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RESEARCH ARTICLE / ARAŞTIRMA MAKALESİ

The Effect of the Pandemic on the Carbon Footprint of Health Care Institutions: A Case Study

Senem TEKSOY BAŞARAN [1], Mehmed Kamil İLTER [2]

[1]*İstanbul Medeniyet Üniversitesi, Mühendislik ve Doğa Bilimleri Fakültesi, Biyomühendislik Bölümü, İstanbul, Türkiye*

[2]*İstanbul Medeniyet Üniversitesi, Lisansüstü Eğitim Enstitüsü, Çevre ve Enerji Sistemleri Mühendisliği Programı, İstanbul, Türkiye*

Abstract
Healthcare institutions contribute significantly to global greenhouse gas (GHG) emissions due to their energy consumption, material use, and waste generation. The COVID-19 pandemic altered hospital activities, affecting their carbon footprint through changes in patient visits, medical procedures, and resource consumption. This study examines the GHG emissions of two university hospitals in Istanbul, one with 85 beds and another with 95 beds, between the years of 2018 and 2022. Emissions were categorized as direct (Category 1), energy indirect (Category 2), and other indirect (Categories 3 and 4), following ISO 14064-1, IPCC, and GHG Protocol standards. Results indicate that the highest emissions per patient occurred in 2020 (10.6 and 8.2 kgCO2e/person) when the pandemic was at its peak. By 2022, with a nearly twofold increase in patient numbers, per capita emissions decreased by up to 36%. Indirect emissions surged in 2020 due to increased use of single-use medical materials and waste production. These findings highlight the pandemic's dual impact on hospital carbon footprints and emphasize the need for sustainable healthcare strategies.
Keywords: Climate change, Greenhouse gas emissions, Healthcare sector carbon footprint, Pandemic impact.

I. INTRODUCTION

The concept of carbon footprint has gained significant attention in recent years due to its crucial role in climate change mitigation and sustainability planning across all sectors. A carbon footprint refers to the total amount of greenhouse gases (GHGs) emitted directly and indirectly by an entity, activity, or product, expressed in terms of carbon dioxide equivalent (CO_2e). This comprehensive metric offers a holistic perspective on environmental impact, making it a valuable tool for assessing sustainability by identifying emission hotspots, evaluating resource efficiency, and guiding mitigation strategies across the entire value chain [1].

Among the sectors with substantial environmental footprints, healthcare institutions, stand out due to their round-the-clock operations, high energy demands, and intensive material consumption. Hospitals require continuous energy supply for heating, cooling, sterilization, ventilation, and operation of medical equipment. Additionally, they rely heavily on single-use medical devices, pharmaceuticals, cleaning agents, and laboratory chemicals, many of which have carbon-intensive supply chains that add to their indirect emissions [2, 3].

National-level assessments have highlighted the significant contribution of healthcare systems to overall greenhouse gas emissions, emphasizing the importance of integrating carbon management into healthcare sustainability strategies. For example, healthcare activities account for 4.6% of national carbon emissions in Japan, 8.5% in the United States, 4.6% in Canada, 7.0% in Australia, 3.5% in India, and 2.7% in China [4].

Corresponding Author: SENEM T. BAŞARAN, **Tel:** 0216 280 32 21-4044, **E-mail:** senem.basaran@medeniyet.edu.tr
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Despite growing awareness, systematic carbon footprint monitoring at the individual hospital level remains limited in many countries, including Türkiye.

While several studies have evaluated carbon footprints of individual hospital services or care pathways—such as surgical procedures, imaging departments, or waste management systems—comprehensive assessments at the organizational level remain limited. As highlighted in a recent systematic review by Kouwenberg et al. [5], most hospital-related carbon footprint research tends to focus on isolated clinical or operational activities rather than capturing emissions across the full institutional system.

