Universidad de Huelva

Departamento de Enfermería

From triage to sustainability: carbon footprint of the emergency department a nursing responsability

Memoria para optar al grado de doctor
presentada por:

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Fecha de lectura: 25 de junio de 2025

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Huelva, 2025

FROM TRIAGE TO SUSTAINABILITY: CARBON FOOTPRINT OF THE EMERGENCY DEPARTMENT, A NURSING RESPONSABILITY

DEL TRIAJE A LA SOSTENIBILIDAD: HUELLA DE CARBONO DEL SERVICIO DE URGENCIAS, UNA RESPONSABILIDAD ENFERMERA

TESIS DOCTORAL
HUELVA
2025

VNIVERSITAS ONVBENSIS · SAPERE AVDE ·

Universidad de Huelva

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Agradecimientos

Cuando empecé esta aventura hace unos tres años, sabía que el hacer un doctorado llevaría consigo sacrificios a nivel social y personal, pero también entendí que ganaría bastantes habilidades académicas y que mi aportación científica ayudaría a desarrollar nuevas líneas de investigación. También entendí que el planeta necesita de la acción de cada uno de sus seres humanos, y que en el futuro me gustaría mirar a la cara a las nuevas generaciones y afirmar que hice todo lo que estuvo en mi mano para evitar su destrucción.

Todo este trabajo no hubiera sido posible sin el gran apoyo que recibí durante todo este proceso y por todas las personas que me hicieron llegar hasta aquí. En primer lugar, quiero agradecer a Juan Gómez Salgado por animarme a llevar a cabo este doctorado; sin su apoyo, insistencia y confianza no hubiera sido posible emprender este camino. En segundo luga4r, quiero agradecer a Macarena Romero Martin porque sin ella todo este camino no hubiera sido posible. Conseguimos conectar y compenetrarnos desde el primer día. Conseguiste explotar mis habilidades y minimizar mis debilidades. Cuando la motivación flaqueaba, tu estabas ahí en la orilla guiándome en la dirección hacía donde navegar. Se que esta línea de investigación que hemos comenzado aquí no acaba, y que la relación que hemos establecido perdurará.

También quiero agradecer a Zoe Steley por introducirme en el mundo de la sostenibilidad medioambiental en los servicios de urgencias y ayudarme a desarrollar la temática de esta tesis, así como a todos los miembros del Green ED del Royal College of Emergency Medicine – especialmente a Sandy, Tim y James - y de urgencias de Royal Free Hospital que me ayudaron a desarrollar la calculadora. Un agradecimiento especial a Fran

(Housekeeper del Royal Free Hospital) por su dedicación y ayuda en colectar gran parte de la información necesaria.

Quiero también agradecer a mi mujer Cristina Leal Torrealba por su incondicional apoyo y por animarme en todo momento a realizar este proyecto, sin ella nada de esto hubiera sido posible. A mis padres, Jesús y María José, gracias por incentivar mis cualidades y apoyarme en mi desarrollo académico. A mis hermanos Jesús, Lucia, Alba y al resto de mi familia por apoyarme en este camino y siempre estar a mi lado.

Y finalmente a mi hija Olivia, este trabajo va dedicado a ti y a todas las futuras generaciones, para que sepáis que si actuamos todos juntos un futuro sostenible es posible.

Acknowledgements

When I started this adventure about three years ago, I knew that doing a PhD would entail sacrifices on a social and personal level, but I also understood that I would gain significant academic skills and that my scientific contribution would help develop new lines of research. I also understood that the planet needs the action of each one of its human beings and that in the future I would like to look the new generations in the eye and affirm that I did everything in my power to prevent its destruction.

All this work would not have been possible without the great support I received throughout this process and from all the people who helped me get here. First, I want to thank Juan Gómez Salgado for encouraging me to undertake this PhD; without his support, insistence, and confidence, it would not have been possible to embark on this path. Secondly, I want to thank Macarena Romero Martin because without her, this entire journey would not have been possible. We managed to connect and complement each other from day one. You managed to exploit my skills and minimise my weaknesses. When motivation wavered, you were there on the shore guiding me in the direction to sail. I know that this line of research we have started here does not end, and that the relationship we have established will endure. I also want to thank Zoe Steley for introducing me to the world of environmental sustainability in emergency services and helping me develop the theme of this thesis, as well as all the members of the Green ED of the Royal College of Emergency Medicine – especially to Sandy, Tim, and James – and the emergency department of Royal Free Hospital who helped me develop the calculator. A special thanks to Fran (Housekeeper of Royal Free Hospital) for his dedication and help in collecting much of the necessary information.

I also want to thank my wife Cristina Leal Torrealba for her unconditional support and for always encouraging me to carry out this project, without her none of this would have been possible. To my parents, Jesús and María José, thank you for encouraging my qualities and supporting me in my academic development. To my siblings Jesús, Lucia, Alba, and the rest of my family for supporting me on this path and always being by my side. And finally, to my daughter Olivia, this work is dedicated to you and to all future generations so that you know that if we all act together, a sustainable future is possible.

ABSTRACT

Introduction: Healthcare services are responsible for 4-5% of global greenhouse gas emissions. Climate change has been described as one of the major threats to human health in the 21st century. Nurses, along with other healthcare professionals, carry out their daily duties guided by principles such as beneficence and non-maleficence. In addition, nurses engage in health promotion, disease prevention, and care provision. However, healthcare services are both part of the solution and part of the problem. While they play a crucial role in treating illnesses and dealing with the consequences of adverse weather events caused by climate change, they also emit a considerable number of emissions due to their activities. Hence, nurses have a responsibility to reduce these emissions while ensuring safety and enhancing the delivery of care. Over the last year, there has been a surge of new environmental initiatives in the healthcare sector to reduce greenhouse gas emissions and meet national and international goals, as well as comply with climate laws. By adopting an evidence-based and holistic approach to measuring carbon emissions, the healthcare sector can significantly reduce its environmental impact.

Emergency departments see a high volume and acuity of patients worldwide, with up to 136 million attendances per year recorded in the US and 24.4 million in the UK, likely representing a large portion of the healthcare system's carbon footprint.

Objectives: To describe the carbon footprint of healthcare services, identify the hotspots of carbon emissions in the healthcare sector, and develop and validate a tool for and by healthcare professionals to measure the carbon footprint of emergency departments. The ultimate goal is to accelerate environmental initiatives and empower healthcare professionals to take action in reducing their carbon footprint.

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Methodology: The first stage involved a systematic review to describe the carbon footprint of healthcare services and identify the hotspots of carbon emissions in the healthcare sector. The second stage involved developing a prototype assessment tool to evaluate the carbon footprint of emergency departments in the UK, which was divided into five sub-stages: selection of the categories included in the assessment tool, determination of scope and boundaries, selection of conversion factors, data collection, and evaluation method of the carbon footprint. The third stage consisted of the final design and validation with two panels of experts, where the content validity was measured using the Content Validity Index (CVI) and Aiken's V (V). Additionally, a focus group was conducted for assessing the facial validity, the presentation and usability of the tool.

Results: The Greenhouse Gas Protocol (2022) classifies carbon emissions in three scopes; scope 1 or direct emissions are those related to the use of energy and on which the organisation has direct control; scope 2 or indirect emissions are those related to purchased electricity or the use of electricity that has been produced somewhere else; and scope 3, which encompasses the rest of indirect emissions emitted by an organisation and of which production is not controlled by the organisation. The literature review found that between 15% and 50% of the total emissions in healthcare settings corresponded to Scope 1 and Scope 2 emissions, whereas Scope 3 emissions ranged between 50% and 75% of the total emissions. Disposables, equipment (medical and non-medical), and pharmaceuticals represented the highest percentage of emissions in Scope 3. The prototype of the assessment tool was divided into three scopes, and each scope included one or more categories containing several items. Data was collected from different sources such as meters, invoicing and billing, auditing, and surveys. The tool was presented in a Microsoft Excel document. The validation process showed good content validity

(CVI=0.74 and V=0.87 in the first panel; CVI=0.81 and V=0.90 in the second panel). Three main themes emerged from the focus group: calculator overview, data collection, and benefits.

Discussion: The development of carbon footprint calculators provides an opportunity to track carbon emissions and develop strategies to reduce them. Our calculator aims to establish a baseline carbon footprint and identify areas with high emissions in the emergency department, enabling the implementation of targeted environmental initiatives.

Following the first review of the panel of experts and after addressing all the recommendations, the first version of the calculator was produced. The second panel of experts evaluated the scope, accuracy of calculation and pertinence of conversion factors of the first version of the calculator. Finally, the calculator was shared with a group of potential users with the aim to obtain information regarding its clarity, viability, and usefulness, leading to final version of the calculator. The calculator was confirmed as a valid, exhaustive, clear, and easy-to-use tool, allowing the estimation of CO_2 emissions generated by the activity of hospital emergency services. The tool's benefits were emphasised, including its role in raising awareness, facilitating decision-making, and promoting behaviour change among staff and patients, aligning with findings from previous research. The educational aspect of carbon footprint awareness and mitigation was also underscored, suggesting its potential impact on community engagement and change promotion.

Additionally, it has been highlighted the pivotal role healthcare professionals play in carrying out environmental initiatives. By advocating for the utilisation of low-impact practices, promoting sustainable initiatives, and fostering healthier lifestyle choices, healthcare providers can significantly contribute to emissions reduction while enhancing patient outcomes However, achieving sustainability within the healthcare sector mandates systemic transformations surpassing individual endeavours. It calls for a paradigm shift towards a circular economy,

where resources are conserved, repurposed, and recycled whenever feasible. This transition hinges on collaborative efforts among stakeholders, innovative policy frameworks, and a collective dedication to planetary well-being.

Conclusion: The impact of healthcare systems on climate change emphasises the imperative of implementing interventions to minimise it. Evidence-based methodologies, such as the development of carbon footprint assessment tools, are recommended to accurately assess the carbon footprints of healthcare settings and identify emissions hotspots. Such initiatives are pivotal for minimising the environmental impact of healthcare activities and fostering sustainable operational paradigms. The Emergency Department carbon footprint calculator holds potential to drive positive transformations in emergency medicine practices by raising awareness, inspiring change, and facilitating emission monitoring and benchmarking. Moreover, it has the capacity to engage staff and stakeholders toward substantial healthcare delivery reforms and the integration of environmental education within the profession. By empowering the Emergency Department nurses and healthcare practitioners, this calculator serves as a catalyst for environmental stewardship within the healthcare sector.

Keywords: Carbon footprint, greenhouse gas emissions, emergency departments, life cycle assessment, environmental impact, nursing.

RESUMEN

Introducción: Los servicios de salud son responsables del 4-5% de las emisiones globales de gases de efecto invernadero. El cambio climático ha sido descrito como una de las principales amenazas para la salud humana en el siglo XXI. Las enfermeras, junto con otros profesionales de la salud, llevan a cabo sus labores diarias guiados por principios como la beneficencia y la no maleficencia. Además, las enfermeras participan en la promoción de la salud, la prevención de enfermedades y la prestación de cuidados. Sin embargo, los servicios de salud son tanto parte de la solución como parte del problema. Aunque juegan un papel crucial en el tratamiento de enfermedades y en el manejo de las consecuencias de los eventos climáticos adversos causados por el cambio climático, también emiten una cantidad considerable de emisiones debido a sus actividades. Por lo tanto, las enfermeras tienen la responsabilidad de reducir estas emisiones mientras aseguran la seguridad y mejoran la prestación de cuidados. En el último año, ha habido un aumento de nuevas iniciativas ambientales en el sector de la salud para reducir las emisiones de gases de efecto invernadero y cumplir con los objetivos nacionales e internacionales, así como con las leyes climáticas. Los departamentos de emergencia atienden un alto volumen y gravedad de pacientes en todo el mundo, con hasta 136 millones de asistencias por año registradas en los EE.UU. y 24.4 millones en el Reino Unido, representando probablemente una gran parte de la huella de carbono del sistema de salud.

Objetivos: Describir la huella de carbono de los servicios de salud, identificar los puntos críticos de emisiones de carbono en el sector salud y desarrollar y validar un calculador de huella de carbono para los servicios de Urgencias, facilitando el monitoreo y la reducción de emisiones de carbono en estos departamentos.

Metodología: La tesis se desarrolló en 3 fases. En primer lugar, la primera etapa implicó una revisión sistemática siguiendo las normas de la declaración PRISMA para describir la huella de carbono de los servicios de salud e identificar los puntos críticos de emisiones de carbono en el sector salud. Posteriormente, la segunda etapa consistió en el desarrollo de un prototipo de herramienta de evaluación para evaluar la huella de carbono de los servicios de Urgencias en el Reino Unido. Esta etapa se dividió a su vez en cinco sub-etapas: 1) selección de las categorías incluidas en la herramienta de evaluación, 2) determinación del alcance y límites, 3) selección de factores de conversión, 4) recopilación de datos y 5) método de evaluación de la huella de carbono. Por último, la tercera etapa consistió en el diseño final y la validación con dos paneles de expertos, donde se midió la validez de contenido utilizando el Índice de Validez de Contenido (IVC) y la V de Aiken (V). Además, se realizó un grupo focal para evaluar la validez facial, la presentación y la usabilidad de la herramienta.

Resultados: El Protocolo de Gases de Efecto Invernadero (2022) clasifica las emisiones de carbono en tres alcances; el alcance 1, o emisiones directas, son aquellas relacionadas con el uso de energía y sobre las cuales la organización tiene control directo; el alcance 2, o emisiones indirectas, son aquellas relacionadas con la electricidad comprada o el uso de electricidad que ha sido producida en otro lugar; y el alcance 3, que abarca el resto de las emisiones indirectas emitidas por una organización y cuya producción no es controlada por la organización. La revisión de la literatura encontró que entre el 15% y el 50% de las emisiones totales en entornos de salud correspondían a emisiones de Alcance 1 y Alcance 2, mientras que las emisiones de Alcance 3 oscilaban entre el 50% y el 75% de las emisiones totales. Los desechables, equipos (médicos y no médicos) y productos farmacéuticos representaron el mayor porcentaje de emisiones en el Alcance 3. El prototipo de la herramienta de evaluación se dividió en tres alcances, y cada alcance incluyó una o más categorías que contenían varios ítems. Se recopilaron datos de diferentes fuentes como medidores, facturación y auditorías, y encuestas. La herramienta se presentó en un documento de Microsoft Excel. El proceso de validación mostró buena validez de contenido (IVC=0.74 y V=0.87 en el primer panel; IVC=0.81 y V=0.90 en el segundo panel). Del grupo focal surgieron tres temas principales: visión general del calculador, recopilación de datos y beneficios.

Discusión: El desarrollo de calculadores de huella de carbono proporciona una oportunidad para rastrear emisiones de carbono y desarrollar estrategias para reducirlas. Nuestro calculador tiene como objetivo establecer una línea base de la huella de carbono e identificar áreas con altas emisiones en el departamento de emergencia, permitiendo la implementación de iniciativas ambientales dirigidas. Después de la primera revisión del panel de expertos y tras abordar todas las recomendaciones, se produjo la primera versión del calculador. El segundo panel de expertos evaluó el alcance, la precisión del cálculo y la pertinencia de los factores de conversión de la primera versión del calculador. Finalmente, el calculador se compartió con un grupo de usuarios potenciales con el objetivo de obtener información sobre su claridad, viabilidad y utilidad, lo que llevó a la versión final del calculador. El calculador se confirmó como una herramienta válida, exhaustiva, clara y fácil de usar, permitiendo la estimación de las emisiones de CO2 generadas por la actividad de los servicios de urgencias hospitalarias. Se enfatizaron los beneficios de la herramienta, incluyendo su papel en la sensibilización, la facilitación de la toma de decisiones y la promoción de cambios de comportamiento entre el personal y los pacientes, alineándose con los hallazgos de investigaciones previas. También se destacó el aspecto educativo de la concienciación y mitigación de la huella de carbono, sugiriendo su potencial impacto en la participación comunitaria y la promoción del cambio. Además, se ha destacado el papel crucial que juegan los profesionales de la salud en la realización de iniciativas ambientales. Al abogar por la utilización de prácticas de bajo impacto,

promover iniciativas sostenibles y fomentar elecciones de estilo de vida más saludables, los proveedores de atención médica pueden contribuir significativamente a la reducción de emisiones mientras mejoran los resultados para los pacientes. Sin embargo, lograr la sostenibilidad dentro del sector de la salud requiere transformaciones sistémicas que superan los esfuerzos individuales. Se necesita un cambio de paradigma hacia una economía circular, donde los recursos se conserven, reutilicen y reciclen siempre que sea posible. Esta transición depende de esfuerzos colaborativos entre los interesados, marcos políticos innovadores y una dedicación colectiva al bienestar planetario.

Conclusión: El impacto de los sistemas de salud en el cambio climático enfatiza la imperativa de implementar intervenciones para minimizarlo. Se recomiendan metodologías basadas en evidencia, como el desarrollo de herramientas de evaluación de la huella de carbono, para evaluar con precisión las huellas de carbono de los entornos de salud e identificar puntos críticos de emisiones. Tales iniciativas son cruciales para minimizar el impacto ambiental de las actividades de salud y fomentar paradigmas operativos sostenibles. El calculador de huella de carbono del Departamento de Emergencias tiene el potencial de impulsar transformaciones positivas en las prácticas de la medicina de emergencia al aumentar la conciencia, inspirar cambios y facilitar el monitoreo y la comparación de emisiones. Además, tiene la capacidad de involucrar al personal y las partes interesadas hacia reformas sustanciales en la prestación de servicios de salud y la integración de la educación ambiental dentro de la profesión. Al empoderar a las enfermeras del Departamento de Emergencias y a los profesionales de la salud, este calculador sirve como un catalizador para la gestión ambiental dentro del sector salud.

Palabras clave: Huella de carbono, emisiones de gases de efecto invernadero, departamentos de emergencia, evaluación del ciclo de vida, impacto ambiental, enfermería.

Abbreviations

CH_4- methane

CINAHL - Cumulated Index to Nursing and Allied Health Literature

CO – carbon monoxide

CO_2- carbon dioxide

CT - computerised tomography

CVI - Content Validity Index

DEFRA - Department for Environment, Food & Rural Affairs

ED – Emergency Department

EU – European Union

F-gases -fluorinated gases

GHG – greenhouse gas

GP – general practice

GWP – global warming potential

HFCs - hydrofluorocarbons

IPCC - Intergovernmental Panel on Climate Change

LCA - Life Cycle Assessment

MRI - magnetic resonance imaging

N02 – nitrogen dioxide

N_2O - nitrous oxide

NF_3 -nitrogen trifluoride

NHS – National Health Service

O_3 – ozone

Pb – lead

PFCs - perfluorocarbons

PM – particular matter

PRISMA - Preferred Reporting Items for Systematic reviews and Meta-Analyses

PTSD – post-traumatic stress disorder

RCEM – Royal College of Emergency Medicine

SDU - Sustainable Development Unit

SF_6 - sulphur hexafluoride

SO_2 – sulphur dioxide

UK - United Kingdom

UN – United Nations

UNHCR- United Nations High Commissioner for Refugees

US - United States of America

US -ultrasound

WHO – World Health Organisation

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CHAPTER 1: Introduction

1. Greenhouse effect and climate change

The greenhouse effect is the process through which heat is retained in the Earth's atmosphere by greenhouse gases and maintains our planet in a temperature suitable for life. Greenhouse gases absorb infrared radiation from the Sun in the form of heat and this is re-emitted in all directions, thereby maintaining the planet's temperature. The greenhouse effect is a natural phenomenon caused by the presence of greenhouse gases in the atmosphere. However, there has been an increase of greenhouse gas emissions due to human activity over the last century, causing a rapid global warming and leading to a change in the Earth's climate (Costello et al, 2009). The greenhouse gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and a group called fluorinated gases (F-gases), which include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6), and nitrogen trifluoride (NF_3).

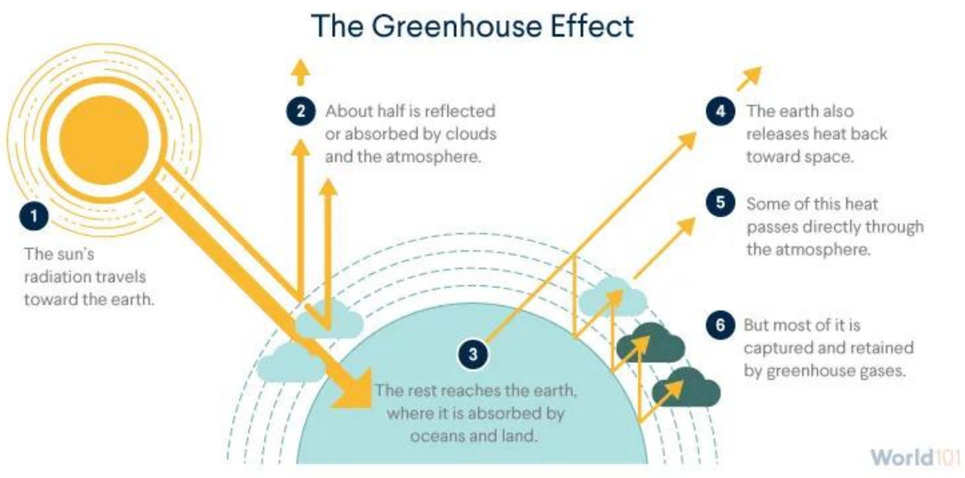

Figure 1. *The greenhouse effect (Council on Foreign Relations, 2023).*

Climate change can be defined as the alteration of weather patterns secondary to changes in the environment provoked by the increase of greenhouses gases released into the atmosphere for a long period of time (Intergovernmental Panel on Climate Change, 2022). Data have shown a rapid acceleration of climate change over the last years with a rapid increase of Earth's temperature and oceans as well as increasing sea levels. Carbon dioxide recorded its highest concentration in 2021 over the last million years, similarly to methane and nitrous oxide, and these concentrations have significantly accelerated over the last two decades (Bereiter et al., 2015). Furthermore, the average global temperature for the period from January to September 2023 was 0.52°C higher than the corresponding 1991-2020 average, and July 2023 was registered as the hottest month on record to date (Copernicus Climate Change Service, 2023). Temperature in the oceans also hit a record high in 2021, and the sea level remains raising with a difference of 97mm comparing sea levels between 1993 and 2021(Thompson et al., 2022). The current trajectory could lead to further temperature increases of between 1.4-2.5°C by 2100, with a high probability that the critical 1.5°C will be exceeded in the next 5 years (Masson-Delmotte et al., 2018).

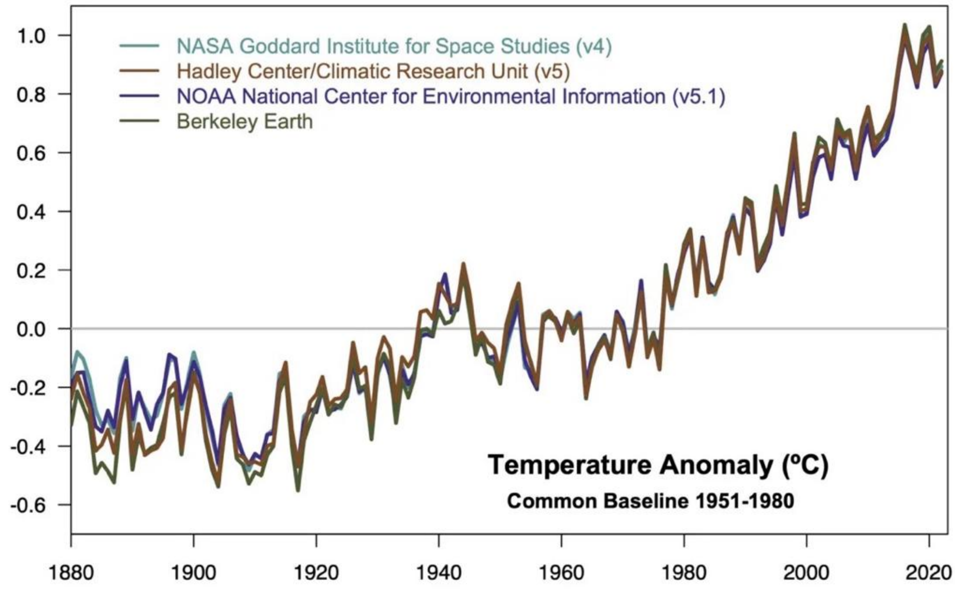

Figure 2. *Temperature trajectory between 1880 and 2021. Comparison of four independent methods for estimating global temperature anomalies (NASA, 2021).*

The Global Warming potential (GWP) refers to how much a greenhouse gas contributes to global warming over a specified period of time, and it is used as unit of measurement (Liu et al., 2017). Carbon dioxide is the gas with the smallest GWP and hence it is used a reference-its value is 1 GWP. The rest of the greenhouse gases have a higher GWP than carbon dioxide; for instance, methane has a GWP of 28 times higher than CO_2, nitrous oxide of 265 times higher than CO_2 and F-gases can reach more 20000 higher than CO_2. The length of time these greenhouse gases stay in the atmosphere varies; for instance, carbon dioxide can remain up to hundreds of years, whereas methane stays around 12 years, and nitrous oxide and F-gases persist for between 114 and 264 years. Despite CO_2 having the lowest GWP, this greenhouse gas represents the highest quantity in the atmosphere. Hence, the literature often refers to the term's "carbon", "carbon emissions" or "carbon footprint" when discussing greenhouse gases or greenhouse gas emissions.

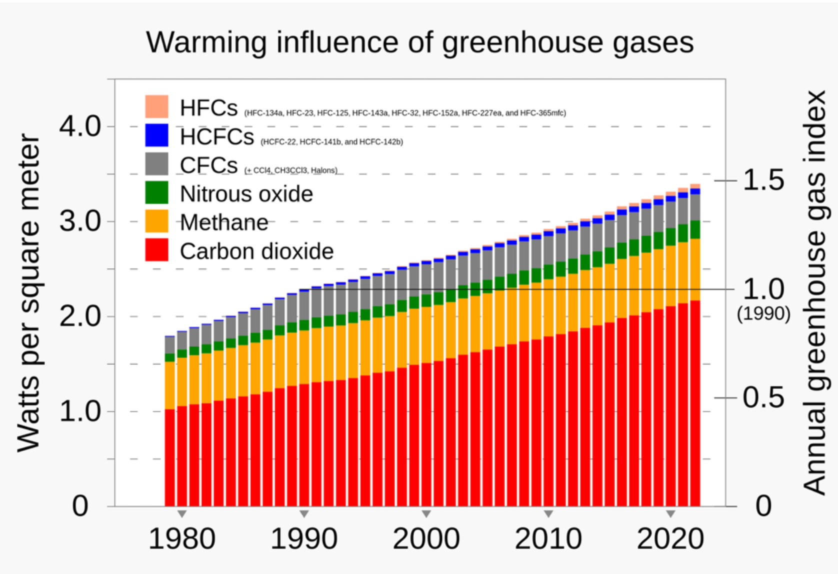

Figure 3. *Global Warming influence of GHGs in the last decades. Warming influence of long-lived atmospheric greenhouse gases has nearly doubled since 1979 (National Oceanic and Atmospheric Administration, 2023).*

2. Climate change and health

Climate change and health are directly related due to complex and interrelated mechanisms, including extreme temperature, extreme weather events, increased air pollution, increased infectious diseases, food scarcity, and the risk of malnutrition, as well as situations with significant mental health impact and migration, among others (Watts et al., 2018). The Lancet Countdown report (Romanello et al., 2021) identified climate change as the biggest threat to public health of the 21st century.

