Received: 24 May 2021 | Revised: 29 July 2021 | Accepted: 5 August 2021

DOI: 10.1111/epi.17046

Epilepsia®

FULL-LENGTH ORIGINAL RESEARCH

Carbon emission savings and short-term health care impacts from telemedicine: An evaluation in epilepsy

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Funding information
Epilepsy Society; Natural Environment Research Council, Grant/Award Number: NE/R01079x/1; NIHR Biomedical Research Centres

Abstract

Objective: Health systems make a sizeable contribution to national emissions of greenhouse gases that contribute to global climate change. The UK National Health Service is committed to being a net zero emitter by 2040, and a potential contribution to this target could come from reductions in patient travel. Achieving this will require actions at many levels. We sought to determine potential savings and risks over the short term from telemedicine through virtual clinics.

Methods: During the severe acute respiratory syndrome coronavirus 2 (SARS-2-CoV) pandemic, scheduled face-to-face epilepsy clinics at a specialist site were replaced by remote teleclinics. We used a standard methodology applying conversion factors to calculate emissions based on the total saved travel distance. A further conversion factor was used to derive emissions associated with electricity consumption to deliver remote clinics from which net savings could be calculated. Patients' records and clinicians were interrogated to identify any adverse clinical outcomes.

Results: We found that enforced telemedicine delivery for over 1200 patients resulted in the saving of ~224 000 km of travel with likely avoided emissions in the range of 35 000–40 000 kg carbon dioxide equivalent (CO_2e) over a six and half month period. Emissions arising directly from remote delivery were calculated to be <200 kg CO_2e (~0.5% of those for travel), representing a significant net reduction of greenhouse gas emissions. Only one direct adverse outcome was identified, with some additional benefits identified anecdotally.

Significance: The use of telemedicine can make a contribution toward reduced emissions in the health care sector and, in the delivery of specialized epilepsy services, had minimal adverse clinical outcomes over the short term. However, these outcomes will likely vary with clinic locations, medical specialties and conditions.

KEYWORDS

climate change, global heating, neurology, pandemic

1 | INTRODUCTION

On October 1, 2020 the UK National Health Service (NHS) adopted formal plans to move from being responsible for 4% of the UK's carbon emissions to being net zero by 2040, with an ambition for an interim 80% reduction by 2028–2032, and with further targets for its extensive supply chain to be net zero by 2045.[1] Achieving such an ambitious target will require significant actions across the NHS.[2] The interventions proposed include care delivery at or closer to home, with fewer patient journeys to hospitals: Of the extended NHS carbon footprint, 5% is attributable to patient travel. Although this proportion is small, patient travel amounts to ~1.25 megatonnes carbon dioxide equivalent (CO2e)/year.[3]

Placing these emissions in the broader context of the transport sector, in 2017, ~20% of the UK's total greenhouse gas (GHG) emissions came from road transport.[4] Mitigation in this fast-growing sector will need to be achieved through policies that reduce transport demand, increase energy efficiency, and/or decrease transport's carbon intensity.[5] Policies in the transport sector have the potential to bring positive health co-benefits, but badly implemented policies could also have negative effects.[6]

The severe acute respiratory syndrome coronavirus 2 (SARS-2-CoV) pandemic has led to dramatic changes in NHS service delivery. The proposed "new service model for the 21st century" includes avoidance of unnecessary hospital visits. Travel savings could be made from both real-time and store-and-forward telemedicine (where clinical information is collected and sent electronically to another site for evaluation)[7]; additional savings will accrue through revised therapy regimens.[8–10] What may previously have been a thought experiment has become reality as a result of the pandemic, offering an opportunity to estimate the benefits and adverse outcomes associated with mass telemedicine and to inform long-term plans to boost out-of-hospital care.[1] We gathered data from a unique site providing adult epilepsy services, and calculated the marginal carbon emissions savings from enforced telemedicine, and documented adverse clinical outcomes.

Key Points

- If ambitious emissions targets are to be met, then changes to healthcare practices will be needed at many levels, one of which is patient travel.
- The severe acute respiratory syndrome coronavirus 2 (SARS-2-CoV) pandemic provided an opportunity to determine net carbon emissions savings from conversion to telemedicine.
- For specialist epilepsy services, telemedicine was feasible, safe over the short term, and associated with sizeable net emissions savings.