In contrast, whole-hospital assessments that encompass multiple emission scopes and multi-year trends are relatively rare in the literature. A case study [6] conducted in an emergency hospital complex in Shanghai validated the model's applicability, revealing that dynamic factors influenced nearly half of the hospital's carbon footprint. The operation phase was the dominant contributor (73.1%), mainly driven by medical equipment (43.3%) and conventional energy systems (>50%). Notably, Lau et al. [7] conducted a hybrid assessment of the Erasmus University Medical Center in the Netherlands, revealing that over 70% of the hospital's emissions originated from scope 3 activities, particularly the procurement of pharmaceuticals and medical supplies. This underscores the significance of comprehensive, institution-wide evaluations.

II. MATERIAL AND METHOD

The study examined the carbon footprint of two hospitals, covering the years 2018 to 2022. Data were collected on energy consumption, patient visits, waste generation, and medical supply use. Emission calculations followed ISO 14064-1:2018 [10] and guidelines from the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (2006) [11] and Greenhouse Gas Protocol (GHG Protocol), developed by World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD) [12].

2.1. Case Study Hospitals

The study focused on two foundation-owned university hospitals within the Istanbul Metropolitan Municipality, one located on the Anatolian side and the other on the European side. Both hospitals provide a wide range of healthcare services, operating 24/7 with intensive care units, surgical facilities, laboratories, emergency departments, and advanced treatment units. Equipped with state-of-the-art operating rooms, they offer various surgical procedures, including microscopic, endoscopic, arthroscopic, laparoscopic, and microsurgical operations across multiple disciplines such as general surgery, gynecology, urology, orthopedics, ophthalmology, otolaryngology, neurosurgery, and plastic surgery. Hospital A has 85 beds with a total area of 6.500 m^2 and Hospital B has 95 beds with a total area of 9.500 m^2. Average number of personnel and patients between the years of 2018 and 2022 were 480 and 186 500 for Hospital A and, 585 and 214 000 for Hospital B, respectively. During the study period, neither hospital had a formal sustainability policy or active greenhouse gas mitigation strategy in place that could influence their operational emissions.

2.2. GHG Emission Categories

The greenhouse gas (GHG) emission inventories of two healthcare institutions from 2018 to 2022 were prepared in accordance with the ISO 14064-1 standard, which provides guidelines for calculating and reporting organizational-level emissions. The study employed a fundamental calculation approach, integrating methodologies from the IPCC Guidelines and GHG Protocol, which are globally recognized frameworks.

The emission inventory was developed through a systematic process: defining organizational and operational boundaries, collecting relevant activity data, and applying emission factors (EFs) sourced from literature, databases, and official reports.

GHG emissions were categorized as follows:

- Category 1 (Direct Emissions): Emissions from heating (natural gas boilers), on-site electricity generation (generators), transportation (cars, ambulances), and fugitive emissions from cooling systems and fire suppression.
- Category 2 (Indirect Emissions from Purchased Energy): Emissions from electricity consumption.
- Category 3 (Other Indirect Emissions): Transportation-related emissions from patient visits, staff commuting, business travel, and supply chain logistics.
- Category 4 (Indirect Emissions from Purchased Goods and Services): Emissions from pharmaceuticals, medical supplies, waste disposal, wastewater treatment, and food services.

Categories 5 and 6, related to product emissions and other sources, were deemed not applicable in this study. Well to Tank or Well to Wheel emissions were not included in GHG calculations.

2.3 Activity Data and Emission Factors

The activity data, their units and sources that were used to calculate the GHG emissions in each of the emission categories are summarized in Table 1. These data have been recruited from relevant administrative units such as technical services, purchasing, human resources, accounting and support services.