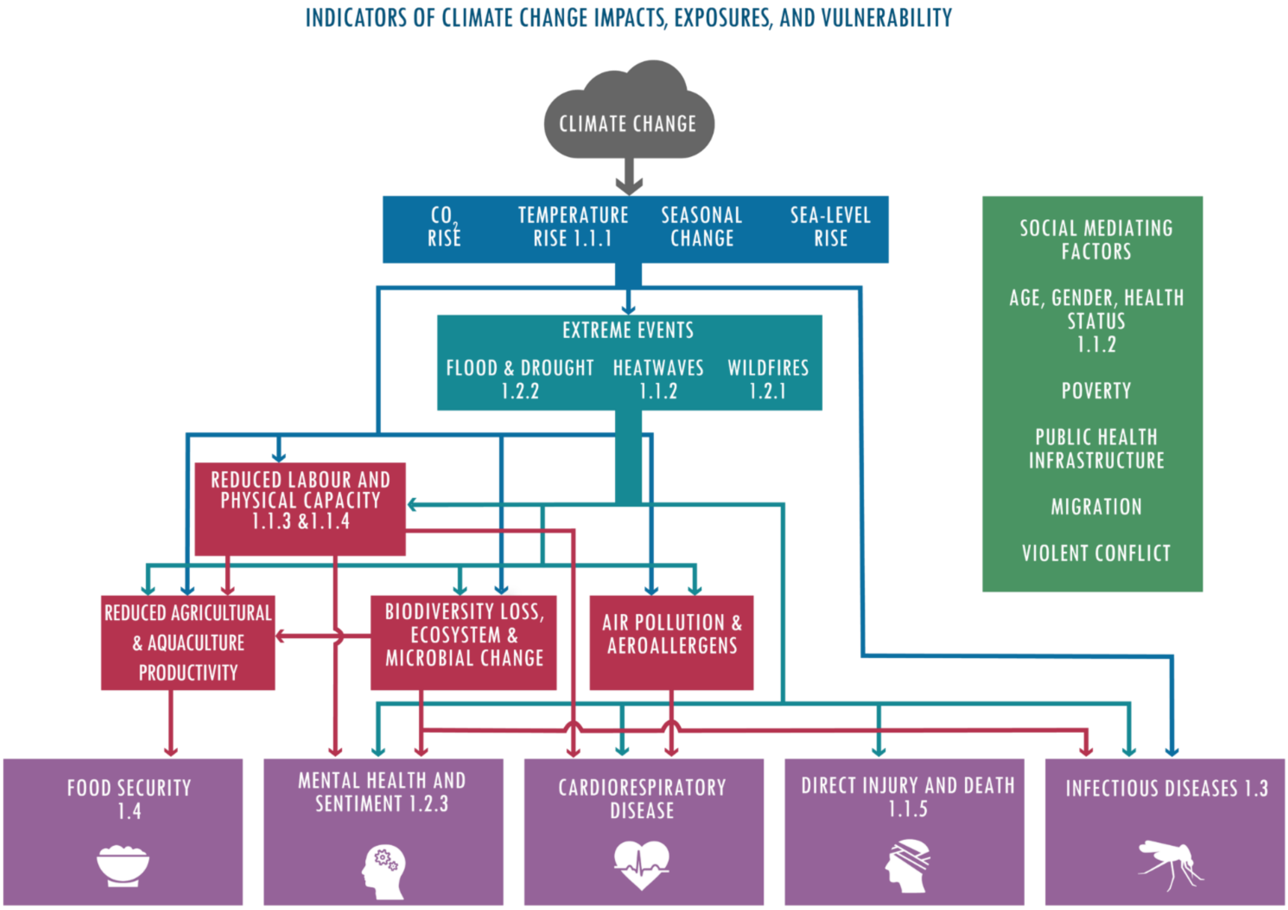

Figure 4. *Climate change's major impact in the environment and health* (Romanello et al., 2023).

Air pollution can be defined as the contamination of the air from any chemical, physical, or biological agent. Air pollution can be divided into outdoor and indoor air pollution. Outdoor air pollution can be classified into natural or biogenic – such as pollen, bushfires, or dust- and human or anthropogenic – such as industry, burning fossil fuel, or motor vehicles. Indoor air pollution is mainly caused by solid fuels - solid materials, such as wood or coal used to provide heating or cooking- tobacco smoke, building materials, pesticides, asbestos, and cleaning products. There are over 100 air pollutants, but the main ones are particulate matter (PM), nitrogen dioxide (NO_2), carbon monoxide (CO), sulphur dioxide (SO_2), lead (Pb) and ozone (O_3) (Jiang, et al., 2016; Tran et al., 2020). The health effects secondary to air pollution depend on the type, concentration, and length of exposure to air polluters as well as the individual characteristics. Air pollution has been associated to minor conditions such eye, nose, or throat irritation as well as more severe conditions such as stroke, chronic obstructive pulmonary disease, trachea, bronchus and lung cancers, exacerbations of asthma, lower respiratory infections, cardiovascular diseases, dementia, pregnancy complications and obesity-related conditions (Murray et al., 2020). Air pollution is associated with increased hospital admissions and increased mortality. A study carried by Imperial College of London estimated that the poor quality of air in London resulted in 1700 admissions secondary to respiratory presentations between 2017 and 2019 (Imperial College, 2022). The World Health Organisation (WHO) reported that 99% of the urban population is exposed to harmful levels of air pollution (WHO, 2022). Furthermore, the mortality associated to air pollution has been estimated as 8.34 million deaths per year worldwide (Lelieveld et al., 2023). Air pollution is also responsible for 6.7 million premature deaths annually and data have shown that air pollution decreases life expectancy by 1.8 years worldwide (Rezakhani et al.,2023).

The human body regulates its temperature normally by sweating to cool down. Body temperature can increase due to external heat from the environmental or internal heat caused by metabolic processes. Continuous exposure to higher temperatures compromises the body’s ability to regulate its temperature, leading to acute and chronic illnesses. Acute illnesses include heat cramps, heatstroke, and hyperthermia, while chronic illnesses include cardiovascular, respiratory, cerebrovascular diseases, and conditions related to diabetes. The effects of heat on human health depend on the duration, intensity, and timing of the exposure, as well as the adaptability of the population. Heat-related deaths continue to rise, especially among the elderly population. Over the last two decades, there has been an increase of up to 54% of heat-related deaths across Europe with 61,672 deaths reported only in 2022 (Ballester et al., 2023). Risk assessments carried out by Quiggin et al. (2021) predict that if emissions are not drastically reduced before 2030, there will be 3.9 million people exposed to major heatwaves by 2040, 400 million people will be unable to work, there will be 10 million heat-related deaths per year and no region will be spared.

Extreme weather events such as floods, heatwaves, droughts, wildfires, and storms have increased over the last decades due to raising global temperatures (Figure 5). These events have a significant impact on society, causing infrastructure damage, increases in morbidity and mortality rates, displacement populations, and deterioration in mental health, among other issues. For example, Pakistan suffered severe floods in 2022, which led to the displacement of up to 7.6 million people (United Nations High Commissioner for Refugees, 2022). Major population displacements can have major consequences not only for the mental health of those affected but also for causing financial strain in the affected regions. There has also been an increase of wildfires in Canada, the United States of America (US), Algeria, Greece, Italy, and Turkey between 2021 and 2022 (Di Napoli et al., 2022). Wildfires have a significant impact on agriculture, destroying habitats and infrastructure, as well as exacerbating mental health issues and increasing migration. Furthermore, wildfires are associated with an increased air pollution, aggravating respiratory conditions and mortality rates. For instance, Australia recorded 450 deaths, 13,000 emergency asthma presentations, and a large number of respiratory and cardiovascular admissions, displacing thousands of people and worsening mental health outcomes, following the bushfires that occurred in 2020-2021 (Biddle et al., 2021).

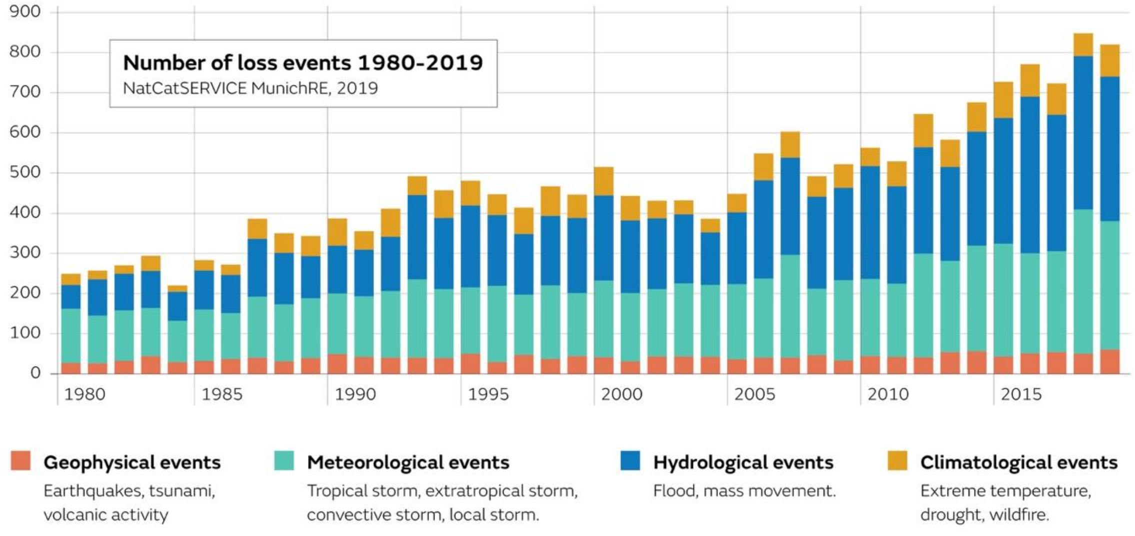

Figure 5. *Incidence of extreme weather event between 1974 and 2019 (Munich Re, 2019).*

Climate change and rising temperatures also facilitate the proliferation and propagation of infectious diseases into regions where they did not previously exist. For instance, malaria has increased by up to 31.3% in areas of America and 13.8% in highland areas of Africa (Brumfield et al., 2021). Dengue cases have increased by 30% compared to data from the 1950s. Both dengue and malaria are expected to be intensify due to climate change, potentially putting 2.25 billion people at risk by 2050 (Intergovernmental Panel on Climate Change, 2022).

Climate change can also lead to crop failures caused by droughts, floods, and/or extreme heat conditions, posing a high risk of mass starvation (Schnitter & Berry, 2019). There has been an increase of food insecurity globally over the last decade, with an estimated 720-811 million people suffering from hunger in 2020 (Botreau & Cohen, 2020). Predictions suggest that Europe could experience increasing severe periods of droughts by 2050, which could lead to shifting weather patterns, changes to ecosystems, unprecedented food insecurity and migration (Quiggin et al., 2021).

Furthermore, climate change can have negative impacts in mental health. Floods have been associated with a high number of mental health issues, with one third of flood victims suffering from depression, anxiety, or post-traumatic stress disorder (PTSD), according to a study conducted by Public Health England in 2014. Nearly a quarter of these individuals still experience mental health issues two years after the event (Public Health England, 2020). Approximately 1.8 million people in the United Kingdom (UK) are living in areas of high risk of flooding and this could increase to 2.6 million by 2040 with the current trajectory, putting a large cohort of the population at risk (The Climate Coalition, 2021).

Climate change can increase adverse weather events or crop failures, leading also to migration. Furthermore, climate change could lead to conditions of severe poverty affecting more than 100 million people worldwide by 2030, and therefore, to a significant increase in migration processes (The World Bank, 2015).

3. Carbon footprint and methods of assessment

The concept of carbon footprint arises from the need to quantify GHGs. A carbon footprint is the sum of direct and indirect emissions of GHGs resulting from a process, a product, or an organisation, and it is calculated in the metric Carbon Dioxide equivalent (CO_2e). This concept encompasses the seven GHGs established by the Kyoto Protocol (European Commission, 2008): carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6), and nitrogen trifluoride (NF_3).

Greenhouse gas emissions resulting from the use of a product, a process, or the activity of an organisation can be divided into:

- Direct emissions: emissions over which an individual or organisation has direct control over. For example, burning fossil fuels for heating on-site or direct transportation used by the individual or the organisation.
- Indirect emissions: emissions related to the activities of the individual or organisation but over which they have no direct control. For instance, emissions resulting from the production of a disposable item or the use of purchased electricity, as these emissions are generated somewhere outside the organisation but are caused by its activities.

According to the Greenhouse Gas Protocol by the World Resources Institute (2022), greenhouse gas emissions can be classified into three scopes:

- Scope 1 emissions: all direct emissions such as energy use, anaesthetic gases, or freight transport (excluding purchased electricity) over which the organisation has direct control.
- Scope 2 emissions: indirect emissions related to purchased electricity or the use of electricity by the individual or organisation that has been produced elsewhere.
- Scope 3 emissions: encompassing all other indirect emissions emitted by an individual or organisation, the production of which is not controlled by the individual or the organisation.

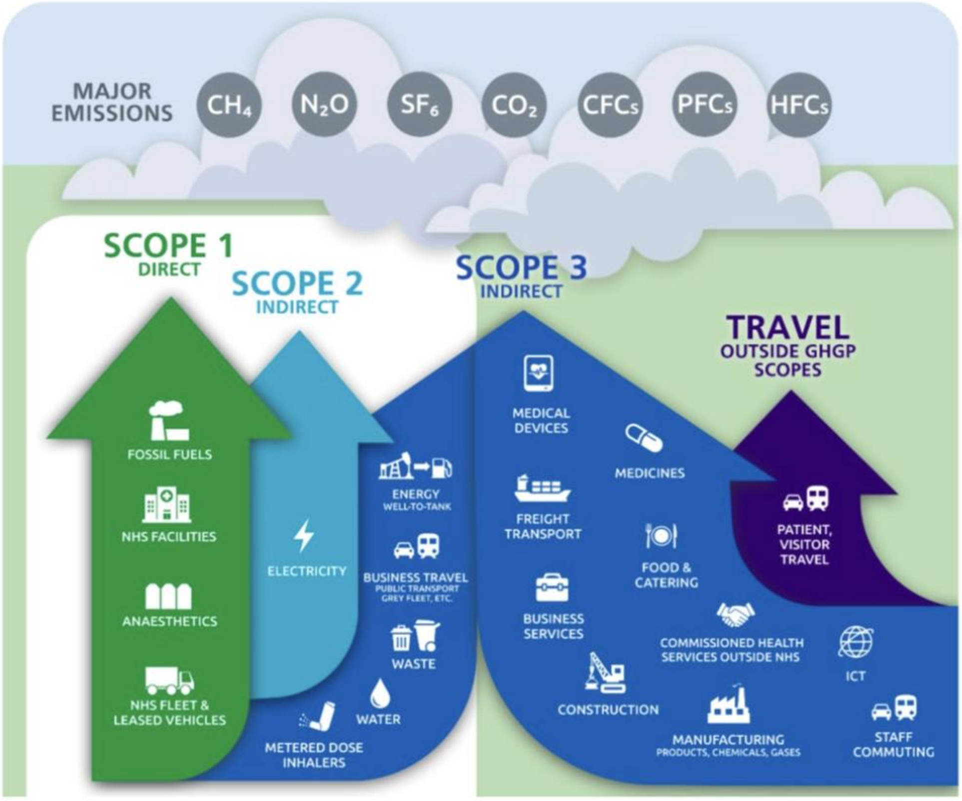

Figure 6. *Greenhouse Gas Protocol Scopes in the Context of the NHS (NHS England, 2022).*

There are three main methods to carry out a carbon footprint assessment: bottom-up lifecycle assessment; top-down lifecycle or economic input-output analysis, and the combination of both, also called hybrid model. Bottom-up assessment analyses each of the materials used to produce an item or a process and this is multiple by a conversion factor. The top-down approach or economic input-output analysis uses the financial cost of a product or a process, and this is multiplied by a conversion factor. The hybrid model is a combination of both, in which, depending on the data's accessibility and availability, either the bottom- up or top-down approach is utilised (Kennelly et al,2019).

4. Climate legislation

In 2015, 196 countries reached a deal, also known as the Paris Agreement, in which they committed to cut emissions to limit the raise in global temperatures well below 2^{o}C and to pursue efforts to limit the temperature increase to 1.5 ^{o}C below pre-industrial levels. The latest Intergovernmental Panel on Climate Change (IPCC) report (2022) shows that these goals will not be achieved during the 21st century unless deep reductions in GHGs are applied. To meet the Paris agreement, GHG emissions should peak between 2020 and 2025, followed by a reduction of GHG emissions in the next decades, reaching global CO_2 emissions net zero by 2050 and global GHG emissions net zero by 2070-75. “Net Zero” is the term used for cutting GHG and/or CO_2 emissions caused by human activity close to zero. Net zero can also be achieved by balancing out GHG emissions with their removal from the atmosphere, either storing them in geological, terrestrial, or oceans reservoirs.

In 2019, the UK was the first major economy to introduce a CO_2 and GHG emissions net zero commitment by 2050. This move preceded the previous the UK Climate Change Act of 2008, which set the statutory targets of cutting emissions to 34% by 2020 and by 50% by 2025, against a 1990 baseline (UK government, 2019). In Europe, the European Climate Law (2021) established the commitment to achieve net zero in the European Union (EU) by 2050 and defined the net zero commitment in the European Union. Other countries have also introduced climate change laws, such as Spain, to be compliant with the European Climate Law and the Paris Agreement. Furthermore, the state members of the United Nations (UN) (2015) established *17 Sustainable Development Goals* to be achieved by 2030, aiming to preserve the planet and improve the lives of the population worldwide. These Sustainable Development goals include: no poverty, zero hunger, good health and well-being, quality education, gender equality, clean water and sanitation, affordable and clean energy, decent work and economic growth, industry innovation, reduced inequalities, sustainable cities and communities, responsible consumption and production, climate action, life below water, life on land, peace, justice and strong institutions and partnerships for the goals (UN, 2015).

Figure 7. *United Nations 17 Sustainable Development Goals (UN, 2015)*

These sustainable goals are in line with climate action, as climate change can make it difficult or slow down the achievement of those goals – for instance, climate change could worsen poverty, hunger, health, decrease the number of jobs or increase inequalities amongst the global population. Climate action targets aim to strengthen climate resilience, integrate climate change measures into national policies, strategies, and planning, improve education and raise awareness, create a Green Climate Fund, and promote climate-related changes.

5. Carbon footprint of healthcare services

Healthcare services are responsible for 4-5% of the global greenhouse gas emissions (Pitchler et al, 2019). If the healthcare sector was a country, it would be the fifth-largest polluter on Earth. Climate change has been described as one of the major threats to human health in the 21st century (Romanello et al., 2021). Climate change is also a threat to the core purpose of healthcare services – to protect and promote health- and hence, healthcare services are part of the problem but also part of the solution. Over the last few years, healthcare services have started taking responsibility the fight against climate change and implementing policies to reduce GHG emissions. The National Health Service (NHS) in the UK was the first national health care system to adopt a net zero commitment and established two clear objectives: to reduce to 0 those emissions directly controlled by the NHS by 2040 and those indirectly controlled by the NHS by 2045 (NHS England, 2022). In Spain, the platform Sanidad #PorELClima was created to take action against climate change and achieve net zero in the Spanish healthcare system. Furthermore, the strategic programme for health and the environment was introduced by the Spanish ministry of health in 2021.

There have been several studies in the healthcare sector to assess GHGs and implement initiatives to reduce them. The National Health Service (NHS) in the UK estimated that their carbon emissions were 6.3% of the total emissions in the UK (Tennison et al., 2021). Similarly, Spain also reported about 5.4% whereas Australia reported 7.2% of their total emissions. Tennison et al. (2021) estimated that the use of a hospital bed per day is equivalent to 125 kg CO_2e, an appointment in an outpatient department is 75 kg CO_2e, an appointment in a general practice (GP) surgery is 66 CO_2e and each ambulance attendance is 75 CO_2e in the UK. Data has shown that scope 3 emissions are larger than scope 1 and 2 in the health sector (Malik et al., 2021; Keller et al., 2021). Nicolet et al. (2022) calculated that the average GHG emissions for a GP surgery in Switzerland were 30 tons of CO_2e per year, of which 45.7% was due to patient and staff transport, 29.8% due to heating, 5.5% due to consumables, 5.8% due to courier transport and 1% blood analysis and X-rays.

The surge of new departments, such as the Greener NHS in the UK, is facilitating the implementation of sustainable programs to be compliant with national and international laws as well as healthcare service commitments. However, despite the implementation of large projects at the national level, the importance of local initiatives to bring about change has been highlighted (IPCC, 2022).

6. Environmental initiatives in healthcare services

Over the last year, there has been a surge of new environmental initiatives in the healthcare sector to reduce GHG emissions and meet the national and international goals, as well as comply with climate laws. The development of environmental initiatives at all levels is important to achieve net zero emissions. These initiatives collectively aim to create a more ecologically responsible healthcare sector, recognising the interconnectedness of environmental sustainability, public health, and overall well-being. The Greener NHS in the UK is an example of the healthcare systems' resilience, by creating a dedicated and specialised team to address the climate crisis within the healthcare service. The Greener NHS was founded in 2020 with the aim of achieving net-zero in the NHS through an ambitious and evidence-base strategy and implementation of change (Greener NHS, 2020).

Operating theatres are believed to be responsible for 25% of the emissions in hospital settings. A single operation can range between 6 to 814 kg CO_2e, in which electricity use and consumables are identified as the major carbon hotspots (Rizan et al., 2020). At Solihull Hospital, a surgical team carried out the first net zero carbon operation in the world by introducing several changes in their usual practice, such as using reusable gowns and drapes, administering intravenous medication for general analgesia instead of using anaesthetic gases, minimising electricity use, and utilising individually packed equipment- and they estimated an

80% reduction in carbon output (Greener NHS, 2022). Anaesthetic gases are widely used in operating theatres for general anaesthesia, such as desflurane, which is one of the most common gases used and one of the most harmful. An anaesthetic team at Bristol University Hospital and Weston NHS Foundation carried out a project replacing the use of desflurane for sevoflurane, demonstrating savings of 30,000 Kg CO_2e per month (Greener NHS, 2021).

Transport to and from healthcare settings is also considered a significant source of carbon emissions. Patients and their relatives tend to use private transport rather than public transport for healthcare appointments, which increases the indirect carbon emissions of the healthcare setting, and it is estimated that initiatives to mitigate these emissions could achieve a 30-40% reduction in carbon emissions. Manchester University NHS Foundation Trust achieved a 40% reduction in carbon emissions in 2015 compared to 2013 baseline by improving cycle parking, increasing electric vehicle charging points, facilitating travel discounts, and introducing vehicle and bicycle user groups (Greener NHS, 2022). Telephone consultations have significantly increased during Covid-19 pandemic and have showed benefits such as improving patient's experience and reducing unnecessary emissions due to transportation. The Neurology department at Barking, Havering and Redbridge University Hospitals Trust found that replacing face-to-face appointments with telephone consultations could save up to 131 tons of CO_2e per year (Misbahuddin et al., 2023).

These environmental initiatives show how powerful the action of local initiatives and highlight the importance of measuring carbon emissions to evaluate their effectiveness. Emergency Departments see a high volume and acuity of patients worldwide, with up to 136 million attendances per year recorded in the US or 24.4 million in the UK, and likely representing a large portion of the healthcare system's carbon footprint. The Green Emergency

Department (Green ED) project is an initiative aiming to reduce the environmental impact of emergency services in the UK while also striving to influence and bring about sustainable changes in emergency departments worldwide. As part of the Green ED project, emergency practitioners at Charing Cross Hospital in London carried out a project in 2022 to reduce unnecessary cannulation. They demonstrated that by educating staff, raising awareness, and promoting changes in behaviour, a reduction of 19,000 kg CO_2e and savings of £95,000 savings could be achieved (Greener NHS, 2022). The development of a tool to assess the ED carbon footprint can be game-changing in sustainable initiatives by providing robust data, raising awareness, justifying environmental initiatives, and having an influential effect to bring about change (Burgui-Burgui & Chuvieco, 2020).

7. Climate change and nursing

Nursing professionals are well positioned to act against climate change. First, nurses account for 60% of health professionals globally, they constitute an extensive workforce in healthcare (World Health Organisation, 2020). Secondly, nurses consistently rank among the most trusted professions, underscoring their capacity to effectively convey messages concerning climate change (Butterfield et al., 2021). Moreover, their proximity to the most vulnerable populations affected by climate shifts amplifies their impact (Dupraz & Burnand, 2021). Research also indicates a correlation between higher nurse staffing levels and reduced mortality rates in illnesses linked to climate change (World Health Organisation, 2020). Thus, nurses emerge as pivotal advocates in combating the multifaceted challenges posed by environmental shifts. Nurses can lead by example, not only in direct patient care but also promoting sustainability within healthcare systems (Shaban et al., 2024).

Nurses, along with other healthcare professionals, carry out their daily duties guided by principles such as beneficence and non-maleficence. In addition, nurses have a duty to educate and protect population health, by engaging in health promotion, disease prevention, and care provision activities (International Council of Nurses, 2021). However, healthcare services are both part of the solution and part of the problem. While they play a crucial role in treating illnesses and dealing with the consequences of adverse weather events caused by climate change, they also emit a considerable number of emissions due to their activities. Hence, nurses have a responsibility to reduce these emissions while ensuring safety and enhancing delivery of care.

The nursing profession has been historically connected to climate action and environmental health for over two centuries. In 1859, Florence Nightingale emphasised that all health is environmental health, and that life itself depends on the Earth's fundamental resources. In 1986, the International Council of Nurses called on nurses to address the "vastness and urgency" of environmental issues, emphasising their shared responsibility in protecting the planet. Subsequent position statements were issued in 2008 and 2018.

Health Care Without Harm, a prominent international non-governmental organisation dedicated to reducing the environmental footprint of the healthcare sector, was founded by a nurse and an environmental health activist in 1996. Following this, organisations such as the Alliance of Nurses for Healthy Environments (2008), the Canadian Association of Nurses for the Environment (2009), and the United Kingdom Health Alliance on Climate Change (2016) emerged to further advance the role of nursing in environmental advocacy.

