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ORIGINAL PAPER

Environmental impacts of artificial intelligence in health care: considerations and recommendations

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Abstract

Purpose (stating the main purposes and research question) Anthropogenic resource use contributes to pollution, violent conflict over scarce resources, loss of biodiversity, and diminished quality of life for humans. Moreover, the "safe" amount of carbon dioxide—350 parts per million—has been exceeded. The health care industry is responsible for 4–5% of total world emissions,[i] which is similar to the global food sector.[ii] Health care carbon emissions come from health care infrastructures, supply chains and health care delivery. Increasingly, health care delivery is reliant on technologies which require the use of artificial intelligence to provide supportive care, such as triage algorithms, electronic patient records, and robotics.[iii] While these technological innovations have advanced health care significantly, they also contribute to the negative effects on the environment, among others, through carbon emissions. The environmental impacts of artificial intelligence (AI) in health care—in particular—are understudied. This research seeks to fill this gap.

Methods Our team ran an exploratory search in Scopus and PubMed to identify studies that integrate environmental sustainability, artificial intelligence, and health.

Results Our research initially yielded 735 studies. 77 of these studies focused on an environmental concern of a health technology or AI-application in a health care setting, but most of the articles in this subset addressed lowering energy consumption of a specific technology, such as a sensor or monitoring technology.

Conclusions While there have been studies looking at AI in health care; sustainability in AI; and sustainability in health care, little attention has been paid to the interface between all three. [i] Karliner, J., Slotterback, S., Boyd, R., Ashby, B., & Steele, K. 2019. Health Care's Climate Footprint: How the Health Sector Contributes to the Global Climate Crisis and

[1]after removal of duplicates [Search string used for Scopus: TITLE-ABS-KEY ((medic* OR health* OR clinic*) AND ("environmental sustainability"OR"carbon footprint"OR"energy consumption") AND ("machine learning"OR"AI"OR"artificial intelligence"OR"bots"OR"natural language processing"OR nlp OR"neural network*"OR"semantic analysis*")). Search string used for Pubmed: ("environmental sustainability"OR"carbon footprint"OR"energy consumption") AND ("machine learning"OR"AI"OR"artificial intelligence"OR"bots"OR"natural language processing"OR nlp OR"neural network*"OR"semantic analysis*")].

[2][Search string used for Scopus: TITLE-ABS-KEY ((medic* OR health* OR clinic*) AND (environmental sustainability OR carbon footprint OR energy consumption) AND (machine learning OR AI OR artificial intelligence OR bots OR natural language processing OR nlp OR neural network* OR semantic analysis*)). Search string used for Pubmed: (environmental sustainability OR carbon footprint OR energy consumption) AND (machine learning OR AI OR artificial intelligence OR bots OR natural language processing OR nlp OR neural network* OR semantic analysis*)].

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Opportunities for Action Healthcare Without HarmARUP; September. [ii] Pichler, P. P., Jaccard, I. S., Weisz, U., & Weisz, H. 2019 International Comparison of Health Care Carbon Footprints, Environmental Research Letters 14, no. 6: 064004. [iii] Khaliq, Abdul, Ali Waqas, Qasim Ali Nisar, Shahbaz Haider, and Zunaina Asghar. 2022. Application of AI and robotics in hospitality sector: A resource gain and resource loss perspective. Technology in Society 68: 101807.

Keywords Artificial intelligence · Health care · Environmental ethics · Environmental impact · Health care ethics

Anthropogenic resource use contributes to pollution, violent conflict over scarce resources, loss of biodiversity, and diminished quality of life for humans. Moreover, the "safe" amount of carbon dioxide—350 parts per million—has been exceeded. The health care industry is responsible for 4–5% of total world emissions, [1] which is similar to the global food sector [2]. Health care carbon emissions come from health care infrastructures, supply chains and health care delivery. Increasingly, health care delivery is reliant on technologies which require the use of artificial intelligence to provide supportive care, such as triage algorithms, electronic patient records, and robotics [3]. While these technological innovations have advanced health care significantly, they also contribute to the negative effects on the environment, among others, through carbon emissions.

