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A Telemedicine Center Reduces the Comprehensive Carbon Footprint in Primary Care: A Monocenter, Retrospective Study

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Abstract

Introduction: Telemedicine reduces greenhouse gas emissions (CO_2eq); however, results of studies vary extremely in dependence of the setting. This is the first study to focus on effects of telemedicine on CO_2 imprint of primary care. **Methods:** We conducted a comprehensive retrospective study to analyze total CO_2eq emissions of kilometers (km) saved by telemedical consultations. We categorized prevented and provoked patient journeys, including pharmacy visits. We calculated CO_2eq emission savings through primary care telemedical consultations in comparison to those that would have occurred without telemedicine. We used the comprehensive footprint approach, including all telemedical cases and the CO_2eq emissions by the telemedicine center infrastructure. In order to determine the net ratio of CO2eq emissions avoided by the telemedical center, we calculated the emissions associated with the provision of telemedical consultations (including also the total consumption of physicians' workstations) and subtracted them from the total of avoided CO2eq emissions. Furthermore, we also considered patient cases in our calculation that needed to have an in-person visit after the telemedical consultation. We calculated the savings taking into account the source of the consumed energy (renewable or not). **Results:** 433 890 telemedical consultations overall helped save 1 800 391 km in travel. On average, 1 telemedical consultation saved 4.15 km of individual transport and consumed 0.15 kWh. We detected savings in almost every cluster of patients. After subtracting the CO2eq emissions caused by the telemedical center, the data reveal savings of 247.1 net tons of CO2eq emissions in total and of 0.57 kg CO2eq per telemedical consultation. The comprehensive footprint approach thus indicated a reduced footprint due to telemedicine in primary care. **Discussion:** Integrating a telemedical center into the health care system reduces the CO_2 footprint of primary care medicine; this is true even in a densely populated country with little use of cars like Switzerland. The insight of this study complements previous studies that focused on narrower aspects of telemedical consultations.

Keywords
telemedicine, primary care, carbon footprint, CO2-emission, climate change, sustainability, public health

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Introduction

Telemedicine is well-suited for carrying out medical treatment over long spatial distances and does not necessitate physical presence.[1,2] Consultations with general practitioners and specialists can take place remotely, and the same is true for the surveillance of chronically ill patients.[3] Doctors can decide on medications and treatments, triage patients, and

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issue referrals. In addition to the doctor–patient interaction, doctors can also, for example, request consultations with other doctors, discuss cases, and interpret the results of radiological imaging via encrypted data transmission.[4] Telemedicine can significantly contribute to a more sustainable health care system.[5] Above all, it enables individuals to liaise across long distances, resulting in significant savings in travel distances, associated CO_2eq expenditure, and other resources and costs—with patients reporting high satisfaction.[6] Furthermore, the recent COVID-19 pandemic has accelerated the deployment of audio-visual technologies in patient encounters.[7]

The health care sector accounts for around 5% of greenhouse gas emissions worldwide; if current conditions remain unchanged, these will triple by 2050.[8,9] Responsible voices from the medical-scientific community increasingly call for urgent action to address climate change.[10] Patient and staff journeys contribute significantly to the carbon footprint,[11] which also considerably impacts health: In 2015, 5.5 million illnesses and deaths due to chronic respiratory diseases and lung cancer were contributed by air pollution worldwide.[12] This number is 3 times higher than the cases of AIDS, tuberculosis, and malaria combined.[12] In addition, research has linked prolonged exposure to air pollutants to depression.[13]

It is imperative to investigate solutions such as telemedicine further to reduce carbon emissions.[14,15] Recent research reports that telemedicine offers a broad range of savings, such as shorter travel distances and substantially lower CO_2eq emissions.[6,16,17] In their systematic review of 31 studies with 57 000 patients, Donald and Irukulla,[6] find that savings varied from 0.69 to 893 kg CO_2eq per case and from 6.1 to 3386 km in terms of distance. Most studies in their review examined specialist areas of telemedicine such as endocrinology, urology, oncology, neurology, gynecology, cardiology, orthopedics, dermatology, or kidney transplant surgery, often with postoperative follow-ups in the virtual setting or specific issues in the respective specialty.[6] Although primary care is a critical element of health care, few studies so far address its environmental impact. Overall, the studies primarily focus on the US and UK; for Europe, there are occasional reports on Spain,[18] Sweden,[19] Portugal,[20] or Germany.[21]

In their study on telemedical services in Spain, Morcillo Serra et al,[22] find that the heavy use of telemedicine saved an estimated 6655 net tons of CO_2eq in 2020. Every telemedical consultation helped save an average of 3.057 kg of net CO_2eq, and every downloaded medical report instead of getting them to the patients via conventional ways, another 1.5 kg. Telemedicine-related emissions were calculated using a consultation duration of 9.5 min on average, the energy consumption of data centers and data transmissions, and the use of devices. Distances were calculated based on statistical data on average distances from patients' homes to doctors' offices; however, aspects such as pharmacy visits or direct dispensing of medications by primary care physicians were not considered. The average age of patients attending digital appointments was 39 years. Most of the appointments observed in this study were telemedical consultations on specialized areas of expertise; only 10% took place in a primary care setting.

