Assessing the Carbon Footprint of Telemedicine: A Systematic Review

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ABSTRACT

BACKGROUND: Healthcare is responsible for 4% to 10% of carbon emissions worldwide, of which 22% is related to transport. Telemedicine emerged as a potential solution to reduce the footprint, for example, by reducing travel. However, a need to understand which variables to include in carbon footprint estimations in telemedicine limits our understanding of the beneficial impact telemedicine might have on our environment. This paper aims to systematically assess the reported carbon footprint and include variables assessed by the literature, comparing telemedicine with usual care.

METHODS: The systematic review followed the PRISMA guidelines in PubMed, Medline, Embase and Scopus. A quality assessment was performed using a transparency checklist for carbon footprint calculators. Carbon emissions were evaluated based on four categories, including patient travel, and streamlined life cycle assessment (LCA) for assessing included variables relevant to telemedicine.

RESULTS: We included 33 articles from 1117 records for analysis. The average transparency score was 38% (range 18%-68%). The median roundtrip travel distance for each patient was 131 km (interquartile range [IQR]: 60.8-351), or 25.6 kgCO_2 (IQR: 10.6-105.6) emissions. There is high variance among included variables. Saved emissions are structurally underestimated by not including external factors such as a streamlined LCA.

CONCLUSIONS: Telemedicine aids in reducing emissions, with travel distance being the most significant contributor. Additionally, we recommend accounting for the LCA since it highlights important nuances. This review furthers the debate on assessing carbon footprint savings due to telemedicine.

KEYWORDS: Telemedicine, digital health, carbon footprint, greenhouse gasses, life cycle assessment

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Background

Healthcare is responsible for a substantial portion of global carbon dioxide (CO_2) emissions, estimated at 4% to 10%, higher than aviation.[1-6] Notably, approximately 22% of these emissions are attributed to transport associated with healthcare, which continues to rise as healthcare consumption increases worldwide.[7] This observation has led to a growing consensus in the literature about the need to reduce the environmental impact of healthcare to align with global sustainability goals centred on carbon emission reduction.[8,9]

The potential of telemedicine to significantly reduce carbon emissions within healthcare was particularly evident during the Coronavirus Disease 2019 (COVID-19) pandemic.[10-12] It highlighted how a substantial portion of unnecessary patient travel could be avoided, demonstrating feasibility, benefits and sustainability beyond the immediate demands of social distancing measures.[13] Moreover, telemedicine offers improved access to healthcare services, empowers patients and provides a cost-effective alternative to physical patient travel.[14,15] While telemedicine is assumed to decrease the global carbon footprint, the exact extent of this reduction remains uncertain. There exists confusion between terms such as ‘environmental impact’, which encompasses broader factors beyond carbon emissions, ‘carbon footprint’, which refers to the total amount of CO_2 or CO_2 equivalents (CO_2e) emitted, and ‘greenhouse gas’, which includes not only CO_2 but also other gases like methane and nitrous oxide. There is a need to accurately assess the environmental benefits of telemedicine compared to conventional care, emphasizing the importance of a systematic review to address these gaps in the existing literature.

Assessing the carbon footprint of telemedicine involves numerous assumptions, variables, and too simplified (or complex) calculations that may not be readily accessible to clinicians. Moreover, since outcomes heavily depend on the assumptions and variables included, interventions should be transparent in their calculations. For this, *the carbon footprint* *transparency checklist on virtual care interventions* by Lange et al[16] was developed, which is based on three leading guidelines for assessing the carbon footprint of products and services: the *International Organization for Standardization, the International Electrotechnical Commission, and the International Telecommunication Union*.

In summary, a more comprehensive and user-friendly evaluation approach is essential to accurately measuring telemedicine's carbon footprint. Therefore, a systematic review is necessary to address these gaps in the existing literature when comparing the carbon footprint of telemedicine and conventional care. This systematic review aims to provide an overview of variables in the literature used to assess the carbon footprint savings achieved by telemedicine.

Methods

Systematic search procedure

We conducted a systematic literature search in line with PRISMA guidelines and systematic review formatting standards.[17] This search was carried out in March 2023 and updated in February 2024, covering four widely recognized databases: PubMed, Medline, Embase and Scopus. Careful consideration was given to selecting search terms and languages, with a complete list of these terms, derivatives, abbreviations, and synonyms provided in Supplemental File 1. Two reviewers (C.Z. and J.C.) independently screened the records within the Rayyan platform, with any differences of opinion being resolved through consensus with a third reviewer (R.W.). Inclusion criteria for studies required reporting CO_2 or CO_2e, with citations to recent and reliable sources for calculating these emissions. We use the metric CO_2 because it is more readily supplied than CO_2e by reliable sources such as the United States Environmental Protection Agency (US EPA) and, consequently, in included studies.