Table 1. GHG Emission Inventory Activity Data

Category/ Source/Activity Data	Unit	Data Source
Category 1: Direct GHG Emissions and Removals		
Category 1 - Stationary Combustion		
Natural Gas Boiler, Natural Gas Consumption	Sm^3	Natural gas invoice data
Generator, Fuel Oil Consumption	L	Recorded purchases via software
Category 1 - Mobile Combustion		
Automobile, Bus, Ambulance, Fuel Consumption (Gasoline, Diesel)	L	Vehicle tracking system data
Category 1 - Fugitive Emissions		
Cooling Equipment, Refilled Refrigerant Amount	kg	Service provider reports
Fire Extinguishers, Fire Suppression Gas Consumption	kg	Reports from authorized service providers
Category 2: Indirect Emissions from Purchased Energy		
Electricity Consumption, Purchased Electricity	kWh	Electricity invoices
Category 3: Indirect GHG Emissions from Transportation		
Employee Commute, Distance	km	Employee surveys
Patient Transportation, Distance	km	Google API
Transportation of Purchased Goods, Distance	km	Delivery records and Google API
Category 4: Indirect GHG Emissions from Purchased Goods/Services		
Purchased Medications, Quantity	Units	Hospital medication distribution software
Purchased Non-Medical Supplies, Quantity	Units	Procurement records via software
Purchased Food & Beverage Services, Menu and Service Count	Units	Carbon footprint records from outsourced service providers
Waste Disposal, Waste Amount	tons	Environmental Information System (EÇBS) application, municipal records
Wastewater Treatment, Wastewater Volume	L	Water invoices

Emission factors were carefully selected to minimize uncertainty and errors for each emission source. A comprehensive literature review was conducted, prioritizing national studies and reports where available. In cases where country-specific emission factors were not accessible, relevant international sources and scientific studies were referred to determine appropriate values.

For emissions directly related to fossil fuel consumption, such as those categorized under Category 1 emissions, national data sources i.e. the emission factors reported in Türkiye's National Inventory Reports (NIR) [13] for relevant years, which is submitted annually to the UNFCCC Secretariat, were used.

The calculation of emissions from purchased electricity utilized emission factors provided in the Turkey National Electricity Grid Emission Factor Information Form, published annually by the Ministry of Energy and Natural Resources (MoENR) [14]. Emission factors for refrigerants and fire suppression equipment were sourced from IPCC Assessment Reports, specifically from the Global Warming Potential (GWP) tables [15].

For water consumption (bottled water dispensers were excluded) and wastewater treatment related emissions the emission factors for network water usage and wastewater treatment published by Department for Environment, Food and Rural Affairs of United Kingdom (DEFRA) between 2018 and 2023 were used [16].

Transportation-related emissions were categorized into patient travel, staff commuting, purchased goods transportation, and business travel. Where detailed data on vehicle type and fuel were available, appropriate emission factors were applied. For instance, emissions from the transportation of purchased goods were based on DEFRA emission factors for diesel commercial vehicles [16].

However, due to the lack of specific data on the type of vehicles and fuel used by patients and staff, average vehicle emission factors determined by the International Energy Agency (IEA) were applied [17]. Similarly, for public transportation, IEA-derived emission factors were used due to the absence of precise data on vehicle type, fuel, and transfer frequency. Maximum GHG emission for business travel per year was calculated as 2,6 tCO_2e based on travelled air miles multiplied by the average EF of DEFRA short haul-Europe economy class 0,140625 tCO_2e per passenger mile Hence, emissions related to business travel were omitted since they were estimated approximately to have a 0,025% share of the overall emissions.

To estimate emissions from purchased goods, the types of materials used were identified, and appropriate emission factors were sourced from DEFRA and the Villota-Paz et al. (2023) [18] study for cleaning chemicals. Emission calculations for pharmaceuticals were based on price-based emission factors from Tennison et al. (2021) [19]. Finally, emissions from waste were determined according to waste type and disposal method, utilizing emission factors from literature [20, 21], American Petroleum Institute (API) [22], and DEFRA database [15].

Emission factors used in this study are summarized in Table 2.

Table 2. Emission Factor used in the study [13-21]