The environmental impacts of artificial intelligence (AI) in health care—in particular—are understudied. To illustrate this our team ran an exploratory search in Scopus and PubMed to identify studies that integrate environmental sustainability, artificial intelligence, and health initially yielded 735 studies.[1] While 77 of these studies focused on an environmental concern of a health technology or AI-application in a health care setting, most of the articles addressed lowering energy consumption of a specific technology, such as a sensor or monitoring technology.[2]

This article presents the outcomes of the research by exploring each of the subthemes and discussing possible reasons for the gaps in research. It will first, situate the climate crisis with emphasis on health care carbon emissions and AI carbon emissions. These are both issues of environmental ethics. It will, second, enumerate the ways AI is used in health care, with specific relevance for AI in health care data and AI in health care delivery. These are issues for biomedical ethics and ethics of technology to address. Given the impact of both health care and AI generally, and the increasing use of AI in health care specifically, it is striking that, while there have been studies looking at AI in health care; sustainability in AI; and sustainability in health care, little attention has been paid to the interface between all three (See Fig. 1). Therefore in the discussion, we will, third, offer some possible reasons for the gap in research on the environmental impacts of AI in health care. In the fourth section of the article, we provide suggestions on how to amend these gaps. Our conclusion affirms that attention to the environmental impact of AI in health care is a requirement of a lower carbon health care industry.

1 Climate change and health care

The carbon emissions of global health care activities make up 4–5% of total world emissions [4], placing the health care industry on par with the food sector [2]. Health care carbon in between countries varies. The United States health care industry is the second largest in the world, expending an estimated 479 million metric tons (MMT) of carbon dioxide per year; nearly 8% of the country's total emissions. Compare this with China's health care carbon, at 600 MMT, or 6.6% of the country's emissions, or India's health care carbon, at 74.1 MMT, or 3.5% of the country's emissions [2].

Health care carbon emissions come from health care infrastructures and health care delivery. Health care infrastructures include use of heating, lighting, cooling, food services, transportation, and water waste [5]. Health care delivery includes medical activities which have a carbon impact, such as doctor's visits, medical procedures, prescription of drugs [6], and hospitalization [7]. For instance, inpatient admission to a hospital, based on

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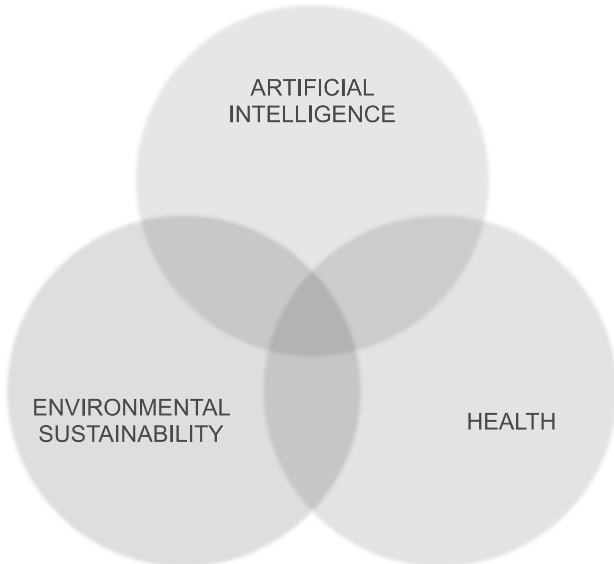

Fig. 1 Articles on AI, sustainability, and health care

admission intake plus 3.6 bed days, emits 380 kg of CO_2 per patient [8].

Beyond carbon emissions of health care, medical waste is a significant environmental problem. While disposable (single-use) medical devices increase safety and confidence, they also use resources, create waste and emit carbon [9]. Not only are landfills occupied with medical waste, but also the contaminated materials in landfills get released in the environment, creating more noxious gasses in the atmosphere. In 2018, 24% of all municipal waste generated in the EU was landfilled according to the European Commission [10].

