JACC: ADVANCES VOL. 2, NO. 3, 2023

ORIGINAL RESEARCH

OUTCOMES AND QUALITY

Impact of Remote Cardiac Monitoring on Greenhouse Gas Emissions

Global Cardiovascular Carbon Footprint Project

Danish Bawa, MD,[a] Adnan Ahmed, MD,[a] Douglas Darden, MD,[a] Rajesh Kabra, MD,[a] Jalaj Garg, MD,[b] Shanti Bansal, MD,[c] Eric Olsen, MD,[c] Donita Atkins, RN,[a] Anam Rahim, NP,[d] Nicholas Pham, BS,[a] Rakesh Gopinathannair, MD,[a] Naga Venkata K. Pothineni, MD,[a] Peter Park, MD,[a] Rangarao Tummala, MD,[a] Scott Koerber, MD,[a] Andrea Natale, MD,[e] Dhanunjaya Lakkireddy, MD[a]

ABSTRACT

BACKGROUND Remote monitoring (RM) of patients with cardiac implantable electronic devices (CIEDs) is efficient and requires fewer resources than conventional monitoring. However, the impact of RM on the carbon footprint (CF) is not known.

OBJECTIVES The authors sought to evaluate the reduction in cost and greenhouse gas (GHG) emissions with RM as compared to conventional monitoring of CIEDs and its relevance to CF.

METHODS Data were obtained from a third-party RM provider on 32,811 patients from 67 device clinics across the United States. Distance from home address to the device clinic for patients on RM was calculated. Savings in total distance traveled over 2 years was calculated using frequency of follow-up required for the device type. National fuel efficiency data and carbon emission data were obtained from the Bureau of Transportation Statistics and U.S. Environmental Protective Agency, respectively. The average gas price during the study period was obtained from U.S. Energy Information Administration.

RESULTS In the study population, RM resulted in a total saving of 31.7 million travel miles at $3.45 million and reduction of 12,518 metric ton of GHG from gasoline. There was a reduction of 14.2-million-page printouts, $3 million in cost, and 78 tons of GHG. Improvement in workforce efficiency with RM resulted in savings of $3.7 million. There was a net saving of $10.15 million and 12,596 tons of GHG emissions.

CONCLUSIONS RM of patients with a CIED resulted in significant reductions in GHG emissions. Efforts to actively promoting RM can result in significant reduction in CF. (JACC Adv 2023;2:100286) © 2023 The Authors. Published by Elsevier on behalf of the American College of Cardiology Foundation. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

From the [a]Kansas City Heart Rhythm Institute, Overland Park, Kansas, USA; [b]Division of Cardiology, Cardiac Arrhythmia Service, Loma Linda University Health, Loma Linda, California, USA; [c]Houston Heart Rhythm and Octagos Health, Houston, Texas, USA; [d]Division of School of Nursing, University of Texas Medical Branch, Galveston, Texas, USA; and the [e]Texas Cardiac Arrhythmia Institute, Austin, Texas, USA.

The authors attest they are in compliance with human studies committees and animal welfare regulations of the authors' institutions and Food and Drug Administration guidelines, including patient consent where appropriate. For more information, visit the Author Center.

Manuscript received February 17, 2023; accepted February 18, 2023.

ISSN 2772-963X https://doi.org/10.1016/j.jacadv.2023.100286

ABBREVIATIONS AND ACRONYMS

CF = carbon footprint

CIED = cardiac implantable electronic device

CRT-D = cardiac resynchronization therapy defibrillator

EPA = Environmental Protective Agency

GHG = greenhouse gas

ILR = implantable loop monitor

RM = remote monitoring

Climate change (CC) is one of the major collective challenges faced by the human race in the 21st century because of greenhouse gas (GHG) emissions from human activities. Health care sector globally contributes around 4% to 6% of the planetary GHG emissions.[1] The U.S. health care sector contributes 8% to 10% of total national GHG emissions, the highest among industrialized countries, accounting for roughly 25% of the global health sector emissions.[2,3] The harmful effects of GHG on overall public health as well as cardiovascular diseases are well documented and have been studied extensively.[4-6] However, the contribution of health care-related activities toward GHG emissions is not well studied, and there is a scarcity of data pertaining to medical specialty-specific activities.[7,8]

The COVID-19 pandemic steered a significant growth in telehealth utilization and remote monitoring (RM) of cardiovascular implantable electronic devices (CIEDs).[9-11] Not only is RM cost-effective and convenient compared to conventional monitoring, but it is also shown to have improved safety and patient satisfaction.[12-14] Having considered these advantages, RM of CIEDs was upgraded to Class I recommendations in all major guidelines.[15-18] RM of CIEDs may also be an important tool in combating CC and to reduce the overall carbon footprint (CF) of health care operations.

