A Pathway to Net Zero for Health Care

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Analysis

A Pathway to Net Zero for Health Care

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Key Messages

- Greenhouse gas emissions from health care are substantial, and with a few notable exceptions such as the British National Health Service, the health sector has lagged most other industries in reducing its carbon footprint.
- Health care leaders and organizations have both a responsibility and an opportunity to chart a path to Net Zero emissions. Doing so, as part of a broader climate-ready health care strategy, can improve health, protect health care delivery by minimizing disruptions, yield economic benefits, and establish the health care sector as a leader in climate action.
- Rising to the challenge of Net Zero in health care will require broad transformative steps that harness levers within and outside of the health care sector, such as reducing demand through preventive care, powering the entire enterprise with clean energy,

choosing medical supplies and equipment with lower carbon footprints, and reducing travel through telemedicine.

Contributors and sources

The authors on this analysis represent diverse perspectives and expertise with an international scope. This project was led by Dr. Renee N. Salas, through which the article was commissioned, who is an emergency medicine physician and climate and health expert based in Boston, MA, USA. Dr. Edward Maibach is a climate and health communication expert based in Fairfax, VA, USA whose work focuses on public understanding of climate change and clean energy. Dr. David Pencheon is a physician and sustainability expert based in Exeter, UK. Dr. Nicholas Watts is a climate and health expert based in London, UK, with additional expertise in sustainability. Dr. Howard Frumkin is a climate and health expert based in Seattle WA, USA with extensive expertise on energy policy. The unique knowledge of each author was leveraged in the conceptualization and construction of this analysis.

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Conflicts of Interest

We have read and understood BMJ policy on declaration of interests and do not have any conflicts of interest to declare.

A Pathway to Net Zero for Health Care

Standfirst

The health care sector has a profound responsibility and opportunity to reduce greenhouse gas emissions to limit the widespread health harms of climate change and as part of a broader climate-ready health care delivery strategy. Renee N. Salas and colleagues chart a path to Net Zero emissions for health care.

Introduction

The Intergovernmental Panel on Climate Change (IPCC) has made clear that limiting global warming to 1.5°C above pre-industrial levels will greatly reduce the probability of sustained public health catastrophes. To achieve this aim, by 2030 human-caused carbon dioxide (CO_2) emissions must fall to roughly half of 2010 levels, and to Net Zero by 2050. Emissions of other greenhouse gases (GHGs) must reach Net Zero soon thereafter (between 2063 and 2068)(1).

"Net Zero" means that net emissions of GHGs are zero. To achieve this aim, emissions from all sources — electricity generation, industry, transportation, buildings, etc. — must be reduced to as close to zero as possible, and any remaining emissions must be balanced by removing CO_2 from the atmosphere, through such means as reforestation and direct physical-chemical removal. While modeled estimates vary on specifics, the needed direction of travel is clear: We must urgently and radically reduce GHG emissions.

Across much of the world's economy, Net Zero is a technically feasible goal, although some sectors, such as steel and cement manufacturing and long-distance air travel, will prove more difficult. Nations, cities, investors, and businesses are increasingly committing to Net Zero targets.

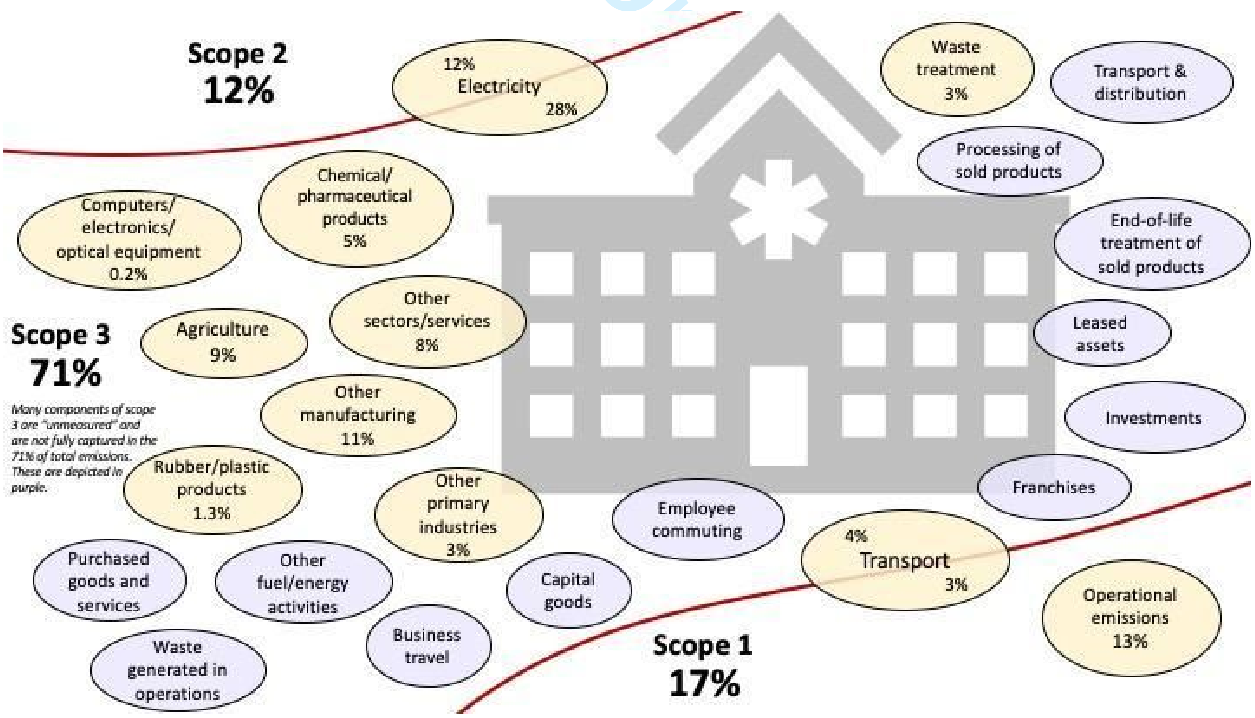
Health care delivery is substantially more energy-intensive than most other commercial and service activities (2), and the health sector has lagged in efforts to reduce emissions. By striving for Net Zero, the health care industry can help limit climate change and its downstream consequences, promote public health through reduced air and water pollution, create cost-savings by eliminating waste and inefficiency, and become leaders rather than laggards in the global effort to limit global warming to 1.5° C.

