TURKISH JOURNAL of ONCOLOGY

Turk J Oncol 2025;40(3):190–199
doi: 10.5505/tjo.2025.4565

ORIGINAL ARTICLE

Investigation of Effects of Radiotherapy Methods Applied with Different Fractions and Doses on Carbon Footprint in Patients with Rectal Cancer

Sultan ZORTUL,[1] Abdulsamet ZORTUL,[2] Yasemin ÖRS[2]

[1]Department of Family Medicine, Erzurum Tortum District State Hospital, Erzurum-*Türkiye*
[2]Department of Radiation Oncology, Erzurum City Hospital, Erzurum-*Türkiye*

OBJECTIVE

This study aimed to compare the greenhouse gas emissions resulting from two different radiotherapy (RT) methods used in the treatment of rectal cancer and to investigate their impact on the carbon footprint.

METHODS

Variables contributing to carbon emissions were identified and quantified. The carbon footprint was evaluated based on the total emissions produced during two RT regimens: 50 Gy in 25 fractions (long-course radiotherapy, LCRT) and 25 Gy in 5 fractions (short-course radiotherapy, SCRT).

RESULTS

A total of 12 patients participated in the study, with a mean age of 68.5±13.83 years. Among them, 83.3% (n=10) were male. The overall carbon footprint from all procedures was calculated as 168.6±85.4 kg CO_2e (carbon dioxide equivalent) per patient. The mean emission for SCRT was 105±9.4 kg CO_2e, while for LCRT it was 231.4±80.6 kg CO_2e per patient—a statistically significant difference (p=0.004). Inpatient treatment resulted in lower carbon emissions than outpatient treatment. The highest contributors to carbon emissions in both groups were radiotherapy and imaging procedures, followed by transportation, electricity use, and heating systems.

CONCLUSION

The study concluded that SCRT, inpatient treatment, proximity of patients' residences to the hospital, and the use of public transportation were associated with reduced carbon footprint values.

Keywords: Carbon footprint; greenhouse gases; radiotherapy; rectum cancer.

INTRODUCTION

Global warming and climate change are anticipated to pose serious threats in the future. These threats stem from the increasing accumulation of greenhouse gases (H_2O, CO_2, CH_4, O_3, N_2O, CFC-11, HFCs, PFCs, SF_6).[1] It has been reported that greenhouse gas emissions account for approximately 4–5% of global emissions.[2–4] Although the healthcare sector in Türkiye has not yet been specifically evaluated in this context, based on the ratio of health expenditures to gross domestic product, it is estimated that the healthcare sector's contribution to emissions in Türkiye is likely comparable.[5]

Received: April 16, 2025
Revised: June 14, 2025
Accepted: July 14, 2025
Online: September 03, 2025

Accessible online at:
www.onkder.org

Dr. Sultan ZORTUL
Erzurum Tortum İlçe Devlet Hastanesi,
Aile Hekimliği Kliniği,
Erzurum-Türkiye
E-mail: sultan.oksuz11@gmail.com

Within the healthcare system, greenhouse gas emissions arise from various sources, including patient transportation to hospitals, diagnostic imaging and treatment procedures, hospitalizations, use of medical and non-medical equipment, electricity consumption, materials used by both patients and staff, heating and cooling systems, anaesthetic gases, and waste generation.[6]

In healthcare systems where greenhouse gas emissions are significant, the rate may be even higher in cases such as colorectal cancer, which require prolonged hospital-based treatment processes.[7] A review of national and international literature reveals a lack of comprehensive data on the environmental impact of oncology services within Türkiye's healthcare system, and no similar study was found evaluating the carbon footprint of radiotherapy modalities used in the treatment of rectal cancer.

This study was conducted to help fill that gap and guide future research. Our aim was to examine the treatment protocols used for rectal cancer patients and to explore potential strategies for reducing the greenhouse gas emissions associated with these protocols.

Ethical Approval

This study received unanimous approval from the Scientific Research Ethics Committee of Erzurum Faculty of Medicine (No: 2024/182, Date: 11/09/2024). The study was conducted in accordance with the declaration of Helsinki.

MATERIALS AND METHODS

Study Type

This study was conducted using a descriptive, cross-sectional, and retrospective design to investigate the impact of greenhouse gas emissions—resulting from different radiotherapy modalities—on the carbon footprints of patients diagnosed with rectal cancer.

Study Design

The study included patients diagnosed with locally advanced stage 3 rectal cancer, who were ineligible for chemotherapy and received radiotherapy between October 1, 2024, and December 31, 2024, at the Radiation Oncology Clinic of Erzurum City Hospital. The patients were divided into two groups, with each group receiving one of two radiotherapy modalities: Short-course radiotherapy (SCRT) administered over 5 days (25 Gy/5 fractions) and long-course radiotherapy (LCRT) administered over 25 days (50 Gy/25 fractions).

