated with raw material extraction and processing; product manufacture, distribution, and use; and recycling or disposal. We followed the International Organization for Standardization 14040 family of standards for life-cycle assessment to capture the inputs and outputs of hemodialysis treatment. The functional unit is provision of one hemodialysis treatment, and the system boundary is shown in Supplemental Figure 1. The data elements above were first translated into manufacturing and disposal (for the waste quantities) unit processes in the ecoinvent 3 database included in SimaPro 9.2.0.1 (PRé Sustainability, Amersfoot, The Netherlands). Supplemental Table 1 lists specific unit processes for supplies, and Supplemental Table 2 lists unit processes used for other inputs. We then used the US Environmental Protection Agency's (EPA) Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts version 2.1 to calculate midpoint environmental effects (in this case, kilograms of CO_2-eq) from unit process data.[8] Upper and lower confidence intervals were calculated as the 2.5 and 97.5 percentiles of 1000 Monte Carlo simulations that take into account the uncertainty and variability inherent in environmental emissions data within ecoinvent.[9] Note, these confidence intervals are not symmetric because environmental emissions are generally not normally distributed and have long tails. We used EPA data to compare emissions from dialysis treatment to emissions from the energy use of homes and automobiles.[10] Recycled waste was not included in these estimates because only one facility participates in recycling, and the proportion of all waste that was recycled was <3%. Medications used during hemodialysis were also excluded because life-cycle inventory data on emissions from pharmaceutic production are not available from manufacturers.

We used descriptive statistics (mean, percent, range, SD, coefficient of variation) to analyze total emissions per facility, emissions per treatment, and emissions per contributor (*e.g.*, electricity), along with variation across facilities, treatments, and contributors. These analyses were performed with JMP Pro 15 (SAS, Cary, NC).

RESULTS

The 15 participating facilities provided a total of 209,481 hemodialysis treatments in the year 2020, for an average of 13,965 treatments per facility and an average treatment time of 3.8 hours. Table 1 includes details about resource use, patient and staff travel, and waste production. For example, patients traveled a total of 310,009 km annually and staff traveled a total of 322,238 km annually per facility. Of all patient travel, 170,164 km (55%) was by van, 127,590 km (41%) was by car, and 12,255 km (4%) was by bus. Supplemental Table 1 lists the composition and weights of all supplies used during hemodialysis treatment.

As indicated in Table 2, the total annual emissions per facility averaged 769,374 kg CO_2-eq (CI limits, 709,388 to 848,180 kg CO_2-eq). The three largest contributors to total emissions were patient and staff transportation (28.3%), electricity (27.4%), and natural gas (15.2%). Emissions per treatment were 58.9 kg CO_2-eq, with a three-fold variation across facilities. There was also a three-fold variation in electricity use per treatment, eight-fold variation in natural gas use, and five-fold variation in water use across the participating facilities. As indicated in Figure 1, the contributors with the largest variation in emissions per treatment were transportation (coefficient of variation, 62.5%), natural gas (42.4%), and water (37.7%).

Table 1. Resource use, patient and staff travel, and waste production in the year 2020 (n=15 facilities)

Item	Annual per Facility	Per Treatment
Electricity use, kWh	346,783 (239,771)	25.9 (7.6)
Natural gas use, m^3	41,358 (35,234)	2.9 (1.2)
Water use, m^3	7858 (5,207)	0.6 (0.2)
Supply use, kg	63,014 (40,392)	4.5 (0.4)
Patient travel distance, km	310,009 (181,905)	28.8 (27.8)
Staff travel distance, km	322,238 (263,584)	23.6 (10.1)
Biohazard waste, kg	17,161 (10,984)	1.2 (0.2)
Landfill waste, kg	173,924 (97,925)	13.4 (4.1)

Values represent mean (SD).

The annual emissions per hemodialysis facility are equivalent to emissions from the annual energy use of 93 homes, whereas emissions per treatment are equivalent to driving an average automobile for 238 km (149 miles). There was a moderate inverse correlation between number of treatments provided by a facility and emissions per treatment (Pearson correlation coefficient, −0.38; P=0.16). There was no correlation between building age and energy-related (electricity plus natural gas) emissions per treatment (correlation coefficient, 0.03; P=0.91). Transportation-related emissions per treatment averaged 12.8, 17.7, and 30.1 kg CO_2-eq at three urban facilities, ten suburban facilities, and two rural facilities, respectively (P=0.26).

