· Investigation ·

Environmental impact of patient travel for cataract surgery

Matthias Fritz Uhrmann[1], Holger Repp[2], Christian Gissel[3]

[1]Ambulatory Healthcare Center of Ophthalmology, Augen Lohr MVZ, Lohr 97816, Germany
[2]Faculty of Medicine, Justus Liebig University Giessen, Giessen 35392, Germany
[3]Department of Health Economics, Rhein Main University of Applied Sciences, Wiesbaden 65022, Germany
Correspondence to: Christian Gissel. Department of Health Economics, Rhein Main University of Applied Sciences, PO Box 3251, Wiesbaden 65022, Germany. cg@phec.de
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Abstract
● **AIM:** To analyze the environmental impact of patient travel for cataract surgery at a German ophthalmology center.
● **METHODS:** All cataract surgeries performed between October 23 and October 27, 2023, were analyzed, and all patient records were reviewed for follow-up visits. All travel distances were calculated, and the associated emissions were quantified. Additionally, patients' utilization of geographically closer branch practices for follow-up care was evaluated, along with the corresponding effects on travel-related emissions.
● **RESULTS:** A total of 69 patients underwent unilateral cataract surgery. The average one-way travel distance was 40.1 km (24.9 mi; SD = 23.6 km). Corresponding emissions were 1284.8 kg of greenhouse gas (GHG), 2.477 kg of nitrogen oxides, and 0.101 kg of particulates. All patients attended at least two follow-up visits. Conducting follow-up visits at branch practices reduced travel distance by 49.1%. The associated GHG emissions from all travel were 1984.3 kg. Emissions from follow-up visits were 54.4% higher than those from the surgery itself. Total GHG emissions amounted to 3269.1 kg, with an average of 47.4 kg of GHG per patient for all travel associated with cataract surgery.
● **CONCLUSION:** A dense network of branch practices contributes to reducing the carbon footprint of cataract surgery-related patient travel; however, the development of digital health approaches for follow-up care is necessary to further optimize the environmental sustainability of cataract surgery.

● **KEYWORDS:** cataract; decarbonization; digital health; health policy; sustainable healthcare
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INTRODUCTION

Cataract surgery is the most performed surgical procedure worldwide. Performed more than 26 million times a year and highly standardized, its systematic environmental optimization is essential to the decarbonization goals of international healthcare systems[1-2].

Healthcare systems are major parts of the economy in many high-income countries. Health expenditure was more than 10% for many countries in 2022. The largest share was spent in the United States (16.6%), and the second and third largest in Germany (12.7%) and France (11.9%) according to Organization for Economic Cooperation and Development data[3].

Along with their economic relevance, healthcare systems are major drivers of greenhouse gas (GHG) emissions. Healthcare systems contribute a major part to each country's national carbon footprint. The United States healthcare system was responsible for 7.9% of the nation's carbon footprint, while it was 6.7% in Germany and 6.9% in France[4].

Governments around the world have defined programs to reduce their GHG emissions, with many aiming to reduce their net GHG emissions to zero, *i.e.* reaching net zero. While there is a broad consensus for the goal of net zero, time lines and methods vary considerably. Both the United States and the French governments have committed to reaching net zero by 2050 while the German government aims to reach this goal by 2045. European Union policy suggestions include measures to reduce GHG emissions as well as an industrial carbon management with carbon capture technologies[5].

Following their governments, representatives of medical organizations have issued climate goals for their healthcare systems. Most notably, 61 US healthcare organizations have committed to reducing GHG emissions 50% by 2030. The 14

European healthcare providers have committed to net zero by 2050. The German Medical Association has committed to reaching net zero for the German healthcare system by 2030[6]. In 2023, German Ophthalmologic Society committed to a reduction in GHG emissions and published a comprehensive set of guidelines covering various aspects to make ophthalmology more sustainable[7]. Among prominent aspects are the reduction of waste during surgery, including unused pharmaceuticals, and an awareness for more sustainable anesthesia. These specific aspects have previously been quantified and analyzed. Findings include that European resource use for cataract surgery was 20-times higher than in India and unused pharmaceuticals in cataract surgery caused 5-30 metric tons of carbon dioxide annually per surgery center[8-9].