All patients in the LCRT group and 50% of patients in the SCRT group were admitted to the palliative care service, and their data were followed up by family physician.

Greenhouse gas (GHG) emissions resulting from hospitalization, travel, and medical procedures—including radiotherapy, imaging, interventions, waste disposal, and the consumption of electricity and natural gas during hospital stays—were calculated for each patient in accordance with the Greenhouse Gas (GHG) Protocol Standards and TS EN ISO 14064 Greenhouse Gas Inventory Standards.

The study included a total of 12 patients: Six received LCRT and six received SCRT. The contributing factors to carbon emissions during the treatment period were identified, and the total carbon emissions associated with each radiotherapy modality were compared. The primary objective of the study was to determine which radiotherapy approach resulted in lower carbon emissions.

Patient Selection

All patients who presented for radiotherapy with a diagnosis of locally advanced stage 3 rectal cancer between October 1, 2024, and December 31, 2024, and who met the inclusion criteria were enrolled in the study. Inclusion criteria were diagnosed with locally advanced stage 3 rectal cancer, followed up at Erzurum City Hospital, aged between 18 and 80 years, provided voluntary informed consent. Exclusion criteria included; presence of acute cerebrovascular events (CVEs) or other neurological conditions affecting mental status, psychiatric disorders, hemiplegia or hemiparesis in the extremities, aphasia, severe visual or hearing impairments, being in the postoperative recovery period. Patients who did not receive concurrent chemotherapy were selected to ensure uniformity in radiotherapy-based carbon emission assessment.

Data Collection and Emission Factor Sources

Data on carbon emissions produced by patients during the radiotherapy process were collected and calculated under the following categories:

Carbon Footprint of Radiotherapy

Radiotherapy for rectal cancer is typically delivered in treatment fractions ranging from 5 to 25 sessions. The carbon footprint of radiotherapy (RT) is calculated by multiplying the fixed emissions associated with the device by the number of treatment fractions and adding the carbon emissions resulting from sulphur hexafluoride (SF_6) leakage. The fixed component re-

Turk J Oncol 2025;40(3):190–199
doi: 10.5505/tjo.2025.4565

fers to the carbon emissions generated by the electricity consumed per treatment fraction, while the variable component corresponds to the total number of planned fractions.[8]

Patients in this study were treated using a tomotherapy device. The electricity consumption of this device was measured at 0.822 kWh per minute. According to Türkiye's national greenhouse gas inventory, 1 kWh of electricity consumption results in 0.439 kg CO_2e emissions. Because treatment durations varied between patients, the carbon dioxide emitted during each patient's total radiotherapy session was calculated individually. Furthermore, the annual SF_6 leakage from the tomotherapy unit was estimated, and the per-fraction SF_6 emission was calculated separately for each patient.

Carbon Footprint of Imaging Methods

All patients underwent positron emission tomography–computed tomography (PET-CT), computed tomography (CT), magnetic resonance imaging (MRI), colonoscopy, and CT simulation prior to radiotherapy. The carbon emissions resulting from these imaging procedures were assumed to be the same for all patients and were incorporated into the total emission calculations accordingly. The average duration of a PET-CT scan was 15 minutes, with an electricity consumption of 1.33 kWh per minute. The CT simulator and CT device each consumed 1.33 kWh per minute as well. The MRI device consumed 0.3155 kWh per minute. For colonoscopy, which was considered part of the diagnostic phase, an approximate carbon emission value was calculated and included in the total emissions.[9] All electricity-based emission factors were applied using Türkiye's national carbon emission inventory data.

Carbon Footprint of Patient Travel

The carbon footprint related to patient travel was calculated based on the distance between the patient's residence and the hospital, the type of vehicle used, and the fuel consumption rate. Among the 12 patients, seven were from four provinces outside Erzurum (Ağrı, Ardahan, Manisa, and Iğdır), while five resided in districts within Erzurum (Çat, Aziziye, Yakutiye, Palandöken, and Pasinler). Nine patients were hospitalized, and their travel emissions were calculated as a single round trip (from home to hospital and back after discharge). Three patients received outpatient treatment, and their emissions were calculated for five days of commuting to and from the hospital. Patients' residential addresses were obtained from hospital records and verified through face-to-face interviews. Travel distances were calculated using Google Maps, and self-reported information regarding travel routes and vehicle types was used. Emissions were estimated using the IPCC 2006 Tier 1 method, the GHG Protocol, and ISO 14064-1 standards. The following assumptions were applied; average fuel consumption of a diesel car: 7.3 L/100 km, average fuel consumption of a diesel bus: 29.9 L/100 km. Carbon emission per Liter of diesel consumed: 2.54 kg CO_2e.[10] Using these parameters, the carbon emissions from patient transportation were calculated and included in the overall footprint analysis.

