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Quantification CO_2e emissions in Tehran's hospitals using the Aga Khan development network's approach

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ABSTRACT

Introduction: Carbon dioxide (CO_2), the most abundant greenhouse gas, has reached an atmospheric concentration of 411 ppm, its highest level in the past 650,000 years. To effectively reduce the carbon footprint, accurately measuring these emissions is a crucial first step. This study focuses on quantifying the Carbon dioxide Equivalent (CO_2e) emissions from six selected hospitals in Tehran, providing essential data to inform targeted sustainability efforts in the healthcare sector.

Materials and methods: This cross-sectional study quantified greenhouse gas emissions from six major hospitals in Tehran using the Aga Khan Development Network (AKDN) Carbon Management Tool, supplemented by emission factors from the UK Department for Environment, Food and Rural Affairs (DEFRA). Data were collected from hospital records and relevant departments using standardized checklists designed according to AKDN guidelines. The sources of emissions assessed included energy consumption, anesthetic gases, inhalation devices, waste management, transportation and supply chain activities. All collected data were converted to Carbon dioxide Equivalent (CO_2e) using established emission factors.

Results: The total CO_2e emissions from the six hospitals amounted to 28,260.74 tons. Energy consumption was the largest contributor, accounting for 57% (16,182.5 tons) of emissions, followed by anesthetic gases at 40% (11,313.67 tons). Waste management (626.36 tons), transportation (89 tons), inhalation devices (26.75 tons), and supply chain activities (22.58 tons) contributed smaller shares.

Conclusion: The study highlights the urgent need for targeted strategies to reduce greenhouse gas emissions in healthcare settings. Recommendations include shifting torenewable energy sources, substituting high global warming potential anesthetic gases with lower-impact alternatives, optimizing supply chain logistics, and improving waste management practices. Implementing these measures can significantly reduce the carbon footprint of hospitals while maintaining quality care. This study provides a foundation for future emission reduction efforts in Iran's healthcare sector, aligning with global climate goals.

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Introduction

Climate change has emerged as one of the most significant global challenges of the 21st century, posing serious threats to human health and well-being. Carbon dioxide (CO_2), the most abundant greenhouse gas, has reached atmospheric concentrations of 411 ppm, representing its highest level in 650,000 years [1, 2]. Anthropogenic activities, particularly the burning of fossil fuels, are indeed the primary drivers of climate change. These activities have lead to severe consequences such as rising sea levels, extreme weather events, and disruptions to ecosystems. If left unchecked, global CO_2 emissions from energy consumption are projected to increase by 10% by 2040 [3]. The carbon footprint is typically expressed in terms of CO_2 equivalent (CO_2e), which accounts for the warming potential of various Greenhouse Gas (GHGs) relative to CO2 [4, 5].

Among the largest contributors to carbon footprints are sectors such as energy, transportation, and healthcare, which play pivotal roles in both social development and environmental degradation [6, 7]. The healthcare sector is responsible for approximately 3–10% of global CO_2e emissions, making it a significant contributor to climate change [8]. Because of their round-the-clock activities, reliance on cutting-edge technologies, and stringent environmental controls, hospitals in particular are among the non-industrial buildings with the highest energy use [9]. For example, hospitals' electricity consumption contributes significantly to their carbon footprint, with average emissions reaching 750 g CO_2e/kWh [8]. The use of anesthetic gases in medical facilities is another significant source of greenhouse gas emissions. The Global Warming Potentials (GWPs) of gases like nitrous oxide, isoflurane, and desflurane are significantly larger than those of CO2. The significance of desflurane as a target for emission reduction programs is highlighted by its noteworthy GWP of 2540 [10, 11]. Effective medical waste management is crucial for reducing environmental damage, as the healthcare sector generates significant amounts of waste annually [12]. The sector's dependence on water resources and transportation contributes to its carbon footprint [13]. Finally, transportation, both for patient care and supply chain logistics, also plays a significant role, particularly in urban healthcare systems [14, 15].