In addition to better waste management and more sustainable anesthesia, German Ophthalmologic Society guidelines identify mobility as a major general field of action requiring improved policies for more sustainable outcomes. In England, the National Health Service estimated patient, staff and visitor travel to be responsible for 10% of overall GHG emissions, with patient travel being most relevant (5% of emissions) [10]. While a study has previously compared cataract surgery to driving a passenger car 500 km (311 miles), the estimate omits patients' actual driving emissions for surgery and follow-up care[11].

In Germany, more than 800 000 cataract surgeries are performed annually, primarily as an outpatient procedure[12]. Only 100 000 surgeries are estimated to be performed in an inpatient setting. For outpatient surgery, patients visit a practice and usually return for three follow-up visits.

In this study, we aim to quantify the environmental effects of patient travel for outpatient cataract surgery and to analyze the effects of different densities of outpatient care on emissions. For our analysis, we choose cataract surgery as the most frequently conducted surgical procedure in ophthalmology and medicine overall. While its safety, outcomes and improvements of quality of life have been studied extensively, research on its environmental effects and their determinants is still in its early stages[13-16]. We hypothesize that the geographical density of ophthalmologic outpatient care facilities has a marked effect on patient travel emissions due to cataract surgery. We aim to add a detailed analysis of patient travel emissions to the discussion of cataract surgery decarbonization.

PARTICIPANTS AND METHODS

Ethical Approval The ethics board of Justus Liebig University Giessen, Germany, was consulted regarding the necessity of the study's approval. The ethics board granted a waiver since no other data than the anonymized date of surgery, address and follow-up visits were used for analysis.

We quantify GHG emissions due to patient travel for cataract surgery and follow-up care within three months of the surgery. We analyze all cataract surgeries conducted in the week from October 23 to October 27, 2023 in an outpatient ophthalmology clinic in Germany. The ophthalmology center consists of the main outpatient clinic with three operating theaters and a network of six ophthalmology practices which are suitable for follow-up care after cataract surgery. Distances between branch practices and the headquarters are 42.4 km (26.4 mi), 20.7 km (12.9 mi), 17.3 km (10.8 mi), 36.4 km (22.6 mi), 59.3 km (36.9 mi), and 72.3 km (44.9 mi).

For consistency and coherence of the analysis, we exclude patients who had cataract surgery on both eyes during the study period. No further exclusion criteria were defined.

In the first step of our analysis, we assess the distance driven by patients to undergo surgery at the headquarters. Travel distance is calculated for each patient based on their home address on file and the fastest route to the clinic headquarters per an online maps service. Rush hour traffic and potential rerouting was discarded.

We analyze all relevant emissions due to patient travel including GHG, nitrogen oxides, and particulates. We use 2022 data from the German Federal Environmental Agency[17]. The surgery and mydriasis at follow-up visits affect patients' fitness to drive, *i.e.* they need to be accompanied by a driver if they visit the practice by car. Since emission data by the German Federal Environmental Agency assumes an occupancy of 1.4 persons per car, we adjust emissions calculations to reflect an occupancy of 2 persons per car.

In the second step, we analyze emissions due to patient travel for follow-up care after cataract surgery. Due to the lack of telemedical infrastructure and technology, no follow-up could be conducted remotely, but all patients had to show up for in-person follow-up visits. Appointments could either be made in the headquarters or in one of the six branch practices. We assess all patient travel and quantify emissions.

To assess the environmental effects of a higher regional density of outpatient specialist care, we assess the effects of running the six branch practices on emissions by patient travel. We calculate hypothetical patient travel necessary to visit the clinic headquarters for all follow-up appointments and calculate the difference compared to actual patient travel to the available branch practices.

Economic assessment of emissions can be conducted based on the price per metric ton of carbon dioxide. However, carbon pricing varies considerably internationally. Emissions trading systems, auctions, and carbon taxes are common sources for carbon pricing. For our analysis, we use emissions prices based on different international carbon pricing mechanism in comparison to the European Union's mechanism.