Carbon Footprint of Electricity Consumption and Heating

Carbon emissions resulting from the electricity and natural gas consumption in patient rooms during hospitalization were calculated using data from national greenhouse gas inventories. On average, 1.5 kWh of electricity was consumed per day per room. Based on Türkiye's emission standards, 0.478 kg CO_2e is released per 1 kWh of electricity. Additionally, 0.82 m^3 of natural gas was used daily for heating, producing 2.1857 kg CO_2e per 1 m^3 of natural gas. All emission calculations were performed according to the relevant national inventory data.[11]

Carbon Footprint of Patient Treatment and Hospitalization

Carbon emissions associated with patient care and hospitalization were calculated based on the following categories: Medical consumables, non-medical consumables, medical equipment, non-medical equipment, waste, and laboratory procedures.

- Medical consumables included: Cotton, bandages, compresses, blood sampling materials, needles, tubes, gloves, urine rapid tests, masks, tongue depressors, infusion sets, face masks.
- Medical equipment included: Electrocardiograms, thermometers, glucometers, otoscopes, scales, flashlights, stethoscopes, and sphygmomanometers.
- Non-medical consumables included: Paper, toner, and paper towels.
- Non-medical equipment included: Computers, printers, and some other electronic devices.
- Waste materials included: Paper, plastic, glass, and hazardous waste.

Carbon emissions for all these items were estimated based on the UK Government's 2024 Greenhouse Gas Reporting Conversion Factors.[12]

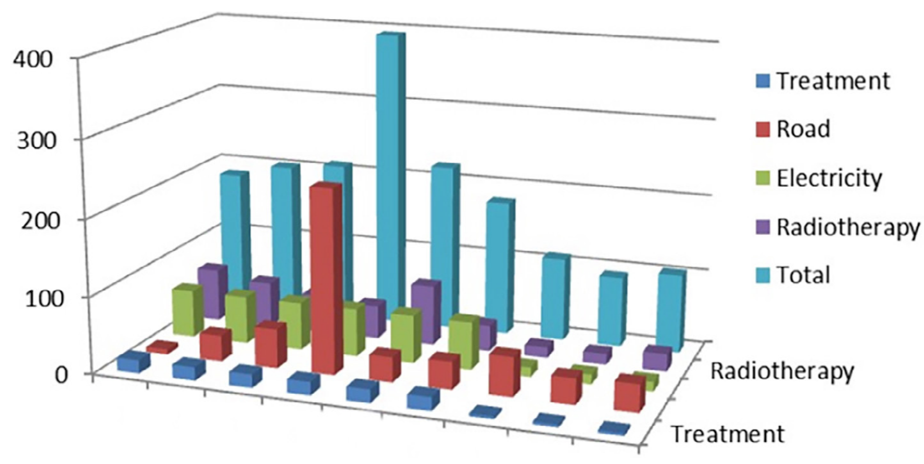

Fig. 1. Distribution of inpatient carbon emission sources.

Data Collection Tools

Personal Information Form

The personal information form was developed by the researcher following a comprehensive literature review.[8,13,14] The form consisted of 22 questions designed to collect data on patients' socio-demographic characteristics, including age, comorbid conditions, distance from residence to hospital, duration of hospitalization, disease duration, type of radiotherapy modality received, and other relevant information such as additional diagnostic procedures, treatments, waste generation, consumed materials, and utility expenses (electricity, water, and heating).

Data Collection

Data were collected through face-to-face interviews conducted by the researchers, after informing the patients about the purpose of the study and obtaining their consent. The following information was recorded using the data collection form; Socio-demographic characteristics, medical history, distance between residence and hospital, type of transportation used.

Radiotherapy-related data for outpatients were recorded daily by a health physicist, who also performed the corresponding carbon emission calculations. For inpatients, data regarding medical treatments, diagnostic examinations, medical and non-medical materials, and equipment usage were recorded by the family physician, and associated carbon emissions were calculated accordingly. Data on electricity and heating consumption in patient rooms were obtained from the hospital's health services directorate and technical department (Fig. 1).

Population and Sample of the Study

The study population included all patients diagnosed with stage 3 rectal cancer who were treated at the Radiation Oncology Clinic of Erzurum City Hospital. The study was conducted over the last three months of the year and was extrapolated to represent an annual estimate.

All patients who met the inclusion criteria, did not meet any exclusion criteria, and voluntarily agreed to participate were included in the study sample.

Data Analysis

The collected data were analysed using SPSS version 26. The normality of continuous variables was assessed using the Kolmogorov-Smirnov test. For normally distributed continuous variables, results were presented as mean ± standard deviation, while frequency and percentage values were used to describe categorical variables.