Given that carbon emissions contribute to poor health conditions related to climate change health hazards, the medical industry should have an interest in carbon reduction generally—as a means to reduce disease burden—and specifically—as health care carbon is counterproductive to patient health. To be sure, the destructive cycle of health care carbon and climate change has been recognized by a number of health care initiatives and publications. In 2021, the National Academy of Medicine (NAM) launched their Action Collaborative on Decarbonizing the United States Health Sector and wrote the Biden Administration advocating decarbonization as part of the US COP26 climate commitments. The 2021 *Lancet* Countdown on Health and Climate Change Report indicates both the seriousness of climate change as a health threat and the culpability of the health care industry in contributing to carbon emissions and climate change [11]. The same year the *New England Journal of Medicine* ran an article on "Decarbonizing the U.S. Health Sector—A Call to Action," which opined tackling the carbon emissions of the health care supply chain is central to decarbonization and pointed to the carbon impact of the biopharmaceutical, biotechnology, and medical device industries [12].

We support these and other efforts to make health care more sustainable and extend the call for health care climate action to the often overlooked area of artificial intelligence (AI) in health care, which is not only widely used but also has a significant carbon cost.

1.1 AI carbon

Modern, technological health care has advanced through the emergence of larger data sets and data sources, which has paved the way for the use of artificial intelligence (AI), autonomous and intelligent systems (AIS), prescriptive and predictive analytics, bioinformatics, and even the Internet of Things (IoT) in health. These technological innovations have advanced and improved health care delivery significantly. Yet, these same technologies also contribute to the negative effects on the environment through carbon emissions in the development, deployment, dissemination, and disposal of medical devices, digital infrastructure and medical services [13].

The energy impact of AI is not limited to its use phase. The computational infrastructure that enables AI systems has significant additional environmental implications. Notably, the largest AI models are doubling in energy necessary to compute every three to four months, thereby severely outpacing the increasing efficiency of hardware [14]. The energy impact of AI is not limited to its use phase. The computational infrastructure that enables AI systems has significant additional environmental implications. For instance, forty days of training Google's AlphaGo Zero game generated the equivalent of 1,000 h of air travel or a carbon footprint of 23 American homes [15]. Google's biggest AI model "The Switch Transformer" now has more than 1.6 trillion parameters—measure that refers to variables in computer programming language used to pass information between functions or procedures [16]. Each training run of a giant transformer like this can generate 626,155 pounds of CO_2 emissions, the equivalent of 17 American life-years (at 36,156 CO_2 emissions / per year), or the "lifetime" of five cars (at 126,000 CO_2 emissions per car) [17]. As health care relies more on AI, so do carbon emissions expand.

Moreover, AI is raising demands for metals and plastics, thereby also generating a lot of electronic waste. The environmental impact of cobalt mining is known to be substantial [18]. Most of the minerals necessary for electronics are mined in conflict areas and mining often takes place under poor labor conditions. The extractive effects on the environment of AI reliant technologies extend well beyond fossil fuel extraction, and include mineral mining for chips, exploitative human labor for labelling training datasets, and the significant waste produced by products designed for planned obsolescence and inevitable upgrades.. Health care

AI use is also complicit in these social and environmental externalities, each of which demands ethical evaluation. These associated concerns will be bracketed, as we now move to a focus on the use of AI in health care specifically, and the environmental impacts.

It is pivotal to acknowledge that any discussion around the environmental impacts of AI software services and the computational infrastructures on which these run cannot be resolved without addressing the role of concentration of power over these platforms and infrastructures, as well as over the organizations that depend on them, by a small number of technology firms. In absence of forced transparency, these companies have no incentive to help users understand their digital footprint. More worryingly, the political economy of AI and computational infrastructure seems to be at sharp odds with what we need to curb its environmental impact. As Meredith Whittaker argues, "tech firms are startlingly well positioned to shape what we do—and do not—know about AI and the business behind it, at the same time that their AI products are working to shape our lives and institutions."[19]

2 AI in health care

AI in health care is used in a variety of ways. Enumerating this situates the breadth of AI in health care, thus building the case of the environmental impact, and therefore, paths towards carbon reduction of AI in health care.

Prior to being able to use some forms of AI in health care, relevant data must be collected from individuals. This is called "health care data." Data collection itself has a carbon impact through the use of electronics utilizing energy sources. Then, when the data is used by AI systems, carbon emissions are compounded. This is "AI in health care data." In addition, and somewhat separately, "AI in health care delivery" includes utilizing AI systems to operate and support devices and technologies in the clinic and hospital setting. Each of these three aspects will be described in the next sections.

