Perspective

We can’t mitigate what we don’t monitor: using informatics to measure and improve healthcare systems’ climate impact and environmental footprint

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ABSTRACT

Climate change, human health, and healthcare systems are inextricably linked. As the climate warms due to greenhouse gas (GHG) emissions, extreme weather events, such as floods, fires, and heatwaves, will drive up demand for healthcare. Delivering healthcare also contributes to climate change, accounting for ~5% of the global carbon emissions. To rein in healthcare’s carbon footprint, clinicians and health policy makers must be able to measure the GHG contributions of healthcare systems and clinical practices. Herein, we scope potential informatics solutions to monitor the carbon footprint of healthcare systems and to support climate-change decision-making for clinicians, and healthcare policy makers. We discuss the importance of methods and tools that can link environmental, economic, and healthcare data, and outline challenges to the sustainability of monitoring efforts. A greater understanding of these connections will only be possible through further development and usage of models and tools that integrate diverse data sources.

Key words: climate change, electronic health records, economic input-output life cycle assessment (EIO-LCA), multiregion input-output (MRIO) tables, health policy, informatics

INTRODUCTION

The planet’s health and human health are inseparable.1 Greenhouse gas (GHG) emissions are rising, warming the planet; and the changing climate leads to more extreme weather events, such as floods, fires, and heatwaves. These are consequential for humans, further driving demand for healthcare.2 Ageing populations, increasing rates of noncommunicable diseases and advances in medical technology will further intensify healthcare requirements.3,4 The effects of climate change on human health are only half of the story; delivering healthcare itself contributes to climate change, accounting for ~5% of the global carbon emissions with hospitals and pharmaceuticals responsible for a significant proportion of these emissions.5 For example, in Australia, it is estimated that 44% of healthcare’s GHG emissions are contributed by hospitals and 18% by the manufacturing and prescribing of pharmaceuticals.6

As demand for healthcare increases, with no or insufficient mitigation, there will be a commensurate rise in the carbon footprint of healthcare systems. Thus a concerted effort is needed to rein in GHG associated with healthcare delivery.4,7 Fortunately, many healthcare systems have pledged to reach net zero carbon emissions by 2050, if not before, and some countries, such as the United Kingdom, have made significant progress already.8,9 But pledges are not actions, nor are they guarantees of meeting future targets. Deeply embedded in the solution is data. Data on all sources of GHG emissions within a healthcare system are required to benchmark current levels, identify easily mitigated sources of emissions,
plan and implement mitigation strategies, and to monitor their effect on emissions.\textsuperscript{7,9–11} The Greenhouse Gas Protocol Corporate Standard, which is the most widely used global framework for GHG accounting, identifies 3 broad sources of GHG emissions, known as scopes, which can be defined by the extent to which they are directly related to organizational activities.\textsuperscript{12} Scope 1 emissions arise from sources directly controlled or owned by the organization; Scope 2 and 3 are indirectly related to its operations. Scope 2 includes activities such as the use of energy for heating or cooling of buildings. Scope 3 comes from activities upstream and downstream in the corporate supply chain, including production and transportation of goods, staff travel, and waste disposal.\textsuperscript{13} Supply chain emissions are a major component of healthcare’s carbon footprint (up to 71% by some estimations).\textsuperscript{4}

Here, we discuss current methods and tools for assessing the environmental impact of healthcare from the national to the local practice level and suggest areas in need of further informatics development if healthcare systems are to meet their carbon reduction pledges.

Current methods to measure and improve the carbon footprint of healthcare systems

To respond to the challenge of reducing emissions, we need to measure the current environmental impact of healthcare systems and make these data available to those who work in healthcare services. This can be difficult. Many sources of data must be synthesized in order to report on progress.\textsuperscript{13} Fragmentation of the healthcare system across sectors and jurisdictions often means that data are held in disparate systems.