Category/ Source	EF	Data Source
Category 1: Direct GHG Emissions and Removals		
Category 1 - Stationary Combustion (tCO_2e/TJ)		
Natural Gas	53.87-55.77	NIR (2021-2023)
Fuel Oil	72.53	
Category 1 - Mobile Combustion (tCO_2e/TJ)		
Diesel	75.27	
Category 2: Indirect Emissions from Purchased Energy (tCO_2e/MWh)		
Electricity	619.8-648.8	MoENR
Category 3: Indirect GHG Emissions from Transportation		
Transportation of Employees and Patients ($kgCO_2e/km$)		
Public	0.054	IEA
Passenger vehicle	0.158-0.167	DEFRA
Transportation of Purchased Goods ($kgCO_2e/km$)		
HGV*-diesel	0.854	DEFRA
Category 4: Indirect GHG Emissions from Purchased Goods/Services		
Pharmaceutical	0.57 $kgCO_2e/GBP$	Tennison et al., 2021
Non-Medical Supplies ($kgCO_2e/ton$)		
Wood	312.61	DEFRA, Material Use, 2018
Glass	1 402.77	
Food	3 701.40	
Paper	919.40	
Metal	5 268.56	
Plastic	3 116.29	
Textile	22 310.00	
Chemical	357.00	Villota-Paz et al. (2022)
Waste Disposal ($kgCO_2e/ton$)		
Lubricant oil	2 930	API, 2023
Contaminated packaging	338	Yaman, 2020
Chemical liquids	1 074	Rizan et al., 2021
Cytotoxic drugs	249	
Batteries	65	
Pathologic drugs	1 074	
Infected waste	569	
Paper/ Cardboard	21.32	DEFRA
Domestic	0.48	DEFRA
Water use	0.251 $kgCO_2e/m^3$	DEFRA (2018-2020)
Wastewater treatment	0.478 $kg\ CO_2e/m^3$	DEFRA (2018-2020)

*Heavy Goods Vehicle

2.3. GHG Emission Calculations

The calculation approach for greenhouse gas (GHG) emissions in the two hospitals was based on multiplying relevant activity data with appropriate emission factors obtained from literature and national reports. The calculation formula for direct emissions from natural gas fired boilers is given in Equation (1):

$$\textit{GHG Emission} = \textit{Fuel consumption } (Sm^3) \times NCV\ (TJ/Sm^3) \times CF \times OF \times EF_{SG}\ (tGHG/TJ) \quad \textbf{(1)}$$

where; NCV: Net Calorific Value, CF: Conversion Factor, OF: Oxidation Factor (assumed as 1), EF: Emission Factor.

2.3. Uncertainty analysis

An uncertainty analysis was conducted for the greenhouse gas (GHG) emission inventories prepared in this study, specifically for direct and energy-related carbon dioxide emissions. The analysis followed the methodology outlined in the GHG Protocol guidelines [12]. According to this approach, total inventory uncertainty was calculated as the cumulative uncertainty sum of activity data and emission factors, using Equation (2):

$$\pm u = \pm \frac{\sqrt{\sum_{i=1}^{n} (H_i * I_i)^2}}{M} \quad \textbf{(2)}$$

where u represents total uncertainty (%), H is the CO_2 emissions from source i, I is the uncertainty of source i, and M is the total CO_2 emissions.

Uncertainty values were determined separately for each data source. If emissions were calculated based on measured data from instruments such as meters, the Maximum Allowable Error (MAE) values defined in the Measuring Instruments Regulation [23] were considered. For other activity data and EFs, uncertainties were selected based on national reports and expert evaluations.

III. RESULTS AND DISCUSSION

GHG emission calculations in ton of carbon dioxide equivalents (tCO_2e) were performed for each emission source under each relevant emission category as per the collected activity data and suitable emission factors. The results were summarized for Hospital A and Hospital B in Table 3 and Table 4, respectively.

Table 3. GHG Emissions of Hospital A between 2018 and 2022

GHG Emission Category	2018	2019	2020	2021	2022
	GHG Emissions (tCO_2e)				
Category 1					
Stationary comb.	274	268	221	262	296
Mobile comb.	23	23	33	30	26
Fugitive emissions	18	31	23	13	48
Category 2					
Pur. electricity	1 348	1 444	1 132	1 296	1 357
Category 3					
Patients commute	1 189	1 243	882	1 344	1 595
Personnel commute	125	117	129	134	148
Trans. of pur. goods	254	266	247	256	250
Category 4					
Pur. Cons.	670	594	760	574	627
Pur. Pharm.	192	211	195	223	251
Waste disposal	20	35	40	37	38
Water and Wastewater	35	32	40	39	38
Total	**4 147**	**4 263**	**3 699**	**4 208**	**4 673**