The Paris Agreement aims to limit global temperature rise to below 2°C, requiring rapid reductions in greenhouse gas emissions, including those from the healthcare sector, requiring sustainable practices, energy optimization, and low-carbon technologies. This commitment applies to all sectors, including healthcare, which in order to effectively contribute to the global climate goals must embrace sustainable practices, optimize energy use, and implement low-carbon technologies [12, 16-18].

The Aga Khan Development Network (AKDN) Tool is a comprehensive solution for analyzing emissions across direct (Scope 1), indirect (Scope 2), and supply chain (Scope 3) domains, providing insights into emission hotspots and enabling targeted interventions in healthcare settings [12, 19]. This study marks the first effort in Iran to estimate the carbon footprint of selected hospitals in Tehran. As of 2017, Iran ranked seventh worldwide among the top global emitters of CO2 [2, 20]. Also, Iran dropped one place this year to the 67th place in the Climate Change Performance Index (CCPI) rankings [20]. Despite its commitments under the Paris Agreement, Iran faces considerable challenges in reducing emissions, particularly in sectors such as healthcare, where sustainability practices are still underdeveloped. This study has three main objective: first, to quantify emissions from key source types, including energy consumption, anesthetic gases, medical waste, and transportation, inhalers; second, quantify emissions of supply chain, and third, to propose actionable strategies for reducing emissions without compromising the quality of healthcare services. By identifying major emission hotspots and proposing targeted interventions, this study aims to bridge the gap between environmental sustainability and quality healthcare delivery.

Materials and methods

This study employed a quantitative cross-sectional design to assess the carbon footprint of six selected hospitals in Tehran (Fig. 1). Data collection and greenhouse gas emissions analysis were conducted using the AKDN Carbon Management Tool, which captures emissions from various sources, including energy consumption, anesthetic gases, water use, medical waste, inhalation devices, transportation, and the supply chain. Emissions were categorized and analyzed according to three scopes:

Scope 1 (Direct emissions): Emissions from on-site sources, including fuel combustion, anesthetic gases, and vehicle fleets.

Scope 2 (Indirect emissions): Emissions related to purchased electricity, heating, and cooling.

Scope 3 (Supply chain emissions): Emissions from activities such as waste management, water consumption, and outsourced transportation [12].

A standardized checklists was developed following the AKDN Carbon Management Tool guidelines to systematically collect relevant data for carbon footprint analysis. The checklist covered variables such as energy consumption, including electricity, gas, liquid and solid fuels, gas cylinders, and thermal networks; the use of anesthetic and other medical gases; medical waste generation and disposal practices; fuel consumption by vehicles such as ambulances, staff service vehicles, and operational fleets; as well as consumption of inhalation medicines, including sprays and inhalers [12]. Each variable was measured using appropriate units (e.g., cubic meters for gas, kilowatt-hours for electricity, liters for fuel) and, data were collected via hospital records, and interviews.This structured approach enabled the comprehensive capture of activity data necessary for accurate carbon footprint estimation. Data collection was carried out during summer 2023, involving relevant departments such as technical offices, pharmaceutical management, environmental health, and procuremen. Energy consumption, including electricity and gas usage, was recorded in kilowatt-hours (kWh) and cubic meters, respectively, and converted to CO_2 equivalent emissions using DEFRA emission factors via the AKDN Carbon Management Tool. The amount and kinds of anesthetic gases used, like isoflurane and sevoflurane, were recorded, and calculations were made using emission factors from the IPCC. Medical waste was weighed in kilograms, and emissions were estimated based on disposal methods like incineration and burial. Water consumption data were obtained from hospital records and converted into greenhouse gas emissions using standard factors. Additionally, fuel consumption by hospital vehicles and outsourced transportation services was collected and analyzed. To ensure accuracy, energy bills and hospital management system records were reviewed and cross-checked.