Table 1 Patient travel for cataract surgery and follow-ups and associated emissions

Parameters	Distance (km)	Greenhouse gases (kg)	Nitrogen oxides (kg)	Particulates (kg)
Cataract surgery at headquarters	5528.3	1284.8	2.477	0.101
Cataract surgery at headquarters per patient	80.1	18.6	0.036	0.001
No branches, all follow-up at headquarters	16764.9	3896.2	5.365	0.218
Follow-up at headquarters or six branch practices	8538.3	1984.3	2.732	0.111
Sum of cataract surgery and follow-ups, no branches	22293.2	5180.9	7.134	0.290
Sum of cataract surgery and follow-ups, with six branch practices	14066.6	3269.1	4.501	0.183
Environmental savings thanks to the branch practices	8226.6	1911.9	2.633	0.107

Table 2 Cost of emissions associated with cataract surgery according to international carbon pricing mechanisms

Parameters	Country	2023 Price (USD) per tCO2e	Cataract surgery at headquarters	No branches, all follow-up at headquarters	Follow-up at headquarters or six branch practices	Cataract surgery and follow-ups total, no branches	Cataract surgery and follow-ups total, with six branch practices	Environmental savings thanks to the branches
Greenhouse Gas emissions			1284.8	3896.2	1984.3	5180.9	3269.1	1911.9
German Carbon Price	Germany	33.30	42.78	129.74	66.08	172.53	108.86	63.66
British Columbia Carbon Tax	Canada	59.20	76.06	230.65	117.47	306.71	193.53	113.18
Quebec Cap-and-Trade	Canada	38.59	49.58	150.35	76.57	199.93	126.15	73.78
Shenzhen Pilot Emissions Trading System	China	9.07	11.66	35.35	18.00	47.00	29.66	17.34
Tokyo Cap-and-Trade	Japan	38.64	49.64	150.55	76.67	200.19	126.32	73.87
Voluntary Carbon Market Auction	Saudi Arabia	6.35	8.15	24.72	12.59	32.87	20.74	12.13
South Africa Carbon Tax	South Africa	10.64	13.67	41.46	21.11	55.13	34.78	20.34
California Cap-and-Trade	USA	38.59	49.58	150.35	76.57	199.93	126.15	73.78

tCO2e: Metric tons of carbon dioxide equivalent.

RESULTS

We screened all patient files from the week of October 23 to October 27, 2023 for cataract surgery and found 70 patients (71 eyes) for analysis. One patient underwent surgery on both eyes and was excluded from the study, *i.e.* we included 69 patients (69 eyes).

All patients traveled to surgery at the clinic's headquarter by car. While the clinic is easily accessible by public transportation, patients regularly travel by car due to long distances to public transportation, inconvenient schedules, fares for two passengers and a feeling of insecurity due to surgery or mydriasis.

The average distance to the headquarters was 40.1 km (24.9 mi; SD=23.6 km) one way, *i.e.* an average of 80.1 km (49.8 mi) driven to undergo surgery in October 2023. Average GHG emitted were 18.6 kg per patient. In addition to GHG, 0.036 kg nitrogen oxides, and 0.001 kg particulates were emitted per patient for travel to undergo cataract surgery as shown in Table 1.

The sum of patient travel for 69 patients was 5528.3 km (3435.1 mi). Total emissions were 1284.8 kg GHG, 2.477 kg nitrogen oxides, and 0.101 kg particulates.

Table 2 presents different carbon pricing policies as found in the World Bank Carbon Pricing Dashboard. At the European Union's 2023 carbon price of 33.30 USD (30.00 EUR), total carbon cost of patient travel for 69 cataract surgeries is 42.80 USD or 0.62 USD per surgery.

All patient files were further screened to identify follow-up visits within three months of the surgery. Out of 69 patients, all patients attended two follow-ups. Totally 67 patients attended a third follow-up. Only 6 patients required a fourth follow-up within three months after surgery. If all patients had to travel to the headquarters, total patient travel for follow-up visits would amount to 16 764.9 km (10417.2 mi) with 3896.2 kg of GHG emitted.