The Global Cardiovascular Carbon Footprint Project is a grassroots group started in 2021 to understand, evaluate, and potentially manage cardiovascular service industry's environmental impact on GHG emissions and CF. Of the various patient-related activities in the cardiovascular management, monitoring of patients' CIEDs is a lifetime repetitive activity whose impact on GHG is largely unknown. In this study, we sought to evaluate the reduction in cost and GHG emissions with RM as compared to conventional monitoring of CIED.

METHODS

STUDY DESIGN AND POPULATION. This is an observational study analyzing deidentified data from a repository of a third-party RM provider Octagos Health. The data repository included patient-level deidentified data within the last 2 years from July 2020 till June 2022 from 67 device clinics across the United States located in 30 cities. The clinics were located in the states of Arizona, California, Florida, Kansas, New Jersey, Oklahoma, Pennsylvania, and Texas. The study was reviewed by the institutional review board and was exempted due to the anonymized and retrospective nature of the study.

CF MEASUREMENT. The CF of health care operations can be estimated by calculating the direct and indirect emissions occurring inside and outside of the boundaries of the system, respectively. These emissions are broadly classified into 3 categories as scope 1, 2, and 3. Scope 1 or direct emissions are defined as emissions that are owned or controlled by the system, scope 2 or energy-indirect GHG emissions are emissions from the consumption of purchased electricity, steam, or other sources of energy (eg, chilled water) generated upstream from the system, and scope 3 or other indirect emissions are the emissions derived from upstream and downstream system activities occurring outside the boundary (eg, travel to and from the clinic) of the system.[19] The major GHG emissions from monitoring of CIEDs (either in-person or remotely) fall primarily under scope 3 emissions, which is most difficult to calculate because of heterogeneity in the modes of transportation, distance travelled, fuel emissions, and other human factors that are hard to be accounted. We considered an indirect method to account for these emissions.

We looked at the number of patient-related activities in a year: 1) number of times a CIED is monitored on a scheduled basis and nonscheduled basis due to unforeseen cardiac activity of significance; 2) assess the distance from patients' primary residence and the device clinic in miles; 3) lost hours in wages from patients' perspective; 4) distance traveled by cardiac device monitoring personnel in miles; 5) cost of device monitoring personnel and hour worked in a day (cumulative monitoring hours); 6) electricity, heating, and building maintenance costs; 7) paper printed during monitoring for each patient and total; 8) lost efficiency in the outpatient clinics and associated lost revenues from fewer patients seen. Of the primary 8 activities associated with CIED monitoring, items 1, 2, 5, 7, and 8 are consistent, and data were easily accessible and verifiable. The other factors were not taken into account due to significant variations in the available data. Microsoft emission impact dashboard was used to calculate the GHG emissions of information technology (IT) devices, servers, and cloud computation.

DATA COMPUTATION AND STATISTICAL ANALYSIS. An indigenous artificial intelligence system was deployed to identify the distance between the patient's home and their respective device clinics where they were being followed up for RM of the device. Microsoft Excel 2011 was used for data collection and performing descriptive statistics. The mean distance (in miles) of all the patients from each clinic was calculated. The average weekly gas price for respective cities (when available) and/or states for the study period was obtained from U.S. Energy Information Administration.[20] Mean gas prices for the study period of 2 years (104 weeks) were calculated using the weekly average gas price data obtained from the U.S. Energy Information Administration as shown in Supplemental Table 1 to 8. National fuel efficiency data in miles per gallon were obtained for respective years (July 2020 till June 2022) from the Bureau of Transportation Statistics.[21] Carbon emission data for GHG emissions from a typical passenger vehicle were obtained from the U.S. Environmental Protective Agency (EPA).[22] Artificial intelligence tools were used to calculate total number of printout pages prevented by using RM and digital access to device reports instead of traditional printout. The average cost of paper printout was obtained from the vendors providing printing services to the clinics included in the study. CF of paper printing was calculated by utilizing "Greenhouse Gas Reporting Program Pulp and paper," which is a publicly available online tool on the EPA webpage for reporting GHG emissions of paper and printing-related activities.[23] We determined the difference in activities and the associated greenhouse effects when the patients are monitored in person vs RM.