The development of models such as the WE ACT PLEASE model and the Ecological Planetary Health Model outlines how nurses can engage in environmental stewardship, lead education efforts, and integrate climate change into their practice and curricula. Furthermore, since the Paris Agreement in 2016, numerous healthcare organisations and bodies have introduced climate adaptation and service transformation into their agendas. The International Council of Nurses exemplifies this commitment through its 2018 position statement on Nurses, Climate Change, and Health, urging national nursing associations and individual nurses to actively engage, collaborate, and advocate against climate change (International Council of Nurses, 2018).

Initiatives like the Nurses Climate Challenge, started by Health Care Without Harm and the Alliance of Nurses for a Healthy Environment, also aim to mobilise nurses in educating both healthcare professionals and the broader community about the profound health ramifications of climate change (Demorest et al., 2019).

The Intergovernmental Panel on Climate Change (IPCC) highlights that reaching sustainable practices depends on the strong commitment of all professionals, especially healthcare workers, who have an important part in this global effort (IPCC, 2022). However, in order to do that is important to analyse and consider the enablers and barriers for nurses to take action. Facilitating factors include adopting a planetary health perspective to increase climate knowledge, while barriers include lack of knowledge, time, and institutional support.

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CHAPTER 2: Objectives

1. General objectives

- To encourage and facilitate effective environmental initiatives in the emergency departments.
- To identify evidence-based approaches to locate carbon hotspots and tackle them more effectively.
- To enable baseline carbon footprint assessments in the emergency departments.

2. Specific objectives

- To describe the carbon footprint of healthcare services and identify the hotspots of carbon emissions in the healthcare sector.*
- Development of an assessment tool to evaluate the carbon footprint of the emergency departments in the UK.**
- To design and validate an assessment tool to facilitate the monitoring and reduction of carbon emissions in the emergency departments.***

*Article 1. *The carbon footprint of healthcare settings A systematic review.*

**Article 2. *Environmental impact of Emergency Services in Public Health: an assessment tool.*

***Article 3. *The Emergency Department carbon footprint calculator: design and validation.*

CHAPTER 3: Methodology

To answer the objectives previously described, this doctoral thesis followed a three-stage process, corresponding to the three published articles.

1. Stage 1

The first part was a systematic review, to describe the carbon footprint of healthcare services and identify the hotspots of carbon emissions in the healthcare sector. The systematic review was conducted in accordance with the PRISMA 2020 Statement (Page et al., 2020). The eligibility criteria included studies that measured the carbon footprint, life cycle assessment, or GHG emissions of healthcare functional units and which incorporated the three scopes recommended in the Greenhouse Gas Protocol (2022). Studies carried out in other fields, such as industrial, economic, waste management or studies not centred on the patient were excluded. Reviews, opinion or popularisation articles, research projects, or other reports that did not provide results of an environmental impact assessment were also excluded. Studies published between 2012 and 2022 were included and which were written in English and Spanish.

The Medline, Web of Science, CINAHL, and Cochrane databases were searched. The search strategy used was: ("carbon footprint" OR "greenhouse gas emission" OR "life cycle assessment") AND (health*). The filters used were year of publication and language.

Data collection was carried out by one of the researchers and verified by two others. A form was designed to extract the data, including country, year of publication, functional unit, methodology, categories analysed, carbon emissions, data collection (including data source and data type), and emissions factors.

2. Stage 2

The next stage was the development of a prototype assessment tool to evaluate the carbon footprint of the emergency departments in the UK. This stage was divided into five sub-stages: selection of the categories included in the assessment tool, determination of scope and boundaries, selection of conversion factors, data collection and evaluation method of the carbon footprint.

The literature review carried out in the first stage facilitated the identification of the most common categories previously analysed in carbon footprint assessments papers in the healthcare field, which were: energy and heating, anaesthetic gases, freight transport, purchased electricity, catering and food, disposables and consumables, medical and non-medical equipment, pharmaceuticals, transport, waste, and water. The research team considered that all these categories could provide a comprehensive carbon footprint assessment and all of them were included in this study. However, anaesthetic gases and freight transport were adapted for the emergency services context.

Data sources varied depending on the category, although they were mainly invoicing and billing, meters, auditing, and surveys. The key data collected reflected the most important data to be obtained for each category. Our methodology followed the environmental reporting guidelines provided by the Department for Environment, Food & Rural Affairs (DEFRA) (2019). The conversion factors selected for all the categories in this assessment tool were obtained from the annual report published by DEFRA, except in the category of waste, in which the conversion factors provided by Rizan et al. (2020) were used. Lastly, the unit of measurement for the data collected was chosen in accordance with the data provided by DEFRA and Rizan et al. (2020) to facilitate its calculation.

The ED carbon footprint calculator applied a hybrid method to quantify carbon emissions in EDs, in which bottom-up and top-down life cycle assessments were used depending on the availability and accessibility of the data.

3. Stage 3

The last stage consisted of the final design of the ED carbon footprint assessment tool and its validation and followed the next steps: evaluation of the prototype version by an expert panel, design of the first version of the ED carbon footprint calculator evaluation of the first version by the expert panel, and evaluation of the first version by focus group.

The prototype was evaluated by an expert panel to assess its content validity. The experts were selected by convenience sampling to meet the inclusion criteria: 1) being a healthcare professional, 2) having at least 3 years of experience in EDs, and 3) having knowledge or experience in sustainability and carbon footprint.

Following the recommendations of Sousa & Rojjanasrirat (2011), a total of 15 experts were invited, among whom 11 agreed to participate in the study. They were given the prototype, and, through an online questionnaire, they were asked to evaluate the relevance of each item (category, data source, data collection, and unit of measurement) with a dichotomous scale (Yes/No). Moreover, they were invited to make additional valuations and suggestions.

The content validity was measured using the Content Validity Index (CVI) for each item and for the entire tool in general, quantifying the degree of agreement among the experts regarding the relevance of each item. Additionally, Aiken's V was also evaluated, which allows assessing the relevance of each item with respect to its construct, although taking into account both the number of categories provided to the experts and the number of participating experts.

The value may range between 0 and 1, being more relevant the closer it is to 1 (Pedrosa et al., 2013).

The contributions of the expert panel were incorporated to the first version of the ED carbon footprint calculator, which was created using Microsoft Excel for Mac v16.65. This version was divided into different Excel sheets following the next order: introduction, content, emergency department details, scope 1 emissions, scope 2 emissions, scope 3 emissions – divided into seven sheets to facilitate its navigation– and results. Each Excel sheet contained several sections and items for each category, as well as a cell at the bottom of the sheet with the total amount of carbon emissions for the category. The ED at the Royal Free Hospital in London was selected as a pilot site for the identification and collection of data between November 2022 and February 2023. Data were collected through observation and from hospital records. The tool was designed to make calculations over a period of one year.

Regarding the conversion factors, we used those proposed by DEFRA in its most recent 2022 report. However, for availability reasons, the conversion factors from the 2019 DEFRA report were used for the category of pharmaceuticals, and those published in the 2012 DEFRA report were used for the categories of disposable/consumables and medical instruments. For the waste category, the conversion factors proposed by Rizan et al. (2020) were maintained. The conversion factor for methoxyflurane was obtained from Hass et al. (2019), as they are not available in the DEFRA report.

The content validity of the first version of the tool was evaluated again by an expert panel. In this case, since the relevance of the items had already been assessed by the same group of experts, the evaluation was focused on the reach of the tool, the calculations, and the conversion factors. The same procedure was followed, inviting the 11 experts from the previous panel to participate in the second panel, among whom eight experts agreed to participate.

The facial validity (or logical association of the items with the concept to be measured) and the presentation and usability of the tool were evaluated by a focus group. The focus group allowed exploring the experiences of the participants about the use of the tool, providing information We ensured that the participants met the profile of the future user of the calculator. To this end, the following inclusion criteria were established: 1) being a healthcare professional, 2) working in an ED, and 3) having no specific experience or knowledge in carbon footprint. A participation invitation was sent to eight people who met the profile, along with the first version of the ED carbon footprint calculator, two weeks before the date set for the focus group, in order to have enough time to manage and test it. The focus group was recorded and transcribed verbatim for subsequent analysis.

The discussion was developed around the following questions proposed by the moderator: How was your experience testing out the ED carbon footprint calculator? How did you find having instructions on "how to use the calculator" in the first excel sheet? How does it influence the presentation of the calculator? How did you feel while filling out the data? What use can have the calculator in your professional practice?

The content analysis was performed by two researchers independently, according to the recommendations of Graneheim and Lundman (2004), and their results were compared to reach consensus, requesting the intervention of a third researcher to resolve any discrepancies, althoh this was not necessary.

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CHAPTER 4: Results

Article 1. The carbon footprint of healthcare settings: a systematic review.

Title: The carbon footprint of healthcare settings: A systematic review.

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Rodríguez-Jiménez, L., Romero-Martín, M., Spruell, T., Steley, Z., & Gómez-Salgado, J. (2023). The carbon footprint of healthcare settings: A systematic review. *Journal of advanced nursing*, *79*(8), 2830–2844. https://doi.org/10.1111/jan.15671

Abstract

Healthcare systems are responsible for 4%–5% of the emissions of greenhouse gases worldwide. The Greenhouse Gas Protocol divides carbon emissions into three scopes: scope 1 or direct emissions secondary to energy use; scope 2 or indirect emissions secondary to purchased electricity; and scope 3 for the rest of indirect emissions.

Aim: To describe the environmental impact of health services.

Design: A systematic review was conducted in the Medline, Web of Science, CINAHL, and Cochrane databases. Studies that focused their analysis on a functional health- care unit and which included. This review was conducted from August to October 2022.

Results: The initial electronic search yielded a total of 4368 records. After the screen- ing process according to the inclusion criteria, 13 studies were included in this re- view. The reviewed studies found that between 15% and 50% of the total emissions corresponded to scopes 1 and 2 emissions, whereas scope 3 emissions ranged be- tween 50% and 75% of the total emissions. Disposables, equipment (medical and non-medical) and pharmaceuticals represented the higher percentage of emissions in scope 3.

Conclusion: Most of the emissions corresponded to scope 3, which includes the in- direct emission occurring as a consequence of the healthcare activity, as this scope includes a wider range of emission sources than the other scopes.
Implications for the profession and/or patient care: Interventions should be carried out by the healthcare organizations responsible of Greenhouse Gas emissions, and also every single individual that integrates them should make changes. The use of evidence-based approaches to identify carbon hotspots and implement the most effective interventions in the healthcare setting could lead to a significant reduction of carbon emissions.

Impact: This literature review highlights the impact that healthcare systems have on climate change and the importance of adopting and carrying out interventions to pre- vent its fast development.

Keywords: carbon footprint, environmental impact, greenhouse gases emissions, healthcare settings, life cycle assessment.

Introduction

Climate change has forced many countries and institutions to declare a climate emergency and carry out changes in different sectors of society in an attempt to reduce Greenhouse Gases (GHGs) (Aidt, 2022). Romanello et al. (2022) described climate change as one of the worst healthcare threats of the 21st century. Climate change can be defined as the alteration of the climate patterns provoked by changes in the environment and the variability of its characteristics, and that keeps happening for a long period of time (Intergovernmental Panel on Climate Change, 2018). Climate change can be caused by natural internal and/or external processes, as well as human activity. GHGs emitted by human activity intensify global warming, increasing the chances of heatwaves, floods, droughts, and/or air pollution, among others. These variations in the climate are directly related to an increase in pathologies such as cardiovascular, respiratory, and/or infectious diseases, as well as malnutrition or mental health issues secondary to the lack of resources and the growth of situations of high emotional distress (Chua et al., 2019). The IPCC report (2022) analysed data from different models of projected risks and found that exposure to climate change could increase heat-related morbidity and mortality up to 16 times. Diseases such as malaria or dengue are expected to be intensified due to climate change, which could potentially put 2.25 billion people at risk (IPCC, 2022). The food industry may also be affected by climate change, posing a risk of malnutrition. Furthermore, climate change could lead to conditions of severe poverty affecting more than 100 million people worldwide and, therefore, to a significant increase in migration processes (The World Bank, 2015). This increased migration along with the intensification of natural disasters could result in a significantly greater number of healthcare demands, thus having an especially significant impact on those countries in which healthcare systems are already fragile (Watts et al., 2018). The COVID-19 pandemic has showed the vulnerability of healthcare systems worldwide and the difficulties experienced when dealing with situations of extreme emergency, so prevention, adaptation, and preparation are key to reduce and slow down the consequences of climate change (Fournier et al., 2022).

Carbon footprint can be defined as the best possible estimation of the impact that something has on climate change (Spruell et al., 2021). Carbon footprint is the sum of direct and indirect emissions of GHGs secondary to a process, a product, or an organisation, and is calculated in Carbon Dioxide equivalent (CO_2e). This concept entitles the seven GHGs established by the United Nations Framework Convention on Climate Change (Paris Agreement, 2015): carbon dioxide (CO_2); methane (CH_4); nitrous oxide (N_2O); hydrofluorocarbons (HFCs); perfluorocarbons (PFCs); sulphur hexafluoride (SF_6); and nitrogen trifluoride (NF_3). CO2 represents 86.0% of the GHGs emissions, hence why GHGs emissions, carbon emissions, and carbon footprint are often used interchangeably. The Greenhouse Gas Protocol (2022) classifies carbon emissions in three scopes; scope 1 or direct emissions are those related to the use of energy (without including purchased electricity) and on which the organisation has direct control, for example the use of fuel for heating; scope 2 or indirect emissions are those related to purchased electricity or the use of electricity that has been produced somewhere else; and scope 3, which encompasses the rest of indirect emissions emitted by an organisation and of which production is not controlled by the organisation. There are three main methodologies for measuring the carbon footprint or Life Cycle Assessment (LCA): bottom-up life cycle assessment; top-down cycle assessment or economic input-output analysis; and the combination of both or hybrid model. Bottom-up LCAs measure all the materials used to produce an item or a process, and multiply each material or item by a conversion factor. Top-down cycle assessment or economic input-output analysis uses the money spent in a product or a process, and this is multiplied by a conversion factor. Finally, the hybrid model is a combination or both (Lin et al., 2013).

Over the last years, there has been a surge of interventions aimed at reducing the effects of climate change (Spruell et al., 2021). The Sustainable Development Unit (SDU) carried out a survey of NHS workers between 2017 and 2019 and found that 98% of them believed in the importance of building a sustainable healthcare service (NHS England, 2017). As different situations serve as evidence of necessary interventions, laws change, as can be seen in the Climate Change Act passed in the UK, which aims to reduce carbon emissions to zero by 2050 (UK Government, 2008). On their part, healthcare systems are responsible of 4-5.0% of the emissions of GHGs worldwide (Pichler et., 2019), so health services have a responsibility in fighting climate change not just to reduce their own carbon footprint, but also to decrease the consequences of healthcare activity on health and to act as a role model for the society (SDU, 2018). The IPCC report (2022) stated that climate resilience could have a strong potential for ameliorating climate change impact on health and that transformational changes would be more effective if they are responsive to regional and local knowledge, considering the many dimensions of vulnerability. The development and implementation of programmes and policies in health systems has followed an evidence-based model over the last years (Hess et al., 2014). The use of evidence-based approaches to identify carbon hotspots and implement the most effective interventions in healthcare could bring about a significant reduction of carbon emissions (Hess et al., 2014). Therefore, the analysis of healthcare settings emissions is essential to decrease the impact of health services on the environment. The contribution and novelty of this literature review lies on collecting the most recent evidence available regarding the carbon footprint of healthcare systems. The results of this study will help to analyse the carbon footprint of the healthcare systems and identify those areas of higher greenhouse gases intensity.

Aim

This review aims to describe the environmental impact of healthcare services by answering the following questions: What is the carbon footprint of healthcare settings? How much greenhouse gas emissions do healthcare services emit? Which are the hotspots of carbon emissions in the healthcare sector?

Methodology

To give answer to the study questions, a systematic review was conducted in accordance with the PRISMA 2020 Statement (Page et al., 2020). The review was registered at PROSPERO ID CRD42022365121.

Eligibility criteria

The eligibility criteria were structured according to the components of the Population, Intervention, Comparator, Outcome (PICO) framework (Booth et al., 2019), in which health care units were considered the population, care activity the intervention, absence of care activity the comparator, and carbon footprint, outcome.

Regarding the population, studies that focused their analysis on a functional healthcare unit, i.e. a complete patient care service, from admission to discharge, were included. Analyses of a single procedure or device were excluded for not performing a holistic assessment of user care. In relation to the intervention, studies carried out in the healthcare field, which analyse patient care were included, and studies carried out in other fields, such as industrial, economic, waste management or studies not centred on the patient were excluded. As for the outcome, cross-sectional studies that measured the carbon footprint, life cycle assessment, or GHG emissions of healthcare functional units and which incorporated the three scopes recommended in the Greenhouse Gas Protocol (2022) were included. Reviews, opinion or popularisation articles, research projects, or other reports that did not provide results of an environmental impact assessment were excluded. Studies published between 2012 and 2022 were included so as to identify the latest evidence, and which were written in English and Spanish, as they are the most frequent languages in the scientific literature.

Information sources

The Medline, Web of Science, CINAHL, and Cochrane databases were searched. Furthermore, a snowball search was performed to retrieve studies not identified in the database search. Reference lists of publications which were eligible for full-text review and references from systematic review reports on a similar topic were reviewed. The initial search was conducted between February and April 2022, and updated in July 2022 after incorporating the results obtained from the snowball process.

Search strategy

The search terms were identified by consulting the titles, abstracts, and keywords of relevant reviews and articles. Several combinations of search terms were tested in the databases beforehand to select the strategy that could identify relevant studies in the most focused way. This process was agreed upon by two of the researchers. The search strategy used was: ("carbon footprint" OR "greenhouse gas emission" OR "life cycle assessment") AND (health*). The filters used were year of publication and language.

Selection and data collection process

The retrieved records were downloaded into a Microsoft Excel spreadsheet that allowed for the identification and elimination of duplicate records. The records were blindly screened by two independent researchers. The titles were reviewed, and the records were pooled to discuss inconsistencies and unify criteria. Then, the abstracts were screened and those that met the inclusion criteria were selected. Discrepancies in the selection were resolved by consensus. In case of doubt, it was agreed upon to include them for full-text review. The same researchers independently reviewed the full text of the selected studies and discrepancies were resolved by consensus, resorting to a third researcher when necessary.

Data collection was carried out by one of the researchers and verified by two others. A form was designed to extract the data, including country, year of publication, functional unit, methodology, categories analysed, carbon emissions, data collection (including data source and data type), and emissions factors (Table 2).

Once the data were extracted, they were analysed and grouped according to the dimensions described by the Greenhouse Gas Protocol (2022): scope 1 (gases directly emitted by the institution, such as anaesthetic gases); scope 2 (indirect cause of gases derived from primary resources, such as electricity); and scope 3 (indirect cause of gases derived from products used by the institution in its production chain, such as medical devices).

Study risk of bias assessment

Two main sources of biases were considered in this review. On the one hand, biases arising from methodological quality, and on the other hand, biases arising from inaccuracies in the measurements made by the reviewed studies. These inaccuracies may lie in the calculation method employed (top-down or bottom-up), the inventory boundaries, and the accuracy of data and assumptions made by the reviewed studies. Therefore, the risk of bias assessment was carried out through an ad hoc tool with elements drawn from the most relevant critical appraisal tools for assessing methodological quality (Zeng et al., 2015; Pussegoda et al., 2017) and elements from the reference guidelines (Greenhouse Gas Protocol, 2022, Department for Business Innovation and Skills, 2011). This assessing method has been used by Rizan et al. (2020) in a previous similar review. The assessment was conducted independently by two researchers who agreed on the discrepancies.

Results

The initial electronic search yielded a total of 4368 records. Duplicated articles were excluded and, after carrying out a title screening, 90 met the inclusion criteria. The abstract review further reduced the number of records to 41, and a full text reading was carried out. Finally, 13 studies were selected for this literature review (Figure 1). Regarding the quality assessment of the studies, all of them scored over 17 out of 24. All the articles were accepted as the magnitude of their analysis and the methodological quality were considered appropriate (Table 1).

The chosen studies were all written in English, and conducted in different locations between 2012 and 2022: one in Morocco; one in Japan; two in the United States; three in Australia; two in Switzerland; one in the UK; one in China; and two in Canada. This literature review included studies that calculated the carbon footprint of a functional unit in a healthcare setting using one of the following methods: bottom-up life cycle assessment (Keller et al., 2021; Lim, Perkins & Agar, 2013; MacNeill et al., 2017; Mtioui et al., 2020); top-down cycle assessment or economic input-output analysis (Eckelman & Sherman, 2016; Eckelman et al., 2018; Malik et al., 2018; Nansai et al., 2020; Wu, 2019); or a combination of both, also known as hybrid model (Malik et al., 2021; Nicolet et al., 2022; Prasad et al., 2021; Tennison et al., 2021).

The functional unit for analysis was stablished by the author/s of each study. Seven studies took the healthcare system of a whole country or a large state within a country as functional unit (Eckelman & Sherman, 2016; Eckelman et al., 2018; Malik et al., 2018; Malik et al., 2021; Nansai et al., 2020; Tennison et al., 2021). Three studies were multicentred: one of them in thirty-three hospitals (Keller et al., 2021); another one in three hospitals (MacNeillet al., 2017); and the third one in ten private primary care settings (Nicolet et al., 2022). The other three studies were carried out in units within a hospital: two of them in haemodialysis units (Lim et al., 2013; Mtioui et al., 2020) and one in an intensive care unit (Prasad et al., 2021).
Not all the studies analysed the same categories and that might be due to the complexity of such analysis. For example, those articles that analysed the entire healthcare system distributed their data in different areas of healthcare (such as public hospitals, primary healthcare, pharmaceutical industry, etc.), whereas those studies carried out in smaller functional units divided the data in more specific categories (such as water, waste, medical equipment, etc.). The main findings of the reviewed studies are summarised in Table 2.

Scope 1 emissions

Scope 1 emissions ranged between 10% to 30% in the analysed studies. Studies that assessed healthcare systems found that scope 1 emissions were around 10% (Eckelman & Sherman, 2016; Eckelman et al., 2018; Malik et al., 2018; Malik et al., 2021; Nansai et al., 2020; Tennison et al., 2021), whereas in those analysing hospital settings or primary healthcare centres, these were around 20% (Keller et al., 2021; MacNeill et al., 2017; Nicolet et al., 2022; and Lim et al., 2013).

There were two exceptions of studies that found disparate results: one that found low levels of emissions, 0.4% (Mtioui et al., 2020), and another one which found high levels, 25.2%

(Prasad et al., 2021). Only three of the studies assessed the use of medical gases, that ranged between 1.9% (Prasad et al., 2021) and 83.7% (MacNeill et al., 2017). Transport freight or transport of goods by the organisation was also part of the direct emissions and they accounted for less than 5% in the studies that looked into them (Mtioui et al., 2020; Nansai et al., 2020 and Nicolet et al., 2022).

Scope 2 emissions

Emissions secondary to purchased electricity differs between the studies analysed. Nicolet et al. (2022) found very low levels of emissions due to electricity (0.3%); however, their scope 1 emissions were higher than those of other studies. Three studies analysed energy and electricity together, thus hindering the individual analysis. Two of them showed higher percentages of emissions for energy and electricity (MacNeill et al., 2017; Prasad et al., 2021). On the other hand, Lim et al., (2013) found relatively low levels, compared to the other two.

Scope 3 emissions

Scope 3 emissions ranged between 50% and 75%. The largest emissions in scope 3 were found to be due to disposables or consumables, equipment (medical and non-medical), and pharmaceuticals. Disposables or consumables were analysed in different ways, yet most of the studies found that the carbon footprint related to them was greater than 20.0%. Studies that analysed healthcare systems found pharmaceuticals to account for between 7.6% (Wu, 2019) and 35.7% (Lim, Perkins & Agar, 2013) of the emissions. Carbon emissions derived from medical equipment were generally high, ranging between 0.4% (Nicolet et al., 2022) and 32.2% (Prasad et al., 2021). Although there were some studies that calculated medical equipment, disposables, and infrastructure together, this was still a significant percentage of the carbon footprint. Only two studies (Lim et al., 2013; Nicolet et al., 2022) found relatively low levels of emissions secondary to disposables. Two other categories, staff travel and building infrastructure, represented around 3.0% (Lim et al., 2013) and 16.6% of the total emissions each (Mtioui et al., 2020). Water, waste, and patient travel generally represented less than 10.0%. The results for catering differed, ranging from 1.9% (Wu, 2019) to 30.3% (Prasad et al., 2021). The two studies that calculated the emissions secondary to food consumption for the whole national healthcare system found the levels relatively low, 3.6% (Nansai et al., 2020) and 6.1% (Tennison et al., 2021), respectively. However, the other two studies calculating catering carbon footprint found higher percentages, of 17.0% (Keller et al., 2021) and 30.3% (Prasad et al., 2021), and this might be so because these studies were carried out in hospital settings, where the provision of food to patients is expected to be high. Furthermore, Prasad et al. (2021) found higher percentages of emissions due to catering, and that is likely to be related to the fact that both staff and patient food consumption were calculated together.

Discussion

The aim of this systematic review was to analyse studies measuring the carbon footprint of healthcare settings and identify hotspots of carbon emissions. Overall, the studies reviewed showed that scopes 1 and 2 emissions were between 15 and 50% of the total emissions. Scope 3 emissions accounted for the rest, ranging between 50% and 75%, in which disposables, equipment (medical and non-medical), and pharmaceuticals represented the highest percentage of emissions. Staff travel and building infrastructure were also found to have a significant impact on the emissions, ranging between 10-15%. Water, waste, and patient travel represented low levels of emissions. Data regarding carbon emissions secondary to catering was limited.

Regarding scopes 1 and 2, the geographic location of the analysed functional unit might influence the results. For instance, Mtioui et al. (2020) measured the carbon footprint in a dialysis unit in Casablanca (Morocco) and found energy only being responsible of 0.2% of carbon emissions; however, electricity represented a 27.7%. The authors explained this finding as due to the little use of heating and air conditioner in this functional unit because of the specific weather conditions in Casablanca (Mtioui et al., 2020). Another factor that could influence scopes 1 and 2 emissions was the age of the buildings. When analysing three different hospitals, MacNeill et al., (2017) noticed that two new hospitals produced less carbon emissions derived from energy and electricity than an old one. Overall, scopes 1 and 2 emissions proved to be linked, as those studies that found higher levels of emissions in scope 1 had lower emissions in scope 2, and vice versa. Reducing scopes 1 and 2 emissions can be achieved by introducing renewable energy in healthcare units as well as the use of insulation materials in the renovation and construction of new buildings (Campion et al., 2016). Furthermore, optimised electrical installations by improving air conditioning and heating systems could lead to a further reduction in energy use (García-Sanz-Calcedo et al., 2018). Montiel-Santiago et al. (2020) carried out a simulation of a digital system to model new systems of lighting and found that energy efficiency improvements could lead to a 47.0% reduction in energy use.

