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Carbon footprints in the urologic field: From diagnosis to surgery

Jongsoo Lee[1,*], Miho Song[2,*], Jae Heon Kim[2]
[1]*Department of Urology, Severance Hospital, Yonsei University College of Medicine, Seoul,* [2]*Department of Urology, Soonchunhyang University Seoul Hospital, Soonchunhyang University College of Medicine, Seoul, Korea*

Climate change and its effects on society represent an increasingly critical concern. The healthcare industry contributes substantially to carbon emissions and bears responsibility for managing its environmental impact. This review examines recent progress, challenges, and future prospects in reducing the carbon footprint of diagnostic urology without compromising patient care, with particular emphasis on imaging. We analyze the environmental effects of urological procedures and devices, along with practices that can minimize greenhouse gas emissions. Promoting sustainability in healthcare requires a comprehensive approach from manufacturing to disposal, including examination of sterilization-related carbon footprints. This work aims to analyze existing literature on urological carbon footprints, focusing on processes and practices within the field.

Keywords: Carbon footprint; Climate change; Environmental impact; Surgical procedures; Urology

INTRODUCTION

A carbon footprint is the total amount of greenhouse gases (GHGs), like carbon dioxide, released into the atmosphere by activities or products. It is measured by looking at all the steps involved, from making a product to throwing it away, or by calculating emissions directly using set guidelines. Knowing this helps doctors find ways to reduce harm to the environment while still providing good care (Fig. 1).

The healthcare industry stands as a primary contributor to carbon emissions and environmental degradation globally [1]. The global healthcare sector ranks as the fifth highest producer of GHGs, with its carbon footprint comprising approximately 5% of worldwide net emissions [2].

Operating theaters generate up to 28% of hospital waste and consume more energy than any other hospital department, making them the largest source of hospital greenhouse gas emissions [3]. This primarily stems from heating, ventilation, and air conditioning requirements. Within the National Health Service (NHS), the supply chain accounts for 62% of its carbon footprint, while staff and patient transport contributes 10%, and healthcare delivery represents 24% [4]. In response, the NHS has initiated a campaign to achieve net-zero carbon emissions by 2050.

Recent years have witnessed significant growth in awareness of climate change's predicted consequences and the imperative to address them. A global consensus acknowledges human-induced climate change through greenhouse gas production [2]. This presents both a challenge and an opportunity, as addressing climate change's trajectory re-

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Corresponding Author: Jae Heon Kim https://orcid.org/0000-0002-4490-3610
Department of Urology, Soonchunhyang University Seoul Hospital, Soonchunhyang University College of Medicine, 59 Daesagwan-ro, Yongsan-gu, Seoul 04401, Korea
TEL: +82-2-709-9378, E-mail: piacekjh@schmc.ac.kr
*These authors contributed equally to this study and should be considered co-first authors.

quires substantial coordinated global effort despite numerous available solutions [5]. Assessing contributions to climate change necessitates consideration of carbon footprints, which quantify greenhouse gas emissions from specific activities [1]. The healthcare sector's contribution of over 5% to global carbon emissions places it among the world's top five pollution sources [2,6], compelling the medical field to minimize its environmental impact.

The resource-intensive nature of urology makes carbon footprint reduction essential [7]. Multiple factors contribute to urological carbon footprints, including guidewires, disposable scopes, irrigation fluids, surgical equipment, anesthetics, diagnostic procedures, and healthcare-related transportation. This review (Table 1) [8-15] evaluates current sustainability practices in urology in an era of increasing urological diseases, emphasizing carbon footprint reduction strategies in urological processes [16,17].

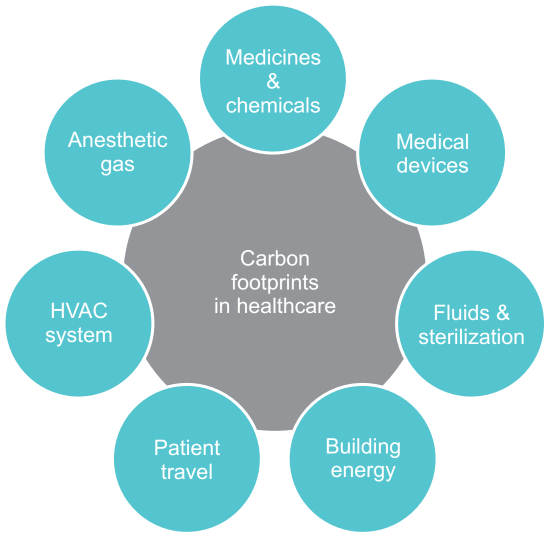

Fig. 1. Key contributors to carbon footprints in healthcare. HVAC, heating, ventilation, and air conditioning.