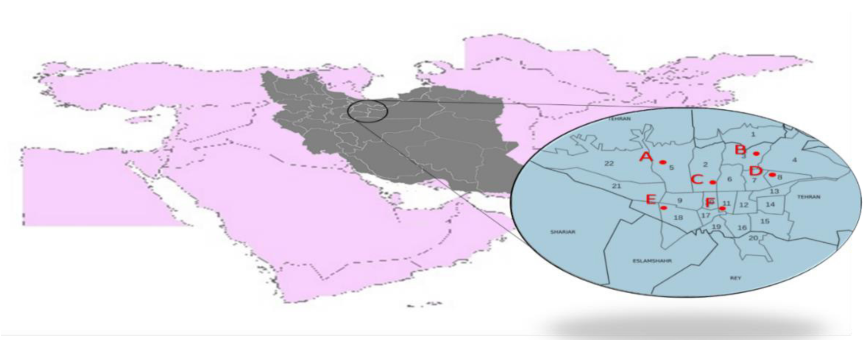

Fig. 1. Geographic locations of selected hospitals in Tehran city

Results and discussion

Table 1 summarizes the key characteristics of the six hospitals included in this study. The hospitals differ substantially in terms of age of construction, backup power systems, infrastructure area, and bed capacity. Hospital E has the largest generator capacity while having fewer beds than Hospitals B and C, which are the largest institutions in terms of both bed count and infrastructure area. The oldest, Hospital A, was built in 1949, and the newest, Hospital E, was built in 2011. These differences in age, size, and infrastructure are important parameters because they can affect patterns of energy use, building system performance, and ultimately the greenhouse gas emissions.

Analysis of resource consumption and waste production

The analysis of resource consumption and waste output across the six selected hospitals (A to F) is shown in Table 2. The findings showed that 11,322,282 kWh of electricity were used by all hospitals throughout the three-month study period. Due to its larger size and higher patient capacity, Hospital B reported using the most power usage (3,804,000 kWh), whereas Hospital D used the least (3,588 kWh), likely due to its smaller operating scale and/or different service patterns. With a total usage of 5,566,560 m3, gas consumption showed a similar pattern, with Hospital B using the most (4,570,711 m3) and Hospital F using the least (209,978 m3). The total amount of anesthetic gas used was 109,877 liters, with Hospital B using the most (99,741 L), possibly as a result of more surgeries, while Hospital F used the least amount (1.2 L). For inhaler usage, 2,397 units were used overall, with Hospital D using the most (912 units) and Hospital C using the fewest (60 units). This difference could be due to variations in patient demographics or treatment regimens. A total of 37,935 L of vehicle fuel were used with Hospital D using the most (31,847 L), suggesting perhaps more extensive transportation demands, and Hospital E using the least (100 L). The total amount of garbage produced by the hospitals was 616,294 kg, with Hospital B producing the most (275,300 kg) and Hospital F producing the least (24,300 kg). In general, Hospital B continuously had the highest levels of waste creation and resource consumption in most categories, underscoring the need for focused sustainability and efficiency initiatives. Alternately, Hospital F produced the least amount of waste production and overall resource use, indicating comparatively more effective operations.

Table 1. General information of selected hospitals in Tehran city

Hospital	Number of bed	The area of the infrastructure	Number of diesel generators	Capacity of the generators	Year of construction
A	146	18000	2	1050	1949
B	557	52000	4	2080	1984
C	497	42000	3	1720	1978
D	295	20000	3	1800	1974
E	196	13800	5	2590	2011
F	100	29000	3	1100	1996

Table 2. The amount of resource consumption of selected hospitals during the study period

Hospital	Electricity Consumption (Kwh)	Gas Consumption (m^3)	Consumption of Anesthetic Gas (L)	Consumption of Inhalers (Number)	Consumption of Vehicle Fuel (L)	Waste Production (Kg)
A	1779600	31450	1136	218	500	48897
B	3804000	4570711	99741	668	3218	275300
C	2616000	452976	85	60	1930	102560
D	3588	25317	2361	912	31847	110755
E	2119094	276128	6553	477	100	54482
F	1000000	209978	1.2	62	340	24300
Total	11322282	5566560	109877	2397	37935	616294