To compare two independent groups, the student's t-test was employed for variables showing normal distribution, whereas the Mann-Whitney U test was applied for variables not meeting normality assumptions. The Chi-square test was used to compare categorical variables between groups. A p-value of less than 0.05 was considered statistically significant.

RESULTS

In our study, a total of twelve patients participated. Of these, 16.7% (n=2) were female and 83.3% (n=10) were male. The mean age was 68.5±13.83 years, ranging from 42 to 89 years. Five participants (41.7%) were single (n=7), while 58.3% were married. Re-

Turk J Oncol 2025;40(3):190–199
doi: 10.5505/tjo.2025.4565

Table 1 Comparison of socio-demographic data and health history by groups

	5 fr		25 fr		p
	n	%	n	%	
Gender					0.12
Male	6		4	66.7	
Female	0		2	33.3	
Marital status					0.79
Single	4	66.7	1	16.7	
Married	2	33.3	5	83.3	
Chronic disease					1
No	3	33.3	2	33.3	
Yes	4	66.7	4	66.7	
Transportation type					0.51
Public	4	66.7	5	83.3	
Private	2	33.3	1	16.7	
Education level					0.51
Primary	1	16.7	2	33.3	
High	4	66.7	2	33.3	
University and over	1	16.7	2	33.3	

	5 fr		25 fr		p
	n	%	n	%	
Working status					0.51
Employed	1	16.7	2	33.3	
Retired	5	83.3	4	66.7	
Tumour location					0.21
Distal	4	66.7	1	16.7	
Proximal	1	16.7	3	50	
Middle	1	16.7	2	33.3	
Tumour stage					0.39
3A	1	16.7	0	0	
3B	2	33.3	4	66.7	
3C	3	50	2	33.3	
T stage					1
T2	1	16.7	1	16.7	
T3	5	83.3	5	83.3	
N stage					0.55
N1	3	50	4	66.7	
N2	3	50	2	33.3	

Chi-square test. fr: Fraction

garding employment status, 25% (n=3) were working, and 75% (n=9) were retired. Educationally, 25% (n=3) had completed primary school, 50% (n=6) had graduated from high school, and 25% (n=3) had university or higher degrees.

The distance from participants' residences to the hospital ranged from 3,6 km to 1593.3 km. Most patients (75%, n=9) used public transportation to reach the hospital, while 25% (n=3) used private vehicles. Regarding chronic diseases, 33.3% (n=4) had no chronic condition, whereas 66.7% (n=8) had at least one chronic disease. Specifically, 37.5% (n=3) had hypertension, 12.5% (n=1) had hepatitis, 12.5% (n=1) had diabetes mellitus, and 37.5% (n=3) had both diabetes mellitus and hypertension.

Income levels varied, with 25% (n=3) reporting income lower than expenses, 66.7% (n=8) reporting income equal to expenses, and 8.3% (n=1) reporting income higher than expenses. A detailed comparison of socio-demographic data and health history is presented in Table 1.

Mean CO_2 emissions from medical treatments were 9.59±8.3 kg CO_2e, from travel 56.46±59.49 kg CO_2e, from electricity and heating 34.49±29.84 kg CO_2e, and from radiotherapy 39.65±21.13 kg CO_2e. All patients underwent colonoscopy, which accounted for an average of 28.4 kg CO_2e emissions.

The total carbon footprint resulting from treatments was calculated as 2023.43 kg CO_2e, with a mean of 168.6±85.45 kg CO_2e (minimum 92.5 kg CO_2e, maximum 392.94 kg CO_2e).

The two treatment protocol groups were homogeneous in terms of cancer type, stage, and other variables, with no significant differences observed (Table 1).

Table 2 presents a detailed comparison of carbon emissions between the two groups. The median travel-related carbon footprint for patients receiving 5-fraction radiotherapy was 47.15 kg CO_2e (Q1–Q3: 35.6–53.7), while for those receiving 25-fraction radiotherapy it was 35 kg CO_2e (Q1–Q3: 26.1–98.65), with no significant difference (p=0.378).

However, the median carbon footprint related to electricity consumption and heating was significantly lower in the 5-fraction group (6.27 kg CO_2e; Q1–Q3: 0.0–12.54) compared to the 25-fraction group (62.72 kg CO_2e; Q1–Q3: 62.7–62.7) (p=0.002).