GREENER ISSUES IN DIAGNOSTICS

Building modernization plays a critical role in reducing hospital energy consumption [18]. The optimization of on-site energy production facilities demonstrates significant potential for reducing harmful emissions in healthcare settings

Table 1. Clinical studies about carbon footprint in urologic procedures

Study	Origin of carbon footprint	Environmental impact	Quantification or estimation of CO_2 per procedure
Davis et al. [8] (2018)	Single-use vs. reusable flexible ureteroscopes	Carbon footprint through life cycle analysis	The single-use flexible ureteroscope generates 4.43 kg of CO_2 per procedure; reusable ureteroscope generates of 4.47 kg of CO_2 per procedure.
Hogan et al. [9] (2022)	Single-use vs. reusable flexible cystoscopes	Carbon footprint through life cycle analysis	The single-use flexible cystoscope generates 2.41 kg of CO_2; reusable cystoscope generates 4.23 kg of CO_2.
Baboudjian et al. [10] (2023)	Single-use vs. reusable flexible cystoscopes	Carbon footprint through life cycle analysis	The disposable flexible cystoscope generates 2.06 kg of CO_2; reusable flexible cystoscope generates 3.08 kg of CO_2.
Kemble et al. [11] (2023)	Single-use vs. reusable flexible cystoscopes	Carbon footprint	The single-use devices generates 2.40 kg of CO_2; reusable devices generates 0.53 kg of CO_2.
Tsang et al. [12] (2022)	Disposable and reusable items in urology procedure	Carbon footprint	Using disposable drapes and gowns, urology procedures generated 87.16 kg CO_2e per operation, which could be reduced by 18.2% to 71.30 kg CO_2e by switching to reusable items.
Leapman et al. [13] (2023)	Prostate MRI and prostate biopsy	Carbon footprint	The carbon footprint of a prostate biopsy protocol, including MRI, targeted and systematic biopsies, was calculated to be 80.7 kg CO_2e, with the MRI component accounting for more than half of the total emissions.
Misrai et al. [14] (2020)	New minimally invasive surgical technologies in urology	Carbon footprint	Comparing robotic-assisted laparoscopy (40.3 kg CO_2e/pt.) to open surgery (22.7 kg CO_2e/pt.), demonstrating a 77% higher carbon footprint for the robotic approach.
Fuschi et al. [15] (2024)	Radical prostatectomy	Carbon footprint through life cycle analysis	Robot-assisted radical prostatectomy generated approximately 47 kg CO_2 per procedure, while LRP produced about 60 kg CO_2 per procedure, with RALP resulting in 22% lower carbon emissions due to more reusable surgical supplies, shorter operative time, and reduced hospital stay.

CO_2e, carbon dioxide equivalent; MRI, magnetic resonance imaging; pt., patient; LRP, laparoscopic radical prostatectomy; RALP, robotic-assisted laparoscopic prostatectomy.

[19,20]. Healthcare facilities have increasingly adopted clean energy sources to enhance resilience against power outages, a growing concern in the context of climate change. This approach also offers the additional benefit of reducing pollution in surrounding communities through localized energy production [18,21].

Hospital carbon footprints can be significantly reduced through regular energy audits and systematic improvements in energy efficiency. These improvements particularly impact high-energy-consumption areas such as laundry facilities and ventilation systems. The implementation of waste reduction programs and transparent carbon footprint reporting further supports these initiatives [22].

Healthcare resources can be optimized across multiple domains to enhance sustainability. This includes improving cancer prevention and treatment protocols, developing targeted screening programs, implementing sustainable anesthetic gas practices in operating theaters, minimizing waste in systemic therapeutics, and advancing medical device efficiency [19,20]. The transition to renewable energy sources represents a crucial component of this optimization. Ureterorenoscopy provides an illustrative example in uro-oncology and stone disease management. When using standard energy sources, reusable flexible ureteroscopes generate a 4.32 kg CO_2 annual impact, compared to 6.25 kg CO_2e (carbon dioxide equivalent) for disposable alternatives [23]. These values decrease significantly when renewable energy sources are employed [8,23]. The implementation of climate-smart infrastructure, following models such as that proposed by MacNeill et al. [24], can accelerate emissions reduction while maintaining quality care and operational sustainability.

The cumulative environmental impact of diagnostic testing warrants particular attention. Individual blood tests generate between 49–116 g of CO_2, which aggregates to a substantial environmental burden given the hundreds of millions of tests performed annually. However, research indicates that this impact can be mitigated through the implementation of appropriate guidelines without compromising patient care or disrupting clinical workflows [18,25].