DISCUSSION

We found that hemodialysis treatment has a sizable carbon footprint, with the largest contributions coming from transportation, electricity, and natural gas. More importantly, there was a great deal of variation in both total greenhouse gas emissions and the contributors to these emissions. This is a surprising finding because similar treatments provided in a single geographic region by facilities that only provide dialysis and are part of the same organization would be expected to have small variations in emission contributors, such as electricity. Strengths of this study include the use of identical data sources for each facility, the ability to obtain and disassemble all supplies, and the analyses of variation at multiple levels, including facility, treatment, and emission contributor.

We also found the relative importance of specific emission contributors is different between hemodialysis treatment and healthcare in general. For example, about 11% of all healthcare emissions in the United States are from purchased electricity use.[3] By contrast, 27.4% of emissions in this study are from electricity, probably due to the energy-intensive nature of hemodialysis treatment. It is likely that the wide geographic area served by the participating facilities, including urban, suburban, and rural regions, and the limited use of public transportation contributed to both the large emissions due to transportation and a high coefficient of variation.

Three previous studies from the United Kingdom, Australia, and Morocco estimated greenhouse gas emissions per hemodialysis treatment as 24.5, 65.1, and 32.8 kg CO_2-eq, respectively.[4–6] However, it is difficult to directly compare those results with each other or with our study because of some differences in the emission contributors included. For example, the United Kingdom estimate includes emissions related to facility construction, vascular access surgery, and outpatient visits, whereas the Moroccan estimate includes computers and furniture.[4,6] Comparisons limited to specific

Table 2. Greenhouse gas emissions by contributor

Contributor	Annual Emissions per Facility		Emissions per Treatment	
	Mean (CI), kg CO_2-eq	Percent of Total	Mean (CI), kg CO_2-eq	Range
Electricity	210,983 (160,472 to 276,405)	27.4	15.7 (12.1 to 20.4)	8.6–25.5
Natural gas	116,999 (102,478 to 131,588)	15.2	8.2 (7.2 to 9.2)	2.0–16.1
Water	12,245 (11,166 to 13,809)	1.6	0.9 (0.8 to 1.0)	0.3–1.6
Supplies	77,662 (71,909 to 85,530)	10.1	5.5 (5.1 to 6.1)	4.9–6.4
Patient and staff transportation	218,015 (208,287 to 227,960)	28.3	18.4 (17.7 to 19.1)	9.0–52.5
Biohazard waste	42,100 (34,749 to 54,909)	5.5	3.0 (2.5 to 3.9)	2.1–3.7
Landfill waste	93,165 (86,263 to 100,528)	12.1	7.2 (6.7 to 7.7)	5.0–13.5
Total	769,374 (709,388 to 848,180)	100.0	58.9 (54.6 to 64.5)	33.3–97.7

contributors, such as energy use and transportation, may be more informative. Emissions related to energy use ranged from 5.1 to 12.1 kg CO_2-eq across the three studies, which is substantially less than the 23.9 kg CO_2-eq we found for electricity and natural gas combined. Emissions related to transportation accounted for 9%–24% of all emissions across the three studies and for 28% of all emissions in our study. These differences likely reflect regional variations in amount of energy use, carbon intensity of local energy sources, distances traveled by patients and staff, and mode of transportation. Studies of carbon footprints of surgical procedures found differences of similar magnitudes across countries.[11]

It would be worthwhile to quantify how much electricity use is from hemodialysis machines and reverse osmosis equipment versus from general building purposes, such as lighting, computers, and other appliances. An Australian study of in-center hemodialysis estimated dialysis-related electricity use at 7.2 kWh per treatment for a mean treatment time of 4 hours.[5] A Canadian study of home hemodialysis estimated dialysis-related electricity use at 4.0 kWh per 4-hour treatment.[12] Another Australian study of a solar-assisted home hemodialysis training unit estimated dialysis-related power use as 5.2 kWh over 4 hours.[13] We did not directly measure hemodialysis and reverse osmosis electricity use at the facilities that participated in our study. However, manufacturer specifications for their dialysis equipment indicate that 5.7 kWh of electricity would be required for a 3.8-hour treatment. By comparison, total