Vidal-Alaball et al,[18] concluded that telemedical service offerings in the Catalonia region of Spain between January 2018 and June 2019 helped save 192 682 km of distance, 3779 h of travel time, and EUR 15 664. However, their study only considered telecmedical onsultations between 2 colleagues. Thus, in the study, patients were spared from traveling from the primary care practice to the specialized hospital in cases where consultation between the 2 physicians allowed open medical questions to be fully clarified through know-how sharing. The distances between the primary care center and the hospital were determined with Google Maps to calculate emissions per kilometer. The calculation of emissions was based on vehicles with average emission values. The result is an average reduction of 3.2 kg of CO_2 per telemedical consultation.

In Switzerland, a recent study estimated the CO_2 footprint for a single primary care consultation to average 4.8 and 30.5 CO_2eq kg for an average practice.[14] Nicolet et al,[14] conducted a retrospective study including 10 primary care practices in western Switzerland and calculated 3 scenarios (average, best, and worst practice cases). The difference between the best and worst practices showed a factor of 10. The topic of prescriptions was not covered in the study. In addition to mobility, they also included the following aspects in the analysis: medical and non-medical equipment and consumables, waste, laboratory analysis, infrastructure, and electricity. They extrapolated the data on patients from a survey of 1 day (6 practices) or 1 week (4 practices) to the whole population. More than half (55.5%) of the carbon footprint was due to overall mobility (patient mobility plus staff mobility plus courier mobility); one third resulted merely from patient mobility (33.2%). The study points out that telemedicine, as one of the potential ways to mitigate CO_2eq emissions, should be further investigated in this regard.[14]

The carbon footprint of telemedicine has not yet been evaluated with a comprehensive footprint approach—especially not in primary care setting and regarding its use in self-dispensing (SD) versus non-SD areas, which is worth comparing. Our retrospective study aims to quantify the impact of a telemedicine center on the carbon footprint of primary care consultations. The research design includes SD and non-SD physician cantons of Switzerland and considers all telemedical consultations the telemedicine center conducted in the investigated model and period.

Methods

Study Design and Participants

We performed a retrospective analysis with data from our company patient management system (PMS). Besides patient data, the PMS contains the names and addresses of the health care providers and pharmacies visited by patients enrolled in an alternative health insurance model. In these health insurance models, the choice of health care providers is managed, and in return, policyholders receive premium discounts.[23] In this study, we investigated the medical core area of the telemedicine center and looked at the telemedical consultations of this patient population to be able to analyze accurate data. Time-limited activities such as pandemic information hotline calls (hotline) or other non-medical information exchange calls such as requests to health insurances (appointment management, remainder) were not included. We investigated a total of 433 890 telemedical records. Patient ages ranged from 0 to 98 years, with a mean age of 35 (IQR 27-45). Male and female patients were represented equally overall, with 48 and 52%, respectively. The age groups ranging from 0 to 18 (male 16.41%; female 13.27%), 40 to 50 (male 19.92%; female 18.03%), and 70 to 80 (male 2.05; female 1.67%) years included a higher proportion of males. Applied the geographical typologies according to the Federal Statistical Office[24] 68% of the patients resided in urban areas, 13% in transitional, and 19% in rural areas (Figure 1). To be able to analyze accurate data regarding distances we excluded cases with incomplete data. Thus, if the address of the doctor or pharmacy to which the patient would have been sent without telemedicine was missing, the case was not included in the concrete analysis. According to this procedure we arrived at a final sample of 35 197 telemedical consultations: 19 121 of them with telemedical completion of treatment. For this sample, we calculated patient movements with an accuracy to distance in kilometers and extrapolated them to the overall insurance model after weighting of clusters and geographies. We observed the period from 2020 to 2021. Given the COVID-19 pandemic, we assumed very high probability that all patient journeys within this timeframe started from the home address, which allowed us to calculate precise distances.

We determined actual prevented and provoked patient journeys based on predefined clusters of common telemedical workflows. We hypothesized that all patients who call the telemedical center would instead go to a doctor's office in a world without telemedicine and used that as a basis for comparison. We grouped the interactions between patients and telemedical center according to the outcome of the telemedical consultation into 3 main categories: telemedical completion of treatment with or without prescription (clusters 1 and 2), referral to a specialist (cluster 3), or triage to a primary health care provider (cluster 4). In the first 3 clusters, patients could avoid in-person medical visits. We verified this by ensuring in the PMS that no other health care providers were involved meaning that patients did not see another provider within the next 5 days. This approach confirmed telecare as patients' disposition. We also formed subclusters depending on whether or not the telephysician issued a prescription and whether the primary health care provider would have been able to SD. In Switzerland, each canton devises different regulations on whether or not primary health care physicians are allowed to dispense