The use of certain anaesthetic gases can have a significant impact on the environment. The study conducted by MacNEill et al., (2017) in three hospitals of different countries (Canada, United States, and UK) identified that the use of anaesthetic gases such as desflurane versus isoflurane and/or sevoflurane could lead to a 46.0% increase. Vollmer et al. (2015) suggested that the use of anaesthetic gases with low global warming potential, as well as limiting their use when possible, could reduce the carbon footprint. Hence, healthcare professionals and organisations should support and demand the use of anaesthetic gases that have a minimal impact on the environment.

The reviewed studies revealed that scope 3 emissions represented between 50% and 75% of the total emissions in healthcare. A previous study carried out in England found that the two largest contributors of scope 3 carbon emissions were medical equipment (13.1%) and pharmaceuticals (12.1%), and that is mainly due to the emissions caused by manufacturing, packaging, and transport of goods (NHS England, 2008). For example, the carbon footprint of pharmaceuticals without including the energy used to produce them has been estimated at 5.0%, showing that most of the emissions come from the energy used in their production and distribution (Karliner et al., 2020). It is important to understand that the carbon footprint of an item represents indirect emissions for the user; however, its production will require energy and electricity (scopes 1 and 2); thus, most carbon emissions come from energy that might be direct or indirect depending on where it is used.

Interventions such as the installation of solar panels in roofs and parking lots in hospitals, changing to a vegetable-based hospital menu, replacing telemedicine for face-to-face appointments when possible, promoting active transport and/or introducing effective lighting and energy appliances, have shown to have a significant impact in the reduction of carbon footprint (Bozoudis et al. 2021; 2022). Nansai et al. (2020) stated that the carbon footprint of a hospital supply chain could be minimised by reducing the demand of goods and services. This can be achieved by restricting unnecessary patient attendance and diagnostic testing, minimising human error, and/or avoiding duplication of processes, such as previous consultations or testing in different services (Malhotra et al. 2017). Ouslander et al. (2016) found that 23% of the emergency visits, hospital admissions, and/or readmissions were preventable. Freund et al. (2013) carried out semi-structured interviews with 12 primary care physicians from 10 primary care clinics in Germany regarding 104 hospitalisations of 81 patients and found that 41% of those hospitalisations were avoidable and could have been managed in ambulatory services. However, this raises the question whether admissions versus ambulatory patients would increase or decrease carbon emissions as, for example, the use of transport-related emissions would be greater. The COVID-19 pandemic has shown how telemedicine can be used as a feasible, acceptable, and effective way of healthcare practice (Hong et al., 2020). Studies such as the one carried out by Purohit et al., (2022) found that telemedicine could significantly reduce the carbon emissions secondary to travelling as well as the demand in healthcare settings. The use of telemedicine could mean an opportunity to reduce attendances in settings such as primary healthcare, where the carbon emissions secondary to patient and staff travelling are much higher than in other healthcare settings (Nicolet et al., 2022).

McAlister et al. (2022) carried out a prospective life cycle assessment of five imaging modalities: chest X-Ray, mobile chest X-ray, computerised tomography (CT), magnetic resonance imaging (MRI), and ultrasound (US). They found that CT and MRI produced 17 and 9 times more carbon emissions than X-rays and US. They recommended using low-impact imaging when appropriate and limiting unnecessary testing in order to reduce the carbon footprint. Human errors such as incidents related to drugs or treatments may also lead to an increase in the carbon footprint. Panagioti et al. (2019) in their metanalysis, found that one in twenty hospitals admissions some kind of preventable error was made. For example, the wrong administration of a drug can lead to anaphylaxis and, therefore, to an increase in the items and resources used. Another example could be a surgery that is not properly performed and, as a result, another surgery needs to be carried out, leading to the utilisation of more resources as well as longer hospital stay of the patient. Consequently, it is important to put in place measures to reduce human errors not only to improve patient’s care but also to reduce the carbon footprint.

The promotion of a healthy lifestyle may also help to reduce the carbon footprint as well as improving physical health. Several studies have shown that shifting towards a healthy diet could contribute to minimising the carbon footprint by adopting diets with low calories or reducing animal-based food (Tukker et al, 2011; Scarborough et al., 2014). Furthermore, the promotion and maintenance of physical activity such as walking or cycling will reduce the carbon emissions secondary to transport, and also improve health by decreasing the incidence of cardiovascular diseases, amongst others (Lindsay et al., 2011; Woodcock et al., 2009). In addition to this, the reduced incidence of certain diseases after adopting healthy lifestyles could diminish the demand for health services, thus reducing the carbon footprint of healthcare settings (Lee et al., 2017).

However, sustainable practice can only be achieved with the commitment of all healthcare professionals and their organisations (IPCC, 2022). As mentioned by NHS England (2022) recommendations, advanced health professionals and their teams should reduce the environmental impact of equipment and resources by, for example, applying the 5 R's: reduce, reuse, reprocessed, renewable, and recycle. In this sense, healthcare professionals should demand manufacturers of healthcare equipment ways of reducing the carbon footprint of their products whenever possible (Chiarini et al., 2017). Furthermore, the move from a linear economy to a circular one, where items are not wasted or replaced by new ones, but fixed or used for different purposes, is also a way of reducing the carbon footprint, so these approaches should be further explored (NHS England, 2020).

The limitations of the present study include those inherent to the systematic review methodology. It is possible that some relevant studies were not identified, although the search strategy was broad and targeted, and measures were taken to retrieve studies such as the review of reference lists. A possible interpretation bias is also acknowledged, yet the data were analysed and peer-reviewed. In addition, possible biases are recognised when comparing the results of the articles reviewed, due to differences in the assessment methodology employed by the researchers or the scope of the study in terms of the service assessed or the level of detail.

Conclusion

The studies analysed in this literature review found that scopes 1 and 2 emissions were between 15% and 50% of the total, whereas scope 3 emissions ranged between 50% and 75%. Disposables, equipment (medical and non-medical), and pharmaceuticals represented the higher percentage of scope 3 emissions. Other variables such as transport and building infrastructure were also significant contributors of carbon emissions.

This literature review highlights the effect that healthcare systems have on climate change and the importance of adopting and carrying out interventions to reduce the impact of healthcare on the development of climate change. Interventions must be carried out by the organisations responsible for those emissions, but also every single individual that integrates them should make changes. In fact, scope 3 emissions represent a high percentage of the total, and individuals in the organisations could have a significant impact on reducing these, or demanding manufacturers to do so, whereas scopes 1 and 2 emissions are more likely to be managed at organisational level. Current healthcare practice should be assessed at all levels, for example by creating or reviewing pathways and policies to not only reduce the carbon footprint, but also improve patient's care and the service provided.

To effectively reduce carbon emissions secondary to healthcare activities, in-depth analysis of individual units is recommended. Evidence-based approaches may facilitate the identification of carbon hotspots, thus achieving a more effective development and application of interventions aimed at reducing carbon emissions. Further research in healthcare's carbon footprint is recommended, as well as the development of tools to measure carbon emissions and identify carbon hotspots, so as to reduce the impact of healthcare activity on the environment.

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Table 1. Quality assessment results.

Category	Scoring system	Mtioui et al. (2020)	Nansai et al.(2020)	Prasad et al. (2021)	Malik et al. (2021)	Keller et al. (2021)	Tennison et al. (2021)	Lim et al. (2013)	Malik et al. (2018)	MacNeill et al. (2017)	Nicolet et al. (2022)	Wu (2019)	Eckelman et al. (2018)	Eckelman et al. (2016)
Completeness	a) To what extent are study inventory boundaries complete for a given functional unit? *Includes all reasonable factors (2) Includes limited/ ambiguous factors (1) Narrow focus (0)*	2	2	2	2	2	2	2	2	2	2	2	2	2
	b) Does the study account for all 3 scopes of GHG associated with the functional unit? *All 3 scopes measured (2) 2 scopes measured (1) scopes limited to 1 (0)*	2	2	2	2	2	2	2	2	2	2	2	2	2
Consistency	a) To what extent is the study consistent with a recognised carbon footprinting guideline? *Stated and referenced (2) Stated, not referenced (1) No guideline stated (0)*	2	2	2	1	2	2	2	2	2	2	2	2	2
	b) For comparative studies, how consistently are methods applied? *Consistently applied throughout (2) Limited consistency (1) Poor consistency (0)*	2	2	2	2	2	2	2	2	2	2	2	2	2
Transparency	a) Are the hypothesis(/es) and study objectives clearly stated? *Both clearly stated (2) Either hypothesis or study objectives stated (1) Neither stated (0)*	1	2	1	2	2	2	2	2	2	1	2	2	1
	b) To what extent are the GHGs included clearly stated? *Number of GHGs included clearly stated (2) Number of GHGs deducible (1) Number of GHGs not deducible (0)*	1	2	1	1	1	2	0	1	1	1	2	2	2
	c) To what extent are study assumptions and exclusions clearly stated? *Both assumptions and exclusions stated (2) Limited (1) Neither stated (0)*	1	2	2	2	2	2	2	2	2	2	2	2	2
	d) To what extent are the number of data points collected per process clearly stated? *Clear for all processes (2) Clear for limited processes (1) Not stated for any processes (0)*	2	2	2	2	2	2	2	2	2	2	2	2	2
	e) How transparent are reported GHG results? *Numerical data for all sub-processes (2) Limited numerical data for some sub-processes (1) Descriptive or graphical data only (0)*	2	2	2	2º	2	2	1	2	2	2	2	2	2
Accuracy	a) What is the specificity of the data sources to the study site? *1° data only (2) Both 1° & 2° data (1) 2° data only (0)**	1	1	1	0	2	2	2	1	2	2	0	0	0
	b) Does the study determine parameter uncertainty? *Clear statistical plan with CI reported (2) CI reported, no clear plan (1) No CI or plan (0)*	2	0	0	0	2	0	0	2	0	1	2	2	2
	c) Does the study determine scenario uncertainty? *Yes, demonstrating minimal uncertainty (2) Yes, demonstrating large uncertainty (1) No (0)*	2	0	1	1	2	2	0	2	0	0	2	2	2
Total	Scores out of 24	20	19	18	17	23	22	17	20	19	19	23	22	21

*1°= primary, 2°= secondary, CI= confidence interval, GHG= greenhouse gas

Table 2. Main results from the reviewed studies.

Authors Year Functional unit Methodology	Categories analysed	Carbon emissions CO_2e (%)				Data collection: Data source	Data collection: Data type	Data collection: Emission factor	Comments
Mtioui et al. (2020)	Energy/heating	0.86 t CO_2e (0.2%)				Invoice and billing	P	IPCC, Base Carbone, ADEME	No use of heating as per location of the study
	Freight transport	0.74 t CO_2e (0.2%)				Invoice and billing	P		High carbon footprint electricity due to large proportion of fossil energy used for its production.
Haemodialysis Unit	Electricity	113.5 t CO_2e (27.7%)				Daily measurement	P		
	Water	0.5 t CO_2e (0.1%)				Source of water supply	P		
	Waste	25.34 t CO_2e (6.1%)				Company providing the service	S		Medical equipment and/or non-medical equipment and building infrastructure were measured together. It included building infrastructure, IT, biomedical equipment, and furniture.
Bottom-up LCA	Staff travel	36.67 t CO_2e (8.9%)				Survey (distance/transport)	P		
	Patient travel	54.86 t CO_2e (13.4%)				Survey (distance/transport)	P		
	Disposable	109 t CO_2e (26.6%)				Service's accounting register	P		
	Equipment	68 t CO_2e (16.6%)				Service's accounting register	P		
	TOTAL	408.98 tons of CO_2e							
Nansai et al. (2020)		**Medical Services***	**Health & higiene***	**Nursing services***	**Fixed Capital***				
National Healthcare system	On-site emissions	5.4 (13.0)	0.08 (9.3)	2.83 (28.1)	0.25 (2.7)	National report of GHGs inventory	S	IPCC, National report of GHGs inventory	Medical services included hospitalisation, non-hospitalisation, dentistry and miscellaneous medical services.
	Freight transport	1.3 (3.1)	0.17 (1.6)		0.12 (1.3)				
	Electricity	7.5 (18.1)	0.22 (27.2)	2.66(26.4)					
	Waste	1.0 (2.4)	0.04 (5.4)	0.28 (2.7)					Health and hygiene included non-profit and for-profit.
Economic input-output analysis	Staff/Patient travel	1.0 (2.4)	0.02 (3.1)	0.38 (3.7)					
	Disposables	2.1 (5.1)	0.02 (2.5)	0.18 (1.7)	0.36 (4.0)				Nursing services included facility services and excluding facility.
	Equipment	1.2 (2.8)			0.94 (10.5)				
	Pharmaceuticals	11.3 (27.2)	0.03 (3.4)						Fixed capital formation included private and public for all the previous categories.
	Building infrastructure	1.0 (2.4)			4.98 (55.6)				
	Catering			0.37 (3.6)					Total emissions 62.5 (4.69%) of the total national GHG emissions
	TOTAL	41.5 (66.4)	0.81	10.07	8.95				
Prasad et al. (2021)		**ICU****		**ACU****					
	Energy/electricity	30.5 (25.2)		30.8 (67.6)		Invoice and billing	P	Ecoinvent 3.4 unit process database	Carbon footprint calculated by floor area and by staff allocation. This table only shows by floor area.
Intensive care unit and Acute Care Unit	Medical gases	2.4 (1.9)		2.4 (5.3)					
	Water	0.3 (0.2)		0.3 (0.6)					
	Waste	4.3 (3.5)		3.4 (7.4)		Auditing over 5 days.	P		
	Staff travel	10.4 (8.6)		4.9 (10.7)		Working days/distance/transport	S		

Hybrid model	Disposables	44.4 (36.7)	12.0 (26.3)	Inventory of the products and the expenditure	P	2013 US EEIO LCA model v1.1	ACU produces the largest portion of the hospital's Non-RCRA Hazardous Pharmaceutical Wastes, 743kg per year or 15%.
	Equipment	30.5 (32.2)	6.5 (14.2)				
	Catering	13.8 (11.4)	13.8 (30.3)	Assumption of 3 meals/patient/year.	S		
	TOTAL	120.8 per bed day	45.5 per bed day				
Malik et al. (2021) Largest state in Australia Hybrid model	GHG emissions	7908 kt CO_2e (6.6%)		Expenditure on the health system in New South Wales (Australia). Customised MRIO table using a government computer platform.	S	Leontief framework	Coal 63%, gas 21%, hydroelectricity 5%, and wind 4% of national energy sources. No conversion to carbon emissions was done for this study.
	Water	246 gigalitres of water use per year					
	Waste	1624 kt of waste per year					
Keller et al. (2021) 33 Swiss hospitals Bottom-up LCA	Energy/heating	26.0%		Invoice and billing of annual demand	P	IPCC, USEtox 2.02	The GWP per hospital changes from 3.2 to 4.9 t CO2-eq which increases the share of electricity on total impact from 9% to 42%. Wastewater was the same as water use. Five areas contribute more than 10 % in some categories on waste assessment. Nitrile gloves are responsible of 45% of medical products and plastics contribute around 70% of housekeeping
	Electricity	9.0%.		Electricity provider	P		
	Water	0.5%.			P		
	Waste	4.5%.		Inventory data from 2 hospitals.	P		
	Medical equipment	3.0% -medical products 4% - housekeeping		Auditing	P		
	Pharmaceuticals	12.0%		Invoice and billing.	P		
	Building infrastructure	15.0%		Energy reference area. Average from three hospitals.	P		
	Catering	17.0%		Meals for patients, staff, visitors.	P		
	TOTAL	3.2 tonnes CO_2eq per FU average/ year					
Tennison et al. (2021) National Healthcare system Hybrid model	Energy and heating	2520 Kt CO2-e (10.0%)		Inventory (ERIC)	P	From UK Governme nt energy ministry publication s, IPCC AR5, BEIS and UK MRIO satellite	Travel emissions include fleet travel (Scope 1), business and staff commuting (scope 3), and personal patient and visitors. Acute services are the largest contributors of total emissions (56%) or 125Kg CO_2-e/ bed-day. 76 Kg CO_2-e/outpatient appointment in acute care. 66 Kg CO_2-e/ GP visit. 75 Kg CO_2-e/ ambulance emergency response.
	Medical gases	1290 Kt CO_2-e (5.1)		NHS pharmacy electronic data.	P		
	Electricity	0.70 Kt CO_2-e (2.8%)		Inventory (ERIC)	P		
	Water and waste	1300 Kt CO_2-e (5.1 %)					
	Staff travel	2400 Kt CO_2-e - (9.5%)		Fleet travel were from expenditure. Staff travelling from the Department of transport: 2015-2019.	P		
	Patient travel	123 Kt CO_2-e (4.9%)			S		
	Visitors travel	29 Kt CO_2-e (1.1%)					
	Disposables	6030 Kt CO_2-e (24.0%)		From UK MRIO and Public Expenditure Statistical Analysis Supply and Use tables from HM Treasury	S		
	Medical equipment	2520 Kt CO_2-e (10%)					
	Non-medical equipment	1960 Kt CO_2-e (7.8)					
	Pharmaceuticals	5060 Kt CO_2-e or (20.2%)					
	Building infraestructure	80 Kt CO_2-e or (5.0%)					
	Catering	154 Kt CO_2-e (6.1%)					
	TOTAL	25040 Kt CO_2-					
Lim, Perkins and Agar (2013)	Energy and heating	22 716 Kt CO_2-e (18.6%)		Activity data/auditing.	P	From Australian governmen	
	Water	9243 Kt CO_2-e (7.6%)		Estimation from haemodyalisis machines			

Haemodialysis unit	Waste	4163 Kt CO_2-e (3.4%)	Auditing/measurement over one week		t publications, individual providers	Electricity and energy were calculated together. Electricity use alone was 18 313 Kt CO_2-e or 15%.
	Staff travel	3369 Kt CO_2-e (3%)	Survey (distance/transport)	P		Water treatment and supply was 1470 Kt CO_2-e or 1.2% and sewerage treatment and management was 7773 Kt CO_2-e or 6.4%.
Bottom-up LCA	Patient travel	7043 Kt CO_2-e (5.8%)				
	Equipment	28490 Kt CO_2-e (23.4%)		P		
	Pharmaceuticals	5060 Kt CO_2-e (35.7%)				Landfill was 1375 Kt CO_2-e or 1.1%, incinerated 3780 Kt CO_2-e or 3.1% and recycled - 992 Kt CO_2-e or -0.8%.
	Aids and appliances	1054 Kt CO_2-e (2.9%)				
	TOTAL	121.9 t CO_2-e/year or 10.2 t CO_2 e/year/patient				

		VGH**	UMMC**	JRH**				
MacNeill et al. (2017)	Energy and heating/ Electricity	2034277(63.2)	2129841 (50.9)	211212 (4.1)	Invoice and billing.	P	DEFRA	Energy, heating and electricity was considered to be scope 2 as the energy is not produced within the operating theatre.
3 hospitals (Canada, US and UK)	Medical gases	534194 (16.5)	1515763 (36.2)	4 344 150 (83.7)	Invoice and billing (pharmacy purchasing records)	P		The difference among medical gases can be due to the use of desflurane.
Bottom-up LCA	Waste	650436 (20.2)	536260 (12.8)	632574 (12.1)	Auditing over 3 weeks.	P		
	TOTAL	3218907 year	4181864 year	5187936 year				

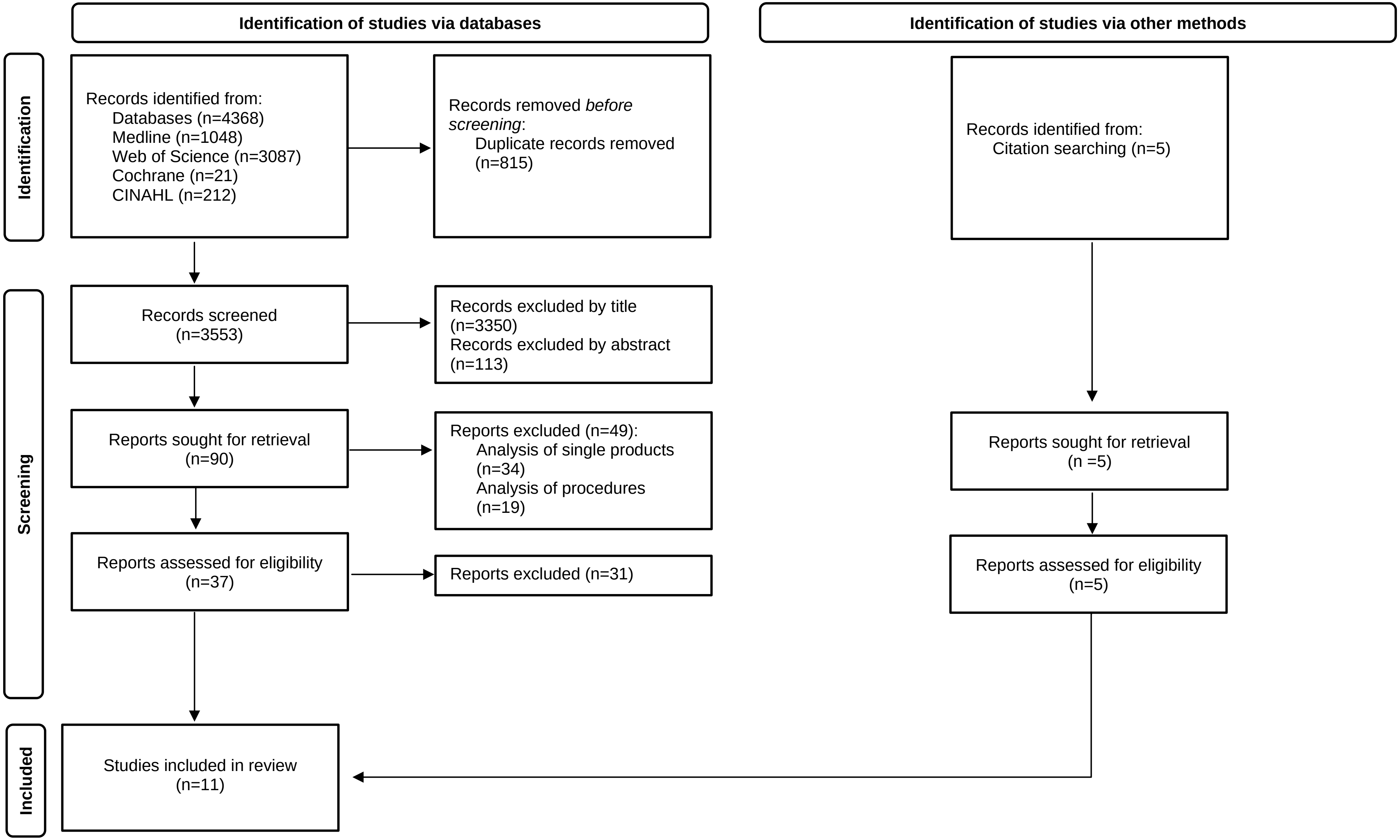
Malik et al. (2018)	Public hospitals	12295 Kt CO_2-e (34.3%)	Health expenditure Australia report (Australian Institute of Health and Welfare) that includes all government and non-government costs. Private and public services were included. Expenditure collected for 16 different categories.	S	Leontief framework. Input-output mathermatical equations.	Scope 2 and 3 emissions shown together.
	Private hospitals	3635 Kt CO_2-e (10.2%)				Healthcare in Australia contributes 7.2 % of the total emissions.
National Healthcare system	All other medications	3347 Kt CO_2-e (9.3%)				
	Pharmaceuticals	3257 Kt CO_2-e (9.1%)				The four largest financial cost categories were: public and private hospitals (39%), pharmaceuticals (12%), specialist medical services (12%) and unreferred medical services (7%)
	Building infrastructure	2776 Kt CO_2-e (7.7%)				
Economic input-output analysis	Patient transport	427 Kt CO_2-e (1.2%)				
	TOTAL	35772 Kt CO_2-e				
Nicolet et al. (2022)	Energy and heating	9106 kg CO_2-e/year (29.8%)	Invoicing and billing.	P	COINVENT	Energy included electric solar, gas and oil.
	Electricity	95 kg CO_2-e/year (0.3%)	Invoicing and billing.	P		Electricity included energy consumption of in-house computer server, and x-ray device.
10 private primary care practices	Waste	491 kg CO_2-e/year (1.6%)	Invoicing billing and staff observation	P		General waste 321 kg CO_2-e/year, special waste (radioactive) was 164 kg CO_2-e/year and paper waste 6 kg CO_2-e/year.
	Staff travel	3816 kg CO_2-e/year (12.5%)	Survey	P		
	Patient travel	10145 kg CO_2-e/year (33.2%)	Survey	P		
Hybrid model	Medical consumables	1 678 kg CO_2-e/year (5.5%)	Invoicing and billing.	P		Equipment was divided in medical equipment (such as stethoscope, examination bed, saturometer, ECG, Xray devices, etcetera) and
	Non medical consumables	338 kg CO_2-e/year (1.1%)				
	Equipment	110 kg CO_2-e/year (0.4%)	Inventory	P		

	Building infrastructure Total	1239 kg CO_{2}-e/year (4.1%) 30.5 tons of CO_{2}-e/year	Invoicing and billing	P		non-medical (such as computer, printer, desk, chair, table)
Wu (2019) National Healthcare system Economic input-output analysis	Electricity and steam Agriculture Pharmaceuticals Medical equipment Catering TOTAL	33 mt CO_{2}-e (10.6%) 25 mt CO_{2}-e (7.9%) 24 mt CO_{2}-e (7.6%) 13 mt CO_{2}-e (4.1%) 6 mt CO_{2}-e (1.9%) 315 mt CO_{2}-e	Data sources for health expenditure include the national input-output table, China Health and Family Planning Statistics, China Construction Statistics, and China Science and Technology Statistics yearbooks.	S	Leontief framework. Input-output mathermatical equations.	
Eckelman et al. (2018) National Healthcare system Economic input-output analysis	Public Hospitals Physicians Dental Services Prescribed Drugs Capital Public Health TOTAL	7.1 mt CO_{2}-e (21.5%) 4.4 mt CO_{2}-e (13.3%) 1.8 mt CO_{2}-e (5.4%) 7.0 mt CO_{2}-e (21.2%) 2.4 mt CO_{2}-e (7.3%) 1.9 mt CO_{2}-e (5.7%) 33.0 mt CO_{2}-e (4.6% of the national emissions)	Data obtained from Statistics Canada Environmental Accounts, the Canadian National Pollutant Release Inventory and then creation of an environmentally extended input-output (EEIO) tables and the National Health Expenditures database maintained by the Canadian Institute for Health Information.	S	Open IO-Canada model b IMPACT2002 + LCA model	
Eckelman and Sherman (2016) National Healthcare system Economic input-output analysis	Hospital care Clinical Services Nursing Care Facilities Prescibed drugs Public Health Activities Structures and equipment TOTAL	238 Mt CO_{2}-e (36%) 77 Mt CO_{2}-e (11.7%) 41 Mt CO_{2}-e (6.2%) 68 Mt CO_{2}-e (10.3%) 29 Mt CO_{2}-e (4.4%) 71 Mt CO_{2}-e (10.8%) 655 Mt CO_{2}-e in 2013 (9.8% of the national total)	US National Health Expenditure Accounts for the decade 2003-2013.	S	IMPACT2002 + LCA model	Total: Suppliers of energy, goods, and services: power generation (36%), government services (8%), non-residential commercial and health care construction (4%) and basic organic chemicals manufacturing (3%)

* mt CO_2e (%); **Kg CO_2e (%)

P= Primary; S= Secondary; LCA= Life cycle assessment; IPCC= Intergovernmental Panel on Climate Change; ADEME= Agence de l'environnement et de la maîtrise de l'énergie (the French Environment and Energy Management Agency); GHG= Greenhouse gas; ICU= Intensive care unit; ACU= Acute care unit; EEIO= Environmentally extended input-output ; GWP= Global Warming Potential ; FU= Functional Unit ; ERIC= ; MRIO= Multi-Regional Input Output modeling ; BEIS= Department for Business, Energy and Industrial Strategy; HM= High Majesty ; VGH= Vancouver General Hospital; UMMC= University of Minnesota Medical Center; JRH= John Radcliffe Hospital.