Table 4. GHG Emissions of Hospital B between 2018 and 2022

GHG Emission Category	2018	2019	2020	2021	2022
	GHG Emissions (tCO_2e)				
Category 1					
Stationary comb.	316	303	237	278	329
Mobile comb.	30	30	43	38	34
Fugitive emissions	47	36	27	15	27
Category 2					
Pur. electricity	1 193	1 182	918	1 060	1 169
Category 3					
Patients commute	944	889	689	1.096	1.373
Personnel commute	135	136	125	120	131
Trans. of pur. goods	90	88	129	112	152
Category 4					
Pur. Cons.	926	806	1.009	738	776
Pur. Pharm.	307	360	309	319	497
Waste disposal	22	40	46	42	43
Water and Wastewater	42	40	50	45	45
Total	**4 052**	**3 911**	**3 580**	**3 862**	**4 574**

Total annual GHG emissions varied between 3 699 tCO_2e and 4 673 tCO_2e for Hospital A; and between 3.580 tCO_2e and 4.574 tCO_2e for Hospital B. The % distribution of emissions among the four categories indicated that category 1, 2, 3 and 4 emissions varied between 7-10 %, 26-34 %, 26-43 % and 20-39 % of total GHG emissions, respectively. The breakdown of GHG among category 1 emissions showed that CO_2 emissions accounted for 87-96% of total GHG emissions in that category. The uncertainty analysis was done for 2018 category 1 and 2 CO_2 emission calculations of Hospital A which was assumed to represent all other inventory years as the activity data, EF and relevant assumptions did not change for these; and the uncertainty was calculated as ±5.84 %.

GHG emission trends (Figure 1) observed in the two hospitals between 2018 and 2022 reveal significant variations due to the COVID-19 pandemic and subsequent recovery phases.

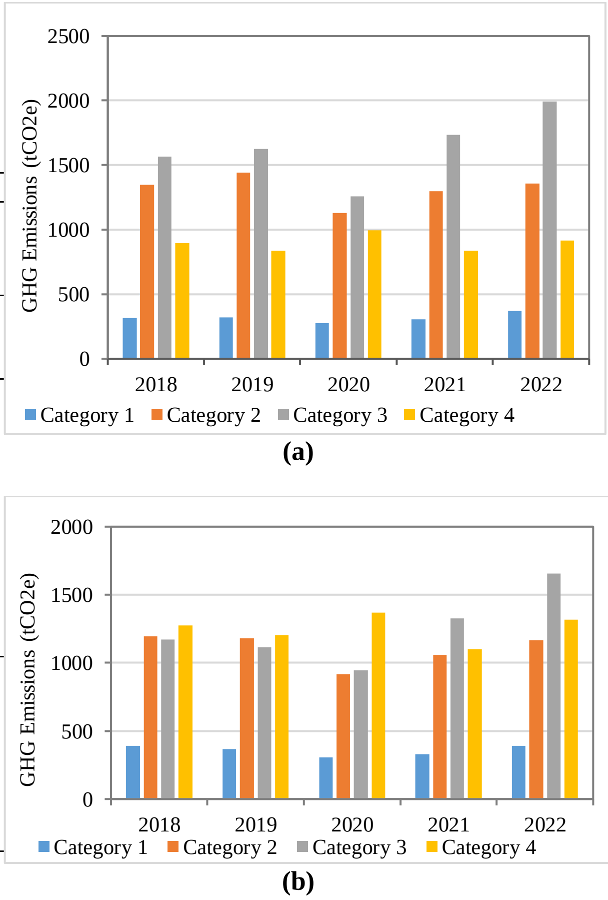

Figure 1. Variation of GHG Emissions as per emission categories between 2018-2022 for (a) Hospital A and (b) Hospital B

Key findings from the data indicate certain general trends such that; 2020 showed a distinct decline in stationary combustion emissions (Category 1) and electricity consumption (Category 2) in both hospitals, correlating with reduced hospital activities during the peak of the pandemic. Conversely, mobile combustion and fugitive emissions fluctuated, with peaks in 2020 likely due to emergency preparedness measures and increased ventilation/heating needs. It was also observed that Post-pandemic recovery (2021-2022) led to a surge in overall emissions, with stationary combustion and electricity consumption surpassing pre-pandemic levels.