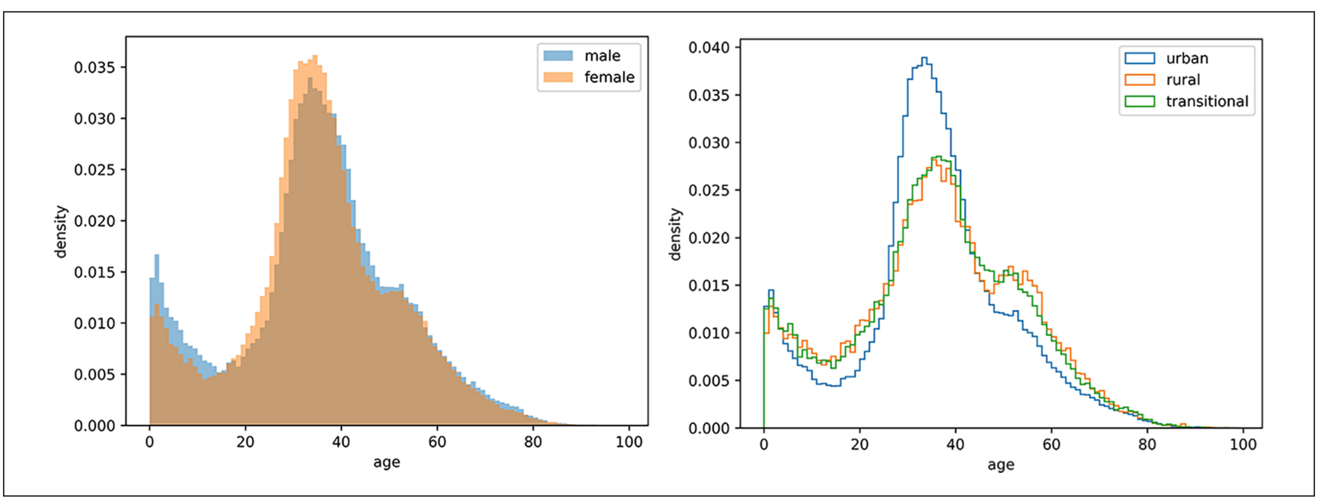

Figure 1. Age and geographical distribution of the investigated population of the 433 890 telemedical consultations (n = 433 890).

Cluster	Patient -> primary HC provider	primary HC provider -> patient	primary HC provider -> pharmacy	Patient -> pharmacy	Pharmacy -> patient	Definition
1	-	-				Telemedical completion of treatment without prescription
2a	-	-		+	+	Telemedical completion of treatment with prescription for cantons with self-dispensation
2b	-		-	+		Telemedical completion of treatment with prescription for cantons without self-dispensation
2ab	-	-	-	+	+	Telemedical completion of treatment with prescription for cantons with only partial self-dispensation (50% with self-dispensation)
3	-	-				Disposition to the specialist with a referral letter to specialists (documented in the PMS)
4						Triage cases and disposition to another primary HC provider (face-2-face consultation)

- Prevented patient journeys
+ Provoked patient journeys

HC: Health care

Figure 2. Clustering of telemedical cases.

drugs to the patients, thereby assuming the function of a pharmacy. Some cantons allow it; others do not; some have blended regulations.[25] We applied the concrete distances to the pharmacy recorded in the PMS in all telemedical treated cases with prescriptions. For the comparison, we assumed that patients who would not get their medications at the primary health care provider (no SD) would visit pharmacies on their way home.

Figure 2 shows caused (red) and saved (green) patient travels in the patient journeys per cluster. As the respective alternative health insurance model determines the primary health care physician, the distance traveled in the triage cases remains the same and is not calculated as savings.

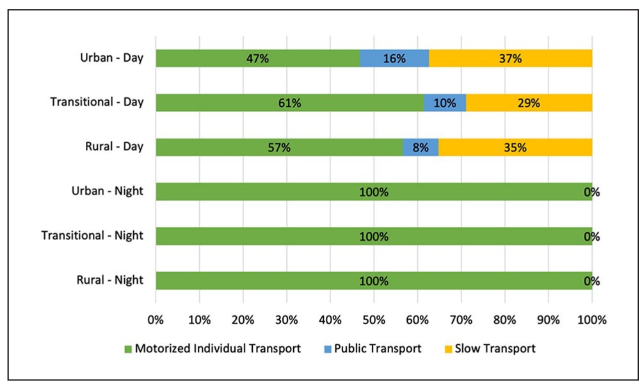

Figure 3. Modal split by area and time.[24,28]

Procedures

We extracted patient home, primary health care provider, and pharmacy addresses from the PMS entries. The determination of the coordinates to the addresses (geocoding) was carried out locally with Nominatim, a software that is often used as a reference in this field.[26,27] We then calculated the shortest distances between the geocoded locations for each patient journey based on patient travels in clusters 1 to 3.

The distances prevented (for example, the green arrows on Figure 3) are the distances that would have had to be travelled by patients in a world without telemedicine but were not required due to the possibility of using the service of the telemedicine center. These distances were given a negative sign. The provoked distances (red arrows on Figure 3) are the distances which were specially caused by telemedicine in some clusters, as for example in cluster 2a. These distances were given a positive sign. We summed the prevented and provoked distances. After calculating the individual distances, we observed cases with total travel distances of more than 100 km. According to checked examples we realized that these patients had moved and either the changes of residence or in case of change of employer, for example, the change of pharmacies used had most likely not been changed in our system to the investigated time. These circumstances gave incorrect distances. To include only the reliable data in the analysis with realistically driven distances we eliminated 1175 cases from the final sample analysis; this resulted in a set of 17 946 sample cases in clusters 1 to 3 at the end. We acknowledge that eliminating the longest distances will result in underestimating the saved kilometers and the CO_2eq footprint. This procedure, however, reflects our overall conservative calculation approach.