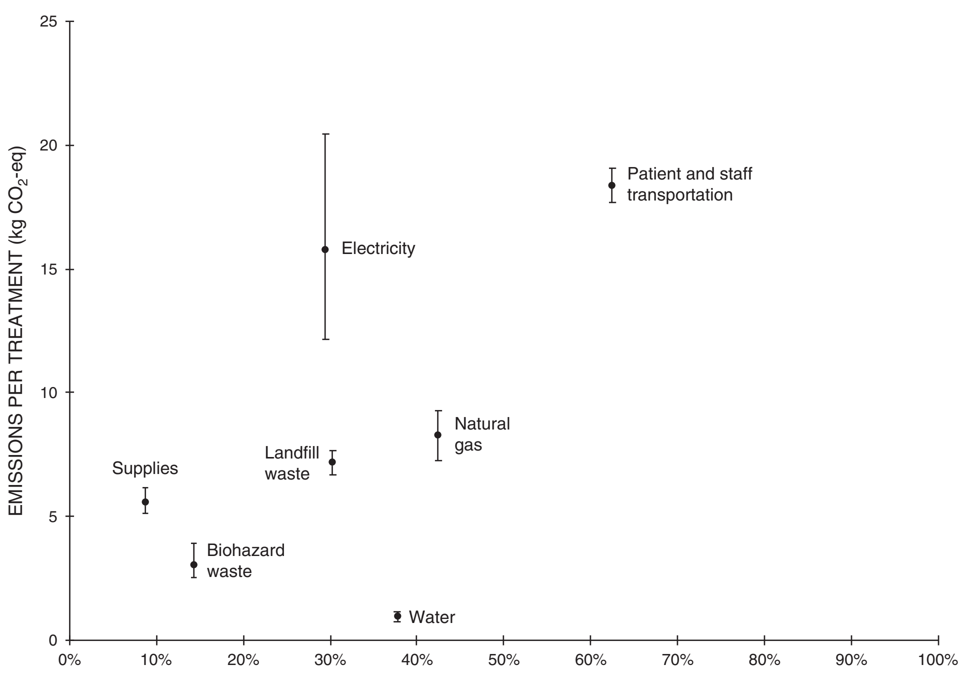

Figure 1. Contributors to carbon footprint of hemodialysis (*n*=15 facilities). The *y* axis indicates magnitude of emissions per treatment, with error bars representing upper and lower CIs. For example, electricity use is associated with 15.7 kg CO_2-eq emissions per treatment (CI, 12.1 to 20.4 kg CO_2-eq). The *x* axis indicates variation across facilities. For example, natural gas use is associated with a 42.4% coefficient of variation in emissions per treatment across the 15 facilities. Other contributors with either a high magnitude of emissions or extensive variation across facilities include landfill waste, water, and transportation. By contrast, supply use and biohazard waste have lower magnitudes and variation.

electricity use per treatment was 25.9 kWh (Table 1). Thus, it is likely that the bulk of electricity usage at the facilities that participated in our study is attributable not to dialysis equipment but to other building purposes. The magnitude of and variation in nondialysis electricity use should be better quantified and addressed as a target of improvement.

Our findings point to four actions that renal providers can take to reduce greenhouse gas emissions. First, they should work with patients, primary care providers, and public health agencies to prevent kidney failure. Screening for and aggressively managing kidney disease and its causes (such as hypertension and diabetes), limiting exposure to potentially nephrotoxic drugs, using angiotensin inhibitors in proteinuric patients, and smoking cessation are all worth pursuing. Preventing, or even delaying, the onset of kidney failure will not only reduce hemodialysis-related greenhouse gas emissions but also decrease healthcare expenditures and enhance patient quality of life.

Second, renal providers should examine and reduce variation in both total emissions and specific emission contributors. The procedures and processes at more efficient facilities may be models for other facilities. This will require comparing data across a number of facilities. As a result, large dialysis organizations or End Stage Renal Disease Networks (regional Medicare renal quality improvement organizations) are well suited to take on this task.[14] Examining variation across countries in the carbon footprint of hemodialysis may also help to identify best practices. In addition, it would be worthwhile to treat greenhouse gas emissions as a marker of quality of care.