Quality appraisal

Included records underwent a quality appraisal using the Lange et al[16] transparency checklist for carbon footprint calculations for virtual care interventions. This checklist comprises 22 items identifying the aim, scope, data and analysis categories. Per author instructions, we computed a score by dividing the tally of reported items by the total number of items listed in the transparency catalogue to provide a quantitative measure of reporting transparency. Since the transparency checklist partly draws from current literature on emissions in telemedicine, there will be some overlap in our collected records.

(Streamlined) life cycle assessment

A Life Cycle Assessment (LCA) is a comprehensive method for evaluating the environmental impacts or carbon footprint of a product, process, or service throughout its entire life cycle from 'cradle to grave'. LCA includes all stages, from the extraction of raw materials to production, use, and disposal. These provide a holistic view of the impact on the environment. However, performing a complete LCA is sometimes challenging since it demands time and resources. Therefore, streamlined LCAs are often used instead.[18] These are 'simplified' or 'streamlined' LCAs (used interchangeably by literature) that focus on inputs that have the most significant impact, use existing data, or narrow the scope. These make analysing life cycles more accessible. Here, the abovementioned transparency checklist is used, informed by three leading guidelines, to assess the strength of the evidence and what can be learned.

Data collection

Hereafter, the records were assessed across four distinct categories:

1. Patient travel distance, since it was assumed to have the most significant impact as a variable.
2. Life cycle assessment with different included variables for telemedicine (LCA), since the transparency checklist valued their 22-item checklist around LCAs and the inclusion of assessed variables.
3. Staff travel, since this covers a substantial part of emissions, though it is more challenging to address in the short term, and therefore should be analysed separately.
4. Emissions beyond CO_2. These are published regularly and provide insights into the broader effects of (1), (2) and (3).

The evaluation criteria were meticulously defined, with particular attention given to travellers using ground transportation, such as medium-sized cars or public transportation.

Results

Review statistics

Figure 1 presents the PRISMA flow diagram depicting the review process. The search encompassed 1117 records across all databases, following the removal of duplicates. After eligibility screening, 33 articles met the criteria for inclusion in the analysis, of which twenty-three were analysed in Category 1, four in Category 2, four in Category 3 and five in Category 4.

Study quality assessment

Descriptives of included studies. Table 1 outlines the characteristics of all the articles included in the patient ground travel analysis (n = 23 of 33). These studies were conducted between 2010 and 2022, primarily in the United States of America (USA), Europe, and the United Kingdom (UK). The patient