Findings also allowed for certain category-specific observations which were summarized as below;

Category 1 Direct Emissions (Stationary and Mobile Combustion, Fugitive Emissions)

- Stationary combustion (fuel usage in hospital operations) dropped significantly in 2020 but rebounded in 2022.
- Mobile combustion (fuel consumption in ambulances and hospital vehicles) peaked in 2020 due to increased emergency services.
- Fugitive emissions (leakage from refrigerants and fire suppression systems) varied, with a substantial rise in 2022, indicating increased Heat, Ventilation, Air Conditioning (HVAC) system reliance and maintenance cycles.

Category 2: Purchased Electricity

- A sharp drop in electricity consumption in 2020 (as low as 917.58 MWh in Hospital B) was likely due to reduced patient intake and fewer operational services.
- By 2022, electricity consumption nearly returned to pre-pandemic levels, reflecting increased hospital activity.

Category 3: Indirect Emissions from Patient & Personnel Transport and Logistics

- Patient commute emissions declined drastically in 2020 due to movement restrictions and lower patient visits.
- Personnel commute emissions remained relatively stable, with a minor dip in 2020 but increasing again in 2022.
- Transportation of purchased goods emissions remained relatively stable, suggesting continued demand for essential medical supplies despite fluctuating hospital activities.

Category 4: Emissions from Purchased Goods, Pharmaceuticals, Waste, and Water

- Purchased consumables and pharmaceuticals emissions peaked in 2020, reflecting increased demand for medical supplies, including PPE, disinfectants, and medications.
- Waste disposal emissions surged in 2020, highlighting the environmental impact of single-use medical waste generated during the pandemic.
- Water and wastewater emissions remained relatively stable, with minor fluctuations, indicating consistent water demand for sanitation purposes.

Our findings agree with the results of the study by Morooka et al. (2022) [9] who investigated the impact of the COVID-19 pandemic on the carbon footprint of the Nagoya University Hospital and Medical Research Centre over a decade, specifically from April 2010 to March 2021. Their findings also revealed that the pandemic significantly altered the hospital's operational dynamics, leading to changes in carbon emissions such that during the COVID-19 epidemic, the carbon footprint decreased slightly, likely which was attributed to the reduced number of patients. However, they observed that carbon footprint per admission increased, which was attributed to more complicated patient backgrounds because of the ageing population. They also noted a marked rise in emissions from medical waste, which surged due to the increased use of disposable personal protective equipment (PPE) and other medical supplies.

GHG emission intensities of the hospitals were also determined as per capita and per square meter of inner area as shown in Table 5. Average annual total GHG emissions per patient between 2018 and 2020 is calculated as 21.2 $kgCO_2e$.

Table 5. GHG Emission intensities for Hospital A and B between 2018 and 2022

Years	**2018**	**2019**	**2020**	**2021**	**2022**
Number of patients					
Hosp. A	172 734	183 162	132 982	202 527	240 992
Hosp. B	197 361	188 472	149 832	237 492	297 482
Total GHG Emissions (tCO_2e)					
Hosp. A	4 147	4 263	3 699	4 208	4 673
Hosp. B	4 052	3 911	3 580	3 862	4 574
GHG Emissions per patients ($kgCO_2e$/patient/a.)					
Hosp. A	24.0	23.3	27.8	20.8	19.4
Hosp. B	20.5	20.8	23.9	16.3	15.4
Carbon intensity ($kgCO_2e/m^2$/a.)					
Hosp. A	638.0	655.9	569.1	647.3	718.9
Hosp. B	415.6	401.1	367.2	396.1	469.1

