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A holistic approach to climate change in the emergency department: Direct impact of environmental factors on patients

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Abstract:

Climate change is no longer a distant threat but a present and escalating burden on emergency departments (EDs) worldwide. Its direct and indirect effects, ranging from heatstroke and hypothermia to vector-borne disease resurgence and mass casualty incidents, challenge conventional models of emergency preparedness. This narrative review explores the intersection of climate dynamics with ED operational and clinical vulnerabilities. We summarize five core physiological mechanisms by which temperature extremes disrupt homeostasis and review high-risk medication classes that may exacerbate heat-related morbidity. In addition, we examine the World Health Organization's mass casualty triage framework and its relevance in climate-driven disasters such as floods, wildfires, and explosions. Special attention is given to low-resource settings and migration-heavy regions, where infrastructure strain and health inequity amplify the impact. We propose integrative, anticipatory planning models that combine clinical vigilance, environmental monitoring, and dynamic triage protocols. By identifying EDs as both front-line responders and sentinel systems, this study underscores the urgency of embedding climate resilience into emergency care strategies. Our synthesis aims to support clinicians, policymakers, and health systems in adapting emergency services to the realities of a warming world.

Keywords:

Adaptation, climate change, emergency department, hyperthermia, hypothermia, impact, normothermia, vulnerability

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Introduction

Since the Industrial Revolution, global temperatures have steadily risen, with the National Aeronautics and Space Administration (NASA) reporting an increase of at least 1.1°C since 1880.[1] A child born today will experience a world that is, on average, four degrees warmer throughout every stage of life, from infancy and adolescence to adulthood and old age, compared to the preindustrial era.[2] According to the World Health Organization (WHO), climate change is expected to cause approximately 250,000 additional deaths per year between 2030 and 2050 due to malnutrition, malaria, diarrhea, and heat stress.[3] These projections are based on the direct impact of climate change on disease dynamics. However, rising temperatures affect not only human health but also the chemical, biological, and radiological components of the environment. Therefore, it is crucial to understand not only the direct effects of temperature changes on human health and disease dynamics but also their indirect impact on environmental risk factors.

The phenomenon of climate change, with its complex and irreversible variations, influences both living organisms and inanimate materials in contact with humans. To comprehensively evaluate the impact of climate change on human health, it is essential to consider the interplay between climate, the environment, and materials, while also thoroughly understanding human pathophysiology. Recognizing these challenges, the American College of Emergency Physicians highlighted the importance of strengthening collaboration between emergency medicine and public health in climate change research in its 2018 policy statement.[4] This document laid the foundation for strategies to mitigate the effects of climate change and enhance resilience against its growing health impacts.

The health impacts of climate change are regionally diverse, shaped by local climate patterns, population vulnerabilities, and healthcare infrastructure. This review is designed to provide emergency physicians with a comprehensive understanding of the impact of climate change on patients they encounter in clinical practice. It aims to examine the effects of climatic conditions on human health, the pathophysiological changes that climate change may induce in human metabolism, and the consequences of extreme heat and cold exposure. In addition, it explores the environmental factors that may become pathological threats due to climate change. By integrating these aspects, this review evaluates the impact of climate change on emergency departments (EDs), their capacity for adaptation, and their vulnerability, using the core framework of impact, adaptation, and vulnerability.

Methodology

This narrative review was conducted to synthesize multidisciplinary evidence on the direct and indirect effects of climate change on EDs, including impacts on clinical practice, patient physiology, environmental risks, and health system operations. Although narrative in nature and not constrained by a rigid systematic protocol, this review employed a structured thematic framework to ensure clarity and coherence in analysis.[5] Selected elements from the PRISMA-ScR checklist were used to enhance reporting transparency and methodological rigor, where applicable.[6]

Objectives and scope

The primary objective of this narrative review is to explore the multifaceted relationship between climate change and EDs, with a focus on clinical, operational, and environmental dimensions. Recognizing the ED as both a frontline responder and a vulnerable system, this review aims to synthesize current evidence on how climate dynamics influence patient presentations, disease mechanisms, environmental hazards, and emergency healthcare infrastructure.

Search strategy

A comprehensive literature search was conducted between November 1, 2024, and March 1, 2025, to identify publications addressing the intersection of climate change and emergency medicine. The review focused on literature published between January 1, 2000, and February 2025, during which this topic had been increasingly explored. Earlier seminal studies were included selectively when cited in updated guidelines or review articles.

The search encompassed PubMed, MEDLINE, Embase, Scopus, Web of Science, and Google Scholar, complemented by gray literature sources and institutional repositories (WHO, Centers for Disease Control and Prevention [CDC], United Nations High Commissioner for Refugees, Intergovernmental Panel on Climate Change, Federal Emergency Management Agency). The search employed a combination of Medical Subject Headings (MeSH) and free-text terms such as Emergency Department, Climate Change, Hyperthermia, Hypothermia, Disaster Medicine, Mass Casualty Incident, Carbon Footprint, Environmental Exposure, Air Pollution, CBRN-E, and Climate Resilience.

To enhance transparency, we have described the general inclusion criteria as English-language publications addressing clinical, operational, or environmental impacts of climate change on emergency medicine. Exclusion criteria comprised single case reports, nonhealth topics, and outdated documents superseded by newer guidance. While this work was designed as a narrative review, selected PRISMA-ScR elements (clarity of search scope and inclusion process) were adopted to ensure reporting transparency. No formal quality appraisal or quantitative synthesis was performed, consistent with the narrative nature of this review.

Terminology

Climate change is generally defined as a long-term shift in climate patterns, such as temperature, precipitation, and wind, occurring over decades or longer. While major organizations like the Environmental Protection Agency, WHO, International Union for Conservation of Nature, and NASA offer slightly different formulations, they converge on the idea of persistent, large-scale alterations in the Earth's climate system, driven by both natural variability and human activity.[7-9] Although different terminologies are used, climate change emerges as a complex phenomenon composed of multiple interconnected components. These variables include changing climate conditions, long-term temperature increases and decreases, and their effects on living organisms [Figure 1].

The Earth is warming due to high greenhouse gas concentrations and is expected to continue warming in the future. Since 1895, when temperature records began, average temperatures in the United States have risen by 1.3°F to 1.9°F, with heat waves becoming more frequent and intense, while cold waves have declined.[10] This gave rise to the term "Global Warming," which, though widely used, has often been misunderstood. While it highlights rising temperatures and long-term ecological effects, it fails to capture the full scope of climate change, particularly cold-related dynamics and broader climatic shifts. A comprehensive understanding requires attention to both heat and cold extremes and their evolving effects on human health and disease. This is critical for designing effective adaptation and mitigation strategies in health care and emergency response systems.

Climate Change and the Pathophysiology of Thermoregulation

For optimal metabolic function, a healthy individual must maintain a core body temperature within a narrow range of 37 ± 0.5°C (98.6 ± 0.9°F).[11] As a key vital parameter in clinical assessments, core body temperature, typically ranging between 36.5°C and 37.5°C, is generally 1°C–2°C higher than skin temperature and reflects the temperature of internal organs.[11,12] Thermoregulation is the homeostatic mechanism that ensures core temperature stability regardless of external conditions by balancing heat production and heat loss. While core body temperature is regulated by the hypothalamus, the skin, as the largest organ of the human body, plays a critical role in heat loss, accounting for approximately 90% of total heat dissipation.[13] This is because the skin serves as the primary interface with environmental factors, making it highly influential in thermoregulation.