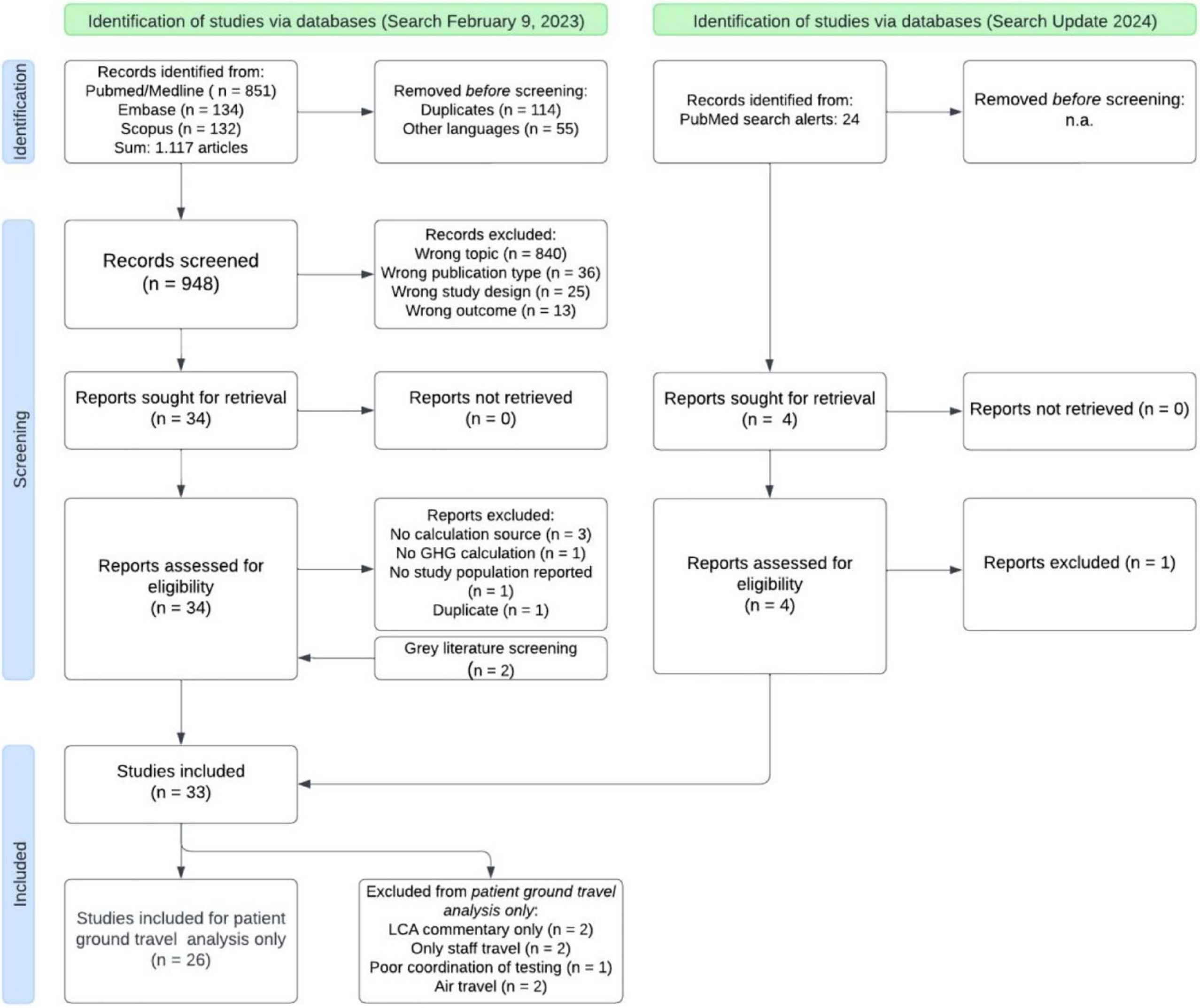

Figure 1. PRISMA study flow diagram.
Abbreviations: GHG, greenhouse gases; LCA, life cycle assessment.

population size varied significantly among the studies, as did data sources for vehicle fuel efficiency. The results of these articles are systematically evaluated in four categories: travel distance, LCA, staff travel, and emissions beyond CO_2.

Quality appraisal. All 33 articles were appraised by the transparency checklist. 13 of these were not evaluated before, which are reported in Supplemental Table 1. Based on the checklist provided by Lange et al, the average transparency score was 38% (minimum 18%, maximum 68%). All studies focussed on telemedicine through teleconsultation, conducted via phone or video, and included an assessment of distance travelled, assuming average-sized vehicles calculated by local authorities. Two-thirds of the studies report outcomes per patient or consultation rather than total emissions, which is preferred for comparability with other studies. While most studies report on geographical interpretation, they may not evaluate temporal, technical, or geographical representativeness.

Category 1: Patient transportation emissions. Our analysis incorporated twenty-three of thirty-three papers from diverse regions addressing patient ground transportation emissions. Each paper contributed one data point, except for Holmner et al, which provided four data points based on a calculation for each of two distinct populations. One source was excluded from Holmner et al due to a lack of recency. In total, 50 962 patients were considered within twenty-four populations, with a median of 324 patients (interquartile range [IQR]: 95-1075). Articles lacking a specific patient count were assumed to have a population size equivalent to the number of visits and vice versa. The median overall emissions per roundtrip amounted to 26.3 kg of CO_2 ($kgCO_2$) (IQR: 10.6-94.4). The median roundtrip travel distance per patient stood at 131 km (IQR: 52.2-386), with a cumulative travel distance of 13 319 035 km for the studied populations. Mean emission savings exhibited variations based on the year, calculation source, and the inclusion of LCA in addition to standard

Table 1. Overview of included studies.

FIRST AUTHOR	YEAR	COUNTRY	SOURCE USED	NUMBER OF PATIENTS (NUMBER OF REMOTE VISITS)	MEAN EMISSIONS PER ROUNDTRIP IN KGCO$_2$	MEAN KM PER ROUNDTRIP	MEAN EMISSIONS PER ROUNDTRIP IN KGCO$_2$/KM	LCA INCLUDED?
Andrew	2020	Aus	US EPA	45 (263)	194	773	0.251	No
Bartlett	2022	UK	BEIS	87 (21)	3.83	20.2	0.190	Yes
Beswick	2016	USA	US EPA	21 (39)	372	1410	0.264	No
Blenkinsop	2021	UK	BEIS	1277 (1567)	24.3	142.7	0.170	Yes
Connor	2011	UK	DEFRA	30 (30)	8.05	39.3	0.205	No
Connor	2019	UK	Carbon Footprint	1008 (1008)	2.91	15.0	0.194	No
Croghan	2021	UK	Carbon Footprint	736 (736)	13.7	67.9	0.202	No
Dullet	2017	USA	US EPA	11 281 (19 246)	102.41	447	0.229	No
Evers	2022	USA	US EPA	75 (75)	91.79	365.6	0.251	No
Holmner	2014	Sweden	Leduc 2010	238 (238)	87.39	345.8	0.253	Yes
					481 (481)	81.21	321.9	0.252
Gupta	2022	UK	DEFRA 2020	16 (16)	8.8	39	0.222	No
Jiang	2021	USA	US EPA	560 (560)	63.39	248.5	0.255	No
Lee	2021	USA	US EPA	113 (175)	28.4	132.5	0.214	No
Masino	2010	Canada	Government of Canada	615 (840)	220	901	0.244	Yes
Miah	2019	UK	Carbon Footprint	409 (409)	3.55	18.2	0.195	No
Mojdehbakhsh	2021	USA	US EPA	192 (192)	32.6	130.0	0.250	No
O'Connell	2021	UK	Carbon Footprint	1476 (1476)	10.4	60.8	0.171	No
Oliveira	2013	Portugal	DEFRA	20 824 (20 824)	22	111	0.197	No
Paquette & Lin	2019	USA	US EPA	87 (146)	11.2	50.2	0.223	No
Patel[a]	2023	USA	US EPA	10 027 (21 489)	19.8	77	0.256	No
					13 201 (27 840)	98.6	386	0.255
Penaskovic	2022	USA	US EPA	3975 (47 582)	22	43	0.251	No
Robinson	2017	USA	US EPA	161 (161)	265	1060	0.250	No
Schulz	2014	Aus	Carbon Neutral	120 (120)	127	454	0.279	No
Udayaraj	2019	UK	NEF/ DEFRA	97 (97)	10.7	58.5	0.182	No
Vidal-Alaball	2019	Spain	Generalitat de Catalunya	9034 (9034)	3.25	21.3	0.152	No
Wootton	2010	UK	DEFRA	2061 (2061)	11.3	53	0.214	No