This paper charts a course to Net Zero emissions in health care. It describes efforts to date, recounts the benefits of Net Zero operations, reviews available strategies, and identifies knowledge gaps.

Health care's carbon emissions

Decarbonizing health care begins with identifying and quantifying the sources of CO_2 emissions, known as the "carbon footprint," as well as the sources of other GHG emissions. This reckoning is complex. It requires defining system boundaries; as shown in **Figure 1**, these encompass the production and transport of medical supplies, patient and staff transportation, energy use in medical facilities, the investment portfolios of health care organizations, and more. Complete accounting requires considering the entire life cycle of health care products and processes and allocating all associated carbon footprint contributions. If a blanket, defibrillator, or medication used in a hospital is manufactured at a distant factory through a production process that emits large amounts of CO_2, then that item is said to carry "embedded carbon", which is attributed to the hospital and not to the manufacturer. Key concepts are shown in **Box 1**.

Figure 1: Measured and Unmeasured Health care Sector Activities that Contribute to Greenhouse Gas Emissions by Scope (3).



134 **Box 1: Key Concepts and Definitions**

Two core concepts for GHG emission quantification:

- **Life cycle analysis:** "Cradle to grave" assessment that captures all emissions associated with a product or activity, from manufacturing through use and disposal.
- **Multi-region input-output (I-O) modelling**: An analytical approach to consumption-based emission and resource accounting. I-O modeling tracks flows of goods and services from different sectors of the economy into the health sector, monetizes these flows, links monetary accounts to GHG emissions in each sector, and allocates "embedded" carbon emissions to the health sector (3,4,28,63,64).

The GHG Protocol defines three emission scopes:

- **Scope 1** emissions fall under the direct control of the health care facility (e.g. on-site fuel combustion, fleet vehicles, anesthetic gas leaks).
- **Scope 2** emissions derive from electricity purchased by the facility.
- **Scope 3** emissions are all other indirect emissions (e.g., embedded carbon in purchased supplies and equipment, employee commuting, waste disposal (65).

Scope 1 emissions afford health care facilities the most control over their emissions. However, it is estimated that over 70% of health care emissions arise from the diverse categories within Scope 3, which very few health systems calculate or report (3). The British National Health System is a notable exception.

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136 On a global basis, the health care carbon footprint in 2016 represented an estimated 4-6% of all
137 emissions (4). **Figure 2** showcases national comparisons. The United States (U.S.) has the second highest
138 per capita emissions, with health care estimated to contribute upwards of 10% of U.S. carbon emissions
139 (5), second only to Iceland where import emissions are significant (6). Emissions rose in many countries
140 between 2007 and 2016, including China (180%), South Korea (75%), Japan (37%), and the U.S. (19%)
141 (4); the dramatic increase in China came during a decade of significant poverty reduction and
142 investment in healthcare services.