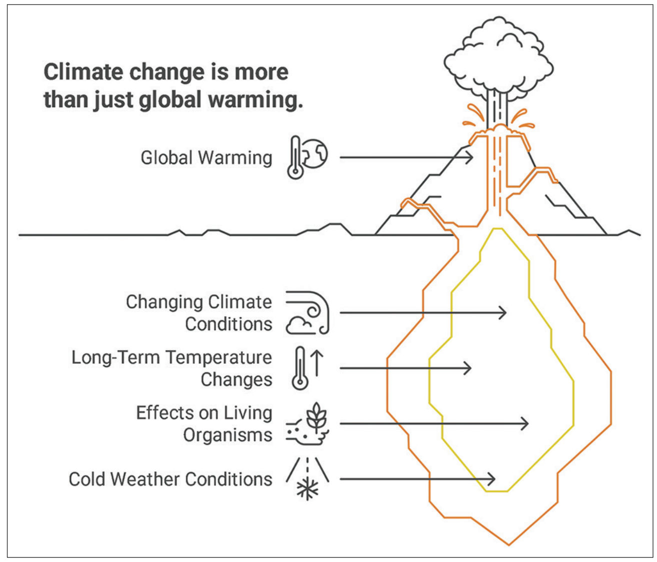

Figure 1: Climate change is more than just global warming

Heat loss occurs through four primary mechanisms: radiation, evaporation, convection, and conduction. These mechanisms regulate hypothermia, normothermia, and hyperthermia, playing a central role in human thermoregulation. The air temperature surrounding the body is a fundamental determinant of core temperature regulation, given that air is the primary environmental element that interacts with the skin.

To understand the impact of air temperature on human metabolism, an important parameter to consider is the heat index.[14] The heat index represents the perceived temperature by the human body when relative humidity is combined with ambient temperature. Thermoreceptors activated by the heat index stimulate physiological mechanisms that respond to temperature variations. Understanding the physiological and systemic consequences of core temperature changes due to the heat index can facilitate the management of climate change-related patient population and contribute to the development of new clinical strategies.

As shown in Supplementary Table 1, rewarming strategies vary by severity of hypothermia and include both external and internal approaches. The five primary physiological mechanisms triggered by core temperature changes are direct consequences of environmental temperature fluctuations and the heat index effect.[15-17] Clinicians must recognize that the impact of decreasing core temperature extends beyond thermoregulation. For instance, reduced thyroid hormone secretion affects not only thermoregulation but also overall metabolism, influencing multiple physiological systems. Decreased sympathetic activity and catecholamine release can lead to a dominance of the parasympathetic nervous system, further altering systemic responses. Thus, climate change is associated not only with increased temperatures but also with abnormally reduced temperatures.

The Effects of Climate Change on the Emergency Department and Its Flora

A comprehensive approach to climate change necessitates evaluating both its clinical impact on patients presenting to EDs and its influence on the environmental conditions in which they live. At first glance, environmental effects related to climate change may not have yet manifested as diseases in individuals, but their presence as risk factors places them within the realm of public health concerns. However, understanding these sources is crucial for emergency physicians in determining the etiology of a patient's condition and developing appropriate treatment strategies. In addition, when discharging patients from the ED, it is essential to consider ways to distance them from these environmental risks. For this reason, every condition caused by climate change that leads to illness and subsequently results in ED visits should be evaluated within a holistic approach. This requires a thorough assessment of climate change-related factors affecting ED care areas, patients themselves, and their surrounding environments.

Impact of climate change on emergency department patients and diseases

A comprehensive assessment of climate change's impact on ED patients should consider both patient-related factors and environmental risks. Direct effects refer to pathological conditions caused by disrupted thermoregulation, including hyperthermia, normothermia, and hypothermia. Indirect effects involve CBRN-E hazards, positioning climate change as a contributing risk factor for such incidents.

These impacts manifest differently across the globe. Vector-borne and zoonotic diseases have expanded in tropical and subtropical regions; cold waves continue to affect Northern and Eastern Europe; wildfires challenge emergency response systems in North America and the Mediterranean Basin; and hurricanes and typhoons remain major threats in Pacific regions. In Türkiye and comparable Mediterranean–continental climates, the combination of heat waves, flash floods, and climate-related migration exerts growing pressure on EDs.

Hyperthermia

As global temperatures rise, increasing heat and humidity elevate the risk of heat stress, with each 1°C rise associated with a 6%–7% increase in atmospheric water vapor.[18] In this context, the heat index becomes a critical parameter in assessing physiological strain. To accurately evaluate hyperthermia in emergency settings, it is essential to distinguish it from fever and heat stroke, which are frequently conflated.

A. Fever: Normal body temperature fluctuates by approximately 0.5°C throughout the day.[19] Fever is frequently confused with hyperthermia, yet it reflects a regulated hypothalamic response to inflammation, involving a deliberate rise in the set-point temperature. In contrast, hyperthermia results from failed thermoregulation, with an uncontrolled rise in core temperature independent of hypothalamic control[20]

B. Hyperthermia: Hyperthermia is defined as a rise in body temperature beyond the normal daily range, with values above 40.5°C (105°F) typically indicating severe hyperthermia. The increasing frequency and intensity of heat waves associated with climate change have amplified both the incidence and severity of heat-related illnesses, underscoring hyperthermia as a growing concern in public health and emergency medicine[21]

C. Heat stroke: Heat stroke is diagnosed when three criteria are met: a core body temperature above 40.5°C (105°F), an external heat load that cannot be adequately dissipated, and central nervous system dysfunction.[22] When triggered by environmental exposure rather than physical exertion, it is termed nonexertional heat stroke. To understand its physiological limits, the concept of critical thermal maximum (CTM) is used, which assesses the highest tolerable body temperature and the duration of exposure before cellular injury occurs.[23] As most CTM data come from animal studies, human thresholds are estimated to be 1°C–2°C lower. This reinforces two key principles in the acute management of heat stroke: rapid cooling and early transport.

Antipyretics are ineffective in reducing body temperature in cases of hyperthermia. The treatment of hyperthermia primarily aims to rapidly lower body temperature through physical cooling methods. In addition, identifying the underlying cause of hyperthermia is crucial, as the treatment approach varies depending on the etiology.

The treatment of heat stroke begins in the prehospital phase, as the fundamental principle is "treat first, then transport." Therefore, international guidelines have been established. As of the 2024 update, the Wilderness Medical Society Clinical Practice Guidelines for the

Prevention and Treatment of Heat Illness represent the most current recommendations for prevention, prehospital care, and ED treatment; the key principles are summarized in Table 1 (adapted from Eifling *et al.*).[24]

Recent large-scale epidemiological data reinforce the clinical relevance of hyperthermia in emergency care. For example, in Clark County, Nevada, 3548 heat-related ED visits were recorded in 2024, with a July peak paralleling extreme ambient temperatures.[25] A meta-analysis of over 22 million ED visits across 2939 US counties found a 66.3% increase in heat-related visits during extreme heat days, defined as the 95th percentile of local warm-season temperatures.[26] Older adults with multiple comorbidities were particularly vulnerable, with ORs exceeding 1.08 during prolonged 2-day heat events.[27] Urban heat islands and rural areas with limited resources also exhibited disproportionately higher ED burden.[28,29] These findings emphasize that hyperthermia is not merely a theoretical risk of climate change, but an increasingly frequent driver of ED utilization among heat-exposed population.