Abbreviations: Aus, Australia; BEIS, Department for Business, Energy & Industrial Strategy; DEFRA, Department for Environment, Food & Rural Affairs; kgCO$_2$, kilograms of carbon dioxide; km, kilometres; LCA, life cycle assessment; NEF, National Education Foundation; UK, United Kingdom; US EPA, United States Environmental Protection Agency.

[a] Holmner et al and Patel et al report multiple subdivisions.

calculations. Depending on the additional factors considered, patient ground transportation emissions were reported to account for 40.6% to 100% of CO_2 emissions. Additional details can be found in Table 1.

Category 2: Life cycle assessment variables for telemedicine. In the context of LCA, four of thirty-three studies were identified concerning the emissions of telemedicine itself, additional when compared to a physical consult (eg, computers, data transfer and energy usage).[6,19-21] These simplified LCAs adopted 'streamlined life cycle inventory' approaches, aiming to encompass the critical facets of telemedicine, albeit with variations among the studies.[22] Holmner et al and Blenkinsop et al examined local networks, data transmission, and computer screen emissions as endpoints. Masino et al assessed emissions from computer screens, while Bartlett et al expanded the scope to encompass variables found within a hospital, including staff travel and overhead. According to these studies, the estimated emissions of telemedicine concerning ground travel ranged from 0.5% to 20.6% compared to face-to-face consultations. To be specific, Holmner reported 1.0% to 6.4% (1.86-8.43 $kgCO_2$ per hour-long appointment), Blenkinsop reported ~0.5% (0.11-0.15 $kgCO_2$ per hour), Masino reported <0.1%< (0.02 $kgCO_2$ per hour), and Bartlett reported ~20.6% (0.99 $kgCO_2$ per hour).

The observed variance is attributable to several factors, including variations in internet energy consumption, a significant contributor to net emissions.[23,24] Data transfer was identified as the primary source of telemedicine-related emissions at higher bandwidths. The energy consumption figures cited by various sources contributed to emission variations. Blenkinsop corrects for a 10-fold decrease in internet energy consumption compared to Holmner, decreasing their contribution in emission. Additionally, Bartlett's study considered hospital factors beyond telemedicine and overhead assessments, including staff travel. Due to the substantial variation in the influence of staff travel, we consider this aspect separately in the following section. Considering LCA without staff travel, estimates range from <0.1% to <6.4% of total CO_2 emissions.

Category 3: Staff travel. Four out of the 33 articles explored the carbon footprint of staff travel. Bartlett et al[19] and Wootton et al[25] accounted for the contributions of both patient and staff travel to overall emissions. Bartlett described a geriatric medicine clinic where three staff members attended to an average of four patients. The study assessed the carbon footprint linked to staff commuting, assuming an average commute distance of 6.4 km for each staff member as part of scope 3, accounting for 29.2% of savings when comparing CO_2 emissions from face-to-face with virtual consultation. The findings highlighted staff travel as the primary contributor to the carbon footprint of virtual consultations and the second-largest contributor to face-to-face consultations. Wootton et al, in analysing the carbon footprint of the Grampian National Health System (NHS) region, also considered the impact of staff and patient travel on emissions. The study revealed that staff travel accounted for 34.4% to 44.0% of the CO_2 emissions from travel.

Dorrian et al[26] and Lewis et al[27] focussed on the carbon footprint attributed to staff travel alone, theoretically resulting in 100% CO_2 savings. Lewis et al presented two surveys demonstrating substantial savings, estimating around 27 $kgCO_2$ per staff member through reduced staff commuting facilitated by telemedicine practices. In the case of Dorrian et al, the study explored the potential reduction of carbon footprint associated with tele-endoscopy. The analysis considered a hypothetical scenario in which an otolaryngology consultant would avoid travelling to see each of their 42 patients in person. The findings suggested potential driving-related emissions savings of approximately 18.3 $kgCO_2$ per person. It is important to note that the study ambiguously reported the specific travel circumstances for individual patients.