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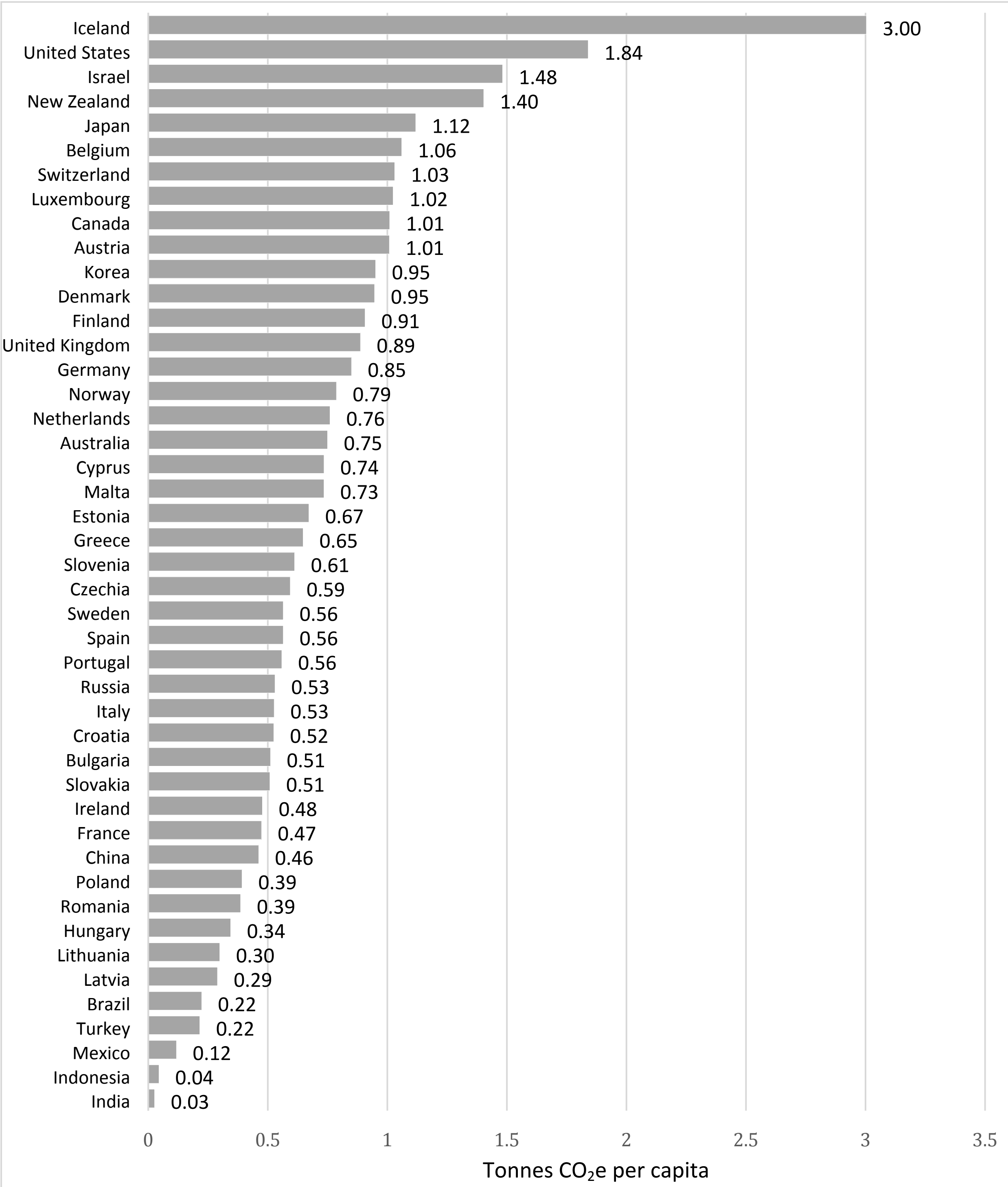
Figure 2: Estimated Carbon Footprint in 2016 Across National Health Systems (4)



Footnote: Only Watts et al (2019) was utilized to allow country comparisons across one methodology. Additional international comparison data, with differences in values given varying methodology, are available from [Karliner et al, 2019](), [Lenzen et al, 2020](), and [Pichler et al, 2019]().

With regard to medical specialties and treatments, key evidence is highlighted in **Table 1.** Individual treatments can range substantially; for example, the carbon footprint of renal dialysis varies 4-fold depending on technique used (7), and the carbon footprint of pharmaceutical manufacturing varies 5-fold across companies (8), suggesting considerable room for improvement among high emitters. There is great variation across treatments, although highly variable assessment methods are used, which stymies comparisons. There remain large gaps in knowledge — entire specialties and treatments whose carbon footprints have not yet been quantified, and the experience of countries other than the U.S., United Kingdom (U.K.), and Australia where most studies have been conducted.

Table 1: Estimated Carbon Footprint Across Specialties, Health Industry Sector, and Treatments

A. Medical specialties or health industry sector				
Specialty	**Setting**	**Carbon footprint**	**Comments**	**Reference**
Renal (inpatient & outpatient care, peritoneal & haemodialysis, transplantation, and administration)	U.K. 1 county renal service (service population 865,000)	3,006 tonnes CO_2e/year	• Building energy 13% • Travel 15% • Pharmaceuticals 35% • Equipment 25%	Connor A, Lillywhite R, Cooke MW. The carbon footprint of a renal service in the United Kingdom. *QJM* . 2010;103(12):965-75. (9)
Surgery	U.S., U.K., Canada Three academic hospitals	3,219-5,188 tonnes CO_2e/ surgical suite/ year 1.7-2.3 tonnes CO_2e/m^2 area 0.15-0.23 tonnes CO_2e/case	Major contributors were anesthetic gases and energy consumption (high HVAC requirements for surgical suites)	MacNeill AJ, Lillywhite R, Brown CJ. The impact of surgery on global climate: a carbon footprinting study of operating theatres in three health systems. The *Lancet Planetary Health.* 2017;1(9):e381-e8. (10)