RESULTS

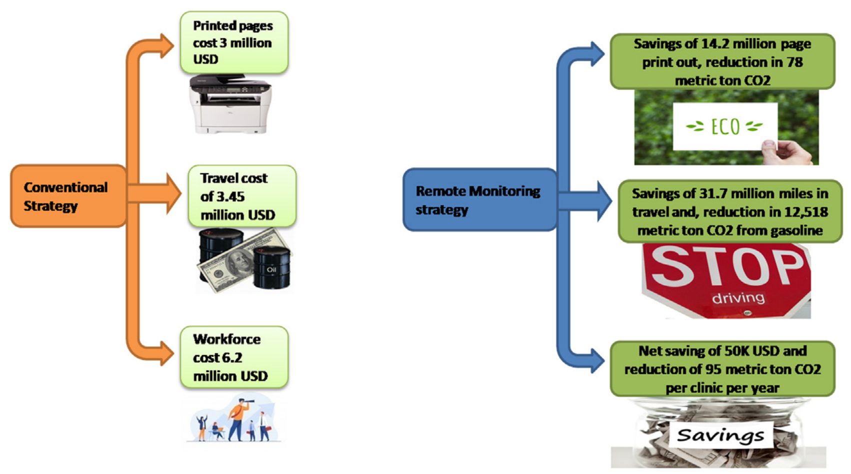
There were 32,811 patients with 7,666 implantable loop monitors (ILRs), 5,589 implantable cardioverter-defibrillators (ICDs), 15,599 pacemakers, and 3,957 cardiac resynchronization therapy defibrillators (CRT-Ds) who were being monitored remotely between July 2020 and June 2022 at the 67 device clinics. ILR patients were followed up on a monthly basis, whereas pacemaker, ICD, and CRT-D were followed up every 3 months. The average distance from home to clinic in patients with ILR, ICD, pacemaker, and CRT-D was 67.5, 73.9, 89.9, and 95.3 miles, respectively. Over a period of 2 years, there was a reduction of 31.7 million miles in distance travelled for the device monitoring from RM of CIEDs. The net savings in cost of gas was $3.45 million at an average gas price of $2.97 per gallon and net fuel efficiency of 22.9 miles per gallon.[20,21] As per the data from EPA, 1 gallon of regular gasoline burnt in a standard passenger vehicle in the United States results in production of 8,887 g of carbon dioxide (CO_2); therefore, RM of patients with CIEDs in our cohort resulted in 12,518 metric ton reduction in CO_2 production from gasoline.

There was a reduction in 14.2 million paper prints across 67 centers in 2 years, which resulted in net dollar cost saving of $3 million (average cost of 21 cents per printout). A sheet of A4-size paper can produce CO_2 emission of 4.3 to 4.7 g based on production methods and energy-use structures as well as the method used to calculate CO_2 emission.[24,25] Additionally, printing 1 sheet of paper from a laser printer can result in 0.08 to 1.2 g of CO_2 production per sheet from ink and energy consumption. Therefore, reduction in 14.2 million paper printouts resulted in net reduction of 78 metric tons (78 million grams) of CO_2 production (average of 5.5 g of CO_2 per sheet). Although the savings in GHG emission from paper printout may seem small as compared to overall savings from gasoline, 78 metric tons of CO_2 is equivalent to 8,777 (approximately 9,000) gallons of gasoline or 193,612 (approximately 200,000) miles driven by an average gasoline-powered passenger vehicle. Moreover, it was found that RM resulted in improved workforce efficiency with 1 technician per 1,500 CIEDs with RM as compared to 1 technician per 500 CIEDs for conventional in-person monitoring. This may result in savings of approximately $3.7 million in workforce efficiency, considering a mean salary of $75K for the cardiac device technician per year in our cohort of 32,811 patients. The cumulative savings from RM of CIED was $6.7 million per clinic, which is equivalent to savings of $50,000 per clinic per year and net GHG reduction of 95 metric tons per clinic (**Figures 1** and **2**). The GHG emission from IT devices, IT servers, and cloud computing was estimated to be 3.52 million metric tons of CO_2 using Microsoft emissions impact dashboard (**Figure 3**, Supplemental Table 2). When accounted for reduction in CF from workforce efficiency with reduced commutes for the employees to and from the office and a work-from-home option, the overall impact was negligible and, therefore, was not accounted in global extrapolation of GHG emissions.