Category 4: Emissions other than CO_2. Five of the 33 studies in this review reported on miscellaneous emissions, encompassing greenhouse gasses (GHGs) such as carbon monoxide (CO), nitrogen oxides (NOx), sulphur oxides (SOx) and volatile organic compounds (VOCs) in addition to CO_2. Masino et al[21] highlighted the avoidance of approximately 360 kg of particulate matter (PM), NOx and SOx emissions, alongside a reduction of 185 159 $kgCO_2$. Detailed calculations of GHG reductions were performed in studies by Vidal-Alaball et al, Paquette and Lin, Dullet et al, and Lee et al.[28-31] Dullet et al computed total particulate matter emissions with sizes of 2.5 microns (PM2.5) and 10 microns (PM10) based on their per-distance unit values. For a comprehensive summary of the emissions reported in the reviewed studies, please refer to Table 2.

Emissions savings correlated with more significant distance reductions, with exceptions stemming from variations in per-unit distance GHG emissions provided by specific sources. For instance, the source cited by Vidal-Alaball et al estimated emissions of 0.19 g CO/km and 0.228 g NOx/km, differing from the values of 5.8 g CO/km and 0.43 g NOx/km reported in the US EPA reports used by Paquette and Lin[30] and Dullet et al.[31] Additionally, based on the conversion table provided by the UK Department for Environment, Food & Rural Affairs (DEFRA), the difference between CO_2e and CO_2 is 0.5%.[32]

Discussion

This study was conducted with the primary objective of systematically reviewing the carbon footprint and included variables from the literature for assessing the carbon footprint achieved by telemedicine. This paper shows that telemedicine contributes to reducing emissions but with high variability in recent literature. While patient travel is the most significant contributor, important nuances exist when considering the contribution of evaluating streamlined LCAs. The prioritization of these aspects based on these results contributes to the ongoing discourse surrounding calculating and interpreting CO_2 emissions in this domain.

Table 2. Total kilometres (km) and emissions in kilograms (kg) for five articles that reported emissions other than carbon dioxide (CO_2). These included carbon monoxide (CO), nitric oxides (NOx), sulphur oxides (SOx), particulate matter (PM), volatile organic compounds (VOCs), particulate matter size 2.5 microns (PM2.5) and 10 microns (PM10), methane (CH_4), nitric dioxide (N_2O), and hydrofluorocarbons (HFCs). Emissions were rounded to the nearest whole number.

ARTICLE	TOTAL KM SAVED	EMISSIONS SAVED (KG)										
		CO_2	CO	NOX	SOX	PM	VOCS	PM2.5	PM10	CH_4	N_2O	HFC
Masino et al.	757 234	185 159		360								
Vidal-Alaball et al.	192 682	29 384	37	44	29							
Paquette and Lin	7331	1632	43	3			5					
Dullet et al.	8 602 912	1 969 000	50 000	3700			5500	22	24			
Lee et al.	23 195	4983								5	41	108

Our analysis encompassed the remote treatment of 51 028 patients, resulting in a combined reduction of 13 318 882 km in travel. The analysis revealed notable variations in travel distances, with a median visit distance of 131 km (IQR: 60.8-351) and an associated median emission of 25.6 $kgCO_2$ per visit (IQR: 10.6-105.6). These estimates have a high variability. The distance that patients and staff travel varies per region, as can typical emissions for vehicles in each region, not to mention diversity in the distribution of vehicle types and transportation options. However, geographical data is only sometimes adequately assessed. For example, one study used US travel emissions in Australia, and another used global estimates for vehicle fuel efficiency when their country is often reported as having the lowest emissions. Additionally, the studies need to be interpreted in the context of how emissions might vary over time with technological advancements (eg, a computer or a car had different emissions in 2000 compared to 2020). Only a few studies analysed emissions beyond travel, such as overhead, electricity use, energy consumption related to the local energy grid, life cycle stages, and the emissions of other greenhouse gasses.

The results show that the saved emissions are structurally underestimated by not including external factors such as a streamlined LCA. This result may be counterintuitive, but it direct results from the authors' freedom to consider only the variables they select, often resulting in weighing telemedicine's carbon footprint without accounting for in-person clinic emissions. For example, Masino et al solely included computer screen emissions, contrary to Bartlett et al, who considered LCA variables unrelated to telemedicine, such as staff travel and overhead. Authors should consider using a systematic approach, such as the transparency checklist used in this review.[35] Calculations also vary widely due to differences in the efficiency of product manufacturing, internet speed, energy use, and transport emission rates.[20-22,36-38] Consider that energy consumption per gigabyte significantly declined between 2000 and 2015.[6,33] Although solvable, these uncertainties increase the difficulty of estimating and comparing (streamlined) LCAs. Notably, our findings shed light on the significant role of staff travel in shaping potential carbon savings, particularly in the healthcare sector, where it accounts for a considerable share of emissions. In light of these findings, the complexities of altering current staff travel practices are acknowledged. It represents a vast quantity of emissions as health care is a labour-intensive industry and rapidly increases its contribution to emissions, making it the primary contributor to the carbon footprint of virtual consultations and the second largest contributor to the carbon footprint of face-to-face consultations. Although crucial to analyse, staff travel is challenging to decrease in current practice patterns, where professionals often physically examine multiple patients daily (ie, mixed with teleconsultations). One can imagine a future where multiple staff members work remotely from a longer-term perspective, for instance, by aggregating telemedicine consultations in one workday or when clinics serve fewer patients daily.