Economic activity data is the most complete and accessible form of data for every level, from organization to government-wide spending. The development of large-scale, multiregion input-output (MRIO) models have facilitated comparisons across and between sectors and countries, using such data to measure cross-flow transactions.\textsuperscript{5,13,14} To understand a country’s or healthcare system’s carbon footprint, these data are paired with carbon emission data to create environmentally extended MRIO (EE-MRIO) models.\textsuperscript{4} The Industrial Ecology Virtual Laboratory,\textsuperscript{15} developed in Australia in conjunction with the Australian Bureau of Statistics, is an example of an EE-MRIO tool that uses this, combined with other models, to evaluate the carbon footprint of a healthcare system.\textsuperscript{6,14}

Economic Input-Output Life Cycle Assessment (EIO-LCA) models extend data on monetary flow to enable evaluation of the environmental impact of a product or process throughout its lifespan (from extraction of raw materials to final disposal).\textsuperscript{16} The models rely on data from economic sources (eg, in the United States, the federal Bureau of Economic Analysis [BEA] combined with energy data (from the US Environmental Protection Agency [EPA] or Energy Information Administration [EIA]) coupled with commodity data for the healthcare industry.\textsuperscript{13,15}

These models can be forged into a decision support tool to enable evaluations of the environmental impact of healthcare systems. Freely available online resources designed to facilitate decision-making by organizations on how to measure and reduce their GHG emissions (eg, Greenhouse Gas Protocol,\textsuperscript{12} Carnegie Mellon University EIO-LCA,\textsuperscript{16} and the US Environmentally Extended Input-Output [USEEIO] Models\textsuperscript{13,15}) are now being used for modeling GHG emissions within healthcare systems.\textsuperscript{7,17}

In addition to these system-wide accounting methods, life cycle assessment (LCA) models enable product and process level analysis of GHG contributions. LCAs can cover all stages from raw material extraction to manufacturing, use (and in a circular system, reuse), and final disposal, including transportation as a factor in every step of the chain.\textsuperscript{20} LCAs can be used to compare practices or products to determine which has the lower environmental impact (eg, the GHG emissions from different anesthetic gases)\textsuperscript{21} or to assess a single process to identify which steps in the process are the most carbon intensive.\textsuperscript{20,22}

Commercially software packages that draw on large-scale databases are now available to assist with LCA modeling.\textsuperscript{23,24}

These models, applied at different levels of the healthcare system, provide systems-wide and process level information enabling the identification of areas where policy levers can be applied to most effectively make change (Table 1).\textsuperscript{23} For example, the largest system-wide reduction in GHG emissions could be realized through decarbonization of the supply chain (Scope 3). Without a full understanding of the entire value chain, identification of actions that provide the highest return can founder.

How are healthcare systems monitoring their environmental impact?

Efforts to monitor the environmental impact of healthcare systems require collaboration across government organizations and between government and private industry.\textsuperscript{19} Formed in 2008, the UK’s Greener National Health Service (NHS) Programme (formerly, the Sustainable Development Unit) is longest running and only national-level reporting performed by a public healthcare agency.\textsuperscript{9} The NHS utilizes the GHG Protocol Corporate Standard\textsuperscript{12} to apply the UK’s MIRO model to measure commissioned health services and the NHS supply chain. For product or location specific information, data is sourced from government environment and energy agencies and combined with information from a comprehensive national-level database on energy consumption for all NHS owned buildings.\textsuperscript{7,13} Data from suppliers, hospitals, hospital pharmacies, and dental clinics are harnessed to measure the contribution of anesthetic gases.\textsuperscript{32} The NHS uses these data for both benchmarking and monitoring system change over time.\textsuperscript{33} By 2019, the United Kingdom had reduced its healthcare GHG emissions by ~60 kg CO\textsubscript{2} equivalent per capita compared to 2007.\textsuperscript{34}

Many other healthcare systems have now set policies on reducing their carbon footprint.\textsuperscript{33,35} However, the comprehensiveness of emissions reporting is not uniform across healthcare systems. Some Australian state governments, for example, do not report Scope 3 emissions\textsuperscript{36} and the Australian Institute of Health and Welfare (AIHW), an independent national, statutory data collection agency designed to inform policy making, only reports aggregated GHG emissions for all of Australia. It does not provide a breakdown for the healthcare system.\textsuperscript{17}

Large scale databases (such as the UK Estates Return Information Collection [ERIC] system),\textsuperscript{32} mandatory emissions reporting,\textsuperscript{36} and the ability to link across data types are essential for informatics-based monitoring GHGs. However, data collection and data linkages across healthcare organizations to provide details about GHG emissions remain a significant challenge. Monitoring efforts in many healthcare systems remain primitive.