RELATIONSHIP BETWEEN ENVIRONMENTAL FACTORS AND UROLOGIC CANCERS

1. Bladder cancer

Epidemiological research has extensively documented the relationship between environmental factors and urinary tract carcinoma. Several environmental risk factors have been identified in connection with urothelial carcinoma development, including tobacco use, occupational exposure to aromatic amines in chemical industries, and exposure to arsenic-contaminated drinking water exceeding 300 micrograms per liter (μg/L). The presence of arsenic contamination extends beyond drinking water to food sources, tobacco products, and in certain cases, atmospheric exposure [26]. Climate change is expected to exacerbate arsenic contamination in food and water sources [18]. The contamination of groundwater with arsenic presents a significant public health challenge, affecting millions globally. The prolonged exposure to arsenic has been established as a major environmental carcinogen, with substantial impacts on human health [27]. Despite these known risks, there remains a notable gap in research examining the relationship between arsenic exposure through drinking water and the demographic and clinicopathological characteristics of bladder cancer patients in arsenic-exposed regions [28].

2. Prostate cancer

The treatment of prostate cancer, a hormone-dependent malignancy, primarily focuses on disrupting androgen availability or androgen signaling pathways. In this context, endocrine-disrupting compounds (EDC) and other hormonally active substances are increasingly recognized as potential contributors to disease development [18,29]. EDCs are defined in scientific literature as "exogenous substances or mixtures that alter function(s) of the endocrine system and consequently cause adverse health effects in an intact organism, its progeny, or (sub)populations" [30]. Research has investigated prostate cancer's relationship with various EDC categories, encompassing phthalates, phytoestrogens, mycoestrogens, and bisphenols [31]. The environmental impact of different treatment approaches varies significantly in terms of carbon emissions [18,32], with evidence suggesting that invasive, CO_2-intensive treatments may not always be necessary [33].

Clinical research has demonstrated that mortality rates remain notably low in prostate cancer cases detected through prostate specific antigen elevation, regardless of the chosen treatment pathway—whether active surveillance, prostatectomy, or radiation therapy [34]. While disease progression rates were lower in patients receiving radical surgical or radiotherapeutic interventions compared to active surveillance, these more aggressive approaches did not translate to improved prostate cancer mortality outcomes [35]. This evidence underscores the importance of careful consideration of treatment options when diagnosing localized prostate cancer, requiring physicians and patients to weigh the relative benefits and drawbacks of various therapeutic approaches [33,35].

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CARBON FOOTPRINTS IN DIAGNOSIS

Magnetic resonance imaging (MRI) is a cornerstone in prostate cancer diagnosis [36]. Ensuring consistent, high-quality imaging is critical to maximizing its diagnostic benefits. The recently developed PI-QUAL v2 scoring system offers a comprehensive framework for improving and standardizing MRI quality, thereby reducing variability and enhancing diagnostic accuracy [37]. Adherence to these standards minimizes the need for repeat scans, which not only optimizes resource utilization but also significantly reduces the environmental impact of diagnostic imaging. Furthermore, research shows that performing MRI prior to biopsy can eliminate the need for nearly 30% of biopsy procedures [38]. This reduction results in an estimated decrease of 1.4 million kilograms of carbon dioxide emissions per 100,000 patients, underscoring the environmental and clinical benefits of strategic MRI implementation within the diagnostic pathway.

Current discourse in the field centers on the comparative efficacy of multiparametric MRI versus non-contrast MRI protocols for detecting clinically significant prostate cancer. The environmental implications of this debate are significant, as contrast-enhanced protocols generate approximately 10% higher carbon-based emissions compared to non-contrast alternatives [13]. The potential verification that non-contrast MRI provides comparable diagnostic accuracy could facilitate a transition toward more environmentally sustainable imaging practices. To establish the viability of this environmentally advantageous approach, ongoing investigations such as the PRIME trial are evaluating whether healthcare centers can safely adopt these greener imaging protocols [39].

This optimization of diagnostic pathways illustrates how evidence-based modifications to clinical protocols can simultaneously enhance environmental sustainability and maintain high standards of patient care [40]. Such approaches demonstrate the potential for reducing healthcare's environmental impact through thoughtful refinement of diagnostic strategies [41].