We found the checklist provided by Lange et al useful for evaluating transparency and found that our additional 13 articles had a similar distribution of transparency (38% average, minimum 18%, maximum 68%) compared to their original 23 (38% average, minimum 14%, maximum 68%). However, their transparency score is given by the ratio of included elements to all elements, while all aspects are not weighted equally. For example, a study that only provides baseline information about a CO_2 source and travel distances may have the same theoretical transparency score of 2/22 = 0.10 as a study that only reports on LCA without travel distances. However, the former would be less of an underestimation of emissions, and the latter would be of higher value in decreasing the barrier to future estimations of LCA in telemedicine. Thus, while we similarly support increased transparency in reporting, we also understand the practicalities of prioritization to capture the contributions of a given study. However, while most of the literature in this field currently reports on travel savings alone in the interest of accuracy and simplicity, streamlining LCA with the goal of practical conversion guidelines will only be possible with larger quantities of representative data.

We advise readers to use the metric reported by the authority most geographically relevant to them and qualify whether this is CO_2 or CO_2e. However, based on the DEFRA conversion table, the difference between CO_2e and CO_2 is just 0.5%. Additionally, according to DEFRA, there are only international conversion factors based on CO_2, not CO_2e, because the proportion can vary widely depending on the emissions sources and the mix of greenhouse gasses.[34] Therefore, we argue that studies based on CO_2 or CO_2e are directly comparable, considering that limited literature exists and that per-consultation emissions are significantly more dependent on factors such as travel distance and regional fuel efficiency.

The strength of our study lies in our practical and comprehensive approach to telemedicine's carbon footprint. Our appraisal of LCA encompasses both CO_2 savings and CO_2 emissions, particularly when weighed against clinical overhead. By incorporating this aspect into our evaluation of telemedicine's environmental footprint, we provide a more holistic perspective that also considers the practicalities of CO_2 reporting, that is, accessible data on distances and vehicle fuel economy. One challenge is the ambiguous interpretation of 'streamlined' LCAs. This ambiguity results in significant variability in the findings among different articles, complicating attempts to provide a unified estimate of telemedicine emissions that can account for these assessments. Additionally, the limited number of studies available may constrain the inclusivity of LCA data in estimating of telemedicine emissions, partly due to potential inconsistencies in the reports used to estimate CO_2 emissions worldwide, as diverse sources may update their data at varying intervals. Moreover, a notable limitation is the simplification of emissions calculations for vehicles. The analyses employ generalized approaches to estimate emissions, which may not capture the nuances of every region, vehicle, or (telemedicine) clinic.

There is a shift in how health care regards the role of emissions in society. Usually, societal gains are solely observed by comparing the additional effect of a new intervention (eg, clinical outcomes or quality of life) to the additional costs this intervention might bring to society, which are evaluated in Health Economic Evaluations (HEE). However, the carbon footprint typically falls outside the scope of HTA research despite the vast impact of emissions on society itself.[35,36] Emissions cause significant harm to population health.[37-39] Thus, carbon footprint accountability should be considered everyone's responsibility in combating climate change, especially in healthcare research assessing societal gains of new interventions. Nonetheless, defining the place of carbon footprint in HEE research is challenging and, therefore, requires further research in health economics.[40]

In addition to environmental considerations, our research highlighted various drivers behind the implementation of telemedicine, including overcoming geographical barriers, enhancing accessibility, and addressing the challenges posed by the COVID-19 pandemic. The potential for cost savings and the broader reach of healthcare services further underscored the significance of the ongoing digital transformation in healthcare.[41-44] As we look to the future, the evolving healthcare landscape may shift towards smaller or entirely digital healthcare facilities, with examples such as *Kysos* and *Mobile Doctors*.[45,46] This transformation aligns with the broader trend of digitalization aimed at addressing the challenges facing the healthcare sector in the coming years. It is crucial to maintain a nuanced understanding of the carbon footprint in this evolving landscape and collectively work towards addressing climate change concerns.

Conclusions

Our systematic review shows that telemedicine reduces carbon footprint, with travel distance as the most significant contributor. We underline the relevance of assessing at least streamlined LCAs to highlight important nuances in the carbon footprint calculations. Moreover, the quality of studies could be improved. Thus future research needs to be more holistic and feasible regarding transparency and accuracy. By elaborating on the contribution of telemedicine to carbon footprint savings, we gain perspective on its role in working towards climate goals in the healthcare environment.