Carbon Footprint Results of Radiotherapy

Detailed calculations for each patient are presented in Table 3. The annual SF_6 leakage from the radiotherapy device is approximately 360 grams. Given that 1 kg of SF_6 gas corresponds to 23,500 kg CO_2e, the estimated annual greenhouse gas emissions due to SF_6 leakage

Table 2 Comparison of two groups in terms of carbon emissions

	5 fr (mean±SD)	25 fr (mean±SD)	Statistic	p
Radiotherapy and imaging technics	23.27±7.60	56±16.74	t=-4.36	0.001
Electricity consumption and heating	6.27±6.80	62.72	z=-3.12	0.002
Total carbon footprint	105.76±9.40	231.47±80.60	t=-3.79	0.004
Hospitalization				
No	3 (50):109.5±5.8	0	t=-2.68	0.031
Yes	3 (50):101.9±8.7	6 (100):(231.47±80.6)		

Student's T test, Mann Whitney U test. Carbon footprint unit is kg CO_2 equivalent. fr: Fraction; SD: Standard deviation

Table 3 Details of CO_2 emission of radiotherapy

Patient number	1	2	3	4	5	6	7	8	9	10	11	12
Fraction												
Number	25	25	25	25	25	25	5	5	5	5	5	5
Time	7.4	6.3	5.3	4.7	8.4	3.6	14.8	7.4	7.5	12.2	16.5	15.7
Carbon emission	66.76	56.839	47.81	42.4	75.78	32.486	26.7	13.35	13.53	22.01	29.77	28.33
Sf_6 carbon emission	2.9785	2.54	2.133	1.89	3.381	1.449	1.1914	0.5957	0.6	0.8121	1.33	1.2635

Carbon footprint unit is kg CO_2 equivalent. Fraction time is minute

from a tomotherapy device amount to approximately 8,460 kg CO_2e. Consequently, the CO_2 emission attributable to SF_6 leakage per minute was calculated as 0.016 kg CO_2e. The carbon dioxide emissions resulting from leakage were calculated individually according to each patient's fractionation time.

Carbon Footprint Results of Imaging Methods

The average imaging time for PET CT was 15 minutes, during which 20 kWh of electricity was consumed, leading to calculated emissions of 8.78 kg CO_2e. MRI consumed 6.31 kWh over a 20-minute scan, corresponding to 2.77 kg CO_2e emissions. The electricity consumption of CT and CT simulator devices was measured as 1.33 kWh per minute, with an associated carbon emission of 0.58387 kg CO_2e per minute. The average CO_2 emissions from a colonoscopy procedure were estimated at 28.4 kg CO_2e.[6]

Carbon Footprint Results of Patient Treatment and Hospitalization

The average daily carbon footprint from medical consumables was 0.6979 kg CO_2e, resulting in a total of 3.49 kg CO_2e for a 5-day period and 17.45 kg CO_2e for 25 days. These values were calculated using emission factors and conversion coefficients drawn from the literature. For instance, gloves emitted 0.026 kg CO_2e per unit, masks 0.02 kg CO_2e, bandages and compresses 0.28 kg CO_2e, blood sampling materials 0.057 kg CO_2e, and general medical waste 0.7 kg CO_2e. Medical equipment such as ECG devices and otoscopes contributed approximately 0.02 kg CO_2e per unit. The mean daily consumption included 10 pairs of gloves, 2 tubes, 5 injection syringes, 1 mask, and 0.6 kg of waste, which were recorded and used for calculations.[13,15]

Carbon Footprint Results of Electricity and Heating Systems

Natural gas consumption over 5 days was 4.1 m^3, corresponding to 8.96 kg CO_2e emissions, while over 25 days it was 20.5 m^3, producing 44.8 kg CO_2e. Electricity consumption over 5 days was 7.5 kWh, resulting in 3.59 kg CO_2e, and over 25 days was 37.5 kWh, corresponding to 17.93 kg CO_2e.

Carbon Footprint Results of Travel

Participants included two patients from Ardahan, two from Iğdır, one from Manisa, two from Ağrı, and five from districts within Erzurum. Detailed travel emission calculations are provided in Table 4.

DISCUSSION

Decarbonization efforts in radiation oncology can be effectively advanced through hypofractionation

Turk J Oncol 2025;40(3):190–199
doi: 10.5505/tjo.2025.4565

Table 4 Carbon footprint caused by patient travel

Patient number	1	2	3	4	5	6	7	8	9	10	11	12
Hospitalization	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No
Fraction no	25	25	25	25	25	25	5	5	5	5	5	5
Distance to hospital (km)	43.6	225	341.2	1593.3	58.2	240	11.6	341.2	225	240	4.31	3.6
Total distance travelled (km)	87.2	450	682.4	3186.6	116.4	480	116	682.4	450	480	43.1	36
Vehicle	public	public	public	public	private	public	public	public	public	public	private	private
Carbon emission	6.57	33.93	51.45	240.27	32.7	36.2	43.73	51.45	33.93	36.19	60.55	50.58

Carbon footprint unit is kg CO_2 equivalent

and by minimizing patient travel via the use of environmentally friendly vehicles and fuels (Table 4). In our study, comparison between short-course radiotherapy (SCRT, 25 Gy/5 fractions) and long-course radiotherapy (LCRT, 50 Gy/25 fractions) revealed that LCRT generated a significantly higher carbon footprint than SCRT (p=0.004). This finding aligns with results from Shenker et al.,[16] who reported higher carbon equivalents per course in LCRT (mean 11.32 kg CO_2e, range 4.29–20.41) compared to SCRT (mean 4.36 kg CO_2e, range 1.95–5.00), although their study did not account for transportation or hospitalization-related emissions.[16] In our analysis, when excluding emissions related to imaging, hospitalization, medical treatments, and travel, LCRT's carbon footprint remained elevated due to the longer number of treatment days. This underscores the importance of adopting hypo fractionated regimens as a key step toward decarbonization.