2 | METHODS

This work formed part of a service evaluation registered and independently approved by the Clinical Audit and Quality Improvement Subcommittee, Queen Square Division, University College London Hospitals NHS Trust (UCLH). This approval waives the need for approval by an ethics committee, in accordance with UK legislation and NHS operating procedures. Outpatient clinics, usually held entirely face-to-face at the Chalfont, Buckinghamshire site of the ULCH National Hospital for Neurology and Neurosurgery (https://www.uclh.nhs.uk/our-services/find-service/neurology-and-neurosurgery/epilepsy/epilepsy-chalfont-centre), were included. All the clinics serve adults, typically those with more complicated epilepsies needing specialist expertise. Because public transport to the site is extremely limited, almost all attendees are driven to the site; some people with epilepsy who meet the UK driving regulations may drive themselves to the site. Journeys from Northern Ireland and Jersey, for which attendance would necessitate air or ferry travel, were omitted. These excluded journeys comprised 12 of the total data set.

All the clinics evaluated were screened for remotely held appointments between March 16, 2020 and September 30, 2020, totaling 1567 appointments for 1277 patients. The postcode for the origin of the journey was taken from electronic health records for the last recorded home address for the patient; only the first half of the postcode was used (postcode districts), according to the approved protocol for the service evaluation (eg, our center has the postcode SL9 0RJ: only SL9 would have been used if this had been the patient's home postcode). Where relevant data were available, travel distances for additional attendees (eg, parents of adult children in residential care; n=112) were calculated as separate journeys.

The ArcGIS Online[11] and Google Maps routing tools were used to determine journey distances and times. Using ArcGIS, the centroids of postcode districts were first calculated to generate a list of starting points. Google Maps similarly selects the centroid when supplied with a partial postcode and has been used in previous studies.[12,13] Reflecting the national referral base for the specialist clinics, Figure 1 illustrates the wide geographical reach of patient home postcodes.

Carbon emissions associated with each journey were estimated using conversion factors for passenger transport GHG emissions published by the UK Department for Business, Energy and Industrial Strategy (BEIS) (2020