Figure 1. Article selection flowchart.



5. Article 2. Environmental impact of Emergency Services in Public Health: an assessment tool.

Title: Environmental impact of Emergency Services in Public Health: an assessment tool.

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Rodríguez-Jiménez, L., Romero-Martín, M., & Gómez-Salgado, J. (2023). Impacto medioambiental de los servicios de Urgencias en la Salud Pública: una herramienta de valoración [Environmental impact of Emergency Services in Public Health: an assessment tool.]. *Revista espanola de salud publica*, *97*, e202306044es.

Abstract

Background: Climate change is directly related to increasing medical conditions such as cardiovascular, respiratory and/or infectious diseases, as well as malnutrition and mental illness caused by the reduction of available food and the growth of situations with significant emotional impact, respectively. Evidence showed that healthcare services are responsible for 4-5% of the green- house gas emissions worldwide. The aim of this study is the development of an assessment tool to evaluate the carbon footprint of emergency departments.

Methods: The development of the proposed assessment tool followed five stages. Firstly, the categories of GHGs to be included in the assessment tool were determined through a literature review. This was followed by the establishment of scopes and boundaries, selection of conversion factors, data collection from the Emergency Department at the Royal Free Hospital in London as a pilot site, and finally, the development of methodology to assess the carbon footprint.

Results: The assessment tool was divided in three scopes and each scope included one or more categories containing several items. Data was collected from different sources such as meters invoicing and billing, auditing, and surveys. The tool is presented in a Microsoft Excel document.

Conclusions: This carbon assessment tool offers an opportunity to monitor carbon emissions in emergency departments, aiming to proliferate environmental strategies. The assessment tool seeks to provide a baseline carbon footprint assessment, identif- ying carbon hotspots within the department. The identification of these areas of intensive carbon emissions can help guide and focus local environmental initiatives that can later be monitored with a follow-up assessment to evaluate their effectiveness.

Keywords: Carbon footprint; Greenhouse gases emissions; Emergency departments; Life cycle assessment; Environmental impact.

Resumen

Fundamentos: El cambio climático está directamente relacionado con el aumento de ciertas patologías como enfermedades cardiovasculares, respiratorias y/o infecciosas, así como con la desnutrición, provocada por la reducción de los alimentos disponibles, y el deterioro de la salud mental. La evidencia ha señalado que los servicios sanitarios son responsables del 4%-5% de las emisiones de gases efecto invernadero en todo el mundo. El objetivo de este estudio fue diseñar una herramienta de evaluación de la huella de carbono de los servicios de Urgencias.

Métodos: Se diseñó la herramienta a través de cinco etapas. En primer lugar, se seleccionaron las categorías a incluir en la herramienta desde una revisión de la literatura. Posteriormente, se determinaron el alcance y límites, se seleccionaron los factores de conversión, se recopilaron datos del servicio de Urgencias del Royal Free Hospital de Londres como sitio piloto y se seleccionó el método de cálculo de la huella de carbono.

Resultados: La herramienta resultante se dividió en tres ámbitos, y cada ámbito en una o más categorías que contienen varios elementos. Los datos se recopilaron de diferentes fuentes, como facturación, medidores, auditorías y encuestas. La herramienta se presentó en un documento de Microsoft Excel.

Conclusiones: Esta herramienta de evaluación de carbono ofrece una oportunidad para monitorear las emisiones de carbono en los servicios de Urgencias. Pretende proporcionar una valoración de la huella de carbono de referencia, identificando puntos críticos de emisión dentro del servicio, que puede dar lugar a iniciativas ambientales locales.

Palabras claves: Huella de carbono; Emisiones de gases efecto invernadero; Servicios de Urgencias; Evaluación del ciclo de vida; Impacto medioambiental.

Introduction

Climate change can be defined as the shift in temperatures and weather patterns secondary to increasing greenhouse gas emissions released by human activity into the atmosphere [(1)]. Greenhouse gases (GHGs) are gases that retain the heat within the earth's atmosphere causing what is called the greenhouse effect, thereby increasing global warming, and changing the Earth's climate [(2)]. Increasing temperature leads to extreme weather conditions such as heatwaves, floods, droughts, and/or environmental hazards [(3)]. Furthermore, climate change is directly related to increasing medical conditions such as cardiovascular, respiratory and/or infectious diseases, as well as malnutrition and mental health caused by the reduction of available food and the growth of situations with significant emotional impact, respectively [(4)]. In 2022 alone, 7.6 million people were displaced in Pakistan due to floods [(5)]. An increase of 68% of heat-related deaths caused by heatwaves was also observed between 2000 and 2021 [(6)]. Climate change does also favour the proliferation and propagation of infectious diseases such as dengue, for which favourable conditions for its propagation has increased a 30% in Europe in comparison with data from the 1950s. The increase of temperatures is also provoking earlier floral seasons compared with data from last the 40 years and this is related to an increase of allergens and allergies, which currently affects 40 per cent of the global population. The impact of climate change on people's health is already noticeable and is expected to increase in following years.

According to the Paris Agreement in 2015, the greenhouse gases are: carbon dioxide (CO_2); methane (CH_4); nitrous oxide (N2O); hydrofluorocarbons (HFCs); perfluorocarbons (PFCs); sulphur hexafluoride (SF_6); and nitrogen trifluoride (NF_3). Carbon dioxide represents 86% of GHGs and it is for this reason that often the literature, including this document, refer to carbon footprint when referring to greenhouse gas emissions although they include the rest of all

GHGs [7]. Carbon footprint can be defined as the best possible estimation of GHG emissions produced by human activity [8]. GHGs are classified into direct emissions - those in which an individual or organisation has direct control -, and indirect emissions - those related to the activity of the individual or organisation but over which there is not control of the source-. According to the Greenhouse Protocol [9], GHG emissions can be divided into three scopes:

- Scope 1: includes direct emissions produced by the organisation, for example emissions secondary to fuel use for heating, use of anaesthetic gases and/or freight of transport.
- Scope 2: includes indirect emissions produced from purchased electricity, and therefore electricity that has been produced somewhere else in which is out of the organisation's control.
- Scope 3: includes the rest of indirect emissions that are mainly those related to the chain-supply, and in which the organisation has not direct control over.

Carbon footprint analysis can be divided mainly into three different methodologies: bottom-up cycle assessment; top-down cycle assessment or economic input-output analysis; and the combination of the two previous methods, also known as the hybrid model [10]. Bottom-up cycle assessment consists of the analysis of the carbon emissions attributed to each element of an item, which are converted into carbon equivalent using a conversion factor. Top-down cycle assessment or the economic model uses the money spent on each item and multiplies this by a carbon conversion factor. The hybrid model combines both models. Estimations are used to calculate the carbon footprint of organisations. It is necessary to quantify the activity that generates carbon emissions and multiply it by a conversion factor, which represents the amount of GHGs emitted by that activity. The unit to measure carbon footprint is CO_2eq, using this gas as referent as it is the most influential in global warming [11].

Evidence has revealed that healthcare services are responsible for 4-5% of GHG emissions worldwide [12]. In 2015, the state members of the United Nations, due to the crisis of the planet as a sustainable space to be home to everyone in a fair and equal manner, established 17 Sustainable Development Goals to preserve the planet and improve everyone's lives and anticipated to be achieved by 2030 [13]. These Sustainable Development Goals include, amongst others: zero hunger, good health and well-being, clean water and sanitation, affordable and clean energy, sustainable cities and communities and climate action. The Sustainable Development Goals are interrelated and configured as a global strategy, since for instance, the goals of reducing tropical diseases or reducing deaths and illness from hazardous chemicals, and air, water and soil pollution and contamination, are directed related to climate action. Climate action targets aim to strengthen climate resilience, integrate climate change measures into national policies, strategies, and planning, improve education and raise awareness, create a Green Climate Fund and promote climate related changes.

The National Health Service (NHS) in the UK was the first health system to introduce net zero policies into legislation, with the objective to reduce their carbon emissions to zero by 2045 [14]. The Intergovernmental Panel on Climate Change (IPCC) 2022 report highlights the importance of regional and local initiatives to reduce carbon emissions [15]. Local sustainability initiatives in the healthcare field can have a significant impact in reducing carbon emissions and produce a snowball effect in other health services, however evidence is necessary to make a case of these initiatives [8]. The Green Emergency Department (*Green*ED) project is an initiative led by the Royal College of Emergency Medicine (RCEM), which aims to reduce the environmental impacts, including greenhouse gases emissions, resulting from activity in the delivery of emergency healthcare services in NHS hospitals.

The development of tools to evaluate the carbon footprint of healthcare services can be a way to provide evidence of the environmental impact of a given activity, and an opportunity to identify carbon hotspots, and to quantify and reduce carbon emissions. The aim of this study is the development of an assessment tool to evaluate the carbon footprint of EDs in the UK.

Methodology

The methodology to develop the ED carbon assessment tool followed the following steps:

- Selection of the categories included in the assessment tool, through a literature review.
- Determination of scope and boundaries.
- Selection of conversion factors.
- Data collection.
- Evaluation method of the carbon footprint.

Categories selection

To begin with, the research team conducted a literature review to identify the most common categories previously analysed in carbon footprint assessments papers in the healthcare field. The literature review was carried out using the Medline, Web of Science, CINAHL and Cochrane databases with the key words: carbon footprint, greenhouse gases, life cycle assessment and health. This literature review revealed that the categories analysed in the selected studies were energy and heating, anaesthetic gases, freight transport, purchased electricity, catering and food, disposables and consumables, medical and non-medical equipment, pharmaceuticals, transport, waste, and water. The research team considered that all these categories could provide a comprehensive carbon footprint assessment and all of them were included in this study. However, anaesthetic gases and freight transport were adapted for the emergency services context.

Scope and boundaries

The assessment tool has been designed for the period of time that the user considers appropriate. The ED premises for this tool include all areas in which emergency care is provided (such as Minors, Majors, Resus and Same Day Emergency Care (SDEC) ambulatory units) for adults and/or paediatrics. Radiology departments that are shared or exclusively used by the ED are also included. Furthermore, administration offices that are within the ED premises and that are part of its management and functionality are included. This study does not include building infrastructure, supporting services (such as financial or other administrative services) and other diagnostic services (such as laboratories or imaging departments such as nuclear medicine or ultrasound departments). Other services such as ambulance services are included as a form of transport, however the carbon footprint originating from activities whilst the patient is in the ambulance (for instance disposables use) is not included. Laundry services are also not included due to this being a process external to an ED; also, there are not specific conversion factors for this activity, making the data inaccessible [16,17].

Conversion factors selection

The emissions factors utilised for this tool are based on the publication made by the Department for Environment, Food & Rural Affairs (DEFRA). DEFRA provides yearly conversion factors for organisations reporting GHG emissions. The data provided by DEFRA offers easy access, most up to date conversion factors and has an international recognition. The only exception was in the category of waste, as DEFRA does not provide specific data for the waste streams of health services; in this case conversion factors provided by Rizan et al. were used [18].

Data collection

Data sources were identified in the literature review and the research team carried out a key data collection, creating an inventory of items for each category. The ED at the Royal Free Hospital in London was selected as a pilot site for the identification and collection of data between November 2022 and February 2023. Data was collected through observation and hospital records. Microsoft Excel for Mac Version 16.25 was used for the organisation of collected data and calculations.

- *Energy, heating, purchased electricity and water*

Data regarding energy, heating, electricity, and water are usually obtained from meters, however specific submeters for EDs are rarely available. For this assessment tool, the approach utilised by Prasad et al. [19] was adopted, according to which the total consumption of the site is multiplied by the department's surface and divided by the total surface of the site. This formula can provide an estimation of the department's consumption and subsequently its carbon footprint. This data can be obtained from supplier companies or the administration team through billing records. Specific use of green energies sources was not included in the calculator; however, the use of green energies is applied in the conversion factors provided by DEFRA, hence the increase of green energy use will decrease the conversion factor.

- *Anaesthetic gases*

It was observed that anaesthetic gases are rarely used in ED and, when used, are normally managed and ordered by the anaesthetics team rather than emergency practitioners. Hence, this category only included nitrous oxide and methoxyflurane that are often used as short-acting anaesthesic agents in EDs.

- *Freight transport*

Freight transport was excluded from our assessment tool. Freight transport is often controlled by the organisation rather than individual departments, hence the analysis of specific freight transport for EDs is not accessible and feasible for this study. However, the transport of patients to different sites within a trust are included in this category, as they represent direct emissions controlled by the department. Interhospital transport can be defined in this study as the transport of patients between different sites in or different trust due to, for example, requiring specialist input or diagnostic tests that are not available on site. However, ambulance services as a method of transport for patients to go from their house or place of incident to the hospital are categorised as indirect emissions and are analysed in another category.

- *Disposables/consumables and pharmaceuticals*

The data for disposables or consumables and pharmaceuticals can be obtained from the department's ordering records. Departmental records should include the prices of each item and the number of items ordered either monthly or yearly. Due to the large number of items for these two categories, the authors applied a top-down approach for these two categories. Furthermore, medicines that were rarely used and for which the price was less than £1 were excluded since their contribution to the carbon footprint would be negligible; to expedite the calculation, it was decided to exclude them.

- *Medical and non-medical equipment*

Medical equipment includes a comprehensive list of equipment utilised in ED, such as observation machines, thermometers and ultrasounds. Medical equipment lists can be obtained from the medical devices department. All the medical items provided by the medical devices department were included in this assessment tool. Furthermore, information from manufacturers regarding life expectancy for each item was included.

Non-medical equipment included were paper, pens, computers, and printers. An audit carried out showed that these items were the most used in ED and therefore they were selected for this category.

- *Patient and staff transport*

Data regarding patient and staff transport can be collected through a survey. The survey must offer a comprehensive list of methods of transport and calculate the distance per return journey from the individual's house to ED. The list of methods of transport includes active transport, cars of different sizes (small, regular and large) and fuel (petrol, diesel, hybrids and electrics), motorcycles, and public transport (bus, tube and train). The survey is anonymous and its participation voluntary and includes the miles between the patient's house or place of incident per journey and the method of transport. The survey will be carried out over a two weeks period and estimations will be made for a year period. Regarding staff, an audit will be carried out including the number of full and part time staff, the mileage per journey and the method of transport. DEFRA provides a comprehensive list of conversion factors for each mile travelled in different methods of transport, such as journeys in trains, buses, motorcycles, regular diesel or petrol cars amongst others.

- *Food and catering*

Numbers of meals served in ED can be calculated through auditing. DEFRA provides conversion factors for food and drinks based on weight and cost. Our assessment tool provides calculations based on weight per meal served. Furthermore, several items of catering are included. This assessment tool does not differentiate between vegetarian and non-vegetarian meals and is considered one of our limitations.

- *Waste*

Waste calculations include recycled waste, domestic waste, non-infectious offensive waste, infectious waste, clinical waste, medicinal contaminated sharps, anatomical waste, medicinal waste, reusable surgical instruments, and batteries. Data can be collected through auditing over a period of time, obtaining the weight of each type of waste. As previously mentioned, DEFRA does not provide these specific conversion factors, hence the conversion factors provided by Rizan et al. are used [(18)]. Rizan et al. carried out a carbon footprint assessment of the waste in three different hospitals of the UK, producing a list of conversion factors for healthcare waste through the obtained data. The NHS database provides the expenses secondary to hospital waste and hence, allows the calculation of each type of waste, which Rizan et al. utilised in their study. Rizan et al. included in their study the transportation of waste between the hospital and the waste plant, the energy and water used to process waste, and direct emissions. The method for waste disposal was in three groups: autoclave, heat waste or incineration and recycling.

Evaluation method of the carbon footprint.

Our assessment tool utilises a hybrid method to quantify the ED carbon footprint, combining bottom-up and top-down life cycle assessments depending on the availability and accessibility to the data collected. The assessment of energy and heating, anaesthetic gases, electricity, catering and food, transport, waste, and water related carbon emissions are calculated through a bottom-up approach, whereas the rest apply a top-down or financial model.

Results

Our proposed carbon footprint assessment tool for EDs is divided in three scopes and each scope contains one or more categories containing several items (Table 1). The categories selected are energy and heating, anaesthetic gases, interhospital patient transport, purchased electricity, catering and food, disposables and consumables, medical and non-medical equipment, pharmaceuticals, transport, waste, and water. Data is collected through four different sources: meters (for example energy meter or water meters), invoicing and billing, auditing, and survey. Key data is obtained from each category over a period of a year. Assumptions are made in the categories of energy/heating, electricity, and water when submeters are not available, however the user is able to introduce exact values if submeters are present. Furthermore, the categories of catering and food, and waste are audited over a week and values extrapolated from that calculation.

The tool is presented in a Microsoft Excel document. The user can navigate the Excel and introduce the amount required for each item when available. The amount introduced is multiply by a conversion factor that originates the amount of carbon emissions. Most of the data can be obtained directly from the service, however, there is some data regarding energy, electricity and water use that will likely need to be obtained from the Estates Management team or ERIC database.

Discussion

This carbon assessment tool offers an opportunity to monitor carbon emissions in EDs, with the aim to develop environmental strategies to reduce carbon emissions. The assessment tool seeks to provide a baseline carbon footprint, identifying carbon hotspots within the department. The identification of carbon hotspots or areas of high carbon emissions can lead to local environmental initiatives that later can be monitored with a follow-up assessment to evaluate their effectiveness. The development of the tool is not only beneficial for the Emergency Department but can also incentivise the development of similar tools in other healthcare fields [20].

Our study is similar to the calculator previously made by Sawyer, who developed a calculator for GP practices in the UK [21]. The GP calculator divides the carbon footprint into three areas: operational (including energy use, travel, professional services, and other activities such as procurement, office and medical consumables, water and waste), investigations and pharmaceuticals. Sawyer highlighted the importance of developing these assessment tools to meet national reduction targets. Furthermore, carbon footprint calculators could lead to positive actions such as establishing key priorities, changing behaviours, recognising the benefit of action, and influencing others to carry out green initiatives. Health service for the climate (*Sanidad por el clima* in Spanish) is a platform that was created as a result of COP25 in 2019 and that has recently developed a free carbon footprint assessment tool for healthcare organisations in Spain[22]. Their assessment tool incorporates similar categories that our assessment too, however, leaves out some other categories such as medical equipment and consumables that we considered important in our study. Nevertheless, their assessment tool is designed to help organisations as a whole and hence, it is not adapted to a more detailed service such as Accident and Emergency. Other calculators such as the one proposed by the Ecologic Transition and Demographic Challenge ministry (Spain) facilitates the calculation of scope 1 and 2 emissions, however it does not calculate scope 3, which it is considered of great relevance in the development of local initiatives within healthcare professionals [23].

Local initiatives have proven the potential of significant impact in the reduction of carbon emissions in EDs. A multidisciplinary team carried out a project to reduce unnecessary cannulation in an ED at Charing Cross Hospital in London [24]. A baseline audit revealed that 86 per cent of the patients attending ED were cannulated and 40 per cent of those were not used. The team led a project to educate, raise awareness and encourage staff to change behaviour towards unnecessary cannulation, highlighting the cost and environmental impact of those actions. A follow-up audit showed a 25 per cent reduction of cannulation in ED, suggesting a potential reduction of 19000 kgCO2 per year and saving around £95000. Furthermore, Manchester University NHS Foundation Trust, which sees about 2 million visitors per year and employs over 20000 staff, carried out a sustainable travel programme to encourage people to use more sustainable and active travel options [25]. The programme focused on increasing bus use, reducing single-occupancy car journeys, and increasing walking and cycling as method of active transport. To accomplish these targets, the trust improved their infrastructure with more cycle parking spaces and extra electric vehicles charging points and offered discount schemes for travelling amongst other initiatives. These measures resulted in a 40 per cent increase of more sustainable transport use amongst the staff in the trust.

Similar initiatives have also been developed in Spain. Infanta Elena hospital in Huelva reduced their GHG emissions 36 per cent, from 3070 tonnes of CO_2eq in 2019 to 1130 CO_2eq in 2020, thanks to a campaign to improve the management of fuels. Petrol boilers were replaced by natural gas, which has a coefficient of less than 40 per cent. Furthermore, there was a 13 per cent reduction in natural gas consumption for heating and hot water as consequence of responsible use, adapted to the time of the day and needs of the service, and the isolation of windows and doors to preserve better the temperature [26]. In 2021, Gregorio Maranon hospital in Madrid put in place a sustainable management plan to reduced single use plastics, eliminating the purchase of plastic tableware and replacing it with biodegradable materials. This resulted in a reduction of 217000 straws, 21 700 trays, 668 200 spoons, 102 300 knives, 139 900 forks, 229 300 plates and 256 5850 cups. Furthermore, the bin bags are made from 100 per cent recycled material [27].

The limitations of the current study include, first of all, the estimations in the calculation of carbon emissions in some of the categories that could influence the obtained results. The consumption of energy and heating, electricity or water could not be collected through direct meter readings, which might affect the calculated carbon footprint. Furthermore, the research team acknowledged that the bottom up LCA approach would provide more accurate data, especially for categories such as consumables and pharmaceuticals, however, this methodology is not feasible for some of the categories in this study. Equally, there is possible uncertainty associated with the reliability of the conversion factors. In relation to the data regarding transportation of patient, since it is collected through a survey completed by the users, it must be recognised that there is bias associated with the representativeness of the sample, and the information provided.

Conclusion

Our research team proposes a comprehensive carbon footprint assessment tool for EDs. This initiative highlights the importance of assessing carbon emissions in healthcare units in order to carry out environmental initiatives in line with the UN sustainability goals and national net zero policies. This tool is the first carbon footprint assessment tool specifically for EDs, available for free access. Its use will allow EDs to calculate their carbon footprint in a standardised and efficient manner. Furthermore, the use of this tool can lead to raised awareness, increase climate resilience, and promote climate action by patients and staff. This study facilitates the production of robust evidence to back up environmental initiatives and presents an opportunity for further research.

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Table 1. Contents of the ED carbon footprint assessment tool.

Scope	Categories	Data sources	Key data collected	Example of items	Conversion factor	Unit
1	Energy and heating	Invoicing and billing. Energy meters	Annual consumption*	Natural gas, burning oil, green energies, etcetera	DEFRA database**	Litres, kWh
	Anaesthetic gases	Invoicing and billing	Annual consumption	Nitrous oxide and methoxyflurane	DEFRA database**	£
	Freight transport	Practice inventory/auditing	Survey	Patients transport between different sites	DEFRA database**	
2	Electricity	Invoicing and billing. Electricity meters	Annual consumption *	Electricity consumption	DEFRA database**	kWh
3	Catering and food	Practice inventory/auditing	Number of meals per patient	Meals, sandwiches, milk, fruits, biscuits, etcetera	DEFRA database**	Kg
	Disposables and consumables	Practice inventory/auditing	Inventory of disposables and consumables	Office consumables such as tones, paper, batteries, clothing, etcetera. Medical consumables such as couch rolls, aprons, gloves, blood sample tubes, cannulas, catheter, disposable incontinence, etcetera	DEFRA database**	£
	Medical equipment	Practice inventory/auditing	Inventory of medical equipment	Miscellaneous medical equipment (stethoscopes, thermometer, pen torch, electrical equipment and machinery, electrical items	DEFRA database**	£
	Non-medical equipment	Practice inventory/auditing	Inventory of non-medical equipment	Computers, trolleys, beds, metal equipment, pillows, etcetera	DEFRA database**	£
	Pharmaceuticals	Practice inventory/auditing	Annual consumption	Injectables, fluids, tablets, creams, nebulisers, inhalers, eyedrops, etcetera.	DEFRA database**	£
	Transport	Survey	Survey to patients, relatives, and staff. Mean of transport and distance.	Transport of patients, relatives and staff. Includes means of transport such as active transport, carrs by size (small, medium and large) and combustible (petrol, diesel, LPG, hybrids and electrics), motorbikes and public transport (bus, tube and train).	DEFRA database**	Km
	Waste	Invoicing and billing. Practice inventory/auditing	Inventory of waste	Recycling, domestic, non-infectious offensive, infectious, clinical, anatomical, and medicinal waste.	Rizan et al.	Kg
	Water	Practice inventory/auditing. Water meters	Annual consumption *	Water consumption	DEFRA database**	m3

*If data not available specifically (sub-metered) for the department, total use for the hospital will be divided by the sqm of the department. ** Department for Environment, Food & Rural Affairs (DEFRA

6. Article 3. The Emergency Department carbon footprint calculator: design and validation.

Title: The Emergency Department carbon footprint calculator: design and validation.

Short running title: Carbon footprint calculator.

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Abstract

Introduction: Carbon footprint calculators could lead to positive environmental actions, raise aware-ness, and justify sustainable actions. Emergency departments worldwide receive a large number of patients every year, representing a high carbon footprint. Our tool aims to provide a comprehensive tool created by emergency nurses to measure the carbon footprint of Emergency departments.

Methods: A literature review was conducted to establish the boundaries of the calculator. The pertinence of the resulting boundary inventory was evaluated by a panel of experts. A version 1 of the calculator was designed including the experts' suggestions. The scope, accuracy of calculation and pertinence of conversion factors were assessed by the same panel of experts. Tool was also tested by a group of health professionals as potential users, in terms of clarity, ease of use, viability, and usefulness.

Results: The agreement among experts was measured with the Content Validity Index and Aiken's V. The results showed good content validity (CVI=0.74 and V=0.87 in the first panel; CVI=0.81 and V=0.90 in the second panel). Three main themes emerged from the focus group: calculator overview, data collection and benefits. A validated, and comprehensive tool was obtained for carbon footprint calculation, offering a thorough analysis of scope 1, 2 and 3 emissions in the Emergency department.

Keywords: Carbon footprint; greenhouse gas emissions; emergency departments; life cycle assessment; environmental impact; nursing.