Given the anticipated adverse effects of global warming and climate change—including increased mortality risk—it is plausible that treatment methods which reduce carbon footprints may indirectly mitigate these harms. Shortening the radiotherapy course can lower emissions and treatment burden, while also enhancing patient quality of life. Consequently, such approaches could positively influence Disability-Adjusted Life Years (DALYs) by simultaneously improving cancer outcomes and reducing environmental impact. Hypofractionation offers multiple benefits, including reducing the carbon footprint, shortening hospital stays, decreasing productivity losses, and lowering infection risks. It also improves patient comfort and decreases healthcare costs. Our findings are consistent with those of Moore et al.,[17] Dupraz et al.,[8] and Zhou et al.,[18] who demonstrated that hypofractionation, while maintaining clinical efficacy, reduces carbon emissions by shortening treatment duration.

When examining SCRT patients, inpatient treatment was associated with a lower carbon footprint compared to outpatient treatment (Fig. 2). This suggests that frequent travel for outpatient treatments increases carbon emissions relative to inpatient care where patients are monitored continuously. Contrarily, Nansai et al.[19] reported higher carbon emissions from inpatient oncology services compared to outpatient ones. This discrepancy likely arises because their analysis included multiple clinics with varying treatment intensities, potentially skewing the average inpatient emissions upward.

Our study also highlights the critical impact of treatment centre proximity on carbon emissions. Patients traveling long distances daily by private vehicle incur higher carbon footprints. Therefore, it is advisable to treat patients at centres close to their residences, and where centres are lacking, new facilities should be established. Among outpatients receiving short-course radiotherapy (SCRT), those who used public transportation had a lower carbon footprint compared to those who travelled by private vehicle. This finding aligns with the results reported by Frick et al.,[20] who similarly demonstrated that the use of public transport is associated with reduced carbon emissions. In their study, Frick et al.[20] observed that patients undergoing long-course radiotherapy (LCRT) travelled an average of 1,417 miles, whereas those receiving SCRT travelled an average of 319 miles—a statistically significant difference (p<0.001). These findings are consistent with our results.

In our study, radiotherapy and imaging modalities were the largest contributors to carbon emissions during treatment, followed by travel-related emissions. Heating and electricity consumption ranked third, while medical and non-medical consumables accounted for the smallest proportion (Fig. 3). These findings are in agreement with Nicolet et al.,[14] who reported that road-related emissions constituted the

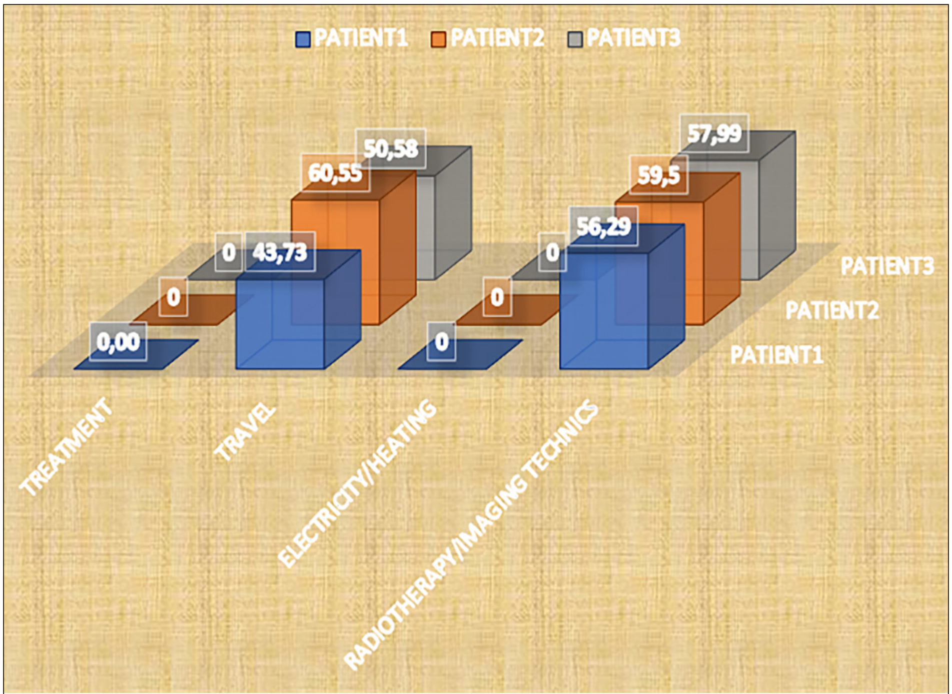

Fig. 2. Distribution of outpatient carbon footprint sources.