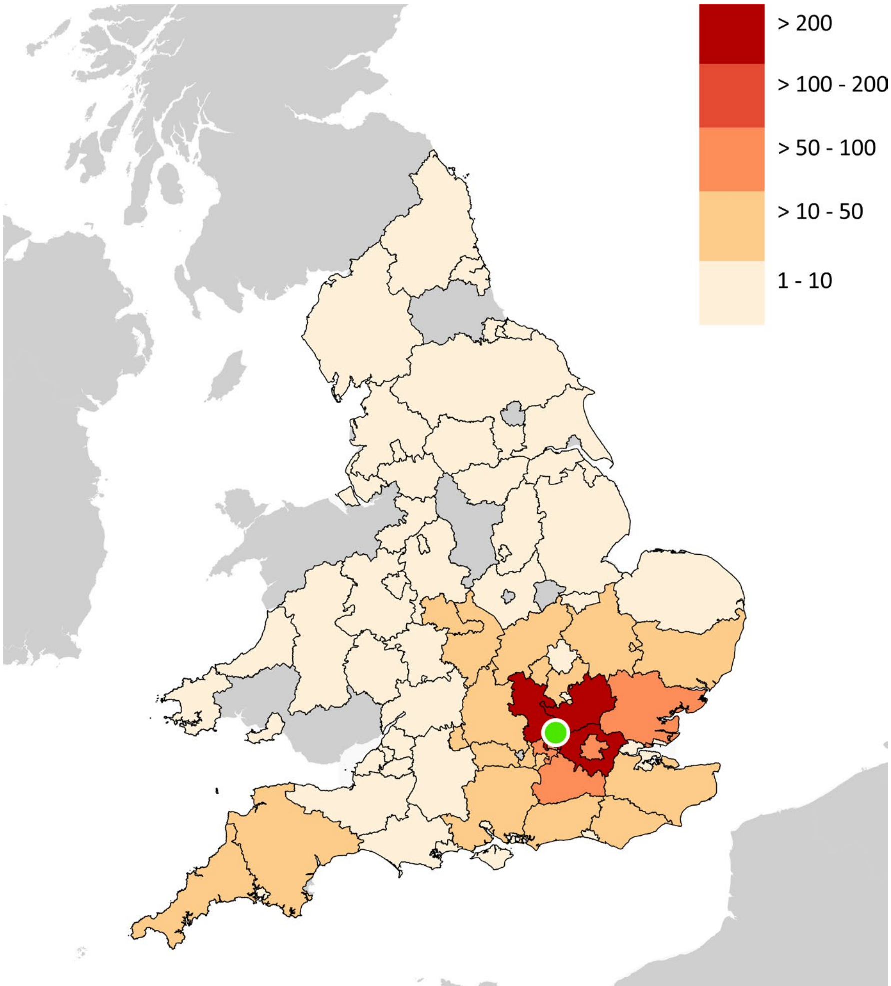

FIGURE 1 Number of return journeys avoided during the period of investigation for each county aggregated from the centroid of each home postcode district. The color scale represents the number of return journeys made from each outlined area (county). The green dot represents the location of the clinics (UK postcode: SL9 0RJ)
Sources: Postcode district and county-level boundaries: Esri, Michael Bauer Research GmbH, Office for National Statistics (ONS)/UK Statistics Authority, Scottish Government, Northern Ireland Statistics and Research Agency, Eurostat. Basemap: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community

release).[14] These factors enable organizations and individuals to calculate GHG emissions from a range of activities, including energy use, water consumption, and transport, here converting distance traveled in kilometers directly into emissions, including non-CO_2 GHGs, methane (CH_4), and nitrous oxide (N_2O),[15] presented as CO_2 equivalents (CO_2e) in kilograms. Conversion factors are provided for different fuel types and for different sizes and types of cars. We were therefore able to assess the uncertainty associated with some of the assumptions made in the calculation of emissions by using different profiles of car use for the journeys made and compared these emission ranges with an estimate for those generated by teleclinics.

For a random 50% of the total number of patients (639 patients) who had remotely held appointments, all further clinical interactions up to February 8, 2021 (range of duration of follow-up: 131–329 days) documented in the electronic health record system were reviewed by a consultant epileptologist to determine whether any adverse consequences or unexpected benefits of remote consultation were identifiable. Only records held at UCLH were accessed. All treating clinicians were also directly questioned on February 1, 2021 for recollected adverse outcomes of remote consultation.

TABLE 1 Conversion factors and total emissions for different car sizes assuming all journeys were by the same size car for diesel and petrol fuelled cars

	Conversion factor		Total estimated emissions (kg CO_2e)	
	Diesel	**Petrol**	**Diesel**	**Petrol**
Average car	0.16844	0.1743	37 659	38 969
Small car	0.13721	0.14836	30 677	33 170
Medium car	0.16637	0.18659	37 196	41 717
Large car	0.20419	0.27807	45 652	62 169

Note: Abbreviations: kg = kilogram; CO2e = carbon dioxide equivalent

3 | RESULTS

3.1 | Saved emissions associated with avoided travel to clinics

The total return distance that would have been traveled in 1667 return journeys commencing in mainland Great Britain was calculated at ~224 000 km using the ArcGIS method and 241 000 km using Google Maps, corresponding to ~5.3 times around the equator. ArcGIS yields a median return journey distance of 69.5 km and a maximum of 483.5 km. The lower ArcGIS distances were subsequently used to calculate conservative estimates of GHG emissions savings for the main car fuel types and for different car sizes to provide an understanding of the influence of vehicle types. Results from Google Maps were, however, also used to test the sensitivity of the results to the distance algorithm.

Given that data are not collected on the type of car used by each patient, we first used the "average" car conversion factor, which leads to a total of 37 659 and 38 969 kg CO_2e for diesel and petrol cars, respectively (Table 1). Using conversion factors for cars of different sizes, we estimated the additional emissions if all journeys were made using large petrol cars rather than small ones as ~29 000 kg CO_2e. It is extremely unlikely that all journeys would have been made in one car type but these ranges are useful in assessing the range of reductions in emissions associated with remote teleclinics. We further refined our estimates by assuming that the vehicle type distribution reflects the proportion of licensed cars for each fuel type for Great Britain obtained from the Department of Transport[16] (Table 2). Using an average-sized car for each fuel type yielded a figure of 38 095 kg CO_2e, consistent with the range identified above, and unsurprising because diesel and petrol account for ~98% of licensed cars. For these proportion-corrected estimates, if everyone used a small or a large car, the carbon emissions would have been 31 880 or 54 995 kg CO_2e, respectively (data not shown). We repeated these calculations using the longer distances calculated by the Google Maps algorithm for an average car to estimate the potential uncertainty arising from the choice of distance algorithm used, yielding a figure of 41 088 kg CO_2e (~8% higher). We thus conclude that a range of 35 000–40 000 kg CO_2e is a reliable estimate of the emissions that could be attributed to these cancelled journeys, and that assumptions on size of car used is a greater potential source of uncertainty than the distance algorithm.