DISCUSSION

Our study demonstrated that the RM of 32,811 patients with CIEDs seen between 2020 and 2022 at 67 centers throughout the United States resulted in a reduction in GHG emissions of 12,596 metric tons as compared to conventional monitoring over a period of 2 years. This is equivalent to a reduction of 31.7 million travel miles, or 2 million gallons of gas saved. The cumulative favorable impact of RM is equivalent to saving 14,907 acres of forest land or

FIGURE 1 Comparison of Cost and Carbon Accounting Between Conventional Strategy and Remote Monitoring Strategy for Patients With Cardiac Implantable Electronic Devices



planting 208,276 new tree seedlings grown for 10 years (**Central Illustration**). This is calculated to be a reduction of 0.384 metric ton GHG emission per patient per year, equivalent to 6.3 seedlings grown for 10 years. RM also resulted in cost reduction of $3.45 million for the patients as well as reduction in cost of about $6.7 million in terms of workforce efficiency and paper printout for the device clinic, with a net savings of $10.15 million in overall health care spending. Numerous studies have demonstrated that RM of CIED is less resource-intense, efficient, and cost-effective; improved patient compliance and care; and reduces the number of planned as well as unplanned clinic visit as compared to conventional monitoring.[26-31] In addition to these advantages, our study shows that RM is also one of the important tools to help reduce CF of cardiovascular health care operations.

In the United States, cardiac arrhythmias impact an estimated 14.4 million patients, with more than 300,000 individuals receiving new CIED implants every year in the United States.[32] Furthermore, it is estimated that there are around 10.5 million existing CIEDs globally at any given point, whereas approximately 1.4 million CIEDs are implanted globally each year.[33] These numbers are growing exponentially because of increased aging population as well as improvement in diagnostic abilities of cardiac arrhythmias. Whether the purpose of CIED insertion is arrhythmia surveillance such as with ILR or it is inserted for therapeutic purposes such as ICD, CRT-D, cardiac resynchronization therapy pacemaker, or

FIGURE 2 Cost Savings With Remote Monitoring of Cardiac Implantable Electronic Device in Gas, Paper, and Work Efficiency

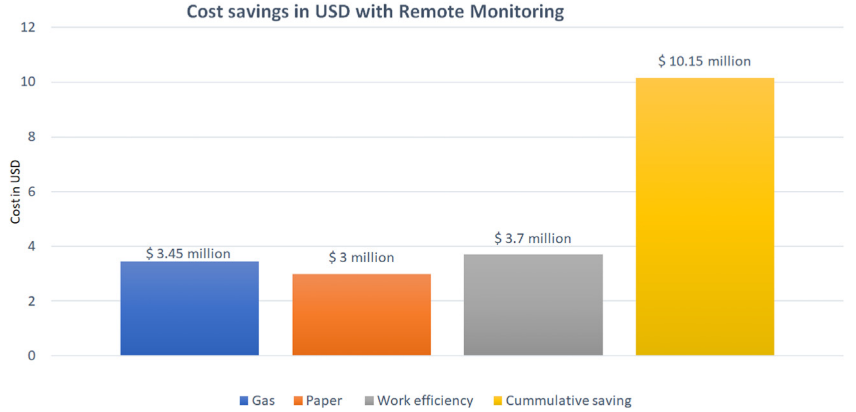
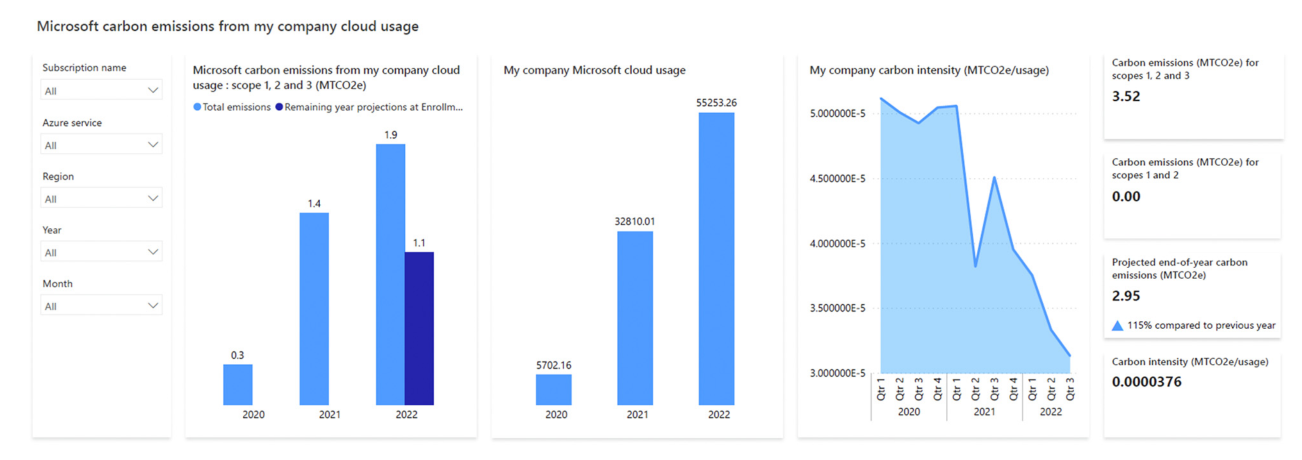