We obtained data on the means of transportation from a comprehensive review of the different modes of transportation used by the Swiss population, provided by a study commissioned by the Federation of Public Transportation.[28] Modes of transportation were divided in the study into 3 main categories: motorized individual transport (MIT), including mostly cars but also motorcycles; public transport (PT) like busses, trains, or trams; and slow transport (ST), referring to walking or biking. The category "Others" was below 2% and excluded from this study due to unclear description.

Instead of modeling the specific mode of transportation for every single case, we applied the latest modal split defined in the study to all cases. A modal split describes the average share of each transport mode used over a traveled distance.[28] The study differentiates modal splits depending on the level of urbanization. Accordingly, we used different modal splits depending on the area where the patients in our sample lived. Data available in our system covered 3 different areas: urban, transitional, and rural. In an earlier study, the Federation of Public Transport (VöV) determined modal splits for 7 area types,[24,28] which we aggregated to the 3 area types in our study:

- Urban: Agglomeration core municipality divided into core city, main core, and secondary core
- Transitional: Agglomeration belt community, multi-oriented community
- Rural: Core community outside agglomeration and rural community without urban character

We further distinguished between modal splits during the daytime (7 a.m. until 7 p.m.) and nighttime (7 p.m. until 7 a.m.). We assumed that doctor appointments at night are likely to be emergencies, meaning the patient would usually drive or be driven to the hospital with a motorized vehicle. Figure 3 shows the final modal splits per area. Each row displays a modal split for the combination of time and area. For example, in an urban area at daytime, 47% of traveled distances are traveled by MIT, 16% by PT, and 37% by ST.

We obtained emission factors from mobitool,[29,30] a Swiss platform for mobility management tools and environmental data processing. Generally, literature distinguishes between 3 types of emission factors depending on the chosen system boundaries[29,30]:

1. Tank-to-Wheel (T2W) emissions refer solely to the related combustion of (fossil) fuels for transportation or use of electricity or energy, meaning the end-of-pipe emissions.
2. Well-to-Wheel (W2W) emissions include, in addition to T2W emissions, all emissions related to fuel production, processing, distribution, and use phase (upstream emissions).
3. System-Level (SL) emissions also include emissions of the so-called infrastructure and related maintenance. This means emissions for construction of traffic routes such as roads and rail tracks including maintenance, construction of transport vehicles such as passenger cars, railway cars, trams, busses, bicycles.

Our study focuses on W2W emissions, which include a wider scope of the emission impact than T2W emissions as they also cover upstream emissions related to the extraction, processing, and transport of fuels. The W2W approach does not consider infrastructure emissions due to the high degree of uncertainty of such data and related assumptions, for example, regarding the allocation of such emissions. Using the SL approach would thus make it difficult to compare findings with existing studies and may lead to misinterpretations of results.

Mobitool collects emission factors for many diverse transport vehicles, including a Swiss average for MIT and PT.[29] It does not offer data on ST as a collective term; hence, for ST, we calculated an average value leaned on data from the Federal Office for Spatial Development,[31] assuming that 50% of distances are covered by walking, 35% by biking with a normal bike, and 15% by biking with an e-bike. We then multiplied each emission factor with the net distance, and again multiplied it with the respective modal share. We summed the results to calculate the change in emissions stemming from telemedicine appointments per case. We applied the following formula to every case, depending on the area and time of appointment:

$$Net\ distance * emi\ factor_{MIT} * modal\ share_{MIT} = Emission\ share_{MIT}$$

$$Net\ distance * emi\ factor_{PT} * modal\ share_{PT} = Emission\ share_{PT}$$

$$Net\ distance * emi\ factor_{ST} * modal\ share_{ST} = Emission\ share_{ST}$$

$$SUM = Total\ Emissions$$

Negative emission values, equaling emission savings, stem from negative net traveled distances.

In order to determine the net ratio of CO_2eq emissions avoided by the telemedical center, we subtracted the emissions associated with telemedical consultations from the total of avoided CO_2eq emissions. To calculate the emissions generated during telemedical consultations, we considered the following factors for the investigated telemedical cases: energy consumption of physicians' equipment used for the telemedical consultations; energy consumption of