Intensive care	U.K. Royal Cornwall Hospital critical care unit	0.009 tonnes CO_2e/bed day	Considered only Scope 1 and Scope 2 electricity use	Pollard AS, Paddle JJ, Taylor TJ, Tillyard A. The carbon footprint of acute care: how energy intensive is critical care? *Public health*. 2014;128(9):771-6. (11)
Emergency medicine	U.S. and Canada 15 EMS systems	Median emissions: 0.037 tonnes CO_2e/response 0.0035 tonnes CO_2e/service-area resident	75% emissions from diesel and gasoline fuel	Blanchard IE, Brown LH. Carbon footprinting of North American emergency medical services systems. *Prehosp Emerg Care* 2011;15(1):23-9. (12)
Dentistry	Scotland 22 community dental clinics in Fife		• Travel 45% • Procurement 36% • Building energy 18% Five-fold variation across clinics	Duane B, Hyland J, Rowan JS, Archibald B. Taking a bite out of Scotland's dental carbon emissions in the transition to a low carbon future. *Public health*. 2012;126(9):770-7. (13)
Pharmaceuticals	15 largest pharmaceutical companies	49 tonnes CO_2e/M USD revenues for total pharmaceutical sector 35 tonnes CO_2e/M USD for the group of 15 companies	Considered only Scope 1 and 2 emissions Considered only the 15 (of 200) companies that reported emissions 2012-15 Industry mean (49 tonnes CO_2e/M USD) is 55% higher than	Belkhir L, Elmeligi A. Carbon footprint of the global pharmaceutical industry and relative impact of its major players. *J Cleaner Production.* 2019;214:185-94. (8)

			automotive sector (31 tonnes CO_2e/M USD)	

B. Procedures and treatments		
Procedure or treatment	**Carbon footprint**	**Reference**
Cataract surgery	0.180 tonnes CO_2e/cataract surgery (University Hospital Wales, Cardiff, U.K.) 0.006 tonnes CO_2e/cataract surgery (Aravind Eye Hospital, Pondicherry, India) *Note: The U.K. analysis included patient and staff travel, paper and ink, and food while the Indian analysis did not. Aligning the two results for comparison yields 0.130 tonnes CO_2e/procedure in the U.K. and 0.0006 tonnes/procedure in India, approximately a 20-fold difference.*	Morris DS, Wright T, Somner JEA, Connor A. The carbon footprint of cataract surgery. *Eye*. 2013;27(4):495-501. (14) Thiel CL, Schehlein E, Ravilla T, Ravindran RD, Robin AL, Saeedi OJ, et al. Cataract surgery and environmental sustainability: Waste and lifecycle assessment of phacoemulsification at a private healthcare facility. Journal of Cataract & Refractive Surgery. 2017;43(11). (15)
Asthma inhalers	0.010-0.036 tonnes CO_2e/device 0.017 tonnes CO_2e/patient/year for Relvar-Ellipta/Ventolin-Accuhaler 0.439 tonnes CO_2e/patient/year for Seretide-Evohaler/Ventolin-Evohaler	Wilkinson AJK, Braggins R, Steinbach I, Smith J. Costs of switching to low global warming potential inhalers. An economic and carbon footprint analysis of NHS prescription data in England. *BMJ Open*. 2019;9(10):e028763. (16) Janson C, Henderson R, Löfdahl M, Hedberg M, Sharma R, Wilkinson AJK. Carbon footprint impact of the choice of inhalers for asthma and COPD. Thorax. 2020;75(1):82-4. (17)
Anesthetics	Global warming potential relative to CO_2: Sevoflurane: 210 Isoflurane: 510 Desflurane: 1620	Sulbaek Andersen MP, Sander SP, Nielsen OJ, Wagner DS, Sanford TJ, Jr., Wallington TJ. Inhalation anaesthetics and climate change. *Brit J Anaesthesia*. 2010;105(6):760-6. (18)

Laparoscopic surgery	355,924 tonnes CO_2/year for all U.S. laparoscopic procedures	Power NE, Silberstein JL, Ghoneim TP, Guillonneau B, Touijer KA. Environmental impact of minimally invasive surgery in the United States: an estimate of the carbon dioxide footprint. *J Endourol*. 2012;26(12):1639-44. (19)
Hysterectomy	212,000 tonnes CO_2e/year for 500,000 hysterectomies in the U.S.	Thiel CL, Eckelman M, Guido R, Huddleston M, Landis AE, Sherman J, et al. Environmental Impacts of Surgical Procedures: Life Cycle Assessment of Hysterectomy in the United States. *Environ Sci Technol* 2015;49(3):1779-86. (20)
Renal dialysis	In-centre: 3.8 tonnes CO_2e/patient/year Home: 1.8-7.2 tonnes CO_2e/patient/year depending on technique	Connor A, Lillywhite R, Cooke MW. The carbon footprints of home and in-center maintenance hemodialysis in the United Kingdom. *Hemodial Int*. 2011;15(1):39-51. (7)