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Author Contributions

CZ and JC contributed equally to this paper, have full access to all the data in the study, and take responsibility for the integrity of the data and the accuracy of the data analysis. Acquisition and analysis of data: CZ and JC Concept, design, and drafting of the manuscript: CZ and JC Interpretation of the data and critical revision of the manuscript for important intellectual content: All authors. Supervision: MK, RL and RW. All authors contributed to the article and approved the submitted version.

Ethics Approval and Consent to Participate

Not applicable.

Consent for Publication

Not applicable.

Availability of Data and Materials

Data analysed in this study were a re-analysis of existing data, which are openly available at locations cited in the reference section. All data generated by this paper will be available to others upon request after publication. Please contact the corresponding author.

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SUPPLEMENTAL MATERIAL

Supplemental material for this article is available online.

REFERENCES

1. Tennison I, Roschnik S, Ashby B, et al. Health care's response to climate change: a carbon footprint assessment of the NHS in England. *Lancet Planet Heal*. 2021;5:e84-e92.
2. Malik A, Lenzen M, McAlister S, McGain F. The carbon footprint of Australian health care. *Lancet Planet Heal*. 2018;2:e27-e35.
3. Eckelman MJ, Sherman J. Environmental impacts of the U.S. health care system and effects on public health. *PLoS One*. 2016;11:1-14.
4. Vogel L. Canada's health system is among the least green. *Can Med Assoc J*. 2019;191:E1342-E1343.
5. Mayor S. NHS should bring in measures to reduce its carbon footprint, BMA says. *BMJ*. 2008;336:740.
6. Holmner A, Ebi KL, Lazuardi L, Nilsson M. Carbon footprint of telemedicine solutions–unexplored opportunity for reducing carbon emissions in the health sector. *PLoS One*. 2014;9:1-10.
7. Pichler PP, Jaccard IS, Weisz U, Weisz H. International comparison of health care carbon footprints. *Environ Res Lett*. 2019;14:064004.
8. Rijksoverheid.nl. Meer duurzaamheid in de zorg | Duurzame zorg. 2022. Accessed February 13, 2024. https://www.rijksoverheid.nl/onderwerpen/duurzame-zorg/meer-duurzaamheid-in-de-zorg
9. UNFCCC. The Paris Agreement. 2015. Accessed February 13, 2024. https://unfccc.int/process-and-meetings/the-paris-agreement#
10. Fierce Healthcare. Shift to virtual care during COVID-19 saved 1.7M gallons of fuel, 15K tons of CO_2 emissions: CommonSpirit Health. 2021. Accessed February 13, 2024. https://www.fiercehealthcare.com/hospitals/commonspirit-health-1-5m-ambulatory-virtual-visits-saved-1-7m-gallons-fuel-15-000-tons
11. Zapka J, Simpson K, Hiott L, et al. A mixed methods descriptive investigation of readiness to change in rural hospitals participating in a tele-critical care intervention. *BMC Health Serv Res*. 2013;13:33.
12. Christensen MC, Remler D. Information and communications technology in U.S. health care: why is adoption so slow and is slower better? *J Health Polit Policy Law*. 2009;34:1011-1034.
13. Cortez C, Mansour O, Qato DM, Stafford RS, Alexander GC. Changes in short-term, long-term, and preventive care delivery in US office-based and telemedicine visits during the COVID-19 pandemic. *JAMA Heal Forum*. 2021;2:e211529.
14. Tuckson RV, Edmunds M, Hodgkins ML. Telehealth. *New Engl J Med*. 2017;377:1585-1592.
15. Het officiële kennisplatform voor zorginnovatie. 'Milieu-impact van digital health is grote bijvangst' - ICT&health. 2022. Accessed February 13, 2024. https://icthealth.nl/online-magazine/editie-04-2022/milieu-impact-van-digital-health-is-grote-bijvangst/
16. Lange O, Plath J, Dziggel TF, et al. A transparency checklist for carbon footprint calculations applied within a systematic review of virtual care interventions. *Int J Environ Res Public Health*. 2022;19:7474.
17. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*. 2021;372:n71.
18. Hochschorner E, Finnveden G. Evaluation of two simplified life cycle assessment methods. *Int J Life Cycle Assess*. 2003;8:119-128.
19. Bartlett S, Keir S. Calculating the carbon footprint of a geriatric medicine clinic before and after COVID-19. *Age Ageing*. 2022;51:1-4. https://doi.org/10.1111/epi.17046
20. Blenkinsop S, Foley A, Schneider N, et al. Carbon emission savings and short-term health care impacts from telemedicine: an evaluation in epilepsy. *Epilepsia*. 2021;62:2732-2740.