1. Introduction

The impacts of Climate Change on human health are already evident and they are most likely to cause more harm over the coming years due to its rapid development [1]. July 2023 was registered as the hottest month on record to date, and the average global temperature for the period from January to September 2023 was 0.52°C higher than the corresponding 1991-2020 average [2]. Climate change can affect human health due to complex and interrelated mechanisms, including extreme temperature, extreme weather events, increase of air pollution, increase of infectious diseases, lack of food and risk of malnutrition, increase of mental health presentations, and migration, among others [1]. Heat-related deaths in the elderly have increased up to 54% in the last two decades, with 61 672 deaths reported only in 2022 across Europe [3]. Extreme weather events, such as wildfires, have caused devastation in Canada, the USA, Algeria, Greece, Spain, Italy and Turkey between 2021 and 2022 [4]. Australia registered 450 deaths, 13,000 emergency asthma presentations and a large number of respiratory and cardiovascular admissions, displacing thousands of people and worsening mental health outcomes, after the bushfires occurred in 2020-2021 [5]. Air pollution has been associated with an increase of diseases such as stroke, chronic obstructive pulmonary disease, trachea, bronchus and lung cancers, exacerbations of asthma and lower respiratory infections, among others [6]. The World Health Organisation (WHO) estimated that 99% of the urban population is exposed to harmful levels of air pollution [7]. Air pollution is responsible for 6.7 million premature deaths annually and da-ta have shown that air pollution decreases life expectancy by 1.8 years worldwide [8]. The incidence rate of infectious diseases such as malaria has increased up to 31.3% in areas of Latin America and 13.8% in the highland areas of Africa, whereas dengue transmission has also risen by about 12% in the same areas from 1951-60 to 2012-21 [9]. There has been an increase of food insecurity globally in the last decade, with 720-811 million people suffering hunger in 2020 [10]. Furthermore, the increased incidence of all these impacts has a significant influence on mental health and human migration [11,12]. Therefore, Climate Change is not only a climate emergency but also a health emergency.

The term carbon footprint emerges as a necessity to quantify greenhouse gas (GHG) emissions comprehensively. It includes both direct and indirect emissions of GHGs attributable to various processes, products, or organisational activities, and is measured in carbon dioxide equivalent (CO_2e). These emissions correspond to the seven GHGs specified by the Kyoto Protocol: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). Direct emissions refer to those emissions over which an individual or organisation holds direct control - for instance, burning fossil fuels for on-site heating or utilising transportation directly managed by the entity. In-direct emissions refer to emissions related to the activities of the individual or organisation but occurring outside their immediate control - examples include emissions from the production of disposable items or the use of purchased electricity, as the emissions are generated elsewhere but attributed to the organisation's activities. The Greenhouse Gas Protocol outlined by the World Resources Institute classifies GHG emissions into three scopes: scope 1 emissions or direct emissions such as energy usage, anaesthesia gases, or in-house freight transport (excluding purchased electricity) under the organisation's direct purview, scope 2 emissions or indirect emissions linked to purchased electricity or electricity usage sourced from external providers, and scope 3 emissions which include all the other indirect emissions not directly controlled by the organisation, including those from supply chains and employee commuting [13].

Methodologies for carbon footprint analysis include bottom-up life cycle assessment-analysing the materials and processes involved in producing an item, multiplying each by a conversion factor-, top-down economic input-output analysis -utilising the financial costs associated with a product or process, multiplied by a conversion factor-, hybrid models -combining both bottom-up and top-down approaches, selecting the most suitable depending on data accessibility and availability- [14].

The healthcare sector is responsible for 4-5% of greenhouse gas (GHG) emissions [15]. Several studies have assessed the carbon footprint of national healthcare systems [15, 16], whereas others have investigated the carbon footprint in regional [17,18] and local healthcare settings [19,20] The National Health System (NHS) in the United Kingdom (UK), for instance, conducted an extensive evaluation, revealing that its carbon foot-print accounted for a substantial 6.3% of the nation's total emissions [15]. Similarly, Spain and Australia have reported analogous figures, with contributions to national emissions hovering around 5.4% and 7.2%, respectively. Tennison et al. delineated the carbon footprint associated with various healthcare activities in the UK [15]. For in-stance, the utilisation of a hospital bed on a daily basis was found to correspond to a significant emission of 125 kg CO_2e, while outpatient appointments generated 75 kg CO_2e per visit, and General Practitioner (GP) surgeries contributed 66 CO_2e per appointment. Studies by Malik et al. [21] and Keller et al. [22] have identified the substantial contribution of supply chain activities and patient transportation to the overall carbon footprint of healthcare operations. Furthermore, Nicolet et al. conducted a carbon footprint analysis focusing on GHG emissions from GP surgeries in Switzerland [18]. Their findings revealed an average emission of 30 tons of CO_2e annually per GP surgery. A detailed breakdown illustrated that a significant proportion—45.7%—was attributed to patient and staff transportation, highlighting the considerable impact of mobility-related activities on carbon emissions.

Heating constituted another substantial portion, accounting for 29.8% of emissions, followed by consumables (5.5%), courier services (5.8%), and miscellaneous services such as blood analysis and X-rays (1%). In conclusion, these studies underscore the multifaceted nature of GHG emissions within the healthcare sector and highlight the pressing need for comprehensive strategies to mitigate their environmental impact while ensuring the delivery of quality healthcare services.

Nurses and other healthcare professionals play a pivotal role in health promotion, disease prevention, and care delivery. However, healthcare activities significantly contribute to the rapid progression of climate change, which, in turn, will affect public health and undermine some key principles of healthcare professions, such as beneficence and non-maleficence. Hence, healthcare professionals have a responsibility to reduce these emissions while ensuring the safe delivery of care and adherence to professional principles. Furthermore, healthcare professionals can make a significant im-pact in both reducing climate change effects and supporting communities to adapt to its consequences [23]. Nurses, doctors, and other healthcare professionals are considered some of the most trusted professions worldwide, and hence have a privileged position to advocate for initiatives against climate change [24]. The Intergovernmental Panel on Climate Change (IPCC) has highlighted that sustainable practice can only be possible with the commitment of all professionals [25].

Emergency departments worldwide receive a large number of patients every year; for instance, nearly 136 million patients visit the emergency department annually in the US, while 24.4 million do so in the UK, representing a service of high intensity, which is likely to have a high carbon footprint. The Green Emergency Department (GreenED) project in the UK seeks to transform clinical care and emergency services provision, ensuring that they align with the next zero principles and improve patient's outcomes [26]. The development of a tool to assess ED carbon footprint could have a significant impact on the development of sustainable initiatives within EDs [27] Carbon footprint calculators could lead to positive actions (e.g., establishing areas of high carbon intensity), raise awareness, justify sustainable actions, and have an influential effect to bring about change [28]. Although there have been several approaches to calculate carbon footprints in ED [29,30], our tool aims to provide a comprehensive tool created by emergency nurses that then can be used to implement sustainable changes in the emergency department. The aim of this study was to validate the ED carbon footprint calculator, a tool that will help to carry out baseline carbon footprint assessments in EDs, identify areas of high carbon intensity or hotspots, and facilitate the monitoring of sustainable initiatives. This research was conducted between October 2022 and November 2023.

2. Materials and Methods

The development and validation of the ED carbon footprint calculator followed the phases summarised in Figure 1:

Figure 1. Phases of development and validation of the ED carbon footprint calculator.

2.1. Establishing the boundaries.

The first step in designing the emissions calculation tool was to define the boundaries of the measurement. That is, the area to be covered and the information to be included in the data collection and calculations.

2.1.1. Organisational boundaries.

The ED of a hospital setting was established as an organisational boundary because it is a core unit with a defined function and a structure of material and human resources that respond to that function. The main purpose of the ED is to deal with urgent and emergency cases that require immediate attention, through rapid diagnosis and the administration of effective medical or surgical treatment in a very short time [31]. The direct and immediate access of patients makes it a highly frequented service by the population [32]. Therefore, emission reduction measures implemented in these units would not only contribute to sustainability but would also have a greater diffusion and social impact.

Another argument for focusing the tool on the hospital emergency department is novelty, as there are previous studies on the carbon footprint of operating theatres [33], haemodialysis units [34], intensive care units [20], ambulance services [35], geriatric centres [36], dermatology [37] or radiology [38], but none have been identified for hospital emergency departments.

2.1.2. Operational boundaries.

Once the boundaries of the organisation have been defined in terms of the facilities over which it has sufficient management to perform the emissions calculation with the tool (emergency room), the operational boundaries need to be defined. This involves identifying the direct and indirect emissions associated with the processes within the facility and selecting which ones to include in the analysis.

For this purpose, a literature review was conducted to identify the most common categories included in previous carbon footprint assessments in healthcare settings [39]. This literature review led to a boundary inventory that was summarised in a table of contents including eleven categories, as well as information regarding data sources for carbon footprint calculations, key data collected, and units of data for each category [27]. The eleven categories comprised were: energy and heating, anaesthetic gases, freight transport, purchased electricity, catering and food, disposables and consumables, medical and non-medical equipment, pharmaceuticals, transport, waste, and water. Data sources varied depending on the category, although they were mainly invoicing and billing, meters, auditing, and surveys. The key data collected reflected the most important data to be obtained for each category. Our methodology followed the environmental reporting guidelines provided by the Department for Environment, Food & Rural Affairs (DEFRA) from 2019 [39]. The conversion factors selected for all the categories in this assessment tool were obtained from the annual report published by DEFRA, except in the category of waste, in which the conversion factors provided by Rizan et al. were used [33, 40]. Lastly, the unit of measurement for the data collect-ed was chosen in accordance with the data provided by DEFRA and Rizan et al. to facilitate its calculation [33,40].

The ED carbon footprint calculator incorporated a hybrid method to quantify carbon emissions in EDs, in which bottom-up and top-down life cycle assessments are used depending on the availability and accessibility of the data.

2.2. Validation of the boundaries.

The boundary inventory was evaluated by an expert panel to assess its comprehensiveness. The experts were selected by convenience sampling to meet the inclusion criteria: 1) being a healthcare professional, 2) having at least 3 years of experience in EDs, and 3) having at least 3 years of experience in environmental sustainability initiatives or proven experience in carbon footprint calculation. A total of 15 experts were invited, including nurses and doctors, among whom 11 agreed to participate in the study. They were given the boundary inventory, and, through an online questionnaire, they were asked to evaluate the relevance of each item (category, data source, data collection, and unit of measurement) with a dichotomous scale (Yes/No). Moreover, they were invited to make additional valuations and suggestions. Participation in the panel was voluntary.

The content validity, that is, the capacity of an instrument to measure the phenomena which it was designed for, was measured using the Content Validity Index (CVI) for each item and for the entire tool in general. It allowed quantifying the degree of agreement among the experts regarding the relevance of each item [41]. In accordance with the adaptation proposed by Tristán-López for the panels with a reduced number of members, the CVI was considered as acceptable for values above 0.59 in the case of a panel of 11 experts [42]. Additionally, Aiken's V was also evaluated, which allows assessing the relevance of each item with respect to its construct, taking into account both the number of categories provided to the experts and the number of participating experts. The value may range between 0 and 1, being more relevant the closer it is to 1 [41].

2.3. Design of the version 1 of the ED carbon footprint calculator.

The contributions of the expert panel were incorporated to the version 1 of the ED carbon footprint calculator, which was created using Microsoft Excel for Mac v16.65. This version was divided into different Excel sheets following the next order: introduction, content, emergency department details, scope 1 emissions, scope 2 emissions, scope 3 emissions – divided into seven sheets to facilitate its navigation– and results. Each Excel sheet contained several sections and items for each category, as well as a cell at the bottom of the sheet with the total amount of carbon emissions for the category. The ED at the Royal Free Hospital in

London was selected as a pilot site for the identification and collection of data between November 2022 and February 2023. Data were collected through observation and from hospital records. The tool was designed to make calculations over a period of one year.

2.3.1. Introduction, table of contents and emergency department details.

The introduction included comprehensive information regarding the contents and organisation of the calculator, as well as the scope and boundaries, the conversion factors used, and the "how to use" and "how to navigate" instructions. A content sheet was also created with hyperlinks to direct the user straight to contents desired and facilitate its navigation. The emergency department details sheet contained different cells to introduce data regarding the department details, such as name of the hospital site, floor space of the emergency department and the hospital premises, number of staff working in the emergency department and number of attendances. The surface of the emergency department and the hospital must be introduced when submeters are not available in the department, as the approach by Prasad et al. was applied, according to which the total consumption of the site is multiplied by the department's surface and divided by the total surface of the site, providing and estimation of the department's consumption and subsequently its carbon footprint [20]. This approach was utilised in the categories of energy, electricity, and water consumption.

2.3.2. Scope 1, 2 and 3.

An exhaustive compilation of 1095 items was designed, and these were grouped into the three scopes proposed by the Greenhouse Gas Protocol [13]. Each scope was organised into categories, as described in Table 1. In the calculations based on the financial expenditure, there was a box to facilitate the general calculation, without de-tailing the items.

Table 1. Design of the version 1 of the ED carbon footprint calculator.

2.3.3. Carbon footprint outcome.

The outcome sheet provided a summary of the carbon emissions for scope 1, 2 and 3, as well as a breakdown of the categories of scope 3. The calculator can also provide two diagrams with the total carbon emissions and total scope 3 emissions for the emergency department.

The ED carbon footprint calculator includes all the areas where emergency care is provided at the hospital site – such as Minor, Major, Resus or ambulatory services for adults and/or paediatrics. Furthermore, the imaging department that is used by the emergency team and ED administration offices is also included. However, building infrastructure, support services and other diagnostic services –e.g., laboratories and other imaging departments such as nuclear medicine or ultrasound departments– are not included.

2.4. Validation of the version 1 by an expert panel.

The content validity of the version 1 of the tool was evaluated by an expert panel. In this case, since the relevance of the items had already been assessed by the same group of experts, the evaluation was focused on the reach of the tool, the calculations, and the conversion factors. The same procedure was followed, inviting the 11 experts from the previous panel to participate in the second panel, among whom eight experts agreed to participate. In this case, as the number of experts is reduced to 8, the mini-mum acceptable value of the CVI according to the literature was 0.75 [42].

2.5. Evaluation of the version 1 by a focus group of potential users.

Once the suggestions from the panel of experts II had been taken into account, the face validity (or logical association of the items with the concept to be measured) and the presentation and usability of the tool were evaluated by a focus group. The focus group allowed exploring the experiences of the participants about the use of the tool, providing information from the perspective of the user in terms of its clarity, ease of use, viability and usefulness. We ensured that the participants met the profile of the future user of the calculator. To this end, the following inclusion criteria were established: 1) being a healthcare professional, 2) working in an ED, and 3) having no specific experience or knowledge in carbon footprint. A participation invitation was sent to eight people who met the profile, along with the version 1 of the ED carbon footprint calculator, two weeks before the date set for the focus group, in order to have enough time to manage and test it. Lastly, a virtual focus group was held with three participants who accepted the invitation. The focus group was recorded and transcribed verbatim for subsequent analysis. One focus group was held, as according to the study conducted by Guest et al. on focus group sample size and thematic saturation, 84% of themes were generated by one to three focus groups, with four people able to generate accurate and reliable information [43]. It was moderated by a member of the research team. Participants were selected by convenience. A call was made to ED staff at the Royal Free Hospital, with four reminders.

The discussion was developed around the following questions proposed by the moderator: How was your experience testing out the ED carbon footprint calculator? How did you find having instructions on "how to use the calculator" in the first excel sheet? How does it influence the presentation of the calculator? How did you feel while filling out the data? What use can have the calculator in your professional practice?

The content analysis was performed by two researchers independently, according to the recommendations of Graneheim and Lundman and their results were compared to reach consensus, requesting the intervention of a third researcher to resolve any discrepancies, although this was not necessary [44]. Firstly, several comprehensive readings of the discourses were performed, in order to familiarise with the content and identify the units of meaning. Then, following an inductive approach in which the categories emerged from the obtained data, we coded the units of meaning, assigning a code to them in line with their content. The codes were classified, compared and grouped based on their similarities and differences, in order to generate the categories. Thus, the content groups that shared common elements were gathered in the same category, enabling the identification of the themes that emerged from the content analysis.

2.6. Ethical considerations.

The recommendations of the UK Medical Research Council, the authoritative body guiding our study, were followed. At the outset of our investigation, we requested guidance from the NHS Health Research Authority regarding the necessity of ethical approval. Due to the nature of our study and the participation of experts acting in their capacity as healthcare professionals to provide their opinion on the tool, with the aim of conducting an analysis from their professional standpoint rather than about them or for them, approval from the NHS ethics committee was deemed unnecessary. This has been considered an active partnership between the professionals and researchers to influence and shape our proposed tool. Furthermore, in the focus group, no opinions of a private nature were solicited, nor were lived personal experiences explored to investigate a subjective phenomenon.

Nevertheless, the research was conducted in adherence to ethical quality standards. Regarding the expert panels, participants were selected based on their level of expertise and knowledge in the field. They were provided with prior information on the purpose of the study, methods, the role proposed for them, and what was expected of them. Additionally, they were briefed on the handling and custody of data. The database could not be anonymized as we required knowledge of the origin of improvement comments for potential clarifications. Nonetheless, it was strictly confidential, overseen by one of the researchers, and shared exclusively for peer analysis. Furthermore, participants were given the opportunity to withdraw from the study at any point or request the removal of their comments. Experts were informed of these options and willingly, voluntarily, and disinterestedly agreed to participate (evidence of this process could be provided upon request). Informed consent was requested and obtained from all participants.

Regarding the participants in the focus group, they were similarly informed in advance, under the same terms as the experts. They provided informed consent through a declaration. Regarding the recording of the focus group, verbal permission was sought at the outset of the recording, and all participants consented. The video was securely held and transcribed by one of the researchers, with content analysis conducted confidentially by pairs. In manuscript writing, anonymity of the collected data and opinions has been maintained without providing participant-identifying in-formation (evidence of this process could also be provided upon request).

3. Results

3.1. Validation of the boundaries by expert panel I.

The participants in the expert panel I had an average age of 38.0 (SD=5.4) years, an equal number of males and females, mainly Caucasian ethnicity (63.6%), PhD (90.9%) and MSc (54.6%). All experts were members of the Green ED of the Royal College of Emergency Medicine. The sociodemographic characteristics of expert panel I are described in Table 2.

Table 2. Sociodemographic characteristics of participants.

In general, the relevance of the content of the prototype was good, with a total CVI of 0.74 and Aiken's V of 0.87. Specifically, six items obtained a CVI below the acceptable value, as shown in Table 3. The lowest values of Aiken's V corresponded to the measurement units for catering/food (0.55) and disposable/consumables (0.64). The results of the consensus on the relevance of the items of the prototype are summarised in Table 3.

Table 3. Results from experts panel I.

The comments for improvement provided by the experts and the resulting changes are shown in Supplementary Table 1. In general, six experts highlighted the difficulty of specifically calculating the cost of energy, electricity and water for the ED service, since the billing or meters usually perform a calculation of the total consumption of the hospital. In response, the Prasad et al. approach was applied, according to which the total consumption of the site is multiplied by the department's surface and divided by the total surface of the site. This formula can provide an estimation of the department's consumption and subsequently its carbon footprint [20]. Some comments questioned the aptitude of the measurement units for energy, anaesthetic gases, catering/food, medical equipment and non-medical equipment, as they are neither the most common nor easily obtained. Therefore, the units of the data collected were checked and modified in accordance with the conversion factors provided by DEFRA in order to facilitate the calculations [40]. As suggested by the experts, the brand names of the anaesthetic gases have been replaced by their generic names, for example, from Entonox to nitrous oxide. One of the experts suggested including anaesthetic gases for pipelines, but the research team decided not to consider it, as anaesthetic gases are not commonly used in EDs and, when used, are usually managed by the anaesthesia team rather than the emergency physician. The experts expressed their concern about the data-gathering method in the categories of transport, waste and disposable/consumables, due, in the latter case, to the wide variety of materials comprised in it. We acknowledged that data collection for these categories in particular could be challenging. For the disposables/consumables category, five different sections were created to facilitate the classification of the data. For the other categories, both cross-sectional studies, an audit for waste and a survey for transport were proposed. Moreover, the experts suggested to include the consumption of renewable energies. It was decided not to include the use of green energies in the calculator, as they are al-ready applied in the conversion factors provided by DEFRA.

3.2. Validation of the version 1 by experts panel II.

The second expert panel had an average age of 38.5 (SD=5.6) years, mainly Caucasian doctors (75.0%) and MSc (62.5%). The sociodemographic characteristics of ex-pert panel II are described in Table 2. In general terms, the experts valued the version 1 as relevant, with a total CVI of 0.81 and Aiken's V of 0.90. Discrepancies were detected regarding the relevance of the calculations and conversion factors of scope 3, with CVI=0.50 and V=0.75, as shown in Table 4.

Table 4. Results from experts panel II.

The comments for improvement suggested by expert panel II and the resulting changes are shown in Supplementary Table 2. With regard to the measurement units, two experts suggested revising the units applied in the cells of total fields and conversion factors, so they were checked and corrected. One of the experts pointed out that some items may have been excluded from the category of consumables and disposables. Further to this comment, a black cell in the disposables/consumables category was added for the user to be able to introduce items not available in the calculator. Furthermore, the experts recommended adding a cell to calculate the footprint of the category of disposables and consumables based on the total expenditure instead of doing so item by item, in order to facilitate the calculation for departments in which a thorough calculation cannot be performed. This suggestion was incorporated by including an overall spend field for pharmaceuticals and disposables, given the user option to measure carbon footprint based on the overall expenditure. One of the experts asked whether the costs obtained from the Royal Free Hospital were in line with those of the NHS supply chain catalogue in the category of disposables and consumables, which would question their applicability in other hospitals. Thus, it was compared and con-firmed that the prices obtained from the Royal Free hospital were the same as the prices provided by the NHS supply chain catalogue. Three experts recommended replacing "quantity measured" with "quantity used", since the quantity measured in the department may not coincide with the quantity used, so it was changed. The experts pointed out calculation errors in the category of anaesthetic gases and waste and recommended adding transport and distribution (T+D) and Well-to-tank (WTT) emissions to the category of energy, as well as WTT emissions to the category of transport. These considerations were taken into account in the conversion factors.

3.3. Evaluation of the version 1 by the focus group of potential users.

The sociodemographic data of the participants are described in Table 2. The analysis of the discourses generated a total of 72 units of meaning, which were grouped in 14 categories (Table 5). Three themes emerged from the content analysis: calculator re-vision, data collection and benefits.

Table 5. Results from focus group content analyse.

3.3.1. Calculator overview.

This theme refers to the experiences with the use of the calculator. The participants valued the tool in a very positive manner, describing it as easy to use, friendly, clear, useful and with a good layout. It included comprehensive data and clear information on how to use it, with detailed instructions. They also reported some technical issues, such as displaying errors or wrong measurement units in some of the cells; that were addressed and fixed.

3.3.2. Data collection.

This theme summarises the opinions on the information required to estimate the footprint and the concerns expressed by the participants about the data collection. In general, the experts stated that the data collection was complex and time consuming, due to the large amount of data required. However, they also recognised that the data were relevant, comprehensive and feasible. They identified the most easy-to-gather data, that is, those with an available record, such as billing or stockage (e.g., disposables/consumables, pharmaceuticals). On the other hand, the data without records, those that are managed outside of the ED department (e.g., waste), and those that in-volve demanding third parties with a survey (e.g., transport) were perceived as difficult to obtain and a possible cause of bias.

3.3.3. Benefits.

This theme gathers the comments of the participants about the usefulness of the calculator and the implications for the clinical practice.

3.3.3.1. Monitoring and comparison

The participants stated that the calculator provides quantitative data that allow making an initial diagnosis and identifying the starting point of the unit and the areas of greater emissions. These quantitative data also allow monitoring the processes, by comparing the data and quantifying the reduction of the footprint of each intervention.

3.3.3.2. Raising awareness

Another usefulness identified by the focus group was awareness, since measuring the emissions helps professionals to visualise the environmental impact of their professional activity. The participants also pointed out the need to raise the awareness of the entire team, since this is a common problem in which all participants must be involved. The awareness generated by this calculator can be contagious and trigger a snowball effect that results in a shared commitment. The participants recognised that Climate Change is an important factor for human health, and thus, as professionals, they must engage in its approach.

3.3.3.3. Motivation

In the conversation, another benefit emerged as the motivation of professionals toward more sustainable practices. Although healthcare professionals are a sensitive workforce committed to Climate Change, quantifying the improvements would motivate them to persist with initiatives for the reduction of emissions. The participants also suggested that the calculation of the carbon footprint could be used as an item to evaluate the department and compare it to others, as in a competition.

3.3.3.4. Promoting change

The analysed discourses underlined the capacity of the calculator to promote changes. It was considered as a valuable tool to lead environmental initiatives. Quantifying data will provide evidence and arguments to persuade health professionals to change their practice, encourage them to maintain the new approach and convince others to join them. This tool can challenge professionals to make changes and realise they are accountable for their actions, as daily practice choices can have a significant impact on carbon footprint reduction.

3.3.3.5. Decision making

The participants recognised the need to involve the management teams, and they pointed out the usefulness of the tool to motivate the making of more sustainable decisions.

4. Discussion and conclusions

This study aimed to develop and validate the ED carbon footprint calculator. As a final result, a valid, exhaustive, clear and easy-to-use tool was obtained, which will al-low estimating the CO_2 emissions generated by the activity of hospital emergency ser-vices. This carbon footprint calculator has been designed to be used in the UK, however adaptation and use in other countries could be possible by adjusting the items included.

Regarding the validation of the boundaries by expert panel I, the lowest CVI and Aiken's V values were scored by measuring units used in the categories catering and food categories, disposable and consumables, medical and non-medical equipment. The units of measurement in the category of catering and food scored the lowest CVI and Aiken's V values, indicating that the experts did not agree with the units selected or did not find them relevant. So, we replaced number of meals with weight as recommended, which is also in line with the units provided by DEFRA to calculate the carbon footprint of food and drinks [39]. Disposables and consumables had low CVI and Aiken's V scores for the unit of measurement, which is due to the complexity and extension of this category. The participants also questioned the feasibility of obtaining data regarding waste, although previous studies have shown that it is possible to weigh hospital waste over a period of time and extrapolate these data to the rest of the year [45]. For medical equipment and non-medical equipment, the panel of experts recommended changing the unit of measurement from kilogram to financial cost – which were reflected with low CVI (0.45 and 0.45, respectively); however, DEFRA provides conversion factors based on weight for electronic equipment, and for non-medical equipment based on the material they are made of [40]. Furthermore, manufacturers provide the weight and life expectancy of their products, thus we ap-plied the carbon footprint calculation based on items' weight and life expectancy, as previously applied by Nicolet et al. [18]. Nevertheless, medical instruments' carbon footprint was calculated based on their financial cost, as the weight for each item was inaccessible to the research team.