Hypothermia

Although global climate change is generally associated with rising temperatures, it also significantly influences cold weather conditions. Under current climate conditions, it is estimated that approximately 10 million people are exposed annually to severe cold waves that would typically occur once every 50 years. However, with a global temperature increase of 1.5°C, this number is projected to decrease to 5 million by 2100; with a 2°C increase, to 2.7 million; and with a 3°C increase, to 1.2 million.[30]

Rising temperatures are also expected to increase the frequency and severity of extreme weather events such as storms, floods, tornadoes, and hurricanes. As a result, hypothermia will likely remain a common condition encountered by emergency physicians, not necessarily due to cold climate exposure alone, but as a paradoxical consequence of environmental extremes. Therefore, despite being less frequent today, accidental hypothermia may continue to present commonly in EDs due to the changing etiology associated with climate change.[31]

Contrary to perceptions of global warming reducing cold-related emergencies, hypothermia continues to pose a significant seasonal burden. US data from 1995 to 2004 estimated 15,574 cold-related ED visits, with uninsured individuals over twice as likely to present with hypothermia (rate ratio [RR] = 2.44).[32,33] Cold snaps are associated with delayed spikes in ED use for both hypothermia and cardiovascular illness, particularly in rural and infrastructurally underserved areas.[34,35]

Table 1: Emergency department management strategies for heat-related illnesses (Adapted from Eifling *et al.*, Wilderness Medical Society Clinical Practice Guidelines, 2024)[24]

Category	Recommendations
Risk assessment	Preferably use the WBGT index; if unavailable, use the heat index
Temperature measurement	Core temperature should be measured rectally and monitored continuously. Initiate cooling empirically in altered patients even if core temperature <40°C
Time criteria	Morbidity correlates with hyperthermia duration. Initiate cooling immediately; target <30–60 min if feasible
Target temperature	Actively cool to 38.3°C–38.8°C
Prehospital management	Ensure ABC. Start cooling on scene and continue during transport if risk persists
Cooling methods	First-line: Cold Water Immersion – fastest and most effective method. Second-line: Evaporative cooling if immersion not feasible. Adjuncts: Chemical ice packs may be used (preferably on cheeks, palms, soles if limited)
Hydration	Administer isotonic IV fluids: 1–2 L for adults; 20 mL/kg for children
Pharmacologic agents	Antipyretics (e.g., dantrolene) are not recommended, as the hypothalamic set-point is not elevated
ED transfer criteria	Transport if: (1) no field cooling was applied, (2) patient fails to return to baseline, or (3) fever persists despite cooling
ED treatment – primary goals	Use cold water immersion (e.g., body bag + ice/tap water method) to reduce temperature <39°C in ~10 min
ED treatment – secondary goals	Rapid cooling and multi-organ support. Monitor for complications including shock, AKI, liver injury, DIC, and intestinal ischemia
Alternative methods	Cold IV fluids may support cooling but are not first-line. Avoid body cavity lavage, external cooling systems, or blankets as primary interventions
Supportive care	Oxygen, airway protection, volume resuscitation, bladder catheterization, urine output monitoring, and vasopressors if needed

ABC: Airway, breathing, and circulation, EDs: Emergency departments, AKI: Acute kidney injury, DIC: Disseminated intravascular coagulation, WBGT: Wet-Bulb Globe Temperature

Elderly adults and infants remain the most affected, underscoring the need for targeted prevention strategies during winter.[36]

Accidental hypothermia

In trauma and environmental exposure, accidental hypothermia contributes to the lethal triad of coagulopathy, acidosis, and hypothermia, requiring prompt recognition and management in the ED. It is defined as a core temperature below 35°C (95°F).[37] In suspected cases, clinicians should assess severity by measuring core temperature, interpret associated physiological and laboratory changes, consider differential diagnoses, and initiate early treatment.

Heat is generated by cellular metabolism (most notably in the heart and liver) and reduced via the skin and lungs, maintaining a thermal balance. When core temperature decreases, baroreceptor modulation in the body may initially activate the sympathetic system, increasing systolic blood pressure, respiratory rate, and pulse; however, further decline may abolish these reflex mechanisms.[38] Early metabolic activation seen in blood parameters may, over time, shift toward increased catabolism and ultimately result in death. Therefore, early recognition and rapid management of hypothermia are essential.

Accurate core temperature measurement is essential in hypothermia management. While pulmonary artery readings are the gold standard, their use is limited to select critical care settings.[39] In emergency care, esophageal probes are preferred in intubated hypothermic patients and are among the most recommended current methods for dynamic core temperature monitoring.[24] Epitympanic thermometers provide a practical alternative in conscious patients and are designed to reflect carotid artery temperature, though accuracy may be affected in low-perfusion states.[40] Compared to rectal, bladder, or surface measurements, esophageal and epitympanic methods offer superior accuracy in both prehospital and ED settings.[24,41]

Core temperature measurement guides transport and treatment decisions in prehospital, mountain rescue, and ED settings. However, accuracy can be limited by environmental, device-related, and patient-related factors.[42] Therefore, clinical findings are used to support risk assessment. As shown in Table 2, both the Wilderness Medical Society Classification and Revised Swiss System emphasize clinical evaluation to stage hypothermia.[43] The presence of shivering often indicates a core temperature above 30°C, while unconsciousness and absent vital signs suggest a high risk of cardiac arrest. The Revised Swiss System incorporates the AVPU scale to assess consciousness and predict this risk.[41]

Diagnosing cold-related pathologies and guiding rewarming strategies in the ED can be challenging, particularly given the technical limitations of some diagnostic tools and the variability in underlying causes. Therefore, both diagnostics and treatment must be selected rationally based on available resources. In prehospital settings, unheated intravenous (IV) fluids can worsen hypothermia and should be avoided. The 2023 AHA Focused Update on Adult Advanced Cardiovascular Life Support (ACLS) highlights rewarming as a key component of postcardiac arrest temperature management.[44] While no clear advantage has been shown between passive and controlled rewarming at 0.25°C–0.5°C/h, current evidence suggests controlled rewarming is safer. This slow rewarming rate is generally recommended in practice, though more rapid rewarming may be required in cases of active bleeding or severe cardiac instability. Supplementary Table 2 summarizes diagnostic and rewarming strategies relevant to ED settings.[45] Conversely, in the prehospital setting, early cooling with rapid infusion of cold fluids in patients with shockable rhythms has been studied to hasten target temperature achievement; however, no significant improvement in survival or neurological outcomes has been demonstrated. This may be attributed to factors such as limited personnel, inadequate monitoring, and lack of airway control. As a result, guideline recommendations regarding prehospital rapid cooling have remained unchanged since 2015.

Hypothermic patients require distinct management principles. First, no hypothermic patient should be declared dead until rewarming is complete; exceptions include fatal injuries such as decapitation or chest wall rigidity precluding compressions.[46] These field criteria also apply in the ED. Second, death indicators like fixed pupils or apparent rigor mortis may be unreliable.[47] Third, arrhythmias are common and often persist until rewarming. Fourth, defibrillation should be attempted a maximum of three times if core temperature is below 30°C, and deferred until warming exceeds that threshold. Fifth, ACLS drugs such as epinephrine and amiodarone should not be given below 30°C. Once the temperature reaches 30°C, defibrillation and medications may resume, with extended epinephrine

Table 2: Classification of hypothermia by decreasing core temperature (Adapted from WMS and Revised Swiss System)[43]

System	Category/stage	Temperature (°C/°F)	Clinical features
Nonhypothermic	Cold-stressed	35–37°C/95–98.6°F	Shivering present; alert; able to care for self
Wilderness Medical Society	Mild hypothermia	32–35°C/90–95°F	Shivering present; unable to self-care
	Moderate hypothermia	28–32°C/82–90°F	Altered consciousness; may or may not shiver
	Severe hypothermia	<28°C/<82°F	Unconscious; no shivering
Revised Swiss system	Stage 1	35–32°C/95–89.6°F	AVPU: Alert
	Stage 2	32–28°C/89.6–82.4°F	AVPU: Responds to verbal stimuli
	Stage 3	28–24°C/82.4–75.2°F	AVPU: Pain or unresponsive; vital signs present
	Stage 4	<24–13.7°C/<75.2–56.7°F	AVPU: Unresponsive; no detectable vital signs

AVPU: Alert, verbal, pain, unresponsive

dosing intervals (every 6–10 min), returning to standard intervals (every 3–5 min) at 35°C. This approach minimizes drug accumulation and toxicity due to hypothermia-induced metabolic slowing.