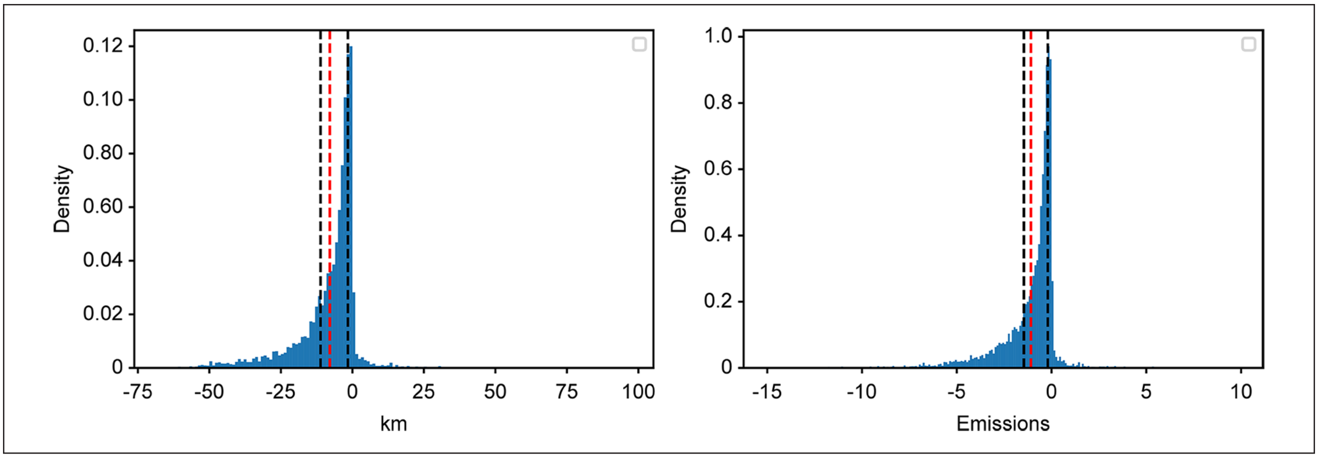

Figure 4. Saved km and CO_2eq per telemedical consultation calculated with clusters 1 to 3.

data management via data centers; and energy consumption of the headquarters' building infrastructure. We multiplied the number of medical cases in the managed care model by the average duration (8 min) of the telemedical consultation. This result divided by 60 gives the total number of working hours for the 2 years under review. We then multiplied the working hours by the hourly consumption of the equipment used in home offices to obtain the total consumption of physicians' workstations. Given that the majority of telemedicine physicians at Medgate work from their home offices (the majority in Switzerland and in second place in Germany), we used a proportion of the emission factors of the Swiss[32] and German[33] electricity mix to calculate CO_2eq emissions.

In order to calculate the energy consumption of the Medgate infrastructure we added the total energy consumption of data centers (6 kW/h) and building for the 2 years under review and included then only the share of energy consumption used for the telemedical consultations within the managed care model. Since 100% of the energy consumed by data centers and building originates in renewable energy sources, we can include this energy consumption in the overall CO_2eq emission calculation with 0 at the end.

Results

Within the observed years 2020 and 2021, the telemedicine center's medical team conducted a total of 433 890 telemedicine consultations with the population in our sample, with an average frequency of 594.37 telemedical consultations per day. Sixty-eight percent of the patients resided in urban areas, 13% in transitional, and 19% in rural areas across Switzerland. The patients in the sample ranged in age from 0 to 98 years, with a mean age of 35 (IQR 27-45). Male and female patients were represented equally with 52 and 48%, respectively. The age groups ranging from 0 to 18 (male 16.41%; female 13.27%), 40 to 50 (male 19.92%; female 18.03%), and 70 to 80 (male 2.05; female 1.67%) years included a higher proportion of males.

These telemedical consultations saved a total of 1 800 391 km of patient travel and avoided 248.48 tons of CO_2eq. We grouped the interactions between patients and telemedical center according to the outcome of the telemedical consultation into 3 main categories: telemedical completion of treatment with or without prescription (clusters 1 and 2), referral to a specialist (cluster 3), or triage to a primary health care provider (cluster 4). In the first 3 clusters, patients could avoid in-person medical visits. The average savings per telemedical consultation differ depending on the approach of calculation. If, as is generally the case in the literature, we only consider the cases of clusters 1 to 3 in the calculation, an average of 7.87 km (IQR 11.12-1.56) and 1.1 kg of CO_2eq (IQR 1.46-0.19) was saved per telemedical consultation (Figure 4). These are the values which are adequate for comparison with results from the literature. If we consider all performed telemedical consultations according to the comprehensive footprint approach—including the triage cases of cluster 4, which do not induce direct savings but are also part of the center's medical activities—we get the footprint of every single telemedical consultation of the center in its core activity, meaning an average of 4.15 km (IQR 4.76-0.00) and 0.57 kg of CO_2eq (IQR 0.6-0.00) was saved per telemedical consultation. These are the values which are relevant from the perspective of the comprehensive footprint approach.

The average savings per telemedical consultation also differ in the literature depending on whether the patient is in a rural, transitional, or urban area. We split the savings within the individual clusters into the urban, transitional, and rural regions to identify possible differences. In this way, we could see—per cluster and region in the