3.2 | Emissions associated with teleclinics

Emissions savings arising from substituting remote clinics for travel to face-to-face clinics need to account for emissions generated by the remote consultations. We accounted for energy used to conduct two-way teleclinics. The weekly teleclinics over the period examined were estimated to last four hours each, giving a total estimated duration of 1152 h. Consultations were held using a mixture of teleconferencing software and, primarily, telephone, but the modes used in each instance were not recorded. We calculated emissions for videoconferencing by using established figures for Zoom, a common teleconferencing solution.

We first estimated the average electrical energy intensity of transmitting data through the internet (measured as kilowatt-hours per gigabyte [kWh/GB]). Estimates for this value vary between locations[17] and with time. Ong et al.[18] calculate an intensity of 2.17–3.61 kWh/GB for 2010, noting a 10-fold decrease in 6 years. Aslan et al.[19] identified that this value had decreased by half approximately every 2 years since 2000. O'Brien and Aliabadi[20] report that rates vary with the time of day/week and the data transfer rate. These factors partially explain the wide range reported for energy use (0.0064–136 kWh/GB).[21] The system boundary (primarily end-use device, ie, desktop, laptop, tablet), access network (eg, ADSL lines, public Wi-Fi hotspots, mobile networks) and ambient temperature conditions are other potential contributors to this uncertainty. Here, we used the estimate of average energy intensity of fixed-line internet transmission networks in the UK in 2015 of 0.06 kWh/GB, but assume a continued halving every 2 years to 0.015 kWh/GB by 2019.[19]

To calculate total electricity usage, we used the data requirements guidance provided for Zoom teleconferencing software, which for one-to-one video calling requires 600 kbps (upload/download) for high-quality video, 1.2 Mbps (upload/download) for 720p HD video, and 3.8 Mbps/3.0 Mbps (upload/download) for 1080p HD video (Zoom, 2021).[22] For example, a 1-hour HD 1080p video meeting would require for each user:

$$3.8\ \text{Mbps} = 0.000475\ \text{GBps} * 3600 = 1.71\ \text{GB (upload) and } 3.0\ \text{Mbps} = 0.000375\ \text{GBps} * 3600 = 1.35\ \text{GB (download)}.$$

TABLE 2 Total emissions by fuel types assuming that the distance traveled reflects the proportions of licensed cars for each type and an average car for each type

	Diesel	Petrol	Hybrid	Plug-in hybrid	Battery electric	Liquefied petroleum gas (LPG)	Total
Licensed proportion	0.385	0.59	0.016	0.005	0.003	0.001	
Average car conversion factor	0.16844	0.1743	0.11558	0.09712	0.05728	0.19754	
Distance (km)	86 076.2	131 909.0	3577.2	1117.8	670.7	223.6	223 574.5
Emissions (kg CO_2e)	14 499	22 992	413	109	38	44	38 095

Applying the energy intensity based on Aslan et al.,[19] for two users this creates an energy demand of:

$$6.12\ \text{GB} \times 0.015\ \text{kWh/GB} = 0.0918\ \text{kWh}$$

We then applied the conversion factor for electricity consumption from the UK Government Department for Business, Energy and Industrial Strategy,[14] which allows emissions to be calculated from electricity usage measured in kilowatt hours (kWh). The current conversion factor is 0.23314 (having decreased by ~10% in each of the two previous years) and, as for passenger travel, quantifies emissions in kg CO_2e. Here we derive emissions for 1 hour of remote consultation as:

$$0.0918\ \text{kWh} \times 0.23314 = 0.0214\ \text{kg}\ CO_2\text{e}$$

For 1152 h of teleclinics this totals ~25 kg CO_2e. For high-quality and 720p HD video, the totals are lower at ~4 kg CO_2e and ~9 kg CO_2e, respectively. As a comparison for electricity energy intensity for internet data transmission using mobile connectivity, we applied the rate of 0.1 kWh/GB,[21] resulting in emissions in the range of ~29 to ~164 kg CO_2e.