Identifying vulnerable groups is essential in hypothermia management. These include elderly patients, those with chronic conditions like hypothyroidism, individuals on temperature-sensitive medications, and children with immature thermoregulatory responses. Patients unable to express shivering or altered consciousness should also be considered high-risk. It is a common misconception that accidental hypothermia offers organ protection similar to therapeutic hypothermia. Unlike the controlled setting of therapeutic hypothermia, used to reduce neuronal injury during ischemia, accidental hypothermia involves unregulated exposure to harmful metabolic and physiological responses.[48]

Normothermia

While examining the impact of climate change-induced temperature variations on the heat index and core body temperature, parallels can be drawn between extreme weather events and physiological responses such as hyperthermia and hypothermia. Core temperature regulation depends on the balance between heat production and dissipation. Studies show that cooler cities experience greater increases in mortality and hospitalizations with rising temperatures than warmer ones.[49] Thus, climate-related deaths reflect not only temperature extremes but also inadequate physiological adaptation. According to the WHO, the health impact of climate change depends on population vulnerability, resilience, and adaptation capacity.[3]

Adaptation is essential for maintaining homeostasis. Beyond identifying heat-related illnesses, there is a need to define "heat-sensitive conditions" and monitor their adaptation. Even within normal core temperature ranges, high temperatures correlate with ischemic heart disease, stroke, asthma, renal failure, neuropsychiatric disorders, and adverse birth outcomes.[50]

In addition, the interaction between medications and temperature regulation is bidirectional: drugs can impair thermoregulation, and temperature changes can alter drug metabolism.[51] CDC has identified commonly used medications in EDs that may increase the risk of heat-related illness through mechanisms such as impaired thermoregulation, volume depletion, or electrolyte imbalance [Table 3].[52] Therefore, medication history is critical in identifying the vulnerable population. Chronic disease epidemiology and treatment strategies must be re-evaluated in the context of climate change.

Environmental Impact of Climate Change (Secondary Disease Risks Related to Climate Change)

We first examined the impact of EDs on climate change and their interrelationship, followed by an analysis of how climate-driven temperature variations affect human health and disease patterns. In this third section, we evaluate environmental hazards linked to climate change, specifically CBRN threats, and the consequences of related explosions on emergency care. This includes both the rising frequency of natural disasters like storms, floods, tornadoes, and wildfires, and the transformation of common environmental substances into CBRN-E threats due to climate change.

Environmental impact of climate change: Natural hazards

According to the United Nations International Strategy for Disaster Reduction, a natural disaster is defined as a natural process or phenomenon that may cause loss of life, injury, property damage, or environmental and social disruption.[53] More recently, the term natural hazard has replaced "disaster" in this context. Climate change contributes to such hazards by influencing temperature, sea levels, drought, floods, and more, thereby affecting water, energy, transportation, agriculture, ecosystems, and indirectly, human health.[54]

Emergencies caused by natural hazards (e.g., earthquakes, floods, hurricanes), technological failures (e.g., chemical spills), conflict-related crises, and outbreaks all pose serious public health risks.[55] The WHO reports that climate change has contributed to an increase in the frequency, severity, and impact of such disasters.[56] Notably, floods and storms account for 68% of the disaster-affected population worldwide.[57]

Table 4 summarizes extreme weather events and their climate-related etiologies. In the early phase of such events, EDs may be structurally compromised, stressing the need for physical resilience and disaster preparedness. Although climate change's link to earthquakes is unclear, lessons from past earthquake responses offer valuable insights into disaster planning. Accordingly, ED preparedness must focus on managing MCIs caused by climate-related extreme weather. Climate-related extreme weather events directly shape medical disaster management. Yilmaz *et al*. illustrated this with an earthquake case, outlining a stepwise model including search and rescue, prehospital care, ED management, and definitive treatment [Supplementary Table 3].[85] Following disasters, ED patients may present with both physical trauma and psychological distress due to the loss of homes, family, and livelihood.[86,87]

Table 3: Commonly used/encountered medications in emergency departments that may increase the risk of harm on hot days and their mechanisms[52] (Reproduced from Centers for Disease Control and Prevention, public domain)

Medication type	Drug class and Examples	Mechanisms
Cardiovascular drugs	Diuretics	Electrolyte imbalance, volume depletion, dehydration, increased risk of syncope and falls – trauma reduced thirst sensation
	Beta-blockers	Decreased peripheral vasodilation, decreased sweating, lower blood pressure, increased risk of syncope and falls – trauma
	Calcium Channel Blockers	Reduced blood pressure, increased risk of syncope and falls, electrolyte imbalance
	ACEi and ARBs	Decreased blood pressure, increased risk of syncope and falls, reduced thirst sensation
	Antiplatelet	Decreased peripheral vasodilation
	Antianginals	Worsened hypotension
Antiseizure	Topiramate, oxcarbazepine, and carbamazepine	Decreased or increased sweating, dizziness and weakness following dose escalation
Antihistamines with anticholinergic	Promethazine, doxylamine, and diphenhydramine	Decreased sweating, impaired thermoregulation
Analgesics	NSAIDs	Kidney damage when combined with dehydration
	Aspirin	Increased heat production with overdose, kidney damage when combined with dehydration
	Acetaminophen	Heat-related liver injury increases risk of acetaminophen hepatotoxicity
Antibiotics	Sulfonamides	Risk of kidney damage when dehydrated
Stimulants	Cocaine	Decreased sweating, reduced skin vasodilation, impaired heat perception
	Amphetamine and methylphenidate	Increased body temperature
Alcohol	Ethanol	Increased sweating, increased urination, impaired heat perception
Hallucinogens	MDMA	Decreased sweating, reduced skin vasodilation, impaired heat perception
Thyroid replacement therapy	Levothyroxine	Excessive sweating

ACEi: Angiotensin-converting enzyme inhibitors; ARBs: Angiotensin II Receptor Blockers; NSAIDs: Nonsteroidal Anti-inflammatory Drugs; MDMA: Methylenedioxy-methamphetamine and alternatives

Thus, triage, treatment, and social support protocols must differ from routine ED care.

The impacts of climate-related hazards on EDs include (1) physical damage to facilities; (2) fluctuations in patient volume; (3) changes in patient demographics and presentation types; (4) increased psychosocial burden; and (5) altered ED length of stay. A modern ED preparedness strategy must integrate four pillars: structurally resilient infrastructure, dynamic epidemiological surveillance systems, early awareness and surge training, and coordination with social support networks. These must be embedded in disaster protocols to ensure that EDs can adapt to the escalating consequences of climate change.