Footnote: U.K. = United Kingdom, CO_2e = carbon dioxide equivalent, U.S. = United States, m^2 = square metres, HVAC = heating, ventilation, and air conditioning, EMS = emergency medical services

Benefits of GHG reduction

Approaching and ultimately achieving Net Zero offers a wide range of benefits for health care institutions. First and perhaps most importantly, Net Zero advances the core mission of health institutions — improving health — because measures that mitigate the climate crisis yield numerous health benefits (often called “co-benefits”). In the long term, these benefits flow from reducing the many adverse health impacts of the climate crisis (21). More immediate benefits (22) include the increased physical activity, improved air quality, reduced noise, and avoided car crashes that come with shifting from automobile travel to walking, cycling, and transit (23); the improved air quality that comes with a shift from fossil fuel combustion to renewable power sources (24,25); the reduced risk of cardiovascular disease and some cancers that comes with a shift from meat-heavy to plant-forward diets (26); and the improved health, well-being, and productivity that come with green, energy-efficient hospitals and clinics (27).

The latest attempt at a global assessment of health care environmental footprints reveals that they are wide-ranging, often avoidable, and predominantly indirect (i.e. Scope 3) (28). Consequently, health care systems need to use their considerable influence (e.g., size, mission, and credibility) to decarbonize, not just their internal operations, but their total supply chains and models of care and prevention. Ever increasing health care delivered in current ways does not necessarily lead to better health, highlighting the need to increase the quality and precision of health care — not simply the amount.

Getting to Net Zero will enable health care providers to deliver high quality care today, and in the future, and these two concepts should be increasingly connected given their interdependence (28). Health institutions can realize substantial financial benefits through reduced costs for energy, maintenance, supplies, and other factors, and through reducing waste, even accounting for up - front investments (29–31). This is especially important given the economic challenges confronting health care systems in the COVID-19 pandemic. For example, the shift to carbon-neutral energy use, together with reduced energy use through conservation, is projected to save Boston Medical Center 153 million USD between 2010 and 2030 (32). In addition, getting to Net Zero offers health institutions an opportunity for broader community leadership (33). Lastly, environmental initiatives can position health care institutions as leaders in their communities, as well as motivate the health care workforce and build employee morale (34).

Solutions within and outside of health care systems

Recovery from the COVID-19 pandemic and the associated economic downturn provides an opportunity to reimagine and transform health care systems toward resilience to future social, economic and environmental challenges, particularly toward Net Zero performance. Given the urgent need for, and benefits of, emission reductions, a range of transformative solutions must be considered both within, and outside of, health care (**Table 2**). Some solutions are system-wide, such as creating a culture of sustainability and implementing consistent and valid carbon metrics, an explicit reduction trajectory, and associated accountability processes. Other solutions pertain to specific operational aspects of health care delivery, from clean, renewable energy to transportation, from food services to supply chain management, and still others relate to individual specialties or treatments. Innovative care models may be more acceptable than ever in the wake of the COVID-19 pandemic. For example, despite the many adverse impacts of COVID-19 on health care, such as reduced cancer screening, many of the adaptive practices that were implemented at scale and pace during the pandemic — more telehealth consultations, more care closer to home, more empowered self — care, less travel — may, if adopted for ongoing use, benefit patient, purse, populations and planet. When inevitable trade-offs arise—such as balancing energy-intensive infection control measures with reduced energy use — they will need to be managed with careful adaptive management based on rigorous data collection and analysis.

Table 2: Example Solutions for the Health care Sector with Potential Internal (Within Health Care) and External Levers (Outside of Health Care)

Category	Solution	Within Health Care	Outside of Health Care
System changes	Create a culture that values sustainability	• Connect sustainability with clinical practice implications and health benefits for patients • Create a Chief Sustainability Officer (CSO) • Divest from fossil fuels – mirroring divestment from tobacco • Require each facility and/or unit to have a sustainability plan and to report on progress • Build sustainability considerations into staff training, quality improvement projects, and staff performance evaluation	• Join the global movement to create cultures where climate and health are intimately connected • Appoint Chief Sustainability Officers (CSO), as in other sectors • Advocate for a global movement of fossil fuel divestment across all sectors
	Standardize, track, and publicly report health care carbon footprints	• Institutional commitment to measuring and reporting Scopes 1-3 emissions across institution and departments following accepted standards	• Create a novel metric that determines carbon intensity of care per unit of health delivered • Create a certification organization to assess and validate GHG

		• Integrate carbon footprint, and other environmental performance metrics, into health quality, outcome, and equality measures (28)	emissions by health care organizations • Transparent reporting (naming and shaming)
	Financial incentives	• Tie departmental financial incentives to sustainability metrics	• Tie reimbursement rates from governments and private insurers to GHG footprint
	Optimize collaboration across international, national, and subnational entities	• Sharing of best sustainability practices • National and international health organizations engaging with other disciplines (e.g. engineering) to advance sustainability efforts	• International agreements on how to measure scope 3 emissions
Supply Chain (35)	Green supply chain sourcing	• Invest in purchasing power agreements with other health care systems	• Transparent disclosures of GHG emissions associated with products • Selective purchasing of low-GHG products
Energy Use	Energy from renewable source	• Produce and/or purchase renewable energy (e.g., solar panels on parking garages)	• Advocate for expansion of local and regional renewable energy production