FIGURE 3 Microsoft Emission Impact Dashboard



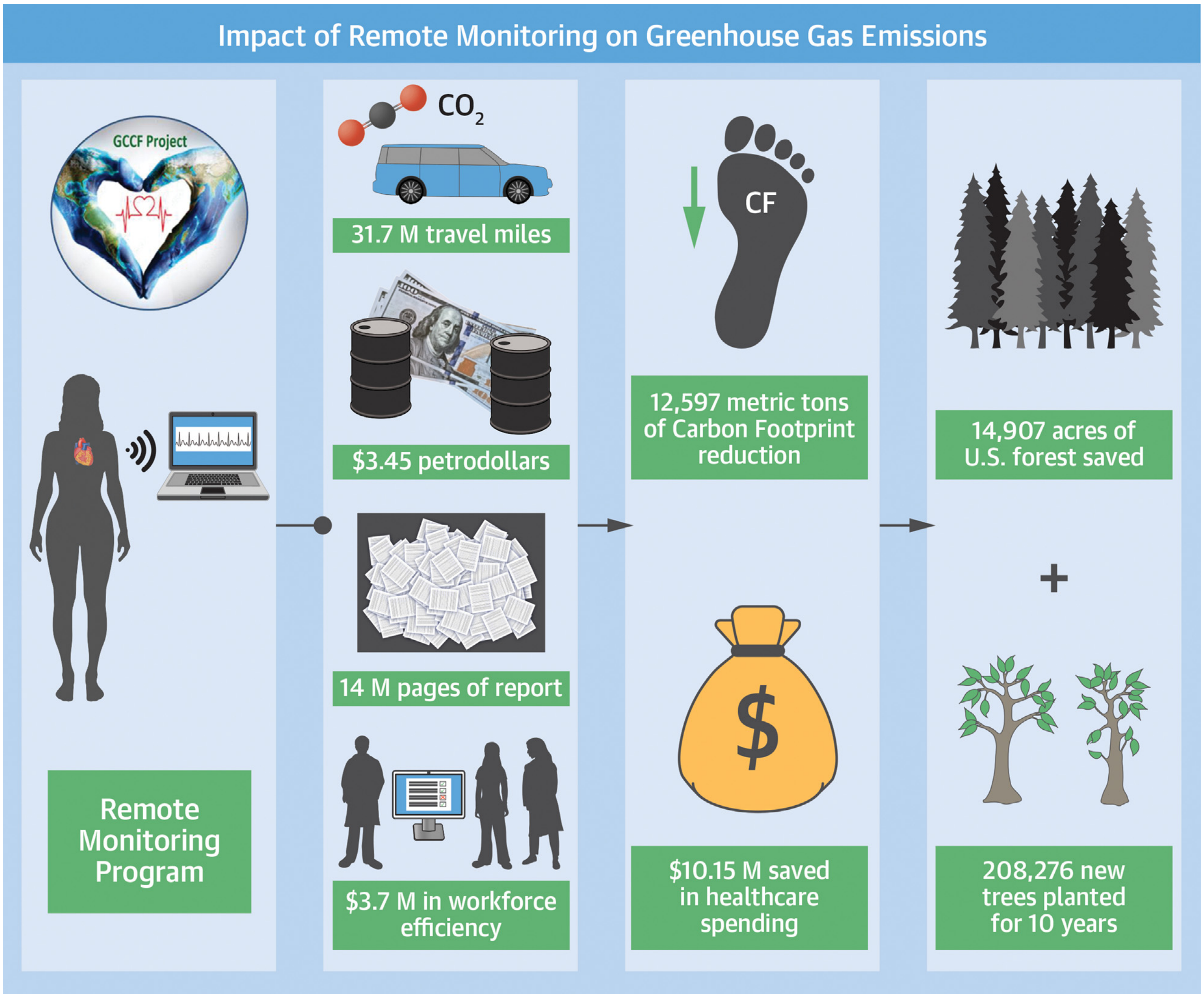
The Microsoft Emission Impact Dashboard reporting the GHG emissions (scope 1, 2, and 3) of IT devices, servers, and cloud computation for remote monitoring of CIEDs. Courtesy of Octagos Health. CIED = cardiac implantable electronic devices; GHG = greenhouse gas; MTCO2e = metric ton carbon dioxide emissions.

prosthesis-patient mismatch, routine monitoring of these devices has evolved to be a standard of care.[34] The data from our database when extrapolated for the global CF reduction with RM showed that it can help reduce about 4.57 million metric tons of GHG emissions based on conservative estimate. This is equivalent to 5.4 million acres of US forests sequestering CO_2 for 1 year or 11.4 billion miles driven by an average gasoline-powered passenger vehicle or GHG transportation output of the entire state of Rhode Island.[35,36] These estimates are conservative as they are based on the assumption that the number of CIEDs implanted and remotely monitored each year remains the same and that there is no growth in the total number of CIEDs implanted each year.