Environmental impacts of climate change: Chemical, biological, radiological, nuclear, and explosive and mass casualty incident implications

Changes in weather patterns due to climate change can lead to alterations in the surrounding chemical (C) and biological (B) environments, while also potentially influencing radiological (R) and nuclear (N) hazards. In addition, all CBRN agents may result in explosions (E), which can subsequently cause MCIs. Contemporary EDs have established CBRN-E and MCI protocols, which are activated during such events.[88,89] Therefore, to better understand the impact of climate change on EDs, it is essential to recognize that the consequences of climate change may culminate in CBRN-E-related MCIs. Framing climate change within the context of potential CBRN-E and MCI outcomes allows for a more integrated, concrete, and memorable approach, facilitating the development of targeted strategies in emergency preparedness and response.

Environmental impact of climate change: Chemical flora

Chemical hazards involve the unintentional or intentional release of substances harmful to humans or the environment, including nerve agents, blister agents, and toxic industrial chemicals.[90] The Earth's spheres, biosphere, hydrosphere, lithosphere, and atmosphere, maintain a delicate equilibrium necessary for climate stability. Human activity, particularly within the biosphere, has disrupted this balance through the alteration of chemical cycles, primarily via increased greenhouse gas emissions.

Key greenhouse gases, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), and tropospheric ozone (O_3), are mainly produced by

Table 4: Impacts of climate change-driven natural hazards on emergency departments: etiologies, trends, and clinical consequences

Natural hazard	Trend	Etiology	Impacts on EDs
Hurricanes	Increasing in severity	Storm systems derive energy from warm ocean water	Structural damage to EDs[58]
			Increased ED admissions[59,60]
			Shift in patient demographics[61]
			Misuse of EDs[59]
			Non-ED treatments being delivered within ED settings[62]
Wildfires	Burning longer and over wider areas	Larger fires occur in hot and dry years	Increased ED visits[63,64]
			Rise in respiratory symptom-related visits[65]
			Acute exacerbations of chronic respiratory diseases
			Demographic variation in exposure; proximity-linked severity[66]
			Burns
			Psychological symptoms[67]
Extreme heat	Becoming hotter	Heat waves pose health risks and stress energy systems	Increased ED visits[68]
			Demographic differences in vulnerability[26]
			Seasonal surges in ED visits[69]
			High patient acuity[70]
			Increased length of ED stay[68]
			Have resulted in mass casualties[71]
			Increased incidence of heat-related illnesses
Drought	Projected to worsen	Higher temperatures lead to drier conditions	Malnutrition and spread of infectious diseases[72]
			Social crises[73]
			Increased risk of chronic dehydration, hyperosmolarity, obesity, diabetes, and metabolic syndrome in ED presentations[74]
Rainfall/flooding	Increased flooding	Extreme hydrological events	Physical damage to ED facilities
			Surge in ED visits[75]
			Injuries such as drowning, trauma, hypothermia[76]
			Changing disease patterns: Increased visits due to pregnancy complications, diarrhea, asthma, and insect bites[75]
			Potential outbreaks of vector-borne diseases such as dengue, malaria, and chikungunya in endemic areas
			Reduced access to medical supplies/services[77]
			Psychological traumas[78]
			Obstetric complications[79]
Sea level rise	Increasing	Causes coastal inundation	Infrastructure damage and clinical impact similar to heavy rainfall events
Winter storms	Becoming more intense	Trapped moisture leads to heavier snowfall	Increased injury risk for ED workers[80]
			Surge in ED visits[81]
			Higher incidence of mass injury incidents[82]
			Shift in disease patterns: increased CO poisoning and hypothermia[80,83,84]
			Socio-demographic disparities in impact[81]
			Increased trauma cases

EDs: Emergency departments

fossil fuel combustion.[91] In this context, uncontrolled greenhouse gas emissions can be viewed as chemical threats, similar to the uncontrolled release of toxic agents.

From a public health standpoint, many chemicals are carcinogenic, mutagenic, or cytotoxic.[92] While some effects are long term, exposure through air, water, or soil can also trigger acute or chronic illnesses that impact EDs, most notably through compromised hydration, food safety, and air quality.[93,94]

Three significant consequences of climate change affecting respiratory health are global warming, increasing weather variability, and elevated air pollution.[95] Polluted air particles induce pulmonary inflammation, oxidative stress, and immune suppression, increasing vulnerability, particularly among individuals with chronic respiratory conditions, children, and the immunocompromised.[93]

Recent large-scale studies have confirmed that short-term exposure to air pollutants, especially $PM_{2.5}$, PM_{10}, ozone (O_3), and nitrogen dioxide (NO_2), is associated with increased ED visits for respiratory diseases such as asthma, chronic obstructive pulmonary disease, and pneumonia. For instance, a national analysis of nearly 40 million ED visits across 894 US counties reported that each 10 μg/m^3 increase in $PM_{2.5}$ was associated with a

2.4% increase in pediatric respiratory visits (RR: 1.024, 95% confidence interval [CI]: 1.018–1.029), and smaller but significant increases in older adults (RR: 1.008, 95% CI: 1.004–1.012).[96] Seasonal climate-related events such as wildfires and heat waves exacerbate these effects by increasing pollutant concentrations.[97] Vulnerable population, particularly children and older people, are disproportionately affected and represent a significant component of the climate-sensitive ED burden.[98,99]

Environmental impact of climate change: Biological flora

Although climate change is known to alter the chemical, biological, and radiological landscape, its full impact on the epidemiology of infectious diseases remains incompletely understood. For a biological agent to significantly affect public health, a climate-driven chain reaction must occur.[100] This chain consists of three interconnected elements: an environmental hazard (such as global warming, heat waves, droughts, floods, or sea-level rise); a pathogen (including bacteria, viruses, fungi, protozoa, animals, or plants); and a mode of transmission (such as vector-borne, airborne, or direct contact). These components form the basis of climate-related infectious disease dynamics. However, contemporary research often focuses heavily on pathogens while overlooking environmental drivers and transmission mechanisms, a gap that may accelerate the emergence and spread of epidemics and pandemics, particularly given the diversity of infectious agents. Even a disruption to one link in this chain due to climate-related change can significantly alter disease patterns.

In the 21st century, EDs have managed outbreaks such as human immunodeficiency virus, severe acute respiratory syndrome, avian influenza, Middle East respiratory syndrome, and COVID-19. Rising temperatures, altered vector behavior, shortened development cycles, and faster viral replication, combined with increased global mobility, have heightened susceptibility to widespread biological threats.[101,102] This highlights the urgent need for strategic preparedness against future biological disasters. As the first point of contact and rapid clinical assessment, EDs are well positioned to respond to emerging infectious diseases driven by climate-related shifts in biological patterns. Syndromic surveillance and structured clinical documentation in the ED may serve as critical tools for enhancing early detection and public health resilience.[103]