2.1 Health care data

According to a 2020 review [20] that builds on the Healthcare Data Spectrum (HDS) [21], there are four core aspects of health care data. First, is patient data, such as genomic data, proteomic data, electronic health records, and data generated by individuals themselves (e.g., data from wearables and social media). The second form of health data is health systems data, like human resources data, service availability and utilization data—for instance, the number of hospital beds, insurance claims data—and performance metrics (e.g., performance assessment results, patient satisfaction surveys). Third, data is collected from routine and non-routine public health data. These routine sources include health facility and community information systems. Non-routine sources are household and other population-based surveys, such as demographic and health surveys, multi-indicator cluster surveys, censuses, civil registration, like births and deaths, and vital statistics systems, disease surveillance systems, health facility surveys, and administrative data systems. Fourth, health care uses data for research on patients and populations by utilizing collected data from genomic and health services data. Health care data is indeed part of the health care industry, and the carbon impact is significant. Particularly, the increasing trends towards digitalization, personalized medicine, and patient bio tracking—in addition to the expanding population and proliferating number of users of health technologies—imply that health data carbon will expand in the future.

2.2 AI in health care data

According to studies in the UK National Health Service's *NHSX*[22] and *BMJ Global Health*,[23] the use of AI in health care data fall into five categories. First, AI is used in diagnostics, such as image recognition, symptoms checker, and decision support. A second area of AI in health data use is through knowledge generation for drug discovery, greater understanding of rare diseases by pooling larger data sources, pattern recognition, and understanding causality, among others. Third, public health relies on AI to interpret health data for purposes of epidemiology, disease outbreak and surveillance. AI is used in 'P4 medicine' (predictive, preventive, personalized and participatory medicine) as well. Fifth, health data required for efficient health care administration—such as maintaining electronic patient records—and some health infrastructure and logistics, including machine learning for improved hospital layout planning, operating room and bed allocation, improved patient scheduling and predicting of scheduled hospital attendance rely on AI systems [24]. As AI becomes an inextricable part of health care data, so do the emissions a troubling side effect which must be addressed for their environmental impact, whilst not disregarding the other ethical concerns of privacy, medicalization, safety, paternalism, and surveillance.

2.3 AI in health care delivery

While the use and disposal of personal protective equipment is obvious—one only has to look in a rubbish bin—what is unseen are the amounts of resources used in durable technologies, like operational tools and medical equipment. The types of AI-enabled technologies in health care vary from "autonomous systems" embodied in robots, for example patient support robots or autonomous surgical robots, to information systems like those that interpret medical images or carry out administrative tasks. Some of these technologies are directly used by patients, for example chatbots for mental health services and some are mediated by health care professionals [25]. Since AI is a technology that enables, rather than constitutes, technological devices, it is particularly hidden. A health care practitioner may record patient information on a computer—the tangible medical device—but the AI that is interfacing with the records is intangible and therefore less obvious. The vast use and dependence on AI in health care data may be invisible to the average patient, health care provider, or administrator because it is digital. Hence, it is important to name and identify the uses of AI in health care delivery so places of sustainability can be employed.

3 Discussion: gaps in research on the environmental impacts of artificial intelligence in health care

First, it seems that as a structural issue, there is pushback amongst non-ethicists against ethical implications of AI in general—which is rooted in resistance to reflections on the ethics of technology more broadly. Second, and similar, we opine that the carbon impact of AI in health care has not been a prominent topic for academics because other ethical aspects of AI in health care, like regulatory compliance, privacy concerns of data integration, and automated non-human interactions have taken the fore [26]. Third, ethical implications on the environmental impact of AI cannot move forward without baseline carbon information. And, as highlighted above, while articles on the carbon impact of health care [27] and the carbon impact of AI [28]are proliferating, the intersection of the three is overlooked. This produces a feedback loop whereby studies on the carbon impact of AI in health care are not done, therefore information with which to change the practices of using (presumably) carbon intensive AI in health care are not offered, therefore data driven examples of sustainable AI are not available. In the next section, we will offer recommendations for a variety of stakeholders that support the first steps towards sustainable AI in health care.