CARBON FOOTPRINTS IN SURGICAL TREATMENTS

1. Surgical field

Surgery represents a fundamental component in the treatment of localized disease within uro-oncology. Comprehensive analyses have identified three primary contributors to the surgical carbon footprint: energy consumption, anesthetic agents, and disposable surgical equipment [18,33]. The environmental impact of perioperative services is particularly influenced by ventilation energy requirements and anesthetic gas usage [22,42]. Within this context, multiple opportunities exist for enhancing sustainability in perioperative care. These improvements can be achieved through the standardization of instrument trays, transition from disposable to reusable equipment (including surgical gowns, drapes, trocars, and instruments), and systematic reduction of material waste [22].

Operating room environmental impact is predominantly driven by heating, air conditioning, and ventilation systems, which account for 90%–99% of energy consumption. Several technological and operational strategies have demonstrated effectiveness in reducing this carbon footprint, including optimized operating room design, renewable energy integration, implementation of occupancy-sensitive controls, reduced air exchange rates during non-operational hours, and development of energy-efficient facilities [33,43]. However, it is essential to note that certain infection prevention measures, particularly advanced air purification systems, may increase greenhouse gas emissions [18]. Research indicates that these systems do not consistently demonstrate improved infection prevention outcomes in the operating environment [44].

2. Endoscopy

The urological field has witnessed an increasing adoption of single-use endoscopic devices [39]. Environmental sustainability assessment in this context necessitates comprehensive life cycle evaluation to accurately measure environmental impact [10,45]. This approach is crucial for identifying and addressing all potential environmental consequences. The ongoing debate regarding single-use versus reusable endoscopic instruments centers on comparing the environmental impact of production and disposal cycles against the carbon footprint associated with sterilization processes for reusable equipment.

Analysis of cystoscopy practices has yielded interesting results, with three out of four studies favoring single-use cystoscopes from an environmental perspective. While Kemble et al. [11] reported contrary findings, the research conducted by Baboudjian et al. [10], Hogan et al. [9], and Jahrreiss et al. [46] demonstrated lower carbon footprints for single-use cystoscopes compared to their reusable counterparts. The variability in these findings appears to correlate with differences in sterilization methods and their associated energy requirements [6]. The studies by Baboudjian et al. [10], Hogan et al. [9], and Jahrreiss et al. [46] evaluated more energy-intensive manual sterilization processes, while Kemble et al. [11] examined more energy-efficient automated systems.

In the context of ureteroscopy, Davis et al. [8] conducted the only known comparative analysis of environmental impact, finding comparable carbon footprints between single-use and reusable devices. The higher susceptibility of ureteroscopes to damage compared to cystoscopes necessitates careful consideration of maintenance intervals and repair requirements when selecting reusable instruments [6].

Previous publications have indicated elevated total estimates for reusable flexible ureteroscopes, primarily attributed to the 3.95 kg CO_2e reprocessing load [8,23]. However, when examining the complete life cycle, the difference in carbon footprint between disposable and reusable ureteroscopes appears minimal [18], though disposable instruments demonstrate a notably higher production-related environmental impact [8]. Further research by Kemble et al. [11] has revealed significant differences between flexible disposable and reusable cystoscopes. When accounting for manufacturing, disposal, and reprocessing, the carbon footprint differs markedly: 2.4 kg CO_2 for disposable versus 0.53 kg CO_2 per use for reusable devices (Fig. 2) [6,8-11,18,47]. Additionally, reusable surgical equipment has demonstrated superior resilience to supply chain disruptions, an increasingly important consideration given climate change-related challenges [18].

CARBON FOOTPRINTS IN RADIATION THERAPY

Radiation therapy maintains a central role in the interdisciplinary management of urological malignancies, encompassing both curative treatment approaches and palliative care for incurable urological conditions [48]. Within prostate cancer treatment specifically, where local irradiation serves as an alternative to aggressive surgical intervention, the environmental impact of radiation therapy presents particular interest [35].

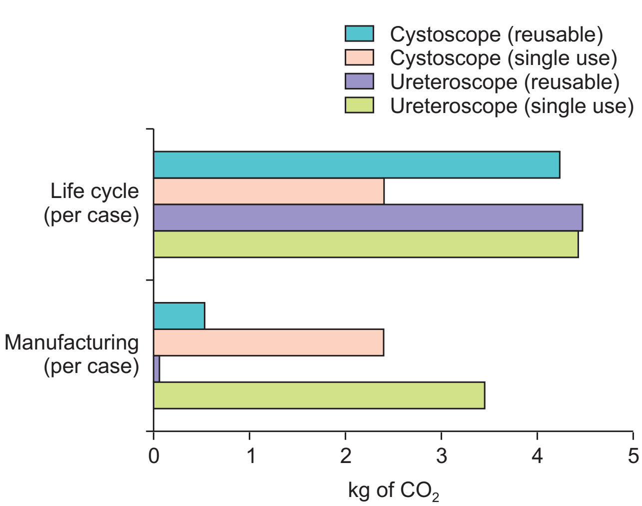

Fig. 2. Carbon footprints between single use and resuable endoscope (kg of CO_2) [8-10,47].