Climate change is projected to have multifaceted impacts on food security, as well as on the hazards affecting food safety. Even a single environmental factor, such as a rise in temperature, is thought to trigger the effects of food contaminants in different ways, potentially increasing the survival of foodborne pathogens (such as *Salmonella* and *Vibrio*). However, due to the complex nature of these effects, they can be difficult to quantify.[104] The main effect of climate change on microbiota is related to biodiversity changes in different regions of the planet, mainly due to temperature variations. Climate change can modify the relationship between humans and pathogens, thereby increasing their probability of contracting infections and diseases. Rising temperatures would modify the host immune system and boost the growth rate of pathogens. Higher temperature increases the growth rate of pathogens, disease perpetuation and transfer, infection transmission of infectious diseases, expansion of geographic ranges, and neglected diseases. Moreover, higher temperatures shorten bacterial replication time, increase generation rates and population growth, and promote mutations, horizontal gene transfer, and antibiotic-resistant infections. For example, it has been reported that every 1°C increase in temperature can increase *Salmonella* cases by 5%–10% and affect *Campylobacter* rates by 3%–20%. Increases in environmental factors such as temperature and precipitation significantly increase the risk of food contamination, including food itself.[105] Rising temperatures, in particular, increase the incidence of *Salmonella* infections; it has been reported that for every 1°C increase in average maximum temperature, there is an approximately 8.8% increase in weekly *Salmonella* cases. Furthermore, increases in precipitation and humidity, along with temperature, increase the spread of foodborne microbes.[106] *Vibrio* species pose a serious risk of food poisoning, particularly in shellfish, as seawater temperatures rise, and cases are predicted to increase in Europe and the United States.[107] Enteric pathogens such as *Escherichia coli* can concentrate in foods, especially leafy greens, under environmental conditions of temperature and humidity.[108,109] During dry and hot periods, maintaining the cold chain, proper storage, and structured harvesting processes are critical. Novel methods (e.g., bacteriophage therapy) should be investigated for biofilm control in raw foods like green leafy vegetables. Pathogen risk mapping (e.g., *Salmonella* and *Vibrio*) and temperature-resilience models can be developed to generate early warnings. Climate-sensitive agricultural surveillance systems, microbial monitoring, and public health education are important for risk management.

Although the COVID-19 pandemic was devastating, it provided invaluable insight into biological disaster response. EDs were at the frontline of care during the most severe biological crisis of the last century. Lessons learned from that experience must be integrated into future preparedness strategies, with careful analysis of gaps and missteps to strengthen response capabilities in future climate-linked biological events.

Environmental impact of climate change: Ultraviolet radiation

At the core of climate change is the concept of radiative forcing, the difference between incoming solar radiation and outgoing infrared radiation.[110] When more energy enters the Earth's atmosphere than exits, the result is a warming effect, driving global climate change. A key component of incoming solar radiation is ultraviolet (UV) radiation, divided into UVA, UVB, and UVC.[111] Nearly all UV reaching the surface is UVA, which penetrates deeper into the skin and remains consistent year-round.

The UV Index (UVI) is used to estimate the level of skin-damaging UV radiation at solar noon. UVI varies throughout the year, peaking around the summer solstice.[112] The higher the UVI, the shorter the time to skin or eye damage.[113] Sunburn is the most common UV-related ED presentation. The burn time, based on the minimal erythemal dose (MED), indicates how long someone can remain in the sun without burning.[114,115] MED values vary with skin sensitivity; for Category 1 skin, the effective MED is 200 J/m^2. In 2000, over 60,000 skin cancer deaths were attributed to UV radiation.[116]

Another metric relevant to EDs is the Wet Bulb Globe Temperature (WBGT), which evaluates heat stress under direct sunlight by incorporating temperature, humidity, wind, solar angle, and UV exposure.[117] Unlike the heat index, which applies only in shade and excludes UV, WBGT better reflects real-world exposure and is widely used by the Occupational Safety and Health Administration (OSHA) and military agencies.[118]

There is no global consensus on whether to use WBGT or heat index alone for climate change studies. However, OSHA recommends WBGT, even at lower heat index values, due to the underestimation of UV-related heat risk.[119] The measurement table for the heat index is presented in Figure 2.

According to the WHO's UV protection framework, essential strategies include: using appropriate exposure metrics (WBGT vs. heat index), updating national sun protection policies, ensuring affordable access to UV-protective products, protecting outdoor workers, creating disease registries, building public shade infrastructure, and promoting daily UVI monitoring.[120] To manage climate change in EDs effectively, we must adopt a holistic approach, integrating patient care, environmental safety, and ecological awareness.

Environmental impact of climate change: Explosion and mass casualty incident effects

Climate change is increasingly associated with extreme weather events and their impact on communities. In the U.S., the average annual number of weather- and climate-related disasters rose from 9.0 (1980–2024) to 23.0 over the last 5 years, with 2024 alone accounting for 27 such events and 568 deaths.[121] The WHO defines a disaster as any event causing damage, ecological disruption, or loss of life on a scale requiring extraordinary response.[122] Disaster impact is shaped by the hazard itself, the vulnerability of the population, and the capacity to respond, frameworks that must guide climate-related hazard planning.

Explosions linked to climate change occur in two main contexts: those caused by environmental degradation and those triggered by temperature extremes, especially in regions affected by conflict. Both scenarios can lead to MCIs, requiring ED preparedness. Historical nuclear tests in the Pacific and Central Asia caused long-term ecological harm, including tsunamis, landslides, and radioactive contamination.[123] More recently, ammunition and grain depot explosions in heat-stressed regions highlight the risks posed by changing environmental conditions.[124,125] Although data are limited, these incidents underscore the need for operational and clinical planning under extreme heat.

Relative humidity (%)	Temperature (°C)															
	27	28	29	30	31	32	33	34	36	37	38	39	40	41	43	47
40	27	27	28	29	31	33	34	36	38	41	43	46	48	51	54	58
45	27	28	29	31	32	34	36	38	40	43	46	48	51	50	58	
50	27	28	29	31	33	35	37	39	42	45	48	51	55	58		
55	27	29	30	32	34	36	38	41	44	47	51	54	58			
60	28	29	31	33	35	38	41	43	47	51	54	58				
65	28	29	32	34	37	39	43	46	49	53	58					
70	28	30	32	35	38	41	46	48	52	57						
75	29	31	33	36	39	43	47	51	56							
80	29	32	34	38	41	45	49	54								
85	29	32	36	39	43	47	52	57								
90	30	33	37	41	45	50	55									
95	30	34	38	42	47	53										
100	31	35	39	44	49	56										

Likelihood of heat disorders with prolonged exposure or strenuous activity: Caution; Extreme caution; Danger; Extreme danger

Figure 2: Heat index calculation table

Climate-driven conflict and migration are significant global challenges. In 2024, 90 million displaced people lived in areas highly exposed to climate hazards, nearly half affected by both conflict and climate change.[126] Countries most impacted include Sudan, Syria, Haiti, and others. For EDs, this intersection of migration and vulnerability, especially in Türkiye, which hosts a large migrant population, demands sensitive management protocols.[127-129] These include identification, secure registration, social support, and patient safety.

The impact of climate change on EDs can be modeled using the formula I = H × V/P × R, where hazard, vulnerability, preparedness, and resilience interact.[102] Accordingly, preparedness strategies must evolve to account for emerging hazards and at-risk population.

The WHO's 2022 guideline on Mass Casualty Preparedness in Emergency Units outlines triage models tailored for EDs [Figure 3].[89] These models include primary and secondary triage phases, allocation to red, yellow, green, or blue zones, and context-specific thresholds for ICU admission or palliative transfer. Robust triage and appropriate referral ensure strategic use of critical resources and continuity of care into intensive or operative services.