The results of the validation of the version 1 by Expert Panel II showed disagreement regarding the category of consumables and disposables, as some items may not have been listed in our calculator, which explains the lower CVI and Aiken's V scores obtained. Therefore, we included blank cells for the user to introduce the item, price and quantity with automatic application of the conversion factor. Furthermore, we added the possibility for the user to introduce the total consumption of energy, electricity and water when sub-meters were available, as well as the option to calculate carbon footprint for pharmaceuticals and disposables and consumables based on the total expenditure. We ensured that the prices obtained at the Royal Free Hospital for disposables and consumables were the same as those available at the NHS supply chain catalogue to enable a wider use of the tool [46].

The focus group evaluated the ED carbon footprint, and three main themes were highlighted: calculator's revision, data collection and benefits. The participants emphasised that the tool was easy to use, thorough and useful. These opinions coincided with the international survey that Collins et al. carried out with 4 245 respondents, which found that a personal carbon footprint calculator was considered a valuable tool for 91% of their participants [47]. Regarding data collection, when they were asked about the appropriateness of the items and how feasible it would be to obtain the data, the participants found that data that are on record should be easier to obtain, whereas others, such as those of transport and waste, which require survey or direct auditing in the field, would be more challenging. Transport was emphasised as one of the most challenging categories, requiring a large sample of participants to be representative; however, previous studies have shown feasibility obtaining these data via survey, in which data were collected for a period of time and extrapolated to the rest of the year [19]. Waste was also considered to be very challenging. Previous studies have applied methods similar to the one provided in our calculator for waste data collection, although we recognised the challenges derived from them [45]. Lastly, a number of benefits were expressed, such as promoting change, raising awareness, monitoring and comparison, education, and decision making. The participants stated that measuring the carbon footprint of the emergency department would not only help to raise awareness and promote change among the staff and patients, but it would also encourage stakeholders in decision making. Previous studies have shown that the general population do not act due to their lack of knowledge regarding how their daily activities aggravate Climate Change, hence the importance of raising awareness to promote change [48]. This would also influence the motivation of the staff and patients to promote change, which is in line with what Collins et al. found in a survey were 78% of the respondents felt motivated and inspired with the creation of a carbon footprint calculator [47]. Furthermore, the ED carbon footprint calculator was described as a key tool to monitor and compare carbon emissions, as previously found in other studies [49]. Finally, the participants highlighted the educational role of healthcare professionals amongst other staff and patients and the importance of educating the community to mitigate the effects of human activity on the environment. The use of ecological footprint education has received increasing attention over the last years, and this could have a significant impact on the promotion of change within the community [47].

Regarding the limitations of the present study, it is important to underline those related to the scope of the tool. It is not possible to make an exact calculation of the carbon footprint, since there are either inaccessible data of activity or no appropriate conversion factors. Thus, it is necessary to establish the boundaries of the evaluation in order for the estimation to be as accurate as possible. The reach of this calculator does not include certain areas, such as freight transport and laundry, due to the insurmountable difficulties in their evaluation. Nevertheless, we obtained a calculator that was as exhaustive as possible, with a variety of 1,095 items. This list makes the tool more comprehensive, but it also makes it more time-consuming. For ease of completion, the items have been grouped into functional categories and subcategories and arranged in alphabetical order.

Another limitation related to the calculation of the carbon footprint is the date of the conversion factor. Although the 2022 report was used in most cases, for some specific calculations it was necessary to employ the 2019 or 2012 reports, due to a lack of availability. Consequently, the calculation is up to date. Moreover, for the calculation of the detailed carbon footprint of pharmaceuticals, the purchase prices of the pilot site Royal Free Hospital were used as reference. The purchase prices may vary among the different trusts according to their commercial contracts. It is estimated that these differences are lower, and, in any case, they would only affect the calculation of the detailed carbon footprint, with no effect on the general calculation of the pharmaceutical expenditure.

With regard to the methodology, another limitation was the small number of participants in the focus group. This reduced the interaction in the group and the capacity to generate discourses. There was also a lack of diversity in the participants in terms of health professionals, as the panel experts were mainly doctors, which may have introduced a bias in the applicability of the tool. However, the focus group participants were predominantly nurses, which may have validated its use by professionals other than doctors.

Despite these limitations, the calculator is presented as a valid tool for the estimation of the carbon footprint in EDs both to evaluate an initial situation and to compare two or more scenarios.

This study concludes that the ED carbon footprint calculator is a valid and comprehensive tool, offering a thorough analysis of scope 1, 2 and 3 emissions in EDs, and the possibility of carrying out a baseline assessment, identifying areas of high carbon intensity and monitoring sustainable initiatives. This tool is in line with the zero carbon-emission commitment of the NHS aiming to reduce emissions to 0 by 2045, and it will provide strong evidence to numerous projects carried out in emergency departments, such as the Green ED.

The methodology that we followed to develop and validate the calculator –expert panels 1 and 2 and focus group–generated a comprehensive and robust tool. It was described by users as a valuable, easy-to-use and user-friendly tool. The data presented in the calculator were valued as representative and appropriate, and their collection seems to be feasible for users.

The ED carbon footprint calculator can lead to positive changes in EDs by raising awareness, promoting change, and facilitating the monitoring and comparison of car-bon emissions. Furthermore, it can influence staff and stakeholders to carry out major changes in the way healthcare is delivered, as well as to introduce ecological education to other colleagues and staff. This calculator will enable nurses and other healthcare professionals working in the ED to carry out environmental initiatives.

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Tables and figures

Supplementary material

Table 1. Design of the version 1 of the ED carbon footprint calculator

Scope	**Category (no. items)**	**Sub-categories**	**Clarifications**
Scope 1	Energy consumption (4)	Burning heating oil Natural gas LPG Coal	These are the main sources of energy consumption used in hospital premises across the UK according to the ERIC database. The conversion factor included Well-to-Tank, which refers to those emissions related to the extraction, refining and transportation of raw fuel to the hospital site.
	Anaesthetic gases (8)	Nitrous oxide (Entonox) Methoxyflurane (Penthrox)	The most commonly anaesthetic gases in ED were included. Nitrous oxide was specified into different sizes according to the capacity of each cylinder and the code of each cylinder was provided to facilitate their identification.
	Hospital transport (1)	Ambulance (inter-hospital)	Freight transport was not included, as it is normally controlled by the hospital procurement team rather than by the ED. Inter-hospital transport or transport of patients between different sites or trusts were included, as they represent direct emissions produced by the activity of the ED. It was calculated based on km in a standard diesel ambulance.
Scope 2	Electricity (1)	Electricity	Renewable energies were not included as such, as they are included in the conversion factor provided by DEFRA and the increase of use of those would decrease the conversion factor for electricity.
Scope 3	Disposable/consumables (481)	Airway Breathing Circulation Disability Gloves and PPI Gynae Hygiene and cleaning Housekeeping Immobilisation Specimens Urology Wound care Others	Each subcategory has a folder with different items for selection, with a total of 481 articles described. A description is provided, together with the units included in each package and the codes to facilitate the identification of the products. The information is added to the calculator as consumed units. Moreover, blank spaces were integrated to add the products that are not included in the folders. The conversion factor was applied based on the financial cost of medical instruments. The financial cost for each item was obtained from the hospital records at the pilot site and these match the NHS supply chain prices, allowing their applicability to other sites ordering through this platform.
	Medical equipment (92)	Medical equipment (electrical) Medical equipment (furniture) Medical equipment (medical instruments) Imaging equipment	Each subcategory has a folder with different items for selection, with a total of 92 articles described. A description of the article, the manufacturer and the model is provided to identify the units that are added in the calculator, or a similar model, if the article is not available. A list of the medical equipment items was obtained from the hospital records at the pilot site. Information regarding the price, weight and life expectancy of each item was obtained from the information provided by manufacturers. Furniture and medical instruments' carbon emissions were calculated based on their cost, while electrical and imaging items were calculated based on their weight. The total carbon footprint of each item was divided by its life expectancy, as this calculator was designed to provide the carbon footprint of one year.
	Non-medical equipment (7)	Non-medical equipment	A list of the entire non-medical equipment was obtained from the hospital site, and seven of the most used items were chosen as representative of this category. Conversion factors for each item were applied based on their weight and the material.
	Pharmaceuticals (407)	Injectables Fluids Oral medication Topicals Nebulisers and inhalers Eye drops TTA pack Enemas and suppositories Diagnostics Nasal medication	Each subcategory has a folder with different items for selection, with a total of 407 articles described. The name (in alphabetical order), dose and presentation are provided to facilitate identification. Additionally, blank spaces were integrated to add the products that were not included in the folders. Pharmaceutical items were obtained from the department's ordering records at the pilot site. Conversion factors based on the financial cost were applied. The price for each item was obtained from the department's ordering records. Due to the large number of items, we excluded those items that were rarely used and had a cost of less than £1, since their contribution to the overall carbon footprint would be negligible.

	Transport (50)	Transport	A comprehensive list of 50 transport methods available in DEFRA (2022) was obtained, including different types and sizes of cars –such as petrol, diesel, hybrid and electric, and small, regular and large–, motorcycles, active travelling –such as walking or cycling– and public transportation –bus, tube and train. We also added a key at the bottom of the sheet explaining the engine sizes corresponding to small, medium and large vehicles. The conversion factor was calculated per km in private vehicles, whereas, for public transportation, km per passenger was applied.
	Waste and water (12)	Waste	Eleven different waste types were included. Conversion factors were applied based on the weight of the waste. Laundry services were excluded, since this is a process external to ED; moreover, due to the lack of non-specific conversion factors available for this activity, the data are inaccessible.
		Water	
	Catering and food (32)	Meals	A list for 32 items regularly ordered by the pilot site was created, which included their weight. We introduced a blank cell in weight for a regular meal or sandwich as weight might differ among sites. The conversion factor based on weight from DEFRA (2022) was chosen, as it would provide more accurate data, since NHS sites do not always share the same ordering system for catering.
		Beverage	
		Breakfast	
		Tableware	
		Pediatric food	
		Others	

ERIC= Estates Return Information Collection.

Table 2. Sociodemographic characteristics of participants.

		M (SD)	n	%
Panel expert I (prototype assessment)				
Age		38.0 (5.4)		
Gender	Female		5	45.5
	Male		5	45.5
	Prefer not to disclose		1	9.0
Ethnic identities	Caucasian		7	63.6
	Asian		1	9.1
	Indian		1	9.1
	Chinese		1	9.1
	Prefer not to disclose		1	9.1
Healthcare profession	Doctor		10	90.9
	Nurse		1	9.1
Years of experience ED		10.4 (4.6)		
Highest degree	Bachelor's degree		3	27.3
	MsC/MA		6	54.6
	MRCEM		1	9.1
Panel expert II (first version assessment)				
Age		38.5 (5.6)		
Gender	Female		4	50.0
	Male		4	50.0
	Prefer not to disclose		0	0
Ethnic identities	Caucasian		6	75.0
	Asian		1	12.5
	Indian		0	0
	Chinese		1	12.5
	Prefer not to disclose		0	0
Healthcare profession	Doctor		8	100.0
	Nurse		0	0
Years of experience ED		10.7 (3.4)		
Highest degree	Bachelor's degree		3	37.5
	MsC/MA/MRes		5	62.5
	MRCEM		0	0

Focus group

Code	Gender	Age	Highest degree	Health profession	Years of experience ED
P1	Woman	37	Bachelor's degree	Nurse	7
P2	Woman	36	MsC/MA	Nurse	9
P3	Woman	40	Bachelor's degree	Doctor	14

M=mean; SD=standar Deviation; ED=Emergency Department; MsC=Master in Sciences; MA=Master; MRes=Master in Research; MRCEM=Royal College of Emercency Medicine

Table 3. Results from experts panel I.

		Appropiate n (%)	CVI	V AIKEN
Energy/ Heating	Category	9 (81.8)	0,64	0,82
	Data source	9 (81.8)	0,64	0,82
	Data collection	9 (81.8)	0,64	0,82
	Unit	10 (90.9)	0,82	0,91
Anaesthetic gases, metered dose inhalers and other medical/surgical gases	Category	9 (81.8)	0,64	0,82
	Data source	9 (81.8)	0,64	0,82
	Data collection	8 (72.8)	0,45	0,73
	Unit	10 (90.9)	0,82	0,91
Electricity	Category	9 (81.8)	0,64	0,82
	Data source	11 (100.0)	1,00	1,00
	Data collection	10 (90.9)	0,82	0,91
	Unit	11 (100.0)	1,00	1,00
Catering/food	Category	9 (81.8)	0,64	0,82
	Data source	9 (81.8)	0,64	0,82
	Data collection	9 (81.8)	0,64	0,82
	Unit	6 (54.5)	0,09	0,55
Disposable/consumables	Category	8 (72.8)	0,45	0,73
	Data source	11 (100.0)	1,00	1,00
	Data collection	10 (90.9)	0,82	0,91
	Unit	7 (63.6)	0,27	0,64
Medical equipment	Category	9 (81.8)	0,64	0,82
	Data source	10 (90.9)	0,82	0,91
	Data collection	10 (90.9)	0,82	0,91
	Unit	8 (72.8)	0,45	0,73
Non-medical equipment	Category	9 (81.8)	0,64	0,82
	Data source	10 (90.9)	0,82	0,91
	Data collection	11 (100.0)	1,00	1,00
	Unit	8 (72.8)	0,45	0,73
Pharmaceuticals	Category	9 (81.8)	0,64	0,82
	Data source	10 (90.9)	0,82	0,91
	Data collection	10 (90.9)	0,82	0,91
	Unit	9 (81.8)	0,64	0,82
Transport	Category	9 (81.8)	0,64	0,82
	Data source	10 (90.9)	0,82	0,91
	Data collection	10 (90.9)	0,82	0,91
	Unit	11 (100.0)	1,00	1,00
Waste	Category	9 (81.8)	0,64	0,82
	Data source	9 (81.8)	0,64	0,82
	Data collection	11 (100.0)	1,00	1,00
	Unit	10 (90.9)	0,82	0,91
Water	Category	9 (81.8)	0,64	0,82
	Data source	11 (100.0)	1,00	1,00
	Data collection	9 (81.8)	0,64	0,82
	Unit	10 (90.9)	0,82	0,91
	Total		0.74	0.87

CVI= Content Validity Index

Table 4. Results from experts panel II.

		Appropriateness n (%)	**CVI**	**V AIKEN**
Scope 1	Comprehensive and representative	8 (100.0)	1	1
	Calculations	7 (87.5)	0.75	0.88
	Conversion factors	7 (87.5)	0.75	0.88
Scope 2	Comprehensive and representative	8 (100.0)	1	1
	Calculations	8 (100.0)	1	1
	Conversion factors	7 (87.5)	0.75	0.88
Scope 3	Comprehensive and representative	8 (100.0)	1	1
	Calculations	6 (75.0)	0.50	0.75
	Conversion factors	6 (75.0)	0.50	0.75
	Total		0.81	0.90

CVI= Content Validity Index

Table 5. Results from focus group content analyse.

Theme	Category	Quote	
Calculator review (n=25)	Positive evaluation(n=2)	*It's a very thorough and very good tool to be honest.*	P1
	Easy to use (n=6)	*I think it's very easy to use. It's very obvious on how to use it.*	P1
		Considering I'm not particularly IT literate, I thought it was OK. I didn't have any major issues with it.	P3
	Friendly (n=4)	*I think is friendly enough. I like the fact that you can do the plus and minus. So it's not too much if you're not wanting to go into a category.*	P1
		It's easy to read language. I like when things are kind of bullet pointed or put out nice and clearly… It looks like it was all nice, kind of clearly little boxes	P3
	Clear information (n=4)	*I don't think it was missing anything (instructions)….I thought it had all the information that it needed.*	P3
		Everything's very clearly kind of documented at the start... It's sort of clearly states what it's for.	P3
	Comprehensive data (n=4)	*It's a lot to put in, but it's all relevant. It's all things that you need to look like.*	P1
		I don't think there is anything I thought it was missing (data).	P2
	Technical (n=5)	*When I put the quantity per pack, it needs to put a pound symbol*	P1
		I like that you have the cake symbols in the last tab with the amounts of each category.	P1
Data collection (n=16)	Time consuming(n=3)	*You just need to have the time and know you're getting into a very thorough process and that's it.*	P1
	Data easy to obtain (n=5)	*Asking states for water and electricity consumption should be easy for instance.*	P1
		There's probably a nice easy record of like what's brought in and how often we need to repurchase it and that sort of thing. And you can easily work things out.	P3
	Data difficult to obtain (n=8)	*I think the more difficult one to be honest, probably with the transport part because you have to involve patients and ask very specific questions.*	P1
		Waste is just a nightmare because there's no record of how much waste we generate… The bags are not used properly anyway. So, what we would document as recyclable waste, a lot of the times is getting incinerated because it's been contaminated with clinical waste.	P3
Benefits (n=31)	Monitoring and comparison (n=6)	*I think once you have something to compare, it's a lot…at least you can see if you're making a difference.*	P1
		Knowing where we could make changes and where we're sort of generating our biggest carbon footprint	P3
		It's gonna be useful going forward to kind of monitor the progress that we're making.	P3
	Rise awareness (n=7)	*If we were able to show that everybody making small decisions actually has an effect, that's cat can only encourage people more to make those little small changes and then hopefully you'd have a little bit of a snowball effect.*	P3
		Climate change is a big factor in patients health and at will going forward probably be a big factor in some of the patients that we're seeing. So I think it's important that we get involved	P3
	Motivation (n=6)	*if you're able to show these are the changes we've made and this is the difference it's made, then that's going to motivate people a little bit more.*	P3
		People love to compete and say we are better than others, so that could be a good way to use it (for motivation).	P1
		I think a lot of healthcare professionals and people who work in the health industry are also quite passionate about things that concern climate change.	P3
	Promote change (n=11)	*If you don't have quantifiable data, then it's really hard to kind of make your argument and to push for changes… It might change their practises more if you're able to kind of hit them with some hard data*	P3
		…can also help make changes on those things are outside of our control. Because if people compare the carbon footprint on the similar size… and there's a big difference between the two of them. You can look at why that is so different and what can you do better on the one that's wasting way too much. And that can be something to use to push those changes from evolve.	P2
	Decision making (n=1)	*that promotes or encourages those in charge who are making decisions beyond our control to actually get involved with it and trying to make changes.*	P3

n=frequency of semantic units; P1=participant 1; P2=participant 2; P3=participant 3

Supplementary Table 1. Comments on expert panel I

Category	Comment	Response
Energy/ Heating	With EM in mind will it be possible to really select out the energy used by an individual department with a meter - this is not currently available. Likewise with billing. This is aspirational but not realistic at present? Key data collected but not measurable on an individual level at present where I work so this would be meaningless and not fillable in.	The approach used by Prasad et al. can be applied, according to which the total consumption of the site is multiplied by the department's surface and divided by the total surface of the site. This formula can provide an estimation of the department's consumption and subsequently its carbon footprint.
	You would require all the above information to know the direct expenditure of source 1 emissions for the department, however, I think this may be difficult to achieve as EDs tend to be part of larger building so unsure if you would be able to get separate energy usage for one department alone.	
	I think it is very hard to collect the energy use of the department - it may have to be modelled based on total hospital energy use	
	Might be difficult to isolate Energy Use by Department (unless metering for ED is separate from other departments?)	
	Perhaps explaining the relationship between total hospital Scope 1 emissions calculation and how to figure out what proportion of that is 'used' by the ED would be helpful? Not sure how this calculation would happen, or if it's even possible aside from a very rough estimation.	
	I think these are all things that need to be considered however it may be quite difficult to get the data for the specific use of them for the emergency department as they are normally located in a large building and there may not be a separate meter for their use in the ED. Could we work out a way to calculate the answer based on the size of the department, this would be less accurate but more manageable.	
	For energy - KWh the main way of measuring this in my experience. What does the L refer to? natural gas? - Standard way of measuring is key here - see below. Not sure what the *means in the table? We have a roof full of solar panels - how can this be integrated into this tool - here or next page?3	The conversion factors provided by DEFRA are expressed in these units; therefore, to facilitate the calculations, these units were selected. We decided not to include the use of green energies in the calculator, as they are already applied in the conversion factors provided by DEFRA.
Anaesthetic gases, metered dose inhalers and other medical/surgical gases	"I'm not sure £ is the right measure here. Separating out the various items in the list will give different units. As below MDI - could be in units dispensed as for penthrox. Cost varies between trusts so not directly comparable and getting the cost is difficult. Also, should cost really be a measure when we are talking about environmental topics because things that are green are often not cheaper, but this shouldn't and can't be a block on measurement and implementation. Entonox Litres, Penthrox Units (or cost), Anaesthetic Gases surely Litres? MDI/DPI - units dispensed or used or cost? Going form £ to CO2e is difficult and wouldn't be possible I don't think?"	The units of data collected in this section have been revised and changed. The units of data collected are expressed in litres.
	May want to consider measuring exact numbers of litres used of Entonox. This would also then capture the Entonox used in departments which have manifolds	
	Consistent units of baseline date is essential. in the example above £ in anaesthetic gases doesn't make sense to me -? L of N20 is what we have measured. For Penthrox we have measured units of penthrox used (I.e 1 box = 1 unit) - either having consistent units of data	

	measurement to allow comparison or having a full scope of different measurables which can be applied to real world practice is key here.	
	This should be slightly easier to quantify and would encourage departments to move away from piped anaesthetic gases (ie using cylinders of nitrous as opposed to piped). If using piped, we had difficulty being able to quantify our specific use in ED and there tends to be a loss from piped supply. Would be easier to quantify MDIs and gases form anaesthetic machines that are bought in set units.	Piped anaesthetic gases have not been included in this calculator, because anaesthetic gases are rarely used in ED and, when used, they are normally managed and ordered by the anaesthetics team rather than emergency practitioners.
	I would change the gas names to the generic ones (e.g., nitrous oxide), from the brand ones (entonox). There are also other ways to measure gases e.g., directly measuring the Litres used. Suggest adding this is as an additional 'data source', 'key data collected' and 'unit of data'	Gas names have been changed to generic names from the brand names.
Electricity	OK for just electric energy. As previous how do we factor solar into this - solar on the roof of our hospital.	We decided not to include the use of green energies in the calculator, as they are already applied in the conversion factors provided by DEFRA.
	Possibly this should be combined with the energy section. Most departments will have a figure for gas and electricity, but this will be the trust average	This section has been separated from the energy section, as one represents direct emissions from the site and the other represents indirect emissions.
	I believe trying to quantify exactly what energy is used by a department will be difficult. When asking our trust the departments did not have set meters for different areas, though I assume this would be possible. Think all the options would be appropriate but unsure if they would be accessible.	The approach used by Prasad et al. can be applied, according to which the total consumption of the site is multiplied by the department's surface and divided by the total surface of the site. This formula can provide an estimation of the department's consumption and subsequently its carbon footprint.
	Probably on a trust level rather than department level? Otherwise not measurable.	
	Similar to the gas bills, making this specific to ED use will be difficult. With the added difficulty that as EDs operate 24/7 I assume we use more electricity per square metre than other areas of the hospital	
	Again, how easy will be it be to isolate ED electricity use from general hospital use? Is it often the case that there are separate meters?	
	I think the relationship between hospital electricity and ED electricity as a proportion of this needs to be explicated, as per the energy Q	
	Great to have in but again may be difficult to get the specific amount used in the ED if they don't have a separate meter	
Catering/food	What are you looking to improve with respect to food? If you say your metric is total kg of food, it sounds like you're suggesting we should be feeding patients less!	This calculator aims to provide a carbon baseline assessment and identify areas of high carbon intensity or hotspots in ED to facilitate sustainable initiatives. Thus, catering should be included in the assessment, as it contributes to the carbon footprint.
	Don't know if weight of food specifically would be that helpful/possible. Looking at total number of meals etc would be easier to assess.	Since there may be differences between hospitals, we considered it would be preferable to count the weight.
	Very broad here. Number of meals doesn't correlate with kg at the end so need to be consistent in the data value again here?	This has been revised and "number of meals" has been changed for "weight of meals".
	Instead, I would suggest a couple of obvious ones around food: increase in plant-based food options; reduction in	This is an intervention rather than a measurement of the

	plastic packaging. There also needs to be something based on reduction in single-use plastic utensils, plates, cups etc	baseline carbon footprint of the ED, which is the aim of this calculator.
	"PLant based meals /menus? Food waste recycling. /Plant based milk use? Packaging of meals. - all more environmentally focussed rather than just number of meals - the patients Just having number of meals for me is meaningless from an environmental perspective?"	
	I would potentially add £ as a unit of data. Also, annual expenditure may be an option for data source. And for 'key data' things like milk/juice, teabags and snacks (e.g. fruit, yoghurt) won't be covered by 'meals provided to patients' so I suggest expanding this section.	The financial cost and annual expenditure to measure this category was considered, although the researchers noted that the ordering process for catering differs between hospitals and is not homogeneous across the NHS.
Disposable/consumables	This is a massive area and should be broken into some of the key items: PPE, cannulas, single-use surgical instruments	This category has been divided into different sections to facilitate its navigation.
	Feel units of data could be in number of units (ie how many gloves etc) as opposed to kg. As most consumables will have different carbon footprints depending on their production and materials they are made of.	
	Once again this is a very diverse list to to be truly comparable and measurable each of the items will need a reliable unit of measurement. Kg isn't ok for some of them - eg cannulas? And also to convert from kg to Co2e for cannulas? would it not be units of cannulas used and then this is converted to kg/co2e? Detail is key here to enable measurement and conversion	
	I would definitely add £ / annual expenditure to the unit of data and key data sections, respectively! This procurement data is easy to get	
	This would obviously be a massive area. Should be able to get figures for most things from procurement figures but would need many categories to assess everything used in ED. Could possibly split into admin/clinical/catering/hygiene etc? This would be a massive body of work to undertake and items used would differ between departments and depend if ordering was done by the individual department or at trust level.	
	May need to include materials consumed (ie plastic, metal, paper). Pounds spent on consumables could be used if taking a top down approach	A top-down approach has been used for this category, based on the financial cost.
Medical equipment	Again, unsure if weight is best form of unit of measurement.	The weight of most of the medical equipment items is available and DEFRA provides a conversion factor for medical equipment based on weight, thus we considered it would be more accurate to measure this category per weight.
	Personally I'm not sure this rings well with me. There are so many types of medical equipment that this will be very tricky to deliniate. Again kg's - I think I might have misread this, but does that mean weighing the obs machines, uss machine etc?!	
	Again May need to consider pounds spent if using a top down approach.	
	Converting these to kg again will be a big task	
	Suggest adding £ as per above	
Non-medical equipment	As above, using number of units as opposed to weight.	The weight of most of the non-medical equipment items are available and DEFRA provides a conversion factor for this non-medical equipment based on weight, thus we considered it would be more accurate to measure this category per weight.
	Suggest adding £ as per above	

	Where does computer efficiency come in - i.e low power mode and screen brightness?	This is outside the boundaries of our calculator and has not been included.
Pharmaceuticals	This is a key one and hasn't been measured at all before. I think Greener NHS is trying to put together information regarding the footprint of individual medications so that will be a good source of information for the calculator.	
	Could break down into those used in emergency department, those given out as TTAs and look between IV/oral in those drugs that have 2 forms. Have found reducing things like IV paracetamol an easy win as save lots of unnecessary waste.	This has been considered and this category has been divided into different sections to facilitate its navigation.
Transport	I like the metric of km travelled - maybe in a 24 hour period, or day period. I.e a snapshot survey to record how many km total was travelled to get to /from the ed on that day or half day - and break down into staff groups etc. and modes - public transport/active travel/car commute. THis would need careful consideration and have a moderator for number of users etc. But could be very good.	Positive review. Nil changes made.
	I think this would have to be a snap shot or a sample size to get enough survey responses for accuracy	
Waste	Key data collection would be great I just wonder how feasible a full years worth of collection is? Maybe a few weeks and multiply up? Just a big commitment if done by clinical staff. Appropriate as a way of measuring if possible to collect.	Data can be collected through auditing over a period and multiplying for 52 weeks, obtaining the weight of each type of waste.
	kg or tonnes the measure here. We have done this and it is tricky but I think the only way. Note recycling is generally lighter than other waste so demonstrating good enviro change is tricky because the light weight doesn't change much. Annual waste in kg would need to be factored up as measurements can only really be done over 12 hours or thereabouts to make it practically possible.	
	I think the weight would be more in tonnes given amount of waste if it's done in the aggregate - suggest giving this as an option	This has been included.
Water	All appropriate, will just depend on the trust as to whether you can get individual data for the department or not.	The approach used by Prasad et al. can be applied, according to which the total consumption of the site is multiplied by the department's surface and divided by the total surface of the site. This formula can provide an estimation of the department's consumption and subsequently its carbon footprint.
	Can anyone really measure this on a departmental level?	
	Again this may be tricky without a meter for the ED itself.	
	Similar to gas and electricity, this may need a monitoring system in place for a week to find out the accurate amount of water the ED uses	

Supplementary Table 2. Comments on expert panel II.