Third, renal providers should pay particular attention to the emission contributors with large magnitudes. For example, we found that landfill waste is the fourth largest contributor to total greenhouse gas emissions. Conducting a waste audit, which is a detailed analysis of a facility's waste stream, may help identify areas for improvement. Recycling all recyclable products and ordering supplies with minimal or recyclable packaging will also help. Emissions from recycled waste are substantially lower than emissions from landfill waste for most materials.[15] In addition, disposing of waste locally will reduce travel-related emissions.

Fourth, renal providers should purchase electricity from renewable sources, such as solar and wind. Electricity is the second largest emission contributor in this study, so switching to renewable sources would greatly reduce greenhouse gas emissions. Using high-efficiency electric heat pumps instead of natural gas for heating would also be beneficial. In addition, renal providers can act as citizens and consumers to encourage a society-wide shift to use of renewable electricity and transportation with electric vehicles. A strategy of electrifying as much as possible, accompanied by using electricity from renewable sources, would virtually eliminate three of the largest sources of hemodialysis-related emissions, *i.e.*, transportation, electricity, and natural gas (Figure 1). Manufacturers should also work to develop dialysis machines that use less electricity and water.

Several limitations must be considered in interpreting our findings. We focused on one dialysis organization in a single geographic region, so our results may not apply to other facilities and regions. We did not include medications administered during dialysis because emission factors for specific medications are not available from manufacturers. Policy makers should require pharmaceutic companies (and other manufacturers) to make emission data readily available. Our emission estimates are determined on the basis of generic industrial processes and may not accurately reflect specific manufacturing steps and inputs for medical equipment. We assumed that all staff traveled by car. We do not have information on other tasks, *e.g.*, getting groceries, that patients and staff may combine with travel to dialysis facilities. Thus, allocating the entire distance traveled to hemodialysis may be an overestimate. The number of participating facilities was too small to make definitive conclusions about the association between emissions per treatment and (*1*) number of treatments provided, (*2*) geographic location of facilities, or (*3*) age of facilities. We did not analyze emissions related to other types of dialysis, such as home hemodialysis or peritoneal dialysis.

Future work on this topic should determine whether similar variation exists across other dialysis facilities. It would also be important to better pinpoint reasons for variation, such as the presence of windows or insulation in walls; water use for reverse osmosis versus other building functions; and energy consumption by specific dialysis machines and by lighting, heating, and cooling systems. The latter will require careful metering of water and energy use for each task or equipment. Other areas to explore include specific hemodialysis parameters (*e.g.*, high dialysate flow rates) and the carbon footprint of home hemodialysis.

In conclusion, hemodialysis treatment has a sizable carbon footprint that varies substantially across facilities, treatments, and emission contributors. The large magnitude of this footprint presents a challenge in addressing climate change, whereas the substantial variation presents potential opportunities to reduce emissions. Our approach may also be useful to understand and address the carbon footprint of other aspects of healthcare.

DATA SHARING STATEMENT

All data is included in the manuscript and/or supporting materials.

DISCLOSURES

A.M. Huml reports having other interests in, or relationships with, the Cleveland Kidney Precision Medicine Project Community Advisory Board; and serving on the Cleveland Minority Organ Tissue Transplant Education Program (MOTTEP) Advisory Board, as chairperson for IPRO ESRD Network of the Ohio River Valley Medical Review Board, and as member of the Medical Director Advisory Council for The National Forum of ESRD Networks. A.R. Sehgal reports serving as associate editor of *Annals of Internal Medicine*. The remaining author has nothing to disclose.

FUNDING

None.

ACKNOWLEDGMENT

The authors appreciate the help of the facilities that participated in this project.

AUTHOR CONTRIBUTIONS

A.M. Huml and A.R. Sehgal were responsible for investigation, project administration, and resources; A.R. Sehgal wrote the original draft, provided supervision, and was responsible for funding acquisition and visualization; A.R. Sehgal and J.E. Slutzman were responsible for formal analysis, software, and validation; and all authors conceptualized the study, reviewed and edited the manuscript, and were responsible for data curation and methodology.

SUPPLEMENTAL MATERIAL

This article contains the following supplemental material online at http://jasn.asnjournals.org/lookup/suppl/doi:10.1681/ASN.2022010086/-/DCSupplemental.

Supplemental Table 1. Composition, weight, and ecoinvent manufacturing unit process inputs of supplies used in hemodialysis treatment.

Supplemental Table 2. Other input ecoinvent unit processes.

Supplemental Figure 1. System boundary for life cycle assessment of hemodialysis.

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