There are a limited number of studies that report GHG emissions from healthcare institutions and the results have to be carefully compared due to the differences in calculation approaches each may have that could affect the results such as the emission categories included, carbon intensity of electricity used, scale of activity etc. The studies found reported per capita and per meter squared category 1 and 2 GHG emissions as 8.02 $kgCO_2e$/cap/a. and 55.4 $kgCO_2e/m^2$/a. [24]; 7.71 $kgCO_2e$/cap/a. and 99 $kgCO_2e/m^2$/a. [25], 4,8 $kgCO_2e$/cap/a. [3] and 96 $kgCO_2e/m^2$/a. [26], from the US, China, Switzerland and Spain, respectively. In this study, average GHG emission intensities considering category 1 and 2 emissions were found as 8.99 and 7.1 $kgCO_2e$/cap/a. and 251.1 and 149.9 $kgCO_2e/m^2$/a. These figures reported for Categories 1 and 2 were calculated separately for comparative purposes using data from Tables 3 and 4; these are not shown in Table 5, which reflects total emissions from all categories. These intensity figures indicate that the carbon intensities in studied Turkish hospitals are similar to global examples in terms of per capita emissions however they are almost two folds higher than the reported average values per m^2. Calculation of emission intensity from the data of Morooka et al. (2022) [9] yielded an average of 359 $kgCO_2e/m^2/a$ from total GHG emissions including category 3 and 4, whereas in our study average for Hospital A and Hospital B were calculated as 646 and 409 $kgCO_2e/m^2/a$ respectively.

In 2020, Hospital A experienced an increase in per patient GHG emissions by approximately 9%, coinciding with the onset of the COVID-19 pandemic, while its area-based carbon intensity decreased due to reduced overall hospital occupancy. By 2021, patient numbers in both hospitals had surpassed pre-pandemic levels, while Category 2 emissions (purchased electricity) did not fully recover to pre-pandemic levels. This discrepancy led to a significant reduction in per capita carbon intensity from 2021 onwards.

Regarding area-based carbon intensity, both hospitals experienced a notable decline in 2020 compared to 2021, with reductions of approximately 21% and 23%, respectively. Hospital B, which has a larger usable area and higher patient density, exhibited a significantly lower area-based carbon load compared to Hospital A. Analysis of activity data and emission calculations suggests that Hospital B operated within a larger space while consuming less electricity, contributing to its lower area-based carbon footprint.

Several factors may account for the substantial differences in carbon intensity between the two hospitals:

- The distribution of outpatient clinics and inpatient beds: Outpatient clinics primarily operate during the day, whereas inpatient rooms require continuous energy supply.
- The functional allocation of hospital beds: Facilities such as neonatal and general intensive care units, physical therapy, and rehabilitation departments may have varying energy demands due to their operational characteristics.
- The use of energy-efficient lighting systems: Hospital B is a new hospital that may have adopted newer, more efficient lighting technologies.
- Architectural planning and natural lighting efficiency: Optimized architectural design may have enabled more effective placement of lighting systems in Hospital B.
- Staff awareness of environmental sustainability: Greater employee engagement in sustainability initiatives and energy conservation practices could have contributed to lower emissions in Hospital B.

These factors collectively highlight the importance of hospital design, operational structure, and sustainability strategies in mitigating carbon emissions and improving energy efficiency in healthcare institutions.

IV. CONCLUSION

During the COVID-19 pandemic, hospitals experienced major operational changes, including increased demand for critical care, changes in medical waste management, and reductions in non-essential medical procedures. Understanding these shifts is essential for developing strategies to reduce emissions while maintaining healthcare quality.

This study highlights the dual impact of the COVID-19 pandemic on hospital carbon footprints. While overall emissions per patient peaked during the pandemic due to operational inefficiencies, the gradual normalization of healthcare services led to emission reductions per patient in 2022. However, the increased reliance on single-use materials underscores the need for improved sustainability policies in healthcare institutions.

To mitigate future environmental impacts, hospitals should invest in energy-efficient technologies, implement circular economy principles for waste reduction, and develop comprehensive emission monitoring frameworks. Future research should explore the long-term effects of healthcare operational changes on carbon footprints and evaluate alternative sustainability strategies.

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