SUPPORTING CLIMATE-CHANGE DECISION-MAKING FOR CLINICIANS AND DECISION-MAKERS

What about on the front lines of care? Although there are methods and tools that policy makers can use to assess GHG emissions at the system, organization, and practice level (Tables 1 and 2), electronic
health records and clinical practice data remain a largely untapped resource for improving the environmental footprint of healthcare. Mining these types of data and feeding them back to coal-face decision-makers has the potential to reduce inefficient practices and GHG emissions.

Wasteful clinical practices, such as unnecessary surgeries, inappropriate diagnostic imaging or pathology test ordering, and over-prescribing of medications, account for approximately one-fifth of all healthcare spending (~8000 kilotons of CO2 equivalent per year in Australia). Since every episode of care emits GHGs and uses resources, reducing these practices would create immediate benefits for patients, healthcare systems, and the environment.

For example, overprescribing of antibiotics not only provides no benefits to the patient, it also contributes to antimicrobial resis-

### Table 1. Examples of several accounting methods for measuring GHG emissions

| Accounting method | Data used | Benefits | Limitations | Resources using this method | Description | Target user of outcomes |
|-------------------|-----------|----------|-------------|-----------------------------|-------------|------------------------|
| Multiregion input-output (MRIO) | Economic input-output (I-O) data for multiple regions and sectors to create an I-O matrix | Widely used for modeling economic interdependency between countries and sectors | Aggregates data at system or national level hence less reliable. Inconsistencies in data collection and standardization make data less useful. | Eora Global Supply Chain Database | Data from 190 countries included. Provides time-series information on input-outflow between countries and sectors | National and international level policy |
| Environmentally extended input-output (EEIO) | Combines economic I-O data from industry sectors with environmental data (eg, land use, energy use, pollution) to create an I-O matrix | International, national, state level coverage | Reveals environmental impacts across sectors and countries. Limited accuracy. Long delay between data updates (eg, 2–5 years). I-O data not available for all commodities. | US Environmentally Extended Input-Output (USEEIO) | Developed by the US Environmental Protection Agency Online resource and framework for customization of models | US-based corporations, healthcare systems, state or national level decision-makers |
| Economic input-output life cycle assessment (EIO-LCA) | Uses monetary data combined with energy sector data and commodity data | Allows for system-level comparisons | Often uses public data, thus higher reproducibility. Useful for studying changes in demand from a sector. | Carnegie Mellon University EIOlca | Provides relative impact of different products, services, or materials. Uses economical and environmental data to benchmark activities. Allows the user to run models for different industries or to create a custom model | State or national level policy makers |
| Life cycle assessment (LCA) | Uses materials data (energy, physical resources) and emissions outputs (GHG emissions, waste products) | Specific to the process or product | Time intensive. Inclusion/exclusion criteria for model effects are necessary. Life cycle inventory (input and outflow inventory) often not available. | openLCA | Open source, free software. ISO 14040 and 14044 (Environmental management Life cycle assessment Principles and framework) compliant | Corporation, hospital, or clinic managers |
Changing default settings for prescribing in electronic medication management systems and using appropriate nudge interventions, which inform clinicians about their performance compared to their colleagues, have been shown to reduce antibiotic prescribing and to support behavioral change.\textsuperscript{46–48} Implementing online tools based on clinical practice performance is another method that can improve adherence to guidelines and promote behavioral change.\textsuperscript{49} The Greener NHS prescribing dashboard (hosted on OpenPrescribing.net) takes anonymized data from the NHS on prescribing practices to provide health service providers with benchmarked information on their performance compared to other NHS practices.\textsuperscript{50,51} The tool includes reasons why the prescribing level matters and evidence-based information on medication management.\textsuperscript{50} However, data on the environmental implications of prescriptions are only available for long-term conditions and asthma inhalers.