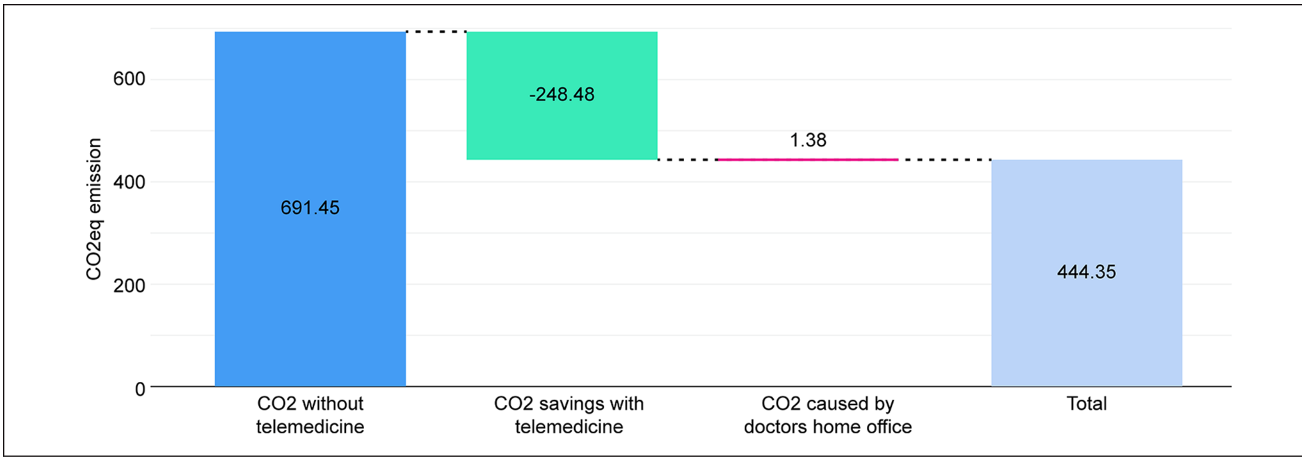

Figure 5. Net savings in CO_2eq of the telemedical center in 2020 to 2021.

investigated population—how many cases were involved and how much the average saved distances and CO_2 emissions per case amount to. Compared to the overall avoided travel distance of 6.7 km on average (looking solely at the urban area), an additional 2.7 km patient travel was saved on average in the transitional area, and another 5.5 km on average in the rural area. In cluster 1, for example, the urban area was represented by 5890 cases in the sample, and by 74 148 cases in the total investigated collective. Using the average savings of 7.82 km and 1.04 kg CO_2eq per case in this category, the total collective in the urban area of cluster 1 amounts to savings of 57 983 736 km and 77.11 tonsCO_2eq.

We find potential savings in driven kilometers and CO_2 emission for most clusters and areas. The more rural the area was, the higher the savings were. One exception is cluster 2a in transitional and rural areas. In these 2 regions, on average 1.18 and 3.4 km per case and, respectively, 0.20 and 0.59 kg of CO_2eq are caused. In this small subpopulation of cluster 2a, due to telemedical prescription of drugs in combination with SD primary health care physicians in the area, the pharmacy can be farther away from the patient than the doctor, which can result in additional kilometers and CO_2 emissions if this approach is pursued. However, this is negligible in the overall number of the cases handled by the investigated telemedical center.

To obtain the total net CO_2eq savings of the telemedical center, we considered the energy consumption of physicians' workplaces as well as of the data center and building. We calculated the energy consumption of the workplaces based on the specific number and average length of telemedical consultations over the 2 years, multiplied by the known consumption of the usual work equipment per hour. Using a proportion of emission factors of the Swiss (54.7 g CO_2eq/kWh)[32] and German (461.5 g CO_2eq/kWh)[33] electricity mix, we arrived at a value of 1.38 tons of CO_2eq emissions for the workplaces.

Data on the energy consumption of data centers and building used for the cases included in the calculation were provided by the Medgate IT department management and the contact persons of the finance department based on invoicing and billing information. The 3.2 tons of CO_2eq emissions from data centers and building were included in the net CO_2eq emission calculation with 0 since the energy consumed by the data centers and building fully originates in renewable energy sources. If the energy had not been supplied by renewable energy sources, we would have had to deduct an additional 3.2 tons of CO_2eq emissions from the total avoided 248.48 tons of CO_2eq in order to get the net CO_2eq savings. Even in this case, the total footprint of the center would have been negative, and a total net of 243.9 tons of CO_2eq would have been saved.

Overall, subtracting the sum of 1.38 tons of CO_2eq emission values caused by the investigated telemedical center in relation with telemedical consultations, a total net of 247.1 tons of CO_2eq was saved (Figure 5). A primary care consultation causes emissions of 4.8 kg of CO_2eq, of which 33.2%, or 1.594 kg of CO_2eq, are generated by patient transport.[14] If all 433 890 consultations had been performed on site in a primary care practice and not through telemedicine, emissions in the amount of 691.45 tons of CO_2eq would have been produced. Instead, the emissions amounted to only 444.35 tons of CO_2eq because the telemedical center handled the cases.

Irrespective of the medical recommendation at the end of the telemedical consultation, 1 telemedical consultation saved on average 4.15 km and 0.57 kg of CO_2eq when calculated with the comprehensive footprint approach. The contribution of electricity consumption was negligible in the overall calculation.

Telemedicine helped treat 228 831 (52.74%) cases. According to the consistent low number of malpractices in the investigated period (<0.001%), telemedical care is safe.

Discussion

This study shows that the 433 890 telemedical consultations carried out in 2020 and 2021 saved a total of 247.1 net tons in CO_2eq emissions, calculated based on realistic distance data and the latest official modal split reported for Switzerland. This equals 0.01% of the share of the entire Swiss health care system, which is responsible for 5.9% of the total national carbon footprint,[34] for 2.7 million tons of CO_2eq.[35] Calculated with the comprehensive footprint approach, the savings per telemedical consultation amounted to 4.15 km and 0.57 kg of CO_2eq (for all telemedical consultation of the center). Our results indicate that digital health care offers provided in a structured, high-volume approach, for example, in the form of telemedicine centers, reduce the requirement for in-person patient visits to doctors. As a result of reducing overall patient movements by transport, ultimately, they help decrease the health sector's environmental impact.