We next calculated the emissions associated with electricity consumed by powering the electrical device(s) used to conduct the clinic (eg, laptop), by converting typical device wattage into kilowatt hours and then using the BEIS[14] conversion factor. Wattage for electrical components by device varies (see Table 3) and is converted into kilowatt-hours (kWh) from which emissions were calculated using the conversion factor for electricity consumption.

Combining these two components for videoconferencing yields in total ~25 to ~131 kg CO_2e for a laptop (lower estimate) or PC setup (upper estimate) or ~32–167 kg CO_2e for a mobile phone, compared with ~2 kg CO_2e if all calls were conducted over telephone.

Comparing the saved emissions totals associated with patient journeys (35 000–40 000 kg CO_2e) with those associated with teleclinics (ranging from 2 kg CO_2e for telephone calls to an upper estimate of 167 kg CO_2e for videoconferencing) indicates considerable savings even given the assumptions made in both components.

3.3 | Clinical impacts of remote consultation

From review of the clinical records, up to 08.02.21 of 639/1277 patients who had remote consultations during the study period between 16.03.2020–30.09.2020, only one issue was documented that was considered a direct adverse outcome of remote consultation (inability to review seizure and drug charts in a telephone consultation). Beneficial outcomes were not explicitly sought, nor documented by clinicians, but anecdotally included: wider participation of family or carers (eg, "the virtual meeting allowed us all to be involved from our own homes safely and we had an opportunity to contribute and give our opinion, ask questions and hear your advice"); participation by patients who otherwise may not have attended on the day for behavioral reasons, but who were able to accept a shorter disruption to their routine, or because they had had a seizure preventing them from traveling; lessened anxiety around attending a health care setting during the pandemic; increased convenience of not having to travel. We note also that the rate of nonattendance for any reason for the virtual appointment was less during the study period, compared to the same period in the previous year for face-to-face appointments (−12.4% on average across the clinics). Carer and family member education for administration of emergency seizure treatment ("rescue") medication continued uninterrupted during the remote consultation period, through video technology.

4 | DISCUSSION

Telemedicine for epilepsy has been well-documented over the course of the pandemic. We show that telemedicine can also contribute net GHG emissions savings. If the UK National Health Service is to meet its declared net zero commitment by 2040, adaptations will be necessary at many levels, including patients' journeys for medical care. At least over the short term studied here, adaptation to telemedicine appears feasible, acceptable, and safe. Moreover, although not systematically recorded over the study period, co-benefits were apparent over this short term of evaluation, including the chance of greater engagement and reductions in rates of missed appointments. We estimate that the reductions in carbon emissions were of the order of 35 000–40 000 kg CO_2e over the 6.5-month study period. Using our estimates, the carbon costs associated with telemedicine represent at most ~0.5% of the carbon costs associated with face-to-face clinics, consistent with the lower bound of 0.4%–0.9% found for a clinic in Sweden, although that study was for a different specialism that included surgery and also included additional embedded emissions through a life cycle assessment (LCA).[23] Such assessments are used to quantify emissions associated at each stage of the life cycles of different products used, from extraction and processing of raw materials, through manufacturing, distribution, and use, through to recycling and final disposal.[24] Our findings are also consistent with those in a review by Purohit et al.,[25] who found robust evidence that the use of telemedicine services leads to a reduction in the carbon footprint of health care, particularly as a result of reduction in travel. This evidence emerged across different services and regions and led them to conclude that telemedicine could play a valuable role in developing a net

TABLE 3 Typical power consumption and associated emissions for hardware devices used over 1152 h of calls

Device	Power consumption (W)	Total emissions (kg CO_2e)
PC hardware		
Desktop	150	80.6
24 in LCD Monitor	30	16.2
Webcam	9.5	5.2
Audio hardware	4.1	2.2
Microphone	2.5	1.4
Laptop	40	21.4
Mobile phone	5	2.6
Cordless telephone	3	1.6

Note: The power consumption is converted to kilowatt hours (kWh) before applying the conversion factor. The total emissions assume both parties to a clinic are using the same type of device.