Analysis of carbon footprint

Table 3 displays the carbon footprint analysis for the six selected hospitals (A through F), taking into account waste management, supply chain, anesthetic gases, energy use, transportation, and inhalation devices. Energy use accounted for 16,182.5 tons of CO_2e, the largest contributor to total emissions by source, with Hospital B being the largest emitter at 10,980 tons. The next largest source, anesthetic gases, accounted for 11,314 tons of CO_2e, with Hospital B being the main source with 7,136 tons. Hospital B once again led the way with 280 tons of CO_2e from waste management, which contributed 626 tons. The majority of the 89 tons of CO_2e emissions connected to transportation came from Hospital D (75 tons). Inhalation devices produced 26.8 tons CO_2e, and the largest sources were Hospitals D and E (7.84 and 7.93 tons CO_2e, respectively). Hospital A contributed the most (6.27 tons CO_2e to the supply chain) which totaled 22.6 tons. Due in significant part to its high energy and anesthetic gas use, Hospital B had the largest overall emissions when compared to other hospitals, producing 18,413 tons of CO_2e. Hospital F had the lowest overall emissions at 880 tons CO_2e, showing lower contributions across all sources, while Hospital A recorded 1,728 tons CO_2e, primarily from anesthetic gases and energy use. With energy consumption accounting for 57.3% of total emissions, it was the largest source in terms of percentage contribution, followed by anesthetic gases at 40.0%. The supply chain (0.08%) and transportation (0.31%) made small contributions (Fig. 2). The average daily CO2 equivalent (CO_2e) emissions per hospital bed for each of the six hospitals (A to F) and the average for all hospitals are shown in Fig. 3. These results show that the hospitals' daily CO2 emissions per bed vary substantially.With daily emissions of around 367 kg CO_2e per bed, which is far higher than the group average, Hospital B had the highest emissions per bed. While Hospitals A and F reported moderate emissions, both below the group average, Hospital E also showed rather high emissions per bed, with 242 kg CO_2e per bed per day. The hospitals with the lowest CO_2e emissions per bed per day were C and D. Around 152 kg CO_2e per bed per day was the average for all hospitals.

Table 3. CO_2e emission by source for selected hospitals during the study period

Hospital	Transportation (tons CO_2e)	Energy Use (tons CO_2e)	Anesthetic Gases (tons CO_2e)	Inhalation Devices (tons CO_2e)	Supply Chain (tons CO_2e)	Waste Management (tons CO_2e)	Total Emissions (tons CO_2e)
A	1	813	855	2.6	6.3	50	1728
B	8	10980	7136	6.6	3.3	280	18413
C	5	2031	64	0.8	4.5	104	2209
D	75	54	506	7.8	2.8	113	758
E	0	1453	2752	7.9	4.8	55	4273
F	1	852	0	1.1	0.9	25	880
Total	89	16183	11314	26.8	22.6	626	28261