Extant literature does not provide a standardized method for calculating CO_2 footprint or CO_2eq savings of different services or entities in medicine.[36] Services can be telemedical consultations, in-person outpatient consultations in primary care practices or by specialists, and various hospital services. Entities are for example telemedicine centers, different practices, medical facilities such as rehabilitation centers or hospitals. This makes a direct comparison of results challenging. In previous studies, authors have roughly estimated many parameters, consequently arriving at a wide range of saved CO_2eq emissions achievable with telemedicine; the results also vary according to country and specific use cases of telemedicine.[6] Donald and Irukulla,[6] in their detailed systematic review, find saved distances ranging from 6.1 to 3386 km per encounter and corresponding emission savings ranging from 0.69 to 893 kg of CO_2eq. When we look at more comparable areas with our geography in the study, such as UK or Switzerland, the results are in narrower range: 6.1 to 11.9 km and 0.7 to 5.3 CO_2eq savings per consultation.[37-39]

Our findings—of 7.87 km and 1.1 kg of CO_2eq respectively 4.15 km and 0.57 kg of CO_2eq savings with the comprehensive footprint approach per telemedical consultation—indicate savings that range toward the lower end of the spectrum, which we can attribute to the following reasons. First, the data we analyze in this study, stem from a primary care telemedicine center in a densely populated European region. In such a region, patient journeys tend to be shorter than in countries such as the US, where patients partly revert to airplanes to reach special care; consequently, the savings potential is lower. Furthermore, we extracted the percentage of patients using MIT for getting to the doctor (47-61%) from data on the general population.[24,28] However, we can assume that, due to their current medical condition, about 75% of patients use the car when they go to the doctor's office.[14]

Second, we deliberately applied conservative approaches to each point of the calculation. We considered the shortest distance between 2 coordinates when calculating patient journeys. As we also eliminated cases with travel distances that appeared not entirely reasonable, our results may underestimate the saved kilometers and the CO_2eq footprint.

Third, in this study, we do not include an essential conceptual aspect of the telemedicine center and neglect that many doctors consulting patients work exclusively in their home offices: they do not have to travel to their workplace, thereby avoiding additional CO_2eq emissions. According to a recent study in Switzerland,[14] doctors' travels to their offices caused 12.5% of the CO_2eq emitted by an average primary health care practice—the third-largest contributing factor.

Our results are on a par with the results of Andrew et al,[37] for London and Southampton in the UK (11.9 km and 1.6 kg of CO_2eq savings per consultation) if we—in our study with our data—according to the method of Andrew et al,[37] only consider the telemedical cases of clusters 1 to 3, cases where telemedical completion of treatment was possible (7.87 km and 1.1 kg of CO_2eq savings per consultation). Miah et al[38] (6.1 km, 0.9 kg to 5.3 kg of CO_2eq) and Connor et al[39] (6.9 km, 0.7 kg to 2.9 kg of CO_2eq) show also results in a corresponding range. The findings of the study by Nicolet et al,[14] on Switzerland are comparable. They found that patient mobility is responsible for 33.2% of the 4.8 kg of CO_2eq emission caused by a single primary care consultation, for 1.6 kg of CO_2eq. Our result of 1.1 of CO_2eq is plausible, given that our study approach was deliberately conservative.

With this study, we address several shortcomings of previous research. Our calculations of patient travel draw on realistic distances (based on actual figures) and the W2W method, which takes into account fuel production and transport. To the best of our knowledge, ours is the first study to perform the calculation of the "footprint of telemedical consultations" in a telemedical center from a primary care telemedicine angle applying a comprehensive approach. This means that our calculation includes all telemedical consultations of the core activity of the telemedicine center, not only those that enable telemedical completion of treatment. Furthermore, we address new aspects that can influence the footprint, such as additional pharmacy visits or SD primary care physicians. While previous studies estimated likely higher potential savings in rural areas,[40] our calculations show that in some rural and transitional SD-areas, patients might even have to travel longer distances to reach a pharmacy than a physician, which generates additional distances—and CO_2eq emissions. We thus recommend that future research considers aspects of supply area and infrastructure.

It is important to approach the interpretation of our findings with caution and recognize their limitations. To calculate net CO_2 emissions, we used the latest Swiss modal split based on a mix of different modes of transport the population in Switzerland relies on. Against this background, our results are not easily translatable to other countries with diverging usage patterns regarding transport modes. How primary care is organized in detail and how medical cases are allocated to more general versus more specialized care also varies from country to country. Hence, selected aspects of our methodology such as the holistic view of the services and infrastructure can inspire the approach for future studies. Nevertheless, a one-to-on transfer to other geographic areas is not feasible as the specificities of national healthcare systems and resulting patient pathways need to be taken into account.