highest share (33.2%) of total carbon emissions during treatment, followed by heating and electrical systems (30.1%). Similarly, Chuter et al.[13] found that road-related carbon emissions ranged between 72.9 and 227.9 kg CO_2e per patient, accounting for 70–80% of total emissions. Notably, idle power consumption of radiotherapy devices constituted the second largest emission source (8–19%). Had their measurements included device usage during treatment, results may have mirrored ours.

Limitations

- Emission factors used in this study are country-specific and vary internationally. While this variability is acknowledged, it is not expected to significantly affect the core variables constituting the carbon footprint. Calculations were based on a general methodology intended to be applicable worldwide, and findings were compared with international studies. To date, no recent carbon footprint studies in the healthcare field have been conducted in Türkiye.
- The study included patients who did not receive chemotherapy due to advanced age or comorbidities to maintain homogeneity and isolate the effect of radiotherapy. This criterion resulted in a small sample size, reflecting the limited number of eligible patients.

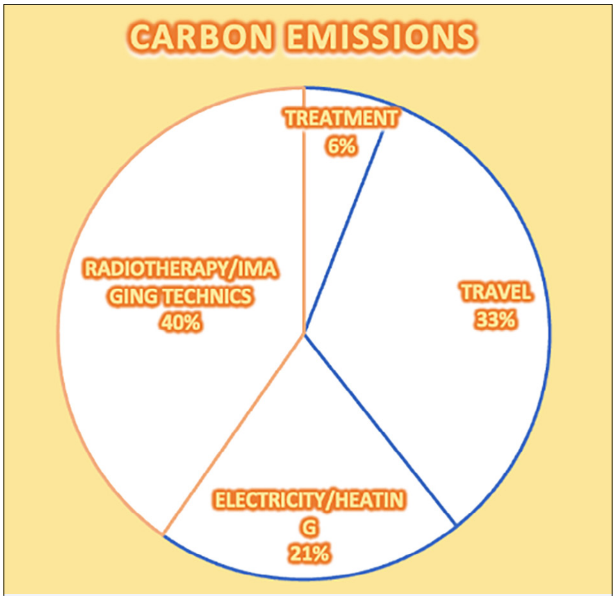

Fig. 3. Percentage of carbon footprint sources.

- SF6 leakage is typically calculated on an annual basis. For this study, annual SF6 emissions were converted to per-minute values to estimate leakage for each treatment fraction virtually.
- The carbon footprint associated with hospital cleaning during patient hospitalization was not included in the calculations.

Turk J Oncol 2025;40(3):190–199
doi: 10.5505/tjo.2025.4565

CONCLUSION AND SUGGESTIONS

This study compared the carbon footprints of two radiotherapy methods, identifying patient radiotherapy and travel as the primary contributors to total emissions. The substantial carbon impact of patient travel highlights the importance of hypo fractionated treatments, where clinically appropriate, alongside the promotion of public transportation use. Encouraging the use of vehicles powered by environmentally friendly fuels is also essential.

To further reduce emissions, clinic appointments should be coordinated and scheduled on the same day to minimize patient visits. For patients living far from treatment centres, hypo fractionated radiotherapy not only reduces the carbon footprint but also decreases hospitalization time. Additionally, establishing radiotherapy units in multiple locations connected to hospitals, but separate from main hospital buildings, can enable patients to receive treatment closer to home. If opening new units is not feasible, providing nearby patient accommodations, such as hostels, could be a viable alternative.

These findings offer valuable insights and can serve as a foundation for future initiatives aimed at lowering carbon emissions within the healthcare sector, promoting more sustainable healthcare delivery and living.

Ethics Committee Approval: The study was approved by the Erzurum Faculty of Medicine Scientific Research Ethics Committee (no: 2024/182, date: 11/09/2024).

Informed Consent: Informed consent was obtained from all participants.

Conflict of Interest Statement: The authors have no conflicts of interest to declare.

Funding: The authors declared that this study received no financial support.

Use of AI for Writing Assistance: No AI technologies utilized.

Author Contributions: Concept – S.Z., A.Z.; Design – S.Z., A.Z., Y.Ö.; Supervision – S.Z., A.Z.; Data collection and/or processing – S.Z., A.Z., Y.Ö.; Data analysis and/or interpretation – S.Z., A.Z.; Literature search – S.Z., A.Z., Y.Ö.; Writing – S.Z.; Critical review – S.Z., A.Z., Y.Ö.