The evolution of a complex convoluted health care system in the 21st century has resulted in several unintended consequences, with GHG emissions being one of the major components of these consequences. A broad consensus and convergence of efforts are needed among health care specialties to tackle the new pandemic of global warming. This study aims to present RM of CIED as a case study to promote the agenda of CC as an integral part of planning and delivery of health care in the future. The global health community can lead the way in innovating and establishing a sustainable health care model to advance the global health agenda without exacerbating the global climate crisis.

STUDY LIMITATIONS. The findings of this study should be interpreted in the context of several limitations. First, this is a retrospective observational study aimed at calculating the reduction in GHG emissions from RM of CIED; therefore, no intervention is performed as part of this study. In the absence of an intervention or comparison group, patients included in our study group served as their own control and were compared with the distance they would have traveled if they were monitored via conventional in-person monitoring. Second, calculation of GHG reduction from RM was mostly computed by calculating the scope 3 emissions for comparison with the conventional monitoring. This is based on the assumption that the scope 1 and scope 2 emissions for conventional and RM are similar. Third, a significant portion of the study period coincides with the peak duration of the pandemic (and stay-at-home mandate), which essentially left RM and telehealth visits as the preferred and sometimes the only available option for the patients. The number of patients being monitored exclusively with RM may have reduced following the end of pandemic. Moreover, we were unable to account for the in-person clinic visits required when additional testing (ie, echocardiograms) and device interrogation occur in concert, as a result of clinically actionable alerts with RM and the number of indicated visits that do not actually occur or were transitioned to telemedicine visit. Fourth, the significant drop in gas prices during the pandemic may have affected the overall cost-analysis. Fifth, mean distances were included for

CENTRAL ILLUSTRATION The Impact of Remote Monitoring of Patients With Cardiac Implantable Electronic Device on Greenhouse Gas Emissions



Bawa D, et al. JACC Adv. 2023;2(3):100286.

This central illustration describes the impact of remote monitoring of patients with a cardiac implantable electronic device in reducing the carbon foot print based on 67 device clinics in the United States. Adapting remote monitoring can lead to reduction in fossil fuel utilization by decreasing travel miles. This can improve the work force efficiency and resource utilization, resulting in overall cost saving as well as carbon footprint. The impact is equivalent to planting more than 200,000 trees or saving 15,000 (approx) acres of U.S. forest land from deforestation.

all patients being monitored remotely at individual clinic based on map locations, which is prone to skewedness in the data. However, the mean distance travelled per person is considered as the standard method for calculating per capita CF of a large population at this time until more sophisticated methods are implemented. The RM effect could have been slightly overestimated due to the inherent noncompliance in adherence and, thereby, fewer events in conventional monitoring.

CONCLUSIONS

Cardiovascular service contributes to GHG emissions. Efforts in reducing GHG by actively promoting RM of patients with a CIED can result in significant reduction in CF. Industry-wide collaborative groups, working together within and across specialties, are needed to reduce CF of health care operations and tackle global climate crisis.

ACKNOWLEDGMENTS The authors would like to acknowledge the contribution of Healthcare Professionals Against Global Warming (HPAGW) (https://hpagw.org/).

FUNDING SUPPORT AND AUTHOR DISCLOSURES

Drs Bansal and Olsen are shareholders in Octagos Health. All other authors have reported that they have no relationships relevant to the contents of this article to disclose.

ADDRESS FOR CORRESPONDENCE: Dr Dhanunjaya Lakkireddy, The Kansas City Heart Rhythm Institute (KCHRI) @ HCA Midwest, The University of Missouri - Columbia, 5100, Suite 200, 110th Street, Overland Park, Kansas 66215, USA. E-mail: Dhanunjaya.lakkireddy@hcahealthcare.com.

PERSPECTIVES

COMPETENCY IN SYSTEMS-BASED PRACTICE: The Global Cardiovascular Carbon Footprint Project is a grassroots group created to recognize the cardiovascular service industry's environmental impact on greenhouse gas emissions and CF. As climate change is a collective challenge faced by humanity, the study aimed to assess the impact of RM of cardiac implantable electronic devices on global greenhouse gas emissions.