4 Practices and policies for environmentally sustainable artificial intelligence in health care

Given the magnitude of the global environmental crisis and the significant contributions of health care delivery, AI, and AI driven health care to carbon emissions and climate change, sustainable AI practices in health care need serious attention—and action. From the three observations above, we offer practices and suggestions to move in the direction of sustainable AI in health care. Essentially, pathways towards sustainability—not only in health care and technology, but in all aspects of social life, from transport, to food, to fashion—need to be more feasible and attractive than current options.

First, structurally, there must be emphasis on sustainable technologies from across many sectors. Manufacturers and engineers who develop health technologies which rely on AI need to design pathways that support sustainability. In order to do this, lifecycle assessments will be required. As with other industries undergoing improvements in environmental responsibility, such as the energy, aviation, and automotive industries, the health care industry can examine procurement emissions. Simply, health care will need to draw on more sustainable sources of energy, which implies that health care services and organizations will need to divest from fossil fuels and use cleaner energy. In addition to solar and wind power, sustainable fuel derived from biowaste blended with traditional fuel has been successful in the aviation industry, whilst electrical energy has propelled the automotive industry. An optional carbon offset program can be introduced in high tech health care facilities. While not perfect, this brings the immediate effect of accounting for and offsetting carbon emissions, thus following the lead of the aviation industry [29] and electricity retailers [30].

Second, attention to the carbon impact of AI in health care must be seen as one among many relevant health care issues in health care itself. Sustainable energy requires more than just purchasing practices, it requires organizational support and clinician advocacy on climate change as part of standards of medical care [31]. AI in health care will continue to be used; it must be used in ways that are sustainable [32]. Policies that incentivize sustainable AI in health care technologies for health care consumers as part of lifestyle alterations for the obese and those at risk for diabetes, hypertension, cardiovascular disease, and renal failure—can be implemented without altering current practices or needing infrastructure upgrades. It should be noted that these AI reliant health care technologies should have a clinical indication and need not be offered to people without medical concerns. Overuse of health care technologies is one of the contributing factors to health care carbon [33] and this includes the use of personal technologies that add minimal or no clinical benefit to the health of individuals. Moreover, health care providers who use AI-driven personalized medicine can focus on preventative care and early diagnosis. This can save health care resources in the long term. However, preventive health care technologies may extend lifespans and thus increase the carbon of health care, both in an individual's life [34] and in the medical industry overall. Thus, carbon reduction in all areas of health care is important so that environmental externalities are minimized.

The third area of attention flagged above are the necessary carbon calculations on AI, health care technologies that use AI, and AI in health care data. Cultivating a bank of studies on the carbon emissions of these services can be supported by transparency. Regulators can require digital service providers to disclose their energy and carbon impact, as well as the broader environmental implications, of their (cloud) computing hardware and broader digital infrastructure [35]. Individual consumers can join these efforts and push for more transparency around carbon of their health care consumption through green informed consent—asking and being told about the carbon side effects of their treatments, the health risks of climate change health hazards, and lower carbon alternatives to proposed treatments [36]. Health care providers will in turn need to be able to find information on the carbon emissions of their practices and draw on current studies, for instance the National Health Service's *Carbon Reduction Strategy* and follow up documents which categorize the carbon of health care sectors [37]. The capacities of AI will become more prominent in health care. If there are changes in practices and policies, sustainable AI in health care can be possible.

5 Conclusion

Society and all of its interactions—from commerce to travel to communication to health care—depend on technology. We, as a society, are more aware of the positive and negative impacts of technology in our lives. Issues of access, justice, and ease-of-use factor into decisions about what makes a techno-benevolent life [38]. With the digital revolution and the advent of the internet and associated technological platforms, most people in the world are direct consumers of some form of technology, invested in better user experiences, efficiency, and the implications of privacy, data monitoring [39], and sustainability.

Social values drive the way technology is received, thus positioning medical consumers, health care providers, and medical engineers for using and developing sustainable AI health care technologies. Indeed, there is a social incentive towards this end. Globalization has demonstrated that technology does not develop in geographical or intellectual isolation. From the prospect of nuclear war to the development of CRISPR-Cas9, technologies impact the world. Humankind is united on one planet and in many ways, will survive or perish together [40]. Technological developments are accountable to far reaching consequences and there needs to be responsibility for the carbon impact of health care and AI technologies. A more sustainable use of AI technologies in health care is a moral requirement of the 21st century and a key component to decarbonization of the medical industry.

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