	Energy conservation	• Renovate existing building design • Build new buildings as Net Zero or positive • Re-imagine operations with energy conservation as a foundation	• Advocate with decision makers for Net Zero health care buildings and energy conservation
Transportation (36)	Low carbon transportation	• Electric ambulance and emergency medical service fleets • Financial incentives for utilizing active transport to get to work • Highlight the health benefits to employees and patients	• Lobby local and regional government officials to expand active travel infrastructure on the basis of improved human and environmental health
	Reduced transportation requirements	• Telemedicine and work from home programs for appropriate employees • Provide care closer to home through more community-based primary care with less reliance on tertiary hospitals	• Advocate for reimbursement parity between telemedicine visits • Incentivize work from home
Food systems	Purchase low-carbon foods and packaging	• Prioritize plant-based foods • Prioritize locally sourced foods • Purchase low-carbon materials that are compostable	• Educate the public about the benefits of plant-based diets • Advocate for government and corporate policies that encourage plant-based diets • Advocate for national policies requiring

			disclosure of GHGs associated with a standard serving
	Minimize food waste	• Re-imagine food preparation to minimize waste • Divert extra food to community sources for consumption	• Create community-wide collaborations to pair facilities with excess food with those that distribute to those in need
Waste Management	Minimizing waste	• Encourage investment in sustainable waste management (e.g., source reduction, reuse, proper waste segregation) • Measurement and transparent reporting	• Transformation of global waste management systems • Cross-sectoral sharing of best practices for sustainable waste management
Innovative Models of Care to Reduce Health care Demand	Prioritize disease prevention and chronic disease management	• Full implementation of evidence-based preventive services in health care and public health agencies	• Advocate for prioritization of preventive care in health care policy and reimbursements, systematic economic incentives
	Reduce overtreatment and overprescribing	• Track and incentivize accepted overtreatment and overprescribing based on evidence-based guidelines	• Minimize litigation and optimize other means to protect patient safety (37)
	Innovative technology	• Wide expansion of telemedicine (38–40)	• National telemedicine expansion across health systems

Additional Scope 3	Reducing professional travel	• Reduce professional travel budgets to encourage virtual meetings • Require a GHG emissions justification and approval for travel requests	• Teleconferencing and Net Zero medical meetings (41)

Creating a culture of sustainability within health care can draw from models in other industries and from successful health care quality improvement and change management efforts, such as in patient safety (42,43). Connecting the climate crisis to clinical practice and the institutional mission (44), as well as to fundamental health care values, such as “do no harm” and defining institutional success according to the triple bottom line (social and health improvements, economic performance, and environmental impact) (28), can create an inclusive culture by engaging individuals at all institutional levels, from non-clinical staff to health professionals. The creation of a Chief Sustainability Officer position, mirroring other industries, can help ensure that sustainability is prioritized across institutional decision-making (45), although senior institutional leaders need to support — and hold to account — a pan-organizational approach to avoid isolating the actions in one department. Individuals skilled at conflict analysis and resolution can be utilized to prevent inevitable conflicts from impeding the rapid transformation required.

Accurate health care carbon footprints are essential to informing decision-making and cost-effectiveness (46). Environmental footprint assessments that extend beyond carbon emissions can also address other environmental impacts (e.g., air pollutants, water depletion) that harm health (28). However, current measurement practices need to be better standardized, and because a large portion of health care emissions relate to the supply chain, Scope 3 emissions need to be routinely included. New metrics could be developed to reflect the carbon intensity of care per unit of health improvement delivered, applying the methods of value-based health care to environmental performance (47,48). Transparent reporting should extend to health care supply companies, such as disclosing the carbon footprints of medical products, and lead to open commercial advantage - assisting in selection by hospitals and incentivizing low-carbon production.

The needed transformation to Net Zero includes efforts that extend beyond conventional clinical care. Primordial and primary prevention — including poverty reduction, strong social networks, tobacco and substance abuse control, healthy diets, and physical activity — is intrinsic to this transformation because it reduces the need for health care and therefore for energy- and resource-intensive treatments. Investment policy is also a part of this transformation. Health care institutions, by divesting their financial holdings in fossil fuels, can both advance their mission and help normalize the withdrawal of social license from this industry (49).

Financial incentives can be tied to the transparent carbon emission reporting, utilizing a historic blueprint from the U.S. Medicare, the national health care insurance program for elderly and disabled people, served a transformative role in urgently desegregating hospitals by withholding reimbursements if a facility was practicing racial discrimination (50). Similarly, reimbursements could be withheld from health care systems not moving toward decarbonization. Such incentives are easier to implement when the health and financial incentives are aligned: where the system monetizes health rather than illness.