Peer-review: Externally peer-reviewed.

REFERENCES

1. Irmak H, İlter H, Ceran A, Eyler N, Pamuk R, Özdemir E, et al. National Program and Action Plan for Reducing the Adverse Effects of Climate Change on Health, 1st ed. Şencan İ, ed. Ankara: Anıl publication - Health Ministry; 2015.
2. Campbell-Lendrum D, Neville T, Schweizer C, Neira M. Climate change and health: Three grand challenges. Nat Med 2023;29(7):1631–8.
3. Karliner J, Slotterback S, Boyd R. Health care's climate footprint report, Health Care Without Harm website ARUP, 2019. Available at: https://global.noharm.org/media/4370/download?inline=1. Accessed Nov 2,2024.
4. Rodríguez-Jiménez L, Romero-Martín M, Spruell T, Steley Z, Gómez-Salgado Ji. The carbon footprint of healthcare settings: A systematic review. J Adv Nurs 2023;79(8):2830–44.
5. Turkish Statistical Institute. Health expenditure statistics, 2022. Available at: https://data.tuik.gov.tr/Bulten/Index?p=Health-Expenditure-Statistics-2022-49676. Accessed Mar 21, 2024.
6. Zhou ZR, Liu SX, Zhang TS, Chen LX, Xia J, Hu ZD, et al. Short-course preoperative radiotherapy with immediate surgery versus long-course chemoradiation with delayed surgery in the treatment of rectal cancer: A systematic review and meta-analysis. Surg Oncol 2014;23(4):211–21.
7. Deniz EB. Cancer epidemiology. Turkey Health Lit J 2022;3(2):102–11.
8. Dupraz C, Ducrot C, Allignet B, Delpon G, Alexis A, Lapierre A, et.al. The carbon footprint of external beam radiotherapy and its impact in health technology assessment. Clin Trans Rad Oncol 2024;48:100834.
9. Lacroute J, Marcantoni J, Petitot S, Weber J, Levy P, Dirrenberger B, et al. The carbon footprint of ambulatory gastrointestinal endoscopy. Endoscopy 2023;55(10):918–26.
10. Kılıç MY, Dönmez T, Adalı S. Change of carbon footprint due to fuel consumption: Çanakkale case study. GUSTIJ 2021;11(3):943–55.
11. Republic of Turkey Ministry of Energy and Natural Resources. Turkey electricity production and electricity consumption point emission factors Information Form. Available at: https://enerji.gov.tr//Media/Dizin/EVCED/tr/ÇevreVeİklim/İklimDeğişikliği/EmisyonFaktorleri/2022_Uretim_Tuketim_EF.pdf. Accessed Mar 10, 2024.
12. Department for Energy Security and Net Zero. Greenhouse gas reporting: Conversion factors 2024. Available at: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2024). Accessed Mar 09, 2024.
13. Chuter R, Stanford-Edwards C, Cummings J, Taylor C, Lowe G, Holden E, et al. Towards estimating the carbon footprint of external beam radiotherapy. Phys Med 2023;112:102652.
14. Nicolet J, Mueller Y, Paruta P, Boucher J, Senn N. What is the carbon footprint of primary care practices? A retrospective life-cycle analysis in Switzerland. Environ Health 2022;21:1–10.

15. Rizan C, Reed M, Bhutta MF. Environmental impact of personal protective equipment distributed for use by health and social care services in England in the first six months of the COVID-19 pandemic. J Royal Soc Med 2021;114(5):250–63.
16. Shenker RF, Johnson TL, Ribeiro M, Rodrigues A, Chino J. Estimating carbon dioxide emissions and direct power consumption of linear accelerator–based external beam radiation therapy. Adv Rad Oncol 2023;8(3):101170.
17. Moore P, Danchenko N, Weidlich D, Tijerina AR. Cost-effectiveness of abobotulinumtoxinA plus best supportive care compared with best supportive care alone for early treatment of adult lower limb spasticity following an acute event. Plos One 2024;19(2):e0296340.
18. Zhou K, Renouf M, Perrocheau G, Magné N, Latorzeff I, Pommier P, et al. Cost-effectiveness of hypo fractionated versus conventional radiotherapy in patients with intermediate-risk prostate cancer: An ancillary study of the PROstate fractionated irradiation trial - PROFIT. Radiother Oncol 2022;173:306–12.
19. Nansai K, Fry J, Malik A, Takayanagi W, Kondo N. Carbon footprint of Japanese health care services from 2011 to 2015. Resour Conserv Recycl 2020;152:104525.
20. Frick MA, Baniel CC, Qu V, Hui C, Brown E, Chang DT, et al. Effect of radiation schedule on transportation-related carbon emissions: A case study in rectal cancer. Adv in Rad Oncol 2023;8(5):101253.