The Carbon Footprint of Emergency Departments

The healthcare mandate of "do no harm" is challenged by EDs, which are at the forefront of healthcare delivery but also contribute significantly to global greenhouse gas (GHG) emissions.[130] Indeed, if the healthcare industry were a nation, it would be classified as the fifth-largest emitter of greenhouse gases globally.[131]

Sources of carbon footprint: Energy consumption

The healthcare system requires a considerable quantity of energy to deliver health services, which immediately leads to high electrical power consumption and, subsequently, increased CO_2 and other GHG emissions.[132] EDs, functioning continuously, are notably resource-intensive sectors within hospitals, considerably impacting per-bed energy use and water usage. CO_2 emissions in an ED mainly arise from the ongoing use of electrical medical devices during patient care procedures.[133,134] For instance, a simulation–optimization analysis conducted in the ED estimated a total carbon footprint of 88–178 kg CO_2-equivalent per patient per day (CO_2-e/patient/day) for a single hospitalized patient.[135]

To accurately measure these emissions, carbon footprint calculators classify them into several scopes. Scope 1

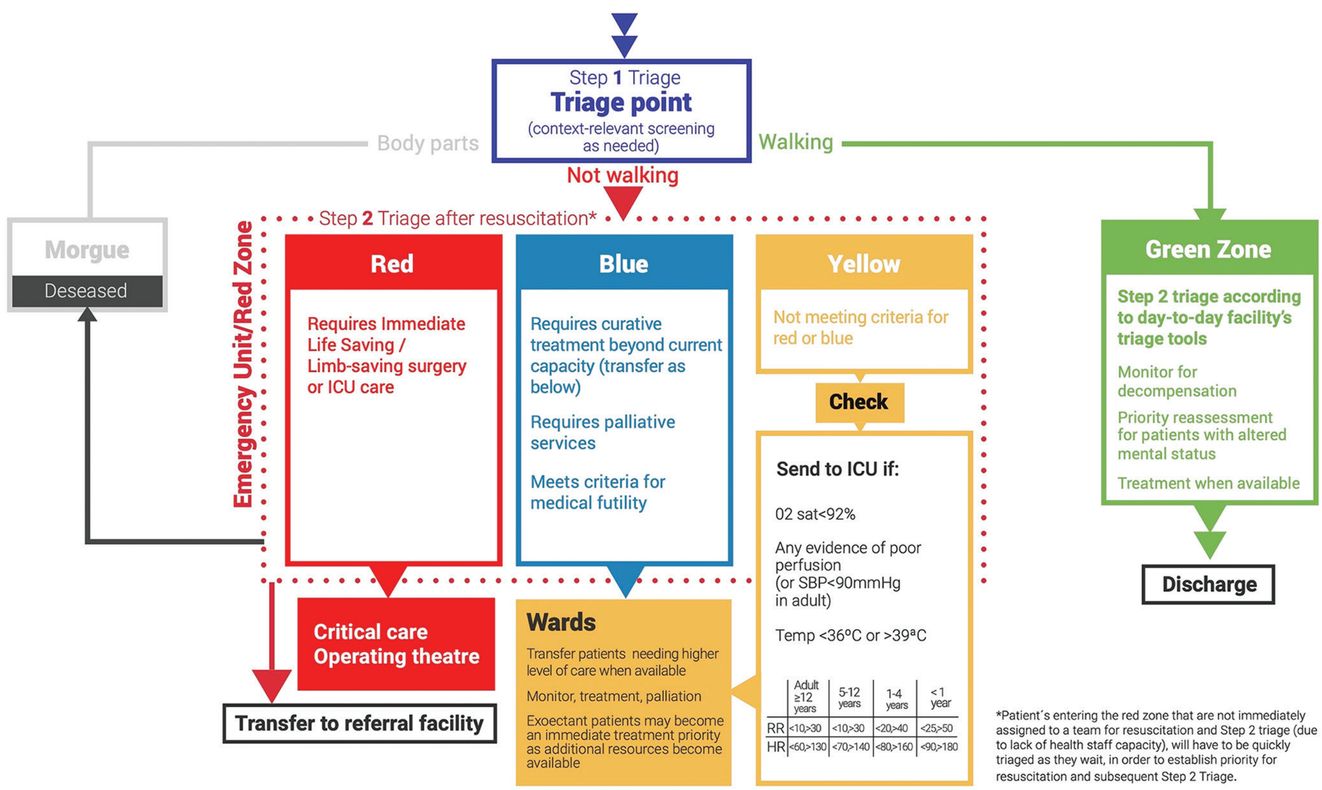

Figure 3: Triage and patient flow scheme for emergency units during mass casualty incidents. Reproduced from the World Health Organization Mass Casualty Preparedness guideline (2022)[89]

emissions refer to the greenhouse gases that a firm or entity releases directly. This may occur via business cars, fugitive emissions (leaks from equipment or infrastructure), or any emissions from owned or controlled sources. These emissions are often the primary emphasis in a company's efforts to mitigate greenhouse gas emissions, since they are directly controllable. Scope 2 emissions refer to the indirect emissions generated by a business via the procurement and use of power, steam, heating, and cooling. These emissions originate from the energy used by a corporation. Scope 2 emissions are often calculable from the usage detailed in energy invoices. Scope 3 emissions are rather more complex. These are the emissions that a business or organization is accountable for across its whole supply chain. This may begin when a consumer makes a purchase from a vendor and continue until the end of the customer's use of the product or service. Scope 3 emissions are often the largest among the three scopes.[136]

In instances when submeters are not accessible for certain departments, the energy consumption for an ED may be approximated by multiplying the hospital's overall energy consumption by the ED's surface area and thereafter dividing by the entire surface area of the facility.[137]

Sources of carbon footprint: Waste generation

In addition to energy, waste production is another significant aspect of ED's environmental footprint. The healthcare sector in the United States produces over 5 million tons of waste each year.[138] Research focused on ED trash indicates a substantial volume of abandoned goods; for instance, one study identified that more than 200 unneeded items, including gloves, saline syringes, IV catheters, and tourniquets, were disposed of daily in a single ED.[139] Unopened or uneaten food is a significant source of real waste in the healthcare sector, accounting for an alarming 20% of all rubbish.[140]

The misuse and overutilization of "red bag waste," intended for regulated medical waste, constitutes a significant environmental and financial violation. More than 85% of garbage disposed of in red bags fails to satisfy the stringent standards for regulated medical waste.[141] Nonetheless, these things need expensive and energy-demanding disposal methods such as sterilization or incineration, resulting in more pollution than the disposal of noninfectious trash. Red bag disposal can be up to ten times more expensive than solid waste disposal, showing that reducing it is the "lowest-hanging fruit" for saving money and helping the environment.[142] Indirect emissions associated with supply chains, and the production of disposable medical devices are included in Scope 3 emissions, which include a wide range of products such as medicines, medical and nonmedical equipment, and disposables/consumables.[143]

Sustainability strategies and mitigation

Mitigating the carbon footprint of EDs is essential for alleviating the effects of climate change on public health, since these departments are at the forefront of the issue, managing the evolving load of diseases and illnesses associated with severe weather events.[144] Medical professionals and ED personnel are well situated to promote and execute sustainable practices within their healthcare institutions.

General "green approaches" in health care include many measures such as sustainable facility design, the use of renewable energy sources, enhancement of insulation, utilization of efficient equipment, and implementation of water reuse systems.[145] Moreover, commitments to energy saving and the use of renewable resources must include the whole life cycle of a healthcare institution, from inception to operation and replacement.[146]

Targeted strategies for waste reduction in the emergency department encompass

- Instituting straightforward modifications such as recycling all metals, glass, and rigid plastics; reprocessing pulse oximeter probes; channeling batteries to electronic waste; composting, diverting, or minimizing all food waste; and restocking or donating all surplus items. These modifications alone might redirect substantial quantities of garbage from landfills annually
- Implementing "upstream changes" via proactive collaboration with suppliers and partners to reduce packaging and facilitate direct material reuse
- Redesigning ED kits to remove superfluous elements and promoting the acquisition of individual components, where feasible, instead of depending on inefficient prepackaged kits
- Reusing equipment, including laryngoscopes, vaginal specula, blood pressure cuffs, and metal instruments in suture kits, is often more economical and ecologically sustainable than single-use disposal, due to the benefits of cleaning and reprocessing
- Minimizing paper use via the implementation of technology for prescriptions, charts, and reports, alongside optimizing printer configurations for duplex printing and reduced margins.