Abbreviation: W = watts; CO2e = carbon dioxide equivalent

zero health care system, but that implementation will depend upon specialty and location.

We have already noted that improved technology has reduced the energy needed for data transmission; reductions in coal generation and increased use of renewables has reduced the emissions associated with electrical use. This trend will likely increase in future years, but it should be noted that improved fuel efficiency and new technology has also reduced emissions associated with passenger travel, with up to ~15% decreases in conversion factors for vehicles since 2013. The margin of difference between the two modes of care delivery means that significantly lower emissions associated with teleclinics are likely to remain, notwithstanding future changes in these rates.

Telemedicine will contribute to the net zero NHS target, thereby minimizing the need for sometimes lengthy car journeys. Co-benefits from telemedicine will also accrue: for example, the need to wake early to get to a face-to-face appointment will be avoided; early rising may lead to loss of sleep, which in many people with epilepsy is a potent stimulus for seizures; time will be saved for patients, as the average return travel time saved in this sample was estimated by the ArcGIS software at just over 2 h, with a maximum of over 12.5 h. But care must be taken to consider the needs of the most vulnerable, and how they might be inadvertently affected by such a shift in practice. In remote areas where high speed broadband networks are less available, a "digital by default" approach could result in another form of exclusion.[26] The results highlight the necessity of considering the dynamics of social vulnerability in planning for a low carbon future.[27] Similarly, with the UK government recently announcing intentions to phase out new diesel and petrol vehicles by 2030,[28] it is worth considering the potential impact of such policies for the kinds of journeys explored in this research, where the reason for travel is a medical necessity, and the journey is too difficult, long, or complex to undertake by public transport. If all the journeys in this study were undertaken in a battery electric vehicle (assuming this was feasible) under current technology, this would generate lower emissions in the range of 10 000–14 000 kg CO_2e. However, people with epilepsy are known to experience disproportionate economic burdens, including lower income and employment rates, and higher health-related costs than people without epilepsy,[29] such that electric vehicle affordability will become a concern potentially entrenching existing socioeconomic disparities.[30] The intersectionality of these issues means that some people with epilepsy may experience more compounding of barriers than others when accessing care if policy shifts are not approached in a holistic manner. Focusing on the most vulnerable in society, rather than national averages, as a measure of policy success, will be important.[31] Such a nuanced and individual approach will add a layer of "climate considerations" to the growing push to precision medicine in epilepsy.[32]

There are limitations to the work. Health outcomes were judged only retrospectively, from medical records. We can also only comment on outcomes for the short duration of follow-up. We recognize that for patients who were under long-term follow-up (the majority), telemedicine may have proved easier as existing rapport between patient and clinician, and familiarity with the patient's condition and circumstances, would have facilitated telemedicine and lowered concerns about important aspects of care being missed. Moreover, additional adaptations were made over the course of the pandemic: for example, with respect to issues such as the need to complete an annual risk acknowledgement form when using the teratogen valproate in women of child-bearing potential, an alternative was instituted to the requirement to complete this form face-to-face. All these factors eased the move to telemedicine for many people under long-term follow-up at this center. The issues may be different for other chronic conditions. We have also noted uncertainties in the calculation of savings from avoided journeys, in the distance algorithm used, and in type of vehicle used by patients. For example, a proportion of patients would have been transported in larger vehicles, including those adapted for wheelchair use, or in hospital transport vans. However, this uncertainty is likely to be less than in other studies due to the low availability of public transport to the clinic location. We also identified uncertainties associated with the emissions due to the technology used to conduct the teleclinics, both in terms of devices used and also in the case of online teleclinics, with the energy cost of data transmission. Our approach has tried to quantify these uncertainties by examining a range of options and demonstrated that the emissions reduction is likely several orders of magnitude larger than these uncertainties. We also note that the clinic duration used in our calculations are estimates, and assume that only one clinician called all patients for a given clinic. More generally, the relative contribution of GHG emissions savings from reduced travel is very dependent on clinic circumstances.[12] Whether clinics are based in urban environments with good public transport and limited private care use, and are generalist compared to specialist or national referral centers, will all have an influence on the marginal carbon savings from reduced travel.