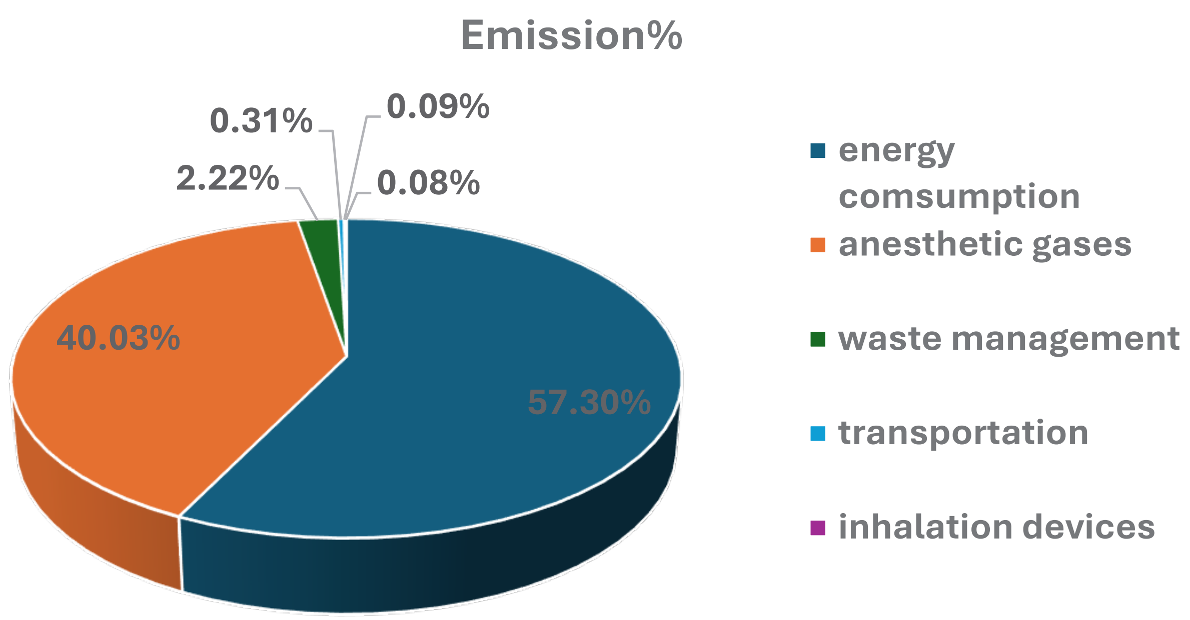

Fig. 2. Percentage of total CO_2e emissions by source during the study period

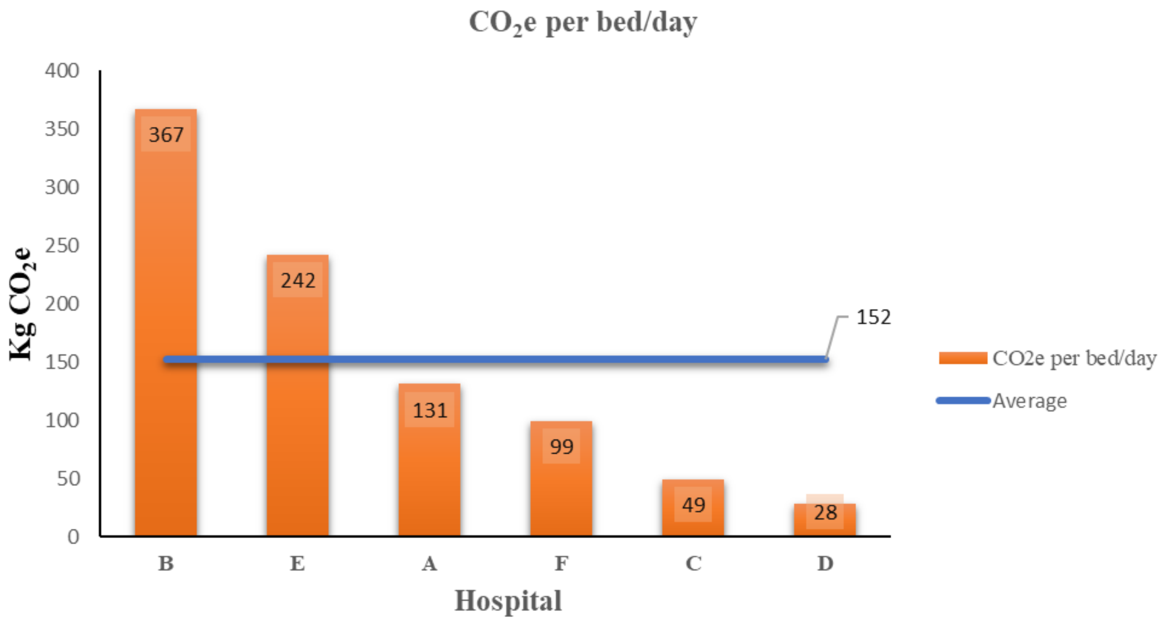

Fig. 3. Carbon dioxide equivalent (CO_2e) emission per bed-day for selected hospitals

By providing the first comprehensive estimates of CO_2e emissions from hospitals in Tehran, this study provides vital information about the environmental impact of healthcare facilities in the region. The findings show that hospitals, being complex and energy-intensive facilities, are major contributors to GHG emissions, with energy use and anesthetic gases being the primary sources. This demonstrates the urgent need for targeted initiatives in this area and supports global research showing that the healthcare sector can account for up to 10% of a nation's carbon footprint [8]. Anaesthesia gases were found to be the second largest contributor, accounting for 40% of total emissions.