Research examining treatment modalities has provided valuable insights into their respective environmental impacts. Studies have demonstrated marked differences in carbon emissions between treatment protocols. Stereotactic body radiation treatment of the prostate, delivered in 5 fractions, generates the lowest average carbon emissions per treatment course at 2.18 kg CO_2 (interquartile range, 1.92–2.30). In contrast, traditional prostate cancer treatment protocols utilizing 28 fractions produce significantly higher emissions at 17.34 kg CO_2 (interquartile range, 10.26–23.79) [49]. To contextualize these figures, these emissions equate to the carbon output of vehicular travel spanning 5.4 miles (8.7 km) and 41.2 miles (66.3 km) respectively in a standard vehicle [18,49].

The environmental impact of radiation therapy equipment warrants particular attention, as a typical radiation device consumes between 64.8 kWh and 112.0 kWh of electricity daily in standby mode alone [49]. However, when compared to surgical interventions, radiation therapy demonstrates favorable environmental metrics. Robot-assisted surgery generates 40.3 kg CO_2e per patient, laparoscopic surgery produces 29.2 kg CO_2e per patient, and open surgery creates 22.7 kg CO_2e per patient. These figures indicate that radiation therapy generally results in lower direct carbon emissions than surgical alternatives [18,49]. Additionally, radiation therapy protocols typically generate substantially less medical waste (Fig. 3) [18,49-51].

The environmental implications of treatment selection underscore the importance of implementing environmentally conscious practices in urological care. Sustainable urology encompasses the adoption of environmentally responsible methods that minimize negative environmental impact while maintaining high standards of patient care and ethical practice [18]. Achieving meaningful reductions in clinical waste and carbon emissions requires systematic changes in operational practices, particularly within surgical settings. Key strategies include enhanced waste recycling programs, increased utilization of reusable equipment, appropriate implementation of local anesthesia when indicated, and optimization of testing and transportation protocols [52].

CONCLUSIONS

Healthcare providers maintain their primary focus on ensuring accurate and efficient patient care, while recognizing the growing imperative to address environmental

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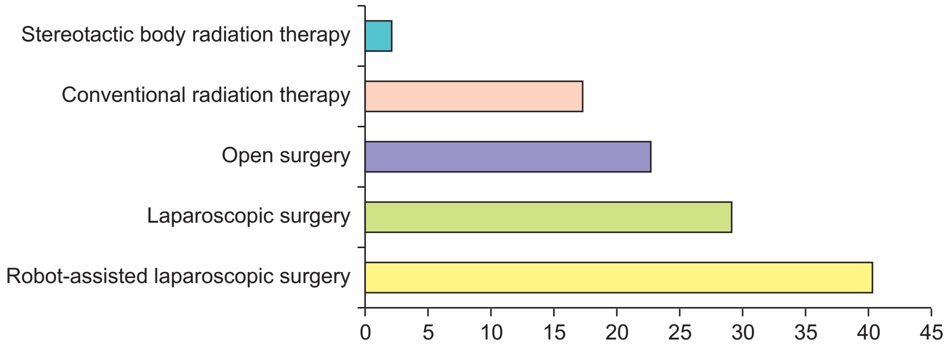

Fig. 3. Carbon footprints (CO_2 per patients) among treatment for urologic cancers (kg of CO_2) [18,51].

impact. The urological field, despite its resource-intensive nature, presents numerous opportunities for reducing carbon footprints without compromising care quality. Evidence demonstrates that implementing environmentally conscious practices across diagnostic, surgical, and therapeutic domains is both feasible and necessary. Through thoughtful consideration of treatment pathways and adoption of sustainable practices, urologists can significantly contribute to healthcare sustainability while maintaining optimal patient outcomes. This balanced approach ensures continued excellence in patient care while advancing environmental stewardship in medical practice.

CONFLICTS OF INTEREST

The authors have nothing to disclose.

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AUTHORS' CONTRIBUTIONS

Research conception and design: Jae Heon Kim. Data acquisition: Jongsoo Lee and Miho Song. Data analysis and interpretation: Jongsoo Lee and Miho Song. Drafting of the manuscript: Jae Heon Kim. Critical revision of the manuscript: Jae Heon Kim. Obtaining funding: Jae Heon Kim and Jongsoo Lee. Administrative, technical, or material support: Jae Heon Kim. Supervision: Jae Heon Kim. Approval of the final manuscript: all authors.

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