21. Masino C, Rubinstein E, Lem L, Purdy B, Rossos PG. The impact of telemedicine on greenhouse gas emissions at an academic health science center in Canada. *Telemed J E Health*. 2010;16:973-976.
22. Seifert C, Koep L, Wolf P, Guenther E. Life cycle assessment as decision support tool for environmental management in hospitals: a literature review. *Health Care Manage Rev*. 2021;46:12-24.
23. Ong D, Moors T, Sivaraman V. Comparison of the energy, carbon and time costs of videoconferencing and in-person meetings. Comput Commun. 2014;50:86-94.
24. Coroama VC, Hilty LM. Assessing Internet energy intensity: a review of methods and results. *Environ Impact Assess Rev*. 2014;45:63-68.
25. Wootton R, Tait A, Croft A. Environmental aspects of health care in the Grampian NHS region and the place of telehealth. *J Telemed Telecare*. 2010;16:215-220.
26. Dorrian C, Ferguson J, Ah-See K, et al. Head and neck cancer assessment by flexible endoscopy and telemedicine. *J Telemed Telecare*. 2009;15:118-121.
27. Lewis D, Tranter G, Axford AT. Use of videoconferencing in Wales to reduce carbon dioxide emissions, travel costs and time. J Telemed Telecare. 2009;15:137-138.
28. Vidal-Alaball J, Franch-Parella J, Lopez Seguí F, Garcia Cuyàs F, Mendioroz Peña J. Impact of a telemedicine program on the reduction in the emission of atmospheric pollutants and journeys by road. *Int J Environ Res Public Health*. 2019;16:1-7. doi:10.3390/ijerph16224366
29. Lee J, Yousaf A, Jenkins S, et al. The positive environmental impact of virtual isotretinoin management. *Pediatr Dermatol*. 2021;38:613-616.
30. Paquette S, Lin JC. Outpatient telemedicine program in vascular surgery reduces patient travel time, cost, and environmental pollutant emissions. *Ann Vasc Surg*. 2019;59:167-172.
31. Dullet NW, Geraghty EM, Kaufman T, et al. Impact of a university-based outpatient telemedicine program on time savings, travel costs, and environmental pollutants. *Value Health*. 2017;20:542-546.
32. GOV.UK. Greenhouse gas reporting: conversion factors 2023. 2023. Accessed April 23, 2024. https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2023
33. Aslan J, Mayers K, Koomey JG, France C. Electricity intensity of Internet data transmission: untangling the estimates. *J Ind Ecol*. 2018;22:785-798.
34. GOV.UK. Greenhouse gas conversion factors: greenhouse gas conversion tool common queries. 2014. Accessed February 13, 2024. https://www.gov.uk/government/publications/greenhouse-gas-conversion-factors-greenhouse-gas-conversion-tool-common-queries
35. Marsh KD, Sculpher M, Caro JJ, Tervonen T. The use of MCDA in HTA: great potential, but more effort needed. *Value Health*. 2018;21:394-397.
36. Pekarsky BAK. The inclusion of comparative environmental impact in health technology assessment: practical barriers and unintended consequences. *Appl Health Econ Health Policy*. 2020;18:597-599.
37. Gao J, Kovats S, Vardoulakis S, et al. Public health co-benefits of greenhouse gas emissions reduction: a systematic review. *Sci Total Environ*. 2018;627:388-402.
38. Markandya A, Sampedro J, Smith SJ, et al. Health co-benefits from air pollution and mitigation costs of the Paris agreement: a modelling study. *Lancet Planet Heal*. 2018;2:e126-e133.
39. Eckelman MJ, Huang K, Lagasse R, et al. Health care pollution and public health damage in the united states: an update. *Health Aff*. 2020;39:2071-2079.
40. Williams JTW, Bell KJL, Morton RL, Dieng M. Methods to include environmental impacts in health economic evaluations and health technology assessments: a scoping review. *Value Health*. 2024;27:794-804.
41. Philips R, Seim N, Matrka L, et al. Cost savings associated with an outpatient otolaryngology telemedicine clinic. *Laryngoscope Investig Otolaryngol*. 2019;4:234-240.
42. Jue JS, Spector SA, Spector SA. Telemedicine broadening access to care for complex cases. *J Surg Res*. 2017;220:164-170.
43. Mokhtar AM. The future hospital: a business architecture view. *Malays J Med Sci*. 2017;24:1-6.
44. Williams PA, Lovelock B, Cabarrus T, Harvey M. Improving digital hospital transformation: development of an outcomes-based infrastructure maturity assessment framework. *JMIR Med Inform*. 2019;7:1-15.
45. Zorgvisie. Eerste virtuele ziekenhuis ter wereld succesvol. 2016. Accessed February 13, 2024. https://www.zorgvisie.nl/amerikaans-ziekenhuis-zonder-patienten-succesvol/
46. Witkamp L. 'Dankzij telemedicine komen artsen eindelijk weer aan patiënten toe' - Zorgvisie. 2019. Accessed February 13, 2024. https://www.zorgvisie.nl/leonard-witkamp-dankzij-telemedicine-komen-artsen-eindelijk-weer-aan-patienten-toe/