The COVID-19 pandemic has catalyzed the rapid expansion of low-carbon practices such as telehealth and virtual meetings. It is difficult to imagine post-recovery health care systems without telehealth; the concurrent carbon benefits will help institutions move toward Net Zero (38). Other innovative models that reduce in-person health care encounters, once their efficacy and safety are documented, will also deliver environmental and economic benefits. Similarly, the rapid expansion of virtual meetings and conferences (41) likely heralds reduced professional travel in the post-COVID-19 era, saving time and money while reducing carbon footprints.

Specific examples of initiatives within health care systems around the globe are shown in **Box 2**.

Box 2: Case Study Examples of Efforts to Reduce Greenhouse Gas Emissions

Nation's Health System

The United Kingdom's National Health Service, already a world leader in sustainability, has announced widespread efforts to both improve the health of the nation and commit to achieving Net Zero emissions in the health sector through its campaign For a Greener NHS by 2050 (66). While this plan is now one of the most ambitious decarbonization efforts underway in the world, the NHS has already demonstrated their capability to reduce its emissions, decreasing total GHG by 18% from 2007 to 2017. The NHS is establishing a new expert panel to plan a path to Net Zero (67) and a current call for evidence (68) will help inform this strategy. Given that a significant portion of the NHS's footprint (about 57%) is attributable to indirect emissions via the supply chain, decarbonizing could have effects that extend globally, far beyond the scope of just the United Kingdom. The NHS has taken additional steps to manage their food waste by using a Waste-to-Water system (69) which allows for the safe treatment of 1,200 kg of food waste a week resulting in a significantly reduced carbon footprint as well as large economic savings.

Individual Health Systems
Gundersen Health System, an integrated health care organization based in La Crosse, Wisconsin, and serving communities in Wisconsin, Minnesota, and Iowa, represents one of the biggest U.S. efforts to achieve Net Zero for its portfolio of buildings. By focusing on two main initiatives — reducing resources consumption through energy efficiency and conservation and investment in clean, renewable energy — Gundersen has made significant progress toward reduced energy use and has identified an additional goal of offsetting all utility energy consumption with equivalent, renewable, local energy generation. Gundersen relies heavily on wind energy; two wind farms in Lewiston, Minnesota and Cashton, Wisconsin each generate about 5 megawatts of energy, enough to collectively power 2,600 homes each year. Gundersen fully converted from fossil fuels to locally produced energy by 2014; together with other efforts, such as waste reduction, it calculates annual operational savings of 3.7M USD (70,71).

Bhagat Chandra Hospital, a multi-specialty, 85-bed facility in Dwarka, New Delhi, India has achieved significant financial and environmental benefits by transitioning to solar energy, conserving approximately 93,000 kilograms of CO_2 emissions since 2016. Through a coordinated, hospital-wide initiative, Bhagat Chandra has installed 50kW solar panels which connect to the electrical system and reduce 20-30% of their energy consumption. In addition to this major change in energy reliance, the hospital has made other significant changes to transition to clean energy including: installation of 4-star electrical appliances, swapping of conventional light bulbs for LEDs, and installation of auto lock on doors to maintain temperature and minimize unnecessary energy use. When taking into account the market cost of solar panels, the economic investment in the panels will be returned in 6 years and will save 65,000 kg CO_2 and 14,800USD in energy costs per year (72).

Buildings
Butaro District Hospital, a 150-bed facility located in the Northern Province of Rwanda, was constructed as a low-carbon building in collaboration with Partners in Health, the Rwandan Ministry of Health, and MASS Design. Butaro Hospital minimizes energy consumption through the use of non-permeable continuous flooring, natural daylight, natural ventilation, and optimized fans and UV lights to ventilate while minimizing transmission of airborne infections. Many of the materials for the construction of the facility were sourced locally (including volcanic rock from the Virunga mountain chain), and conscious labor practices were implemented so that 4,000 jobs were created for local residents and 85% of the costs of building construction were channeled into the local economy, resulting in significant economic savings when compared to other Rwandan hospitals (73–75).

Specialty Specific Interventions
Albert Einstein Hospital, located in Sao Paulo, Brazil tracked their greenhouse gas emissions and found that in 2012, nitrous oxide (N_2O) made up over half of their total hospital emissions. The hospital convened a team focused on limiting reliance on nitrous oxide and was able to reduce nitrous oxide use for anesthetic procedures by 23%. Nitrous oxide need only be used when it lowers the morbidity and mortality of the patient when compared to other anesthetic drugs. Albert Einstein Hospital has

continued to make progress on reducing GHG emissions via less reliance on nitrous oxide and was recently presented with the 2020 Challenge Climate Champions award for a project ensuring a 7% reduction in total GHG emissions solely through reduced N_2O anesthetic use (75,76).

Food

Every day, the Melbourne Health Production Kitchen prepares nearly 3,000 meals for patients at the Melbourne Hospital City Campus in Melbourne, Australia. Previously, all surplus food was sent to landfills. Beginning in February of 2018, the extra food was diverted to the community, preventing 25kg of food from ending up in landfills each day, providing 4,200 meals per month, and reducing emissions due to food waste by 17 tonnes of CO_2e per year (77).