Another limitation is the selection of the population from which we gathered our data. Even though we used a particular sample in order to be able to calculate realistic distances, we assume that our findings can be translated to other models with comparable telemedical primary care systems. Extant literature mostly addresses the link between CO_2 savings and telemedicine in the context of specialty fields, such as urology, dermatology, transplantation, endocrinology, and so on. In addition to specialty fields, the telemedical services observed in these studies frequently engaged in postoperative follow-up consultations. We did not include medical specialty fields in our study because such consultations do not occur often in the day-to-day business of the observed center. A study including such special consultations might arrive at significantly higher potential savings, as in these cases, telemedicine could help avoid patient in-person travels to a more distant specialist or specialty clinic. We thus call for research to investigate specialty consultations in the context of telemedicine centers to assess the potential savings.

We also list the fact that we have focused on CO_2eq emissions as a limitation since CO_2 is often cited as the most important pollutant, although numerous pollutants play a role in air pollution.

In our study, we draw on very accurate, realistic data on distances. However, it was not possible for us to conduct a survey on the modes of transport patients typically use for journeys related to medical issues. Instead, we relied on the latest but general data available in the relevant national statistics.

Reducing the overall carbon footprint of primary health care could help lower global carbon emissions. In the case of Switzerland, an in-person consultation with a primary care physician generates on average 4.8 kg of CO_2eq; an average primary care practice emits 30.5 tons of CO_2eq per year, of which 33.2% result from patient transport.[14] With more than 12.5 million primary care provider consultations per year in Switzerland,[41] the savings from telemedicine bear substantial potential. If calculated conservatively, patient transport could be avoided in about half of the cases, resulting in annual additional savings of 6.875 tons of CO_2eq (1.1 kg of CO_2eq per telemedical consultation according to our study) to 10.000 tons of CO_2eq (1.6 kg of CO_2eq per telemedical consultation according to Nicolet et al.[14] Accordingly, the savings from telemedicine could counteract 0.25 to 0.4% of the share the Swiss health care system causes overall.[34,35] Even if this number initially may seem small, it is a strategic decision to use such mechanisms wherever there is a feasible solution, even if the individual elements alone would have a small effect.

Air pollution is an important public health issue, indoor or outdoor.[12,13,42] Already today a significant number of noncommunicable diseases are causally related to air pollution, and it is most probable that their number will continue to grow without effective countermeasures.[43] A marked shift toward telemedical services can help reduce the number of patients' in-person visits to doctors and contribute to realizing the potential decrease in pollutant emissions, a view the study by Whetten et al,[44] also underlines.

Conclusions

Telemedicine can contribute significantly to a more sustainable health care infrastructure. Our data from the primary care area in Switzerland show that specific patient groups, geographical conditions, and other aspects, such as prescription and self-dispensation, act as independent variables on CO_2 savings. In total, a physician-operated telemedical center with a high patient volume shows a negative CO_2 balance with saved CO_2eq emissions. More detailed future studies should consider further aspects that also affect the amount of savings such as staff mobility. We thus recommend that responsible health care providers, policymakers, and researchers working towards a more sustainable and environmentally-friendly health care system consider it a viable solution to establish structured telemedicine services that are able to handle high patient volumes and integrate this approach into their comprehensive strategy to reduce air-polluting emissions in Switzerland.

The study provides important insights into the potential benefits of telemedicine and highlights the need for continued investment in digital health technologies to promote sustainable health care practices and improve patient care. Digital consultation will also be an important tool in addressing environmental challenges.

We conducted this study with the aim to establish further evidence that the health sector in densely populated areas can help diminish CO_2 emissions by offering telemedical services in daily primary care—and thus contribute to protecting our climate.

List of Abbreviations

CO_2 (carbon dioxide), CO_2eq (carbon dioxide-equivalent), SD (self-dispensing), PMS (patient management system), MIT (motorized individual transport), PT (transport), ST (slow transport), T2W (tank-to-wheel), W2W (well-to-wheel), SL (system-level)

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Author Contributions

Conceptualization, K.SG., C.S. and E.B.; Data analysis, P.B.; Investigation and analysis of sustainability data, E.W. and N.J.; Methodology, K.SG., C.S., D.F. and P.B.; Project administration, C.L.; Visualization, P.B., K.SG. and E.W.; Writing—original draft, K.SG., E.W.; Writing—review & editing, C.S., D.F. and E.B. All authors have read and agreed to the published version of the manuscript.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: E.B. is a member of the Board of Directors of Medgate AG and its subunits. Furthermore, he is an occasional consultant for Medical Affairs International in topics relating Medgate Switzerland. E.B. is also in the Board of Directors of other companies, advisory boards, both commercial as well as in the framework of NGO's. For details see https://www.prof.uzh.ch/apps/interessenbindungen/client/B. K.SG., C.S., and D.F. are exclusively or partly employed at Medgate. Medgate is a company offering telemedical acute health care around the clock and its telemedical care is the basis of this article. Furthermore, D.F. has a commitment as a lecturer at the Reutlingen University, Faculty of Informatics. P.B. was employed at Medgate at the time of the analysis and realization of the study.

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Availability of Data and Materials

Data are available upon reasonable request to the corresponding author.

Supplemental Material

Supplemental material for this article is available online.

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