Effective methods for sustainable health care are shown by Gundersen Health System, which has achieved energy independence by generating more electricity than it consumes for an average of 54 days each year since 2014, with an approximate 80% decrease in harmful emissions via the use of diverse green technology.[147] Their internal infectious waste program effectively reduced ED trash and diverted over 185 tons of infectious waste from landfills annually, with the residual material sent to a local waste-to-energy plant.[148]

Moreover, addressing ED congestion by enhancing patient flow and minimizing superfluous visits is recognized as a vital mitigation strategy, since overcrowding itself exacerbates high emissions.[149] Simulation–optimization techniques, such as OptQuest, have effectively been used to enhance patient flow in EDs, showcasing efficacy in minimizing carbon emissions while simultaneously improving waiting times and duration of stay.[150]

The creation and verification of instruments such as the ED carbon footprint calculator are essential for this transformation. These tools facilitate the identification of high carbon intensity "hotspots," enable the monitoring and comparison of emissions over time, enhance staff awareness of their environmental impact, encourage professionals to adopt sustainable practices, and furnish quantitative data to advocate for change and assist management teams in decision-making.[151] These initiatives correspond with overarching national goals, including the NHS objective of attaining net-zero emissions by 2045.[152]

Nonetheless, many obstacles persist, including the high expenses related to sustainable infrastructure, the extensive existence of obsolete facilities, and antiquated government guidelines that have yet to integrate contemporary energy-efficient technology.[153] The legislative framework for environmental sustainability in health care is usually disjointed, with local governments often spearheading projects due to the lack of comprehensive federal law.[154] To adapt to and lessen their environmental effect in a warming world, EDs must make consistent, cooperative efforts, including operational adjustments, behavioral improvements, and technology breakthroughs.

Conclusion

Climate change has widespread impacts starting from EDs, extending through patient and disease profile management, and ultimately influencing clinical outcomes. These impacts are evolving dynamically over time. To fully understand and address this effect, it is essential to raise awareness of the contribution of EDs to climate change and to develop comprehensive mitigation strategies. These strategies should include management approaches for hypothermia, hyperthermia, and normothermia from a patient- and disease-centered perspective; assessment of the influence of climate change on CBRN-E hazards and MCIs surrounding the patient; and formulation of coordinated response strategies to these threats at both national and international levels. At the core of developing these strategies lies the need for a clear understanding of how climate change impacts human physiology and the pathophysiology of diseases. Only through such understanding can emergency services be adequately prepared for the growing and shifting burden climate change imposes on acute care.

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Supplementary Table 1: Physiopathological changes and clinical effects of core temperature variations[13-15]

Increase		Decrease
Sympathetic activation	**Sympathetic Inhibition**	**Sympathetic activation**
Sweat glands: It causes activation, leading to increased sweating and consequently enhanced heat loss	Blood vessels of the skin: Causes vasodilation and increases heat loss	Blood vessels of the skin: Vasoconstriction of skin arterioles causes blood to bypass the skin, reducing heat loss
		Piloerection (goosebumps): Leads to heat retention
Inflammation: Its most toxic effect is generally on hepatocytes, vascular endothelium, and neurons. Over time, with the systemic inflammation triggered by damaged cells, it progresses to multiple organ failure	Adrenal glands, hypothalamus, thyroid: Reducing the secretion of their hormones leads to a decrease in metabolic rate	Adrenal glands, Hypothalamus, Thyroid:Increases hormone secretion, leading to a decrease in metabolic rate: Activation of the primary motor center in the posterior hypothalamus triggers skeletal muscle contraction and shivering, increasing heat production
Behavioral changes include Reducing movement Adopting an open body posture Removing clothing, and Decreasing appetite		Behavioral changes include Increased movement Adopting a closed body posture, Adding layers of clothing, and Increased appetite

Supplementary Table 2: Rewarming strategies in hypothermic patients

	Mild and cold stress	Moderate	Severe
Warming strategy	PER: Wet clothing should be removed, and the patient should be covered with blankets or other insulation materials If possible, the ambient room temperature should be maintained at approximately 28°C (82°F) When feasible, routine active external rewarming should be added to passive warming to reduce patient discomfort and cardiovascular energy demand	PER + AER and IV or Airway: Warm blankets, heating pads, radiant heat, or forced warm air can be applied directly to the patient's skin Forced warm air is preferred for its simplicity and effectiveness. There is no need to expose extremities during forced-air rewarming Rewarming the airway and using warmed IV or IO fluids can help reduce heat loss when active rewarming techniques are employed, although they should not be considered primary rewarming methods Ideal temperature of warmed, humidified oxygen via airway: 45°C (113°F) To avoid accidental reduction of core temperature during IV fluid administration, fluids should be warmed to 40°C–42°C (104°F–108°F)	AIR: Also known as active core rewarming, this method provides internal heat transfer While endovascular rewarming is the first-line approach, if catheter placement is not feasible, body cavities (e.g., peritoneal and pleural) may be targeted or an esophageal device may be inserted for rewarming If these methods fail, more easily accessible cavities such as the stomach or bladder may also be used Rewarming Target: The recommended rewarming rate ranges between 0.5 and 2°C/h (1 to 4°F/h) Patients rewarmed using PER or AER techniques typically experience an increase in core temperature of at least 2°C/h (4°F/h). Colder patients tend to rewarm more rapidly. Optimal cutoff for favorable neurological outcomes is rewarming at a rate <5°C/h (9°F/h) via ECLS
Rewarming target	The recommended rewarming rate ranges between 0.5 and 2°C/h (1 to 4°F/h)	Patients rewarmed using PER or AER techniques typically experience an increase in core temperature of at least 2°C/h (4°F/h). Colder patients tend to rewarm more rapidly	Optimal cutoff for favorable neurological outcomes is rewarming at a rate <5°C/h (9°F/h) via ECLS

PER: Passive external rewarming, AIR: Active internal rewarming, AER: Active external rewarming, ECLS: Extracorporeal life support, IV: Intravenous

Supplementary Table 3: Golden time periods influencing mortality in earthquakes

Time period	Events	Description	Key factors in mortality mitigation
1st Period (s)	Early death of critically injured individuals after structure collapses	Immediately after structure collapse, high mortality rates are observed following severe injuries such as heart, brain, respiratory system damage, and massive bleeding	Resilient structures and building codes play a critical role in mitigating initial casualties
2nd period (min)	Mortality of severely injured survivors under rubble	Immediate rescue of individuals still trapped under rubble postcollapse is crucial. The speed of local search and rescue teams is critical during this period	Rapid and organized local search and rescue teams are essential for reducing mortality rates
3rd period (h)	Extraction of injured from rubble and transfer to hospital emergency departments	Detection and extraction of injured individuals trapped under rubble, followed by transfer to emergency departments for hydration, electrolyte management, crush syndrome management, and surgical interventions	National preparedness for medical disaster resilience is crucial in this period. Preparation includes medical plans, early management algorithms, and coordinated response efforts
4th period (days, weeks, months)	Mortality process due to intensive care and surgical complications	Long-term period involving intensive care and surgical complications after initial treatments for rescued individuals from collapsed structures. This phase is crucial, where medical resilience plays a decisive role	Continued medical resilience and capacity building are essential for managing prolonged medical complications and ensuring long-term survival outcomes