The urgent need for targeted interventions in clinical practices, such as the installation of improved gas management systems and lower-impact substitutes, is highlighted by the high potential for global warming of gases like nitrous oxide and desflurane [21]. Between 47% and 57% of the six hospitals' total CO_2e emissions had to do with energy use, which is consistent with the well-known high energy requirements of healthcare facilities that run around the clock and rely on cutting-edge medical technology and stringent environmental regulations [22, 23]. The significant difference in energy consumption, especially Hospital B's dominance, shows how differences in a facility's size, infrastructure, and operational scope can significantly affect its emissions profile. Although Hospital B was highlighted due to its dominant contribution to total emissions, it is important to note that energy consumption patterns across all hospitals influence their respective emission profiles. Differences in hospital size, infrastructure age, and operational scope lead to variability in energy consumption and associated emissions. For example, Hospital E, despite having fewer beds, exhibits relatively high greenhouse gas emissions per bed, highlighting the need to improve energy efficiency across all facilities. The second-largest source, accounting for 40% of total emissions, was found to be anaesthetic gases. The substantial potential for substances like nitrous oxide and desflurane to contribute to global warming highlights the urgent need for focused clinical practice interventions, such as better gas management systems and less hazardous substitutes. The anesthetic gas emissions from Hospitals B and F, for example, differ significantly, indicating that anesthesia techniques and surgical volume are important factors in determining emissions in this category.

Other emission sources that contributed less but were still quite significant included supply chain operations, waste management, inhalation devices, and transportation. Transportation, waste management, inhalation devices, and supply chain activities all had smaller but still noticeable emissions. It's interesting to note that Hospital D had a high concentration of transit emissions, which most likely represented differences in the logistics of patients and supplies. According to similar studies, the supply chain's comparatively small contribution may be due to the scope of activities that are taken into account or underestimated.

The emission profiles of Tehran's hospitals are comparable to those of other countries, where energy and anesthetic gases account for the majority of greenhouse gas emissions related to healthcare. The difference in emissions between hospitals, particularly the noticeably higher levels in Hospital B, shows how operational practices, infrastructure, and facility size impact the environment. When compared to global data, some Tehran hospitals had per-bed emissions higher than those found in developed countries, suggesting substantial room for improvement in energy efficiency and sustainability practices.

These findings demonstrate how important it is to use comprehensive strategies to reduce the environmental impact of healthcare facilities. Among the main suggestions are switching to renewable energy, updating outdated structures with contemporary energy systems, maximizing the efficient use of anesthetic gases, improving waste management, and encouraging environmentally friendly transportation and purchasing practices.

A limitation of this study is its seasonal focus that limits its ability to provide a more comprehensive assessment. Future research should incorporate year-round data and a broader range of facilities to present a more complete picture. Important recommendations include moving to renewable energy, replacing isoflurane with sevoflurane and other low-GWP alternatives, increasing recycling and waste segregation, and improving transportation logistics by promoting low-emission vehicles and telemedicine. Despite providing a basic assessment, this study's cross-sectional design and three-month concentration on a limited number of hospitals may limit its generalizability.

In conclusion, this initial analysis shows that energy use and anesthetic gases are the main causes of Tehran's hospitals significant GHG emissions. By implementing focused measures in these areas, Iranian hospitals can drastically lower their carbon footprint and meet both national and international climate targets while upholding good patient care standards.

Conclusion

The results of this study should provide a strong basis for creating long-lasting regulations in the medical field. This groundbreaking analysis of Tehran's hospitals carbon footprints demonstrates the scope of the problem as well as the potential for focused intervention. Iranian hospitals can achieve substantial progress toward national and international climate goals without sacrificing the quality of care by tackling the main emission hotspots—energy use and anesthetic gases—as well as by enhancing waste, supply chain, and transportation procedures. The study offers a strong basis for clinicians, hospital administrators, and legislators to prioritize and carry out sustainability projects in the medical field.

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Competing interests

The authors declare that they have no conflicts of interest.

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Ethics considerations

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc) have been completely observed by the authors.

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