Through a different approach, the Buddhist Tzu-Chi Dialysis Center in Malaysia has reduced its carbon footprint by promoting vegetarianism and utilizing reusable food containers. Implementing an "only vegetarian" policy since the center opened in 1997, the center saves 4.9 kg of CO_2 emissions for every kilogram of tofu served in place of chicken. They have also observed significant reductions in carbon footprint by reducing the use of plastic bags (78).

Travel

Taiwan's Taichung Tzu Chi Hospital has reduced its carbon emissions by a dramatic 3 tonnes per year through the implementation of a hospital carpooling application which has encouraged the carpooling of 6,500 employees and patients since 2016. These efforts have saved 3,112 tonnes of CO_2e from 2011 to 2015 (79).

Landspitali, the National University Hospital of Iceland, has been able to significantly reduce its carbon footprint by increasing eco-friendly travel to and from work from 21% to 40% of employees. Through the design of a Green Travel Agreement, Landspitali has created economic and health gains for its employees all while minimizing CO_2e (80).

Supply Chain Interventions/Responsible Purchasing

The Philippine Heart Center has adopted a strategy of green procurement and incorporating environmental considerations into their decisions about products and services. Moving forward, the Philippine Heart Center plans to acquire knowledge on carbon emission accounting to be able to more accurately estimate the effects of green procurement on carbon output (81).

Kaiser Permanente, an integrated managed care consortium based in Oakland, California, has made concerted efforts to purchase environmentally responsible computers. They have been able to reduce the use of toxic materials and energy, resulting in energy cost savings of 4M USD per year (82).

Unique considerations in low- and middle-income countries

While health care in low and middle-income country (LMIC) settings generally has small per capita carbon footprints and expenditures, the overall environmental intensity can be quite large (28). However many LMIC health care systems may not be in a position to reduce energy use, alter procurement practices, or make other disruptive changes. In fact, with 59% of health care facilities in LMICs reportedly lacking reliable electric power (51), the *scarcity* of energy and materials in many facilities is the pressing challenge (52,53). Insufficient electricity curtails access to lighting, ventilation, water, refrigeration, and functioning diagnostic and treatment equipment - with potentially dire consequences for patients. For example, a study of Ugandan emergency obstetric care found that only 2% of primary health centers, 29% of referral health centers, and 61% of hospitals providing this care had reliable electrical power supplies; this contributed to unacceptably high mortality from uterine rupture, hemorrhage, and other complications of childbirth (54). In a survey of surgeons across 39 African nations, most working in regional or national referral hospitals, 48% reported at least weekly power failures, 40% had experienced compromised surgical field lighting, 32% reported delayed or cancelled surgery as a result, 29% had operated using only mobile phone lights, and 18% had directly experienced poor surgical outcomes as a result (55).

For health care facilities in such circumstances, the path to Net Zero must include provision of reliable electricity. This requires leapfrog technologies — bypassing fossil fuels and conventional electrical grids in favor of solar and wind generation and on-site battery storage — and local innovation (56). Fortunately, this approach is affordable and practical and is increasingly being implemented. For example, between 2008 and 2015 the Indian state of Maharashtra installed 407 hybrid solar photovoltaic systems, mostly in remote health facilities, in an effort to promote reproductive and child health (57). Such strategies are championed by the non-governmental organization Sustainable Energy for All (58), which the U.N. launched in 2011 through its Powering Health Care Initiative (59).

While addressing energy deficits in health care facilities in LMICs is a priority, experience in low-resource settings can offer invaluable guidance for wealthy countries. For example, the carbon footprint of phycoemulsification cataract removal is reported to be 20 times lower in India than in the U.K., with similar clinical outcomes, signaling an opportunity for substantial reductions in emissions in wealthy settings (15).

Critical Knowledge Gaps

Knowledge gaps on the path to health care Net Zero emissions fall into several categories. First, we need a detailed understanding of the sources of emissions across the health care delivery life cycle. Of particular importance are major elements of the supply chain such as pharmaceuticals and medical equipment. This requires sophisticated but user-friendly methods of quantifying carbon footprint, which require further development (60). Second, research and development efforts need to deliver innovative equipment, supplies, and practices that reduce the carbon footprint. Third, we need each of these innovations to be tested to establish safety and efficacy. Fourth, we need economic analyses of low-carbon innovations, to establish their costs and benefits. The research needed to achieve these broad knowledge goals requires multidisciplinary collaborations, including engineers, process analysts, and clinicians.

Conclusion

Without decisive and urgent action, the climate crisis will increasingly undermine human health and disrupt health care delivery. There are both moral and practical reasons for health professionals to be at the forefront of climate action (61,62) — to embrace the drive to decarbonize the economy and to reach Net Zero emissions. This is as crucial in hospitals, clinics, and pharmacies as anywhere. Health care must lead from the front — which entails urgently getting our own house in order by charting a Pathway to Net Zero.

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