TRANSLATIONAL OUTLOOK: RM is cost-effective and convenient, but it is also shown to have improved safety and patient satisfaction. The authors hope adapting and promoting RM of patients with a cardiac implantable electronic device can result in significant reductions in CF. A combined initiative among the medical subspecialties and medical industry is warranted to reduce the CF to confront the current climate change.

REFERENCES

1. Harm HCW. Global Road Map for Health Care Decarbonization- United States of America HEALTH SECTOR EMISSIONS FACT SHEET. Health Care Without Harm. Accessed March 27, 2023. https://healthcareclimateaction.org/fact-sheets/en/English%20-%20United%20States%20of%20America

2. Lenzen M, Malik A, Li M, et al. The environmental footprint of health care: a global assessment. *Lancet Planet Health*. 2020;4(7):e271–e279.

3. Watts N, Amann M, Arnell N, et al. The 2019 report of the Lancet countdown on health and climate change: ensuring that the health of a child born today is not defined by a changing climate. *Lancet*. 2019;394:1836–1878.

4. Goshua A, Gomez J, Erny B, et al. Addressing climate change and its effects on human health: a call to action for medical schools. *Acad Med*. 2021;96(3):324–328.

5. Brauer M, Casadei B, Harrington RA, Kovacs R, Sliwa K, WHF Air Pollution Expert Group. Taking a stand against air pollution - the impact on cardiovascular disease: a joint opinion from the World Heart Federation, American College of Cardiology, American Heart Association, and the European Society of Cardiology. *Glob Heart*. 2021;16:8.

6. Eckelman MJ, Huang K, Lagasse R, Senay E, Dubrow R, Sherman JD. Health care pollution and public health damage in the United States: an update. *Health Aff (Millwood)*. 2020;39:2071–2079.

7. Power B, Brady R, Connell P. Analyzing the carbon footprint of an intravitreal injection. *J Ophthalmic Vis Res*. 2021;16:367–376.

8. Ditac G, Cottinet PJ, Quyen Le M, et al. Carbon footprint of atrial fibrillation catheter ablation. *Europace*. 2023;25(2):331–340.

9. Lok Wong Samson WT, Gina T, Steven S. Medicare Beneficiaries' Use of Telehealth in 2020: Trends by Beneficiary Characteristics and Location. 2021. Accessed December 3, 2021. https://aspe.hhs.gov/reports/medicare-beneficiaries-use-telehealth-2020

10. Suran M. Increased use of Medicare telehealth during the pandemic. *JAMA*. 2022;327:313.

11. Tang M, Nakamoto CH, Stern AD, Mehrotra A. Trends in remote patient monitoring use in traditional Medicare. *JAMA Intern Med*. 2022;182(9):1005–1006.

12. Chew DS, Zarrabi M, You I, et al. Clinical and economic outcomes associated with remote monitoring for cardiac implantable electronic devices: a population-based analysis. *Can J Cardiol*. 2022;38:736–744.

13. Lappegård KT, Moe F. Remote monitoring of CIEDs-for both safety, economy and convenience? *Int J Environ Res Public Health*. 2021;19:312.

14. Walker RC, Tong A, Howard K, Palmer SC. Patient expectations and experiences of remote monitoring for chronic diseases: systematic review and thematic synthesis of qualitative studies. *Int J Med Inform*. 2019;124:78–85.

15. Varma N, Cygankiewicz I, Turakhia M, et al. 2021 ISHNE/HRS/EHRA/APHRS collaborative statement on mHealth in arrhythmia management: digital medical tools for heart rhythm professionals: from the International Society for Holter and Noninvasive Electrocardiology/Heart Rhythm Society/European Heart Rhythm Association/Asia Pacific Heart Rhythm Society. *J Arrhythm*. 2021;37:271–319.

16. Wilkoff BL, Auricchio A, Brugada J, et al. HRS/EHRA Expert Consensus on the Monitoring of Cardiovascular Implantable Electronic Devices (CIEDs): description of techniques, indications, personnel, frequency and ethical considerations developed in partnership with the Heart Rhythm Society (HRS) and the European Heart Rhythm Association (EHRA); and in collaboration with the American College of Cardiology (ACC), the American Heart Association (AHA), the European Society of Cardiology (ESC), the Heart Failure Association of ESC (HFA), and the Heart Failure Society of America (HFSA). Endorsed by the Heart Rhythm Society, the European Heart Rhythm Association (a registered branch of the ESC), the American College of Cardiology, the American Heart Association. *Europace*. 2022;10:707–725.