It must be noted that we have taken advantage of an imposed change and that, at the start of the pandemic, there was no scope to plan a prospective study because of manpower and other limitations, with workforce and institutional services, such as approvals processes, focused necessarily on the pandemic. We provide an envelope of estimates for carbon savings (and costs): the actual net saving will be between these boundaries. In general, our estimates overplay the costs of remote consultation, for example, the electricity intensity for internet data transmission has likely decreased further since the estimate we used was calculated.[19] In contrast we probably underestimate carbon emission savings from travel; for example, we did not calculate travel savings due to staff working remotely, nor the savings from the use of larger vehicles often used to bring people to these clinics. We also did not include any LCAs (for example, the conversion factor for electricity provided by BEIS[14] ignores energy supply chain costs), but we note that it is unlikely that patients or carers bought cars only for clinic attendance, and that the majority of the NHS clinic infrastructure was already in place (the only adaptation was the purchase of video cameras for hospital computers, which occurred only in the latter part of the study period). We have already noted that our estimate of telemedicine representing a maximum of ~0.5% of the carbon costs associated with face-to-face clinics is consistent with the lower estimate of Holmner et al.,[23] which did incorporate relevant life cycles, but even the higher bound in this study (for a very different type of clinic) amounted to only 3.2%–6.4% of travel emissions.

Climate change is just one of multiple environmental impacts that the health care sector must address, for example along with water use and air and water pollution.[33] Increasing amounts of clinical waste have been highlighted as a consequence of the coronavirus disease 2019 (COVID-19) pandemic[34] and include the impact of nonbiodegradable materials and single-use plastic products[35] on land and marine ecosystems. These impacts need to be simultaneously addressed throughout the supply chains of the NHS and other health care systems alongside meeting the challenge of reducing emissions.[36] In the "build back better" mode, there will need to be an informed balance in the NHS programme between GHG reduction targets (and wider environmental impacts) and the best health care outcomes, where those may not align overall. New technologies may offer some assistance in achieving this, for example, Tsagkaris et al.[37] highlighted how artificial intelligence (AI) systems could be combined with telemedicine to offer further carbon footprint reductions. AI can already monitor patients,[38] or undertake triage of patients seeking medical attention, thus avoiding unnecessary consultation.[37] Wider implementation of in-home care could also be a feature of a portfolio of measures. Other new technologies on the horizon will offer new opportunities across the sector, for example, by reducing emissions associated with volatile anesthetics.[3] However, among the barriers to action, Tsagkaris et al.[37] cite a lack of awareness and of reliable data relating to reducing emissions; for example, Purohit et al.[25] call for a greater use of LCAs in quantifying emissions associated with health care. There is therefore a need for clinicians to be educated on the environmental benefits that telemedicine can bring, and how to implement the new technologies that might facilitate these.[37] Nevertheless, we have demonstrated that telemedicine for epilepsy may already result in significant GHG emission savings, with additional short-term co-benefits. Although the extent of such effects may differ between clinic locations, medical specialties, and conditions, telemedicine may have an important impact on GHG savings and should be further assessed over the longer term and across different medical facilities and specialties.

ACKNOWLEDGMENTS

The work was supported by the Epilepsy Society. SB was funded by the Natural Environment Research Council (NERC) standard grant FUTURE-STORMS (grant no. NE/R01079x/1). Part of this work was undertaken at University College London Hospitals, which received a proportion of funding from the National Institute for Health Research (NIHR) Biomedical Research Centres' funding scheme. The map in Figure 1 was created using ArcGIS software by Esri. ArcGIS and ArcMap are the intellectual property of Esri and are used herein under license. For more information about Esri® software, please visit www.esri.com.

CONFLICTS OF INTEREST

SMS has received personal or institutional honoraria or grant support from UCB Pharma and Eisai. The remaining authors have no conflicts of interest.

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How to cite this article: Blenkinsop S, Foley A, Schneider N, Willis J, Fowler HJ, Sisodiya SM. Carbon emission savings and short-term health care impacts from telemedicine: An evaluation in epilepsy. Epilepsia. 2021;00:1–9. https://doi.org/10.1111/epi.17046