We further screened all patient files to identify the branches they used for their follow-up visits. We quantified actual patient travel necessary to visit the branches or the headquarters. Only 44.9% of patients (31 out of 69) traveled to the headquarters. All others used a branch at least for the first follow-up visit. Analysis of all patient files resulted in a total of 8538.3 km (5305.5 mi) of actual patient travel for follow-up care, *i.e.* patient travel for follow-up visits is 54.4% higher than for surgery itself. Totally 1984.3 kg of GHG were emitted. Compared to an outpatient specialist care structure without branches, 1911.9 kg of GHG could be saved, *i.e.* GHG emissions were reduced by 49.1% thanks to the branch practices.

Total actual emissions associated with patient travel for cataract surgery and follow-up visits were 3269.1 kg of GHG or an average of 47.4 kg per patient.

If the opportunity of follow-ups at branch practices was not provided, carbon cost for all follow-ups would be 129.74 USD at the European Union's 2023 carbon price. Follow-ups at branches save carbon emissions priced at 63.66 USD, *i.e.* the actual carbon cost of follow-ups was 66.08 USD using branches. Total carbon cost of 69 surgeries and all follow-ups within three months at branch practices was 108.86 USD.

As shown in Table 2, the carbon cost varies considerably depending on the regional pricing mechanism. Total carbon costs would be 126.15 USD at California's and Quebec's Cap-and-Trade mechanism with a carbon price of 38.50 USD in

2023. While British Colombia's carbon tax is 78% higher than the European Union's price, other mechanisms resulted in far lower prices. Total carbon costs would be 29.66 USD at Shenzhen's Pilot Emissions Trading System.

Voluntary carbon markets have become increasingly important for the private sector[18]. The largest voluntary carbon credit auction that was conducted in Kenya in 2023 led to a price of 6.35 USD which would imply carbon costs of 20.74 USD for all patient travel associated with 69 cataract surgeries.

DISCUSSION

Maintaining comprehensive medical infrastructure in rural areas has long been identified as a challenge in German health policy. A higher density of outpatient specialist care and its regional variations have extensively been discussed in many contexts, often with a focus on questions of quality of care or socioeconomic and health economic determinants[19]. Equitable access to care, prevention of hospitalizations, differences between rural and urban areas, the relationship between healthcare supply and utilization as well as regional variations in quality of care have been extensively analyzed[20-21]. However, the effects on patient travel and corresponding GHG emissions have largely been overlooked[22]. Our findings indicate that a higher density of outpatient specialist care structures is essential to improving the carbon footprint of patient travel in the healthcare system.

Our study is limited by the assumption that all patients travelled to the ophthalmology center or a branch practice from their primary residence on file. If patients travelled from another location, travel distance could differ and GHG could be over- or underestimated. Rush hour traffic, traffic jams, rerouting and driving speed further effect GHG emissions by patient travel. Due to a lack of data, these factors were not considered in our analysis.

In addition to improved emissions data, more forms of travel should be incorporated in further research, including staff and visitor travel[23]. Another field of interest would be the net emissions effect of running branch practices rather than a larger central clinic.

Our analysis of patient travel emissions is an important step towards a comprehensive understanding of cataract surgery emissions[24]. In addition to analyses of patient travel, waste reduction and more sustainable anesthesia, research should be focused on the supply chain[25-26]. Previous analyses of the German medtech industry have shown that more than 60% of GHG emissions and 90% of particulates are caused indirectly by the supply chain[27]. All relevant components should be subject to life-cycle assessments. To gain a comprehensive understanding of life-cycle emissions from oils, assessment of carbon intensity of crude oil production is important for both travel emissions and supply chain emissions[28].

In addition to maintaining medical infrastructure in rural areas, our findings stress the need for digital care alternatives to conventional treatment[29]. Telemedical cataract surgery is not on the horizon yet. However, our study has shown that far more GHG are emitted by travel for follow-up care than by travel for surgery. While surgery cannot be substituted yet, resources should be allocated for developing digital health approaches for follow-up care. Follow-up care after surgery has successfully been digitized in other disciplines before[30].

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Conflicts of Interest: Uhrmann MF, None; **Repp H,** None; **Gissel C,** None.

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