17. Glikson M, Nielsen JC, Kronborg MB, et al. 2021 ESC guidelines on cardiac pacing and cardiac resynchronization therapy: developed by the task force on cardiac pacing and cardiac resynchronization therapy of the European Society of Cardiology (ESC) with the special contribution of the European Heart Rhythm Association (EHRA). *Rev Esp Cardiol (Engl Ed)*. 2022;75:430.

18. Kumar S, Haqqani H, Wynn G, et al. Position statement on the management of cardiac electrophysiology and cardiac implantable electronic devices in Australia during the COVID-19 pandemic: a living document. *Heart Lung Circ*. 2020;29:e57–e68.

19. Caro D. Carbon footprint. In: Fath B, ed. *Encyclopedia of Ecology (Second Edition)*. Elsevier; 2019:252–257.

20. U.S. All Grades All Formulations Retail Gasoline Prices (Dollars per Gallon). U.S Energy Information Administration. Accessed March 27, 2023. https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=emm_epm0_pte_nus_dpg&f=m

21. @USDOT. *Average Fuel Efficiency of U.S. Light Duty Vehicles*. @USDOT; 2023.

22. Greenhouse gas emissions from a typical passenger vehicle. In: USEPAOoTaA, ed *Quality*. Ann Arbor, MI: Office of Transportation and Air Quality; 2018.

23. U.S. EPA Organization. GHGRP Pulp and Paper. United States Environmental Protective Agency. Accessed October 17, 2023. https://www.epa.gov/ghgreporting/ghgrp-pulp-and-paper

24. Dias AC, Arroja L. Comparison of methodologies for estimating the carbon footprint – case study of office paper. *J Clean Prod*. 2012;24:30-35.

25. Tomberlin K, Venditti R, Yao Y. Life cycle carbon footprint analysis of pulp and paper grades in the United States using production-line-based data and integration. *Bioresources*. 2020;15(2):3899-3914.

26. Guédon-Moreau L, Lacroix D, Sadoul N, et al. Costs of remote monitoring vs. ambulatory follow-ups of implanted cardioverter defibrillators in the randomized ECOST study. *Europace*. 2014;16:1181-1188.

27. O'Brien BJ, Connolly SJ, Goeree R, et al. Cost-effectiveness of the implantable cardioverter-defibrillator: results from the Canadian implantable defibrillator study (CIDS). *Circulation*. 2001;103:1416-1421.

28. Sheldon R, O'Brien BJ, Blackhouse G, et al. Effect of clinical risk stratification on cost-effectiveness of the implantable cardioverter-defibrillator: the Canadian implantable defibrillator study. *Circulation*. 2001;104:1622-1626.

29. Hindricks G, Taborsky M, Glikson M, et al. Implant-based multiparameter telemonitoring of patients with heart failure (IN-TIME): a randomised controlled trial. *Lancet*. 2014;384:583-590.

30. Parthiban N, Esterman A, Mahajan R, et al. Remote monitoring of implantable cardioverter-defibrillators: a systematic review and meta-analysis of clinical outcomes. *J Am Coll Cardiol*. 2015;65:2591-2600.

31. Al-Khatib SM, Piccini JP, Knight D, Stewart M, Clapp-Channing N, Sanders GD. Remote monitoring of implantable cardioverter defibrillators versus quarterly device interrogations in clinic: results from a randomized pilot clinical trial. *J Cardiovasc Electrophysiol*. 2010;21(5):545-550.

32. Virani SS, Alonso A, Aparicio HJ, et al. Heart disease and stroke statistics-2021 update: a report from the American Heart Association. *Circulation*. 2021;143:e254-e743.

33. Kusumoto FM, Schoenfeld MH, Wilkoff BL, et al. 2017 HRS expert consensus statement on cardiovascular implantable electronic device lead management and extraction. *Heart Rhythm*. 2017;14(12):e503-e551.

34. Greenspon AJ, Patel JD, Lau E, et al. 16-year trends in the infection burden for pacemakers and implantable cardioverter-defibrillators in the United States 1993 to 2008. *J Am Coll Cardiol*. 2011;58(10):1001-1006.

35. *2019 Greenhouse Gas Emissions Inventory Results Indicate Progress Toward Act on Climate Mandates*. Rhode Island Department of Environmental Management; 2023.

36. U.S. EPA Organization. Greenhouse Gas Equivalencies Calculator. United States Environmental Protection Agency. Accessed October 11, 2023. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

KEY WORDS carbon footprint, cardiac implantable electronic devices, global warming, greenhouse gas emissions, remote monitoring

APPENDIX For supplemental tables and text, please see the online version of this paper.