Table 2. Examples of tools available for measuring healthcare-related GHG emissions

| Focus            | Example                                      | Description                                                                                           | Limitations                                      | Target user                                      |
|------------------|----------------------------------------------|------------------------------------------------------------------------------------------------------|--------------------------------------------------|-------------------------------------------------|
| Facility level   | Global Green and Healthy Offices’ Hippocrates Data Center | Calculates GHG emissions based on energy consumption, transport, waste management, and gases using national or local emissions factors Enables users to enter data from a facility and track change in emissions over time Developed by Global Green and Healthy Hospitals (GGHH) and Health Care Without Harm | Users must know and enter data Does not include GHG from clinical care Requires free membership to access | Hospital managers, health district policy makers |
| General practice | General Practice Nonclinical Carbon Calculator\textsuperscript{56} | Online calculator for general practices to identify noncare-related sources of GHG emissions (eg, energy use, staff travel, waste disposal) Developed by SEE Sustainability in conjunction with Boehringer Ingelheim and Sustainable Healthcare Coalition | Users must know and enter data Does not include GHG from clinical care UK-based calculations | General practice managers |
| Medication prescribing | Greener NHS Dashboard/OpenPrescribing.net\textsuperscript{50} | Allows benchmarking of clinician and health district level performance on medication prescribing Data collected by the NHS Hosted on the OpenPrescribing.net site through government funding to Oxford University | Data is available on the site but not integrated into eHR or purchasing software Limited information on GHG emissions | NHS clinicians, primary care network (health district) managers, hospital administrators, national level policy setters |
| Anesthetic gases | Yale Anesthesia Dashboard\textsuperscript{52} | Provides information of the GHG contribution of different anesthetic gases Allows facilities to benchmark their annual emissions Provides recommendations for reducing emissions | User must know and enter usage data | Clinical teams, operating theatres, hospital administrators |

Not all online tools are directly linked to clinical performance datasets. The Yale Gassing Greener Project (Inhaled Anesthesia Climate Initiative: Project Drawdown) is an online tool for facilities to benchmark their anesthetic gas usage. It provides feedback on ways to lower GHG emissions by switching to less environmentally harmful anesthetic gases.\textsuperscript{52} Unlike the Greener NHS Prescribing tool, Yale’s system requires the facility to input their own data. Both tools require the clinician or organization manager to access the information through external platforms, rather than providing information directly to the end-user through electronic health records (eHRs) or purchasing software.

By integrating GHG and LCA information into electronic health records and dashboards, clinicians and decision-makers would have a more complete picture of the impact of prescribing or referring patients for imaging or other procedures.\textsuperscript{38} Of course, any new methods employed to create behavioral change should be co-designed with the end-users and evaluated from inception through to
implementation to achieve sustainable change. This could reduce the likelihood of unintended consequences (eg, misalignment with workflows, alert fatigue), and provide the necessary information to determine if the intervention is functioning as intended.

**CHALLENGES TO SUSTAINABILITY AND FUTURE MONITORING**

With the development of this suite of monitoring methods, the next big challenge is how to routinely collect and integrate data from all sources. Fragmentation of health records across systems reduces the ability to identify waste and measure the GHG impact of care provided. Incomplete datasets, such as a lack of life cycle inventories required for LCA modeling of pharmaceuticals and pathology testing, reduce the comprehensiveness of models. Potential solutions to these problems include implementing national-level health infrastructure, legislating mandatory reporting on healthcare system performance across all 3 scopes, and standardizing assessment methods. Collectively, these solutions could streamline the data collection process, reduce fragmentation, ensure data are collected, and improve the ability to compare outcomes.

Currently, many of the methods discussed here require considerable expertise, time, and resources to implement. Multidisciplinary teams, public and private partnerships, and open access to consistent and comparable longitudinal data will be essential to the refining of current methods and the development of integrated tools. Government support through legislation and ongoing funding of healthcare system sustainability initiatives is also essential to ensuring efforts to reduce healthcare systems’ GHG emission are released.

**CONCLUSION**

Government and healthcare organizations leaders should routinely draw upon the methods and tools we have presented to improve decision-making to meet GHG emissions reductions for healthcare systems. In the clinic and hospital, electronic health records and dashboards that include data on emissions could facilitate decision-making to reduce healthcare’s carbon footprint, if they are embedded into routine practice and reported upon consistently as part of performance measures. Greater understanding of the connections between climate change, human health, and healthcare will only be possible through further development and usage of models and tools that integrate information across all 3.

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**AUTHOR CONTRIBUTIONS**

CLS, YZ, and JB conceptualized the paper. CLS prepared the original manuscript. YZ and JB provided critical revisions. All authors approved the final the version.

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**CONFLICT OF INTEREST STATEMENT**

None declared.

**DATA AVAILABILITY**

No new data were generated or analyzed in support of this research.

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