Scope	Comment	Response
Scope 1	Total field should have Kg CO2e as units.	Kg CO2 added as unit in the total fields.
	What is the purpose of Hospital Floor Space and Emergency Department Floor Space columns in the Energy Consumption columns? Would WTT be included here even though we are looking at scope 1 emissions?	Hospital floor space and emergency department floor space are necessary to make an assumption of the energy used by the emergency department. Option A and B added. Option A when submeters for ED as available and option B when submeters for ED are not available, also added in electricity and water consumption. Well-to-tank (WTT) emissions are included in this category.
	Calculations are not correct in the anaesthetic gasses section, I.e., 200 cylinders of EA entonox would have a much bigger carbon footprint than 191.67 kg. Change column C to number of cylinders used in the past year, rather than in the department currently.	Error in calculation detected and changed. Column C has been changed from "measured" to "used"
	Looks comprehensive. Probably just something I have missed but are all these quantities for one year? I think we would struggle to get accurate data of kms for hospital transport, but something I would be interested to look into. For our department this would also include things like blood products as these are often brought across by van in emergencies, just possibly something to add in?	Calculator is set for a year, clarification added in the information sheet and several cells of the calculator. We recognise the challenges of monitoring transport; however, this can be attained by using a survey-based systematic approach. Couriers and freight transport are outside of the boundaries of our calculator, as these services are often controlled by the hospital rather than by the emergency department, and thus obtaining the data specifically for the emergency department might not be feasible.
Scope 2	May need to include T+D and WTT	Transport and distribution (T+D) and Well-to-tank (WTT) emissions have been integrated in our calculator.
	I think this is a reasonable way to measure this. Some hospitals may be able to give more direct figures but useful to include even if an assumption, makes more of a case for turning equipment/lights off etc,	Positive review. Nil changes made.
Scope 3	Is the price at the Royal Free Hospital the same as the NHS supply chain? We should be using the price from supply chain for wider use. We should advise users to look at how many of these products they have used or ordered over a set period (ie a year), rather than the number currently in the emergency department, otherwise it only gives a cross section of the carbon footprint, whereas what we really want is a carbon footprint over a certain period. Change the title of Column C to 'Quantity used' over 12 months	We have compared and confirmed that the prices obtained from the Royal Free hospital are the same as the prices provided by the NHS supply chain catalogue. The calculator is set for a year. Clarification added in the information sheet and several cells of the calculator. Colum C changed from "quantity measured" to "quantity used"
	Some units missing for Conversion factors. Would benefit from being able to put in an 'Overall Spend' field, ie say for pharmaceuticals, where the emissions factor is the same throughout the different drugs. This would save time for EDs which don't have time to do a complete audit of all their medicines. Throughout the calculator, it should not look at the Quantity in Department, but the Quantity Used by the Department, over a certain time period.	Units reviewed and added to all conversion factors. "Overall spend field" added for pharmaceuticals and disposables, given the user option A -to measure carbon footprint item by item- or option B -to measure carbon footprint based on the overall expenditure. "Quantity measured in the department" changed for "quantity used in the department".
	Surprised to see the cannula conversion factor is so low. We got a much bigger CO2e in our cannula reduction project	The conversion factor has been revised and we think the mistake might be that the value shown in the calculator is per pack rather than per item. We have included the number of items per pack for each item.
	Do the transport emissions include WTT. These should be included. (Can be found in WTT - pass vehs&travel-land'.	WTT emissions have been added to transport emissions.
	Does this include patient/staff transport- both or one or the other? It should specify which is included.	This a decision to be made by the user collecting data rather than by the calculator itself.

	The units are wrong here. For example, 1000kg of domestic waste leads to only 1.72kg of CO2e, but it should be 172kg of CO2e per tonne. Also I thought from Chantelle's paper, that Offensive waste was 569kg per tonne, but you have 2.49 (again out by factor of 1000)	The units have been revised and an error in calculation has been detected – correction made.
	This is an unbelievable amount of work and looks very thorough. Seems to include most things I can think of. I guess there will be some differences in the catering between trusts. And wonder if possible, to include reusable vs disposable? Whether that would show the differences between the 2? Also, with things like suture packs, to show the difference between reusable and disposable, for things we are trying to change with Green ED?	Comparing reusables versus disposables will be a task to be completed after the carbon footprint assessment, as the carbon footprint of a reusable item will have to be divided by the number of uses.
	I notice that for the blood sample tubes it looks like only one type of system has been accounted for, is the carbon footprint of vacuettes vs vacutainers likely to be similar?	Differences between devices have been acknowledged. We have added a black cell in the disposables/consumables category for the user to be able to introduce items not available in the calculator.
Overall	Nothing I can think of, looks very comprehensive and think will be an invaluable tool.	Positive review. Nil changes made.
	In terms of patient/staff journeys to and from the department - is this outside the scope?	This a decision to be made by the user collecting data rather than the calculator itself.
	This tool will be powerful from an environmental perspective, and probably more so for the Trusts when combined with local financial data. Gathering feedback when it is in use might also lead to non-inferiority studies for alternatives to provide proof that lower carbon alternatives are also safe to use (e.g. oral/PR/IM alternatives to IV medications).	Positive review. Nil changes made.

CHAPTER 5: Discussion

The aim of this doctoral thesis was to describe the carbon footprint of healthcare services, identify the hotspots of carbon emissions in the healthcare sector, and develop and validate an assessment tool to evaluate, monitor, and reduce carbon emissions in the emergency departments. To accomplish this, we began by conducting a systematic review to address the first objective. Subsequently, we developed the assessment and proceeded with its design and validation, addressing the second and third objectives.

The literature review revealed the complex variety of factors that influence the carbon footprint of healthcare services. The studies included in this review showed that scope 1 and 2 emissions ranged between 15% and 50% of the total emissions in healthcare settings, whereas scope 3 emissions accounted for 50% to 75% of the total emissions (Rodriguez-Jimenez et al, 2023). The variability in scope 1 and 2 was often influenced by factors such as geographic (0.2% and 27.7% respectively) in a dialysis unit in Casablanca (Morocco), and this was explained as the low use of heating and air conditioner in the unit due to weather conditions in the site analysed. Furthermore, it was found that newer hospitals or other healthcare settings tend to emit fewer emissions due to modern energy-efficient designs. MacNeill et al. (2017) compared the carbon footprint of operating theatres in three different hospitals and found that the two newer hospitals had considerably lower scope 1 and 2 emissions than the older one. However, it was the scope 3 emissions that carry significantly higher environmental implications for healthcare operations (Rodriguez-Jimenez et al, 2023). These emissions, originating from the supply chain, transportation, and waste management, made up a substantial portion of the total carbon footprint. Disposables, equipment, and pharmaceuticals emerged as key contributors, highlighting the importance of sustainable procurement practices and waste reduction strategies. Disposables or consumables normally ranged between 20 and 30 per cent of the total carbon emissions in healthcare (Mtioui et al., 2021; Prasad et al., 2021;

and Tennison et al., 2021), whereas medical and non-medical equipment represented around 10 to 30 per cent – depending on the nature of the healthcare setting (Mtioui et al., 2021; Nansai et al., 2020; Nicolet et al., 2022; Lim, Perkins and Agar, 2013; Prasad et al., 2021; and Tennison et al., 2021). For instance, a general practitioner surgery had significantly lower carbon emissions than a intensive care unit in this category (Nicolet et al., 2022; Prasad et. al.,2021). Pharmaceuticals also accounted for many emissions in healthcare, ranging between 7.6 per cent and 35.7 depending on the healthcare setting analysed – areas of high acuity such as operating theatres or intensive care unit had a significantly higher use of pharmaceuticals than other settings such as general practice surgeries and therefore higher carbon emissions (Rodriguez-Jimenez et al, 2023).

The development of carbon footprint calculators provides an opportunity to track carbon emissions and develop strategies to reduce them (Lacroute et al., 2023). Our calculator aims to establish a baseline carbon footprint and identify areas with high emissions in the emergency department, enabling the implementation of targeted environmental initiatives. Similar tools have been developed in other healthcare areas, such as a calculator for GP practices in the UK, which emphasises the importance of meeting national reduction targets (Sawyer, 2021). Initiatives like these can drive positive actions, influence behaviour change, and inspire others to adopt green practices. For example, Health service for the climate (*Sanidad por el clima* in Spanish), a platform established after COP25 in 2019, offers a free carbon footprint assessment tool for healthcare organisations in Spain, albeit with some differences in categories covered compared to our tool (Sanidad por el clima, 2019).

The final version of our ED carbon footprint calculator was designed and validated by two panel of experts and a focus group. Prior to the evaluation by the first panel of experts, a literature review was carried out to define the boundaries of the calculator. As a result of the literature review, a boundary inventory was created and evaluated by the panel of experts 1. Following the first review of the panel of experts and after addressing all the recommendations, the first version of the calculator was produced. The second panel of experts evaluated the scope, accuracy of calculation and pertinence of conversion factors of the first version of the calculator. Finally, the calculator was shared with a group of potential users with the aim to obtain information regarding its clarity, viability, and usefulness, leading to final version of the calculator. The calculator was confirmed as a valid, exhaustive, clear, and easy-to-use tool, allowing the estimation of CO_2 emissions generated by the activity of hospital emergency services. The tool's benefits were emphasised, including its role in raising awareness, facilitating decision-making, and promoting behaviour change among staff and patients, aligning with findings from previous research (Collins et al., 2018; Maldonado et al., 2021). The educational aspect of carbon footprint awareness and mitigation was also underscored, suggesting its potential impact on community engagement and change promotion (Collins et al., 2018; Lacroute et al., 2023).

Transitioning towards a net zero healthcare system necessitates a multifaceted strategy. This entails embracing renewable energy sources, deploying energy-efficient technologies and infrastructure, and implementing various interventions across the spectrum. For example, the adoption of solar panels not only diminishes reliance on fossil fuels but also serves as a tangible commitment to sustainability, catalysing similar initiatives across different sectors (Bozoudis et al., 2022). Additionally, it has been highlighted the pivotal role healthcare professionals play in carrying out environmental initiatives (World Health Organisation, 2022). By advocating for the utilisation of low-impact practices, promoting sustainable initiatives, and fostering healthier lifestyle choices, healthcare providers can significantly contribute to emissions reduction while enhancing patient outcomes (International Council of Nurses, 2018).

Local initiatives have showcased considerable potential in curbing carbon emissions within EDs. For instance, a project at Charing Cross Hospital in London yielded a 25% reduction in unnecessary cannulation, leading to noteworthy decreases in CO2 emissions and substantial cost savings (Greener NHS, 2022). Similarly, Infanta Elena Hospital in Huelva and Gregorio Maranon Hospital in Madrid, Spain, have successfully slashed their greenhouse gas emissions through targeted campaigns and sustainable management plans, which included reductions in gas consumption and single-use plastics, respectively. These initiatives underscore the feasibility and benefits of environmental programs within healthcare settings (Servicio Andaluz de Salud, 2021; Hospital Gregorio Marañón, 2021).

However, achieving sustainability within the healthcare sector mandates systemic transformations surpassing individual endeavours (Weimann & Weimann, 2022). It calls for a paradigm shift towards a circular economy, where resources are conserved, repurposed, and recycled whenever feasible (MacNeill et al.). This transition hinges on collaborative efforts among stakeholders, innovative policy frameworks, and a collective dedication to planetary well-being (Pereno & Eriksson, 2020).

In essence, the doctoral thesis not only accentuates the imperative of addressing healthcare emissions but also charts a course towards a greener and healthier future. It serves as a clarion call for healthcare organisations, professionals, and policymakers to prioritise environmental sustainability as an intrinsic component of high-quality healthcare provision.

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CHAPTER 6: Limitations and future lines of investigation

The limitations of this thesis can be divided into two areas: those associated with the literature review and those related to the development of the carbon footprint calculator.

Regarding the systematic review, some relevant studies may have been missed despite efforts to prevent this. Furthermore, interpretation bias must be acknowledged, even though the review was peer-reviewed.

The limitations associated with the development of the tool include, first and foremost, estimations in the calculation of carbon emissions in certain categories, which could influence the results. Energy consumption—including heating, electricity, and water—could not be measured through direct meter readings, potentially affecting the accuracy of the calculated carbon footprint. Additionally, the research team recognised that a bottom-up life cycle assessment (LCA) approach would provide more precise data, particularly for categories such as consumables and pharmaceuticals. However, this methodology was not feasible for some categories in this study. Similarly, there is a degree of uncertainty regarding the reliability of the conversion factors used.

In relation to the data on patient transportation, since it was collected via a user-completed survey, there is an inherent bias concerning the representativeness of the sample and the accuracy of the information provided.

It is also important to highlight limitations related to the scope of the tool. An exact calculation of the carbon footprint is not possible due to inaccessible activity data or the absence of appropriate conversion factors. Therefore, it is necessary to define the boundaries of the evaluation to ensure the most accurate estimation possible. The calculator does not include certain areas, such as freight transport and laundry services, due to the significant challenges in their assessment. Nevertheless, the calculator was designed to be as comprehensive as possible, incorporating a wide range of 1,095 items. While this extensive list enhances the tool's thoroughness, it also increases the time required to complete it. To facilitate its use, the items have been grouped into functional categories and subcategories and arranged in alphabetical order.

Another limitation in the carbon footprint calculation relates to the dates of the conversion factors used. Although the 2022 report was used in most cases, some specific calculations required data from the 2019 or 2012 reports due to a lack of availability. As a result, the overall calculation remains current, but some elements rely on older data. Furthermore, when calculating the detailed carbon footprint of pharmaceuticals, the purchase prices from the pilot site, Royal Free Hospital, were used as a reference. Since purchase prices vary across NHS trusts depending on commercial contracts, there may be some discrepancies. However, these differences are expected to be minor and would only affect the detailed carbon footprint calculation, not the overall pharmaceutical expenditure estimate.

With regard to the methodology, another limitation was the small number of participants in the focus group, which reduced interaction and the ability to generate diverse discussions. Additionally, there was a lack of diversity among participants in terms of healthcare roles, as most panel experts were doctors. This may have introduced a bias in the tool's applicability. However, since the focus group participants were predominantly nurses, their involvement may have validated the tool's usability for professionals beyond doctors.

CHAPTER 7: Conclusion

This thesis highlights the importance of applying evidence-based approaches to calculate carbon emissions in healthcare settings, and more specifically in the emergency departments, to identify carbon hotspots and guide the development of effective sustainable initiatives. Furthermore, the application of carbon assessment tools can help to raise awareness, increase climate resilience, and promote climate action within the healthcare sector. Carbon footprint data can also influence staff and stakeholders to carry out major changes in the way healthcare is delivered, as well as to introduce ecological education to other colleagues and staff.

1. Conclusion first objective

(To describe the carbon footprint of healthcare services and identify the hotspots of carbon emissions in the healthcare sector).

The literature review revealed that scope 1 and scope 2 emissions collectively constitute 15% to 50% of total emissions in the healthcare sector, while scopes 3 emissions encompass a broader range, typically comprising 50% to 75% of the total. Noteworthy contributors to scope 3 emissions include disposables, medical and non-medical equipment, and pharmaceuticals, alongside significant contributions from transportation and building infrastructure.

The review highlighted the impact of healthcare systems on climate change and emphasises the imperative of implementing interventions to minimise it. While primary responsibility to implement such interventions lies with healthcare organisations, individual engagement is indispensable. Scope 1 and 2 emissions can be reduced by implementing organisational management strategies, while scope 3 emissions can be reduced by implementing different interventions in the organisation and by establishing a collaborative relationship with manufacturers and suppliers. Furthermore, current clinical pathways, protocols and policies should be assessed to both reduced carbon footprints and enhance patient care and service provision.

Evidence-based methodologies, such the developments of carbon footprint assessment tools, are recommended to accurately assess the carbon footprints of healthcare settings and identify emissions hotspots. Such initiatives are pivotal for minimising the environmental impact of healthcare activities and fostering sustainable operational paradigms.

***2.* Conclusion second objective**

(Development of an assessment tool to evaluate the carbon footprint of the emergency departments in the UK).

A comprehensive carbon footprint assessment tool was proposed, offering the opportunity to calculate the carbon footprint of emergency departments. Calculating carbon emissions holds significant value as it enables the development of environmental initiatives aimed at reduction. The process begins with a baseline assessment and identification of carbon hotspot, followed by the implementation of interventions and a follow-up assessment to evaluate their effectiveness. Furthermore, the development of carbon footprint assessment tools can incentivise the development of similar tools in other healthcare fields.

This tool was designed to be used by emergency clinicians and support initiatives such as the Green ED project, aiming to make emergency medicine more sustainable. It is also aligned with both the UN sustainability goals and national net zero policies. Moreover, the use of this tool can raise awareness surrounding environmental concerns, increase climate resilience, and advocate climate action among patients and healthcare professionals.

3. Conclusion third objective

(To design and validate an assessment tool to facilitate the monitoring and reduction of carbon emissions in the emergency departments).

The final version of the ED carbon footprint calculator is proposed as a valid and comprehensive tool. It provides an in-depth assessment of scope 1, 2, and 3 emissions within emergency departments, enabling baseline evaluations, pinpointing high carbon intensity areas, and monitoring sustainable endeavours. Aligned with the NHS's commitment to achieve zero carbon emissions by 2045, this tool will furnish compelling evidence.

The methodology utilised to design and validate our tool - two panels of experts and a focus group- has yielded a reliable and user-friendly tool. The focus group, formed by potential users, highlighted its value, ease of use, and appropriateness of its content.

The ED carbon footprint calculator holds potential to drive positive transformations in ED practices by raising awareness, inspiring change, and facilitating emission monitoring and benchmarking. Moreover, it has the capacity to engage staff and stakeholders toward substantial healthcare delivery reforms and the integration of environmental education within the profession. By empowering ED nurses and healthcare practitioners, this calculator serves as a catalyst for environmental stewardship within the healthcare sector.

Conclusiones

Esta tesis destaca la importancia de aplicar enfoques basados en evidencia para calcular las emisiones de carbono en entornos sanitarios y, más específicamente, en los departamentos de urgencias, con el fin de identificar los puntos críticos de carbono y guiar el desarrollo de iniciativas sostenibles eficaces. Además, la aplicación de herramientas de evaluación de carbono puede ayudar a aumentar la concienciación, fortalecer la resiliencia climática y promover la acción climática dentro del sector sanitario. Los datos de la huella de carbono también pueden influir en el personal y las partes interesadas para llevar a cabo cambios importantes en la forma en que se presta la atención médica, así como para introducir educación ecológica a otros colegas y miembros del equipo.

Conclusión del primer objetivo

(Describir la huella de carbono de los servicios sanitarios e identificar los puntos críticos de emisiones de carbono en el sector sanitario).

La revisión de la literatura reveló que las emisiones de los alcances 1 y 2 constituyen colectivamente entre el 15% y el 50% del total de emisiones en el sector sanitario, mientras que las emisiones del alcance 3 abarcan un rango más amplio, representando típicamente entre el 50% y el 75% del total. Entre los principales contribuyentes a las emisiones del alcance 3 se incluyen los productos desechables, los equipos médicos y no médicos, y los productos farmacéuticos, además de contribuciones significativas del transporte y la infraestructura de los edificios.

La revisión destacó el impacto de los sistemas sanitarios en el cambio climático y subraya la necesidad de implementar intervenciones para minimizarlo. Si bien la responsabilidad principal de aplicar estas intervenciones recae en las organizaciones sanitarias, la participación individual es indispensable. Las emisiones de los alcances 1 y 2 pueden reducirse mediante estrategias de gestión organizativa, mientras que las del alcance 3 pueden disminuir con diversas intervenciones dentro de la organización y mediante una relación de colaboración con fabricantes y proveedores. Además, deben evaluarse las vías clínicas, protocolos y políticas actuales para reducir tanto la huella de carbono como mejorar la atención y prestación de servicios a los pacientes.

Se recomienda el uso de metodologías basadas en evidencia, como el desarrollo de herramientas de evaluación de la huella de carbono, para evaluar con precisión la huella de carbono de los entornos sanitarios e identificar los puntos críticos de emisión. Tales iniciativas son fundamentales para minimizar el impacto ambiental de las actividades sanitarias y fomentar modelos operativos sostenibles.

2. Conclusión del segundo objetivo

(Desarrollar una herramienta de evaluación para medir la huella de carbono de los departamentos de urgencias en el Reino Unido).

Se propuso una herramienta integral de evaluación de la huella de carbono, ofreciendo la posibilidad de calcular la huella de carbono de los departamentos de urgencias. El cálculo de las emisiones de carbono es de gran valor, ya que permite el desarrollo de iniciativas ambientales orientadas a la reducción. El proceso comienza con una evaluación inicial y la identificación de puntos críticos de carbono, seguida de la implementación de intervenciones y una evaluación posterior para medir su efectividad. Además, el desarrollo de herramientas de evaluación de la huella de carbono puede incentivar la creación de herramientas similares en otros ámbitos sanitarios.

Esta herramienta fue diseñada para ser utilizada por médicos de urgencias y respaldar iniciativas como el proyecto Green ED, que busca hacer la medicina de urgencias más sostenible. También está alineada con los Objetivos de Desarrollo Sostenible de la ONU y las políticas nacionales de carbono cero. Asimismo, su uso puede aumentar la concienciación sobre cuestiones ambientales, fortalecer la resiliencia climática y promover la acción climática entre los pacientes y los profesionales sanitarios.

3. Conclusión del tercer objetivo

(Diseñar y validar una herramienta de evaluación para facilitar el monitoreo y la reducción de emisiones de carbono en los departamentos de urgencias).

La versión final del calculador de huella de carbono en urgencias se propone como una herramienta válida y completa. Proporciona una evaluación detallada de las emisiones de los alcances 1, 2 y 3 dentro de los departamentos de urgencias, permitiendo evaluaciones de referencia, la identificación de áreas con alta intensidad de carbono y el seguimiento de iniciativas sostenibles. Alineado con el compromiso del NHS de alcanzar cero emisiones de carbono para 2045, esta herramienta proporcionará evidencia sólida.

La metodología utilizada para diseñar y validar nuestra herramienta—dos paneles de expertos y un grupo focal—ha resultado en una herramienta confiable y fácil de usar. El grupo focal, compuesto por posibles usuarios, destacó su valor, facilidad de uso y la adecuación de su contenido.

El calculador de huella de carbono en urgencias tiene el potencial de impulsar transformaciones positivas en las prácticas de los departamentos de urgencias, aumentando la concienciación, inspirando cambios y facilitando el monitoreo y la comparación de emisiones.

Además, tiene la capacidad de involucrar al personal y a las partes interesadas en reformas sustanciales en la prestación de atención sanitaria e integrar la educación ambiental dentro de la profesión. Al empoderar a enfermeras de urgencias y profesionales sanitarios, este calculador actúa como un catalizador para el liderazgo ambiental en el sector sanitario.

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Appendixes

Appendix I. Quality indicators

Article 1. *The carbon footprint of healthcare settings A systematic review.*

The first article was published in the Journal of Advanced Nursing which is indexed in the most prestigious databases. In the Journal Citation Report (JCR), it is included in the Nursing category of the Social Sciences Citation Index (SSCI). In the year of publication, it achieved an Impact Factor of 3.8 and a Journal Citation Indicator of 1.51. It ranked 6th out of 191, placing it in the first quartile (Q1) and first decile (D1). It is one of the highest-impact journals in its category, with an impact percentile of 97.1, and one of the most influential, with an Article Influence Score of 1.021.

In the Scimago Journal & Country Rank (SJR), the journal is classified in the Nursing (miscellaneous) category. In 2023, the year of publication of the article, its SJR index was 1.218 and the H-index was 178. It ranked 6th out of 172, placing it in the first quartile (Q1) and first decile (D1). It is a journal of high relevance, with a citation per document index of 4.343.

The article has had a significant impact on the scientific community. According to the Web of Science (WOS), it has been cited by 58 articles, mainly in the background and the discussion section. When compared to articles in both its category (Nursing) and the same journal, WOS has classified it as above average in both cases. According to the Scopus database, the article has been cited 61 times, placing it in the 99th percentile. It has achieved a Field-Weighted Citation Impact of 12.43.

The results have generated considerable interest in the scientific community. According to the journal's website, the article has been accessed in full text or downloaded 23.973 times.

Altmetrics has ranked it among the top 5% of highest-scoring papers, placing it in the 94th percentile for attention received compared to articles published in the same year, and it has recorded 53 comments on the social network X.

It has served as a source for the technical report *Sustainable Behaviours for Environment and Health Challenges: Behavioural and Cultural Insights Policy Brief* by the World Health Organization, published in 2024. According to PlumX Metrics, it has also been cited in the technical document *Cleaner Health Care: Hospital Emissions Mitigation* by the Bipartisan Policy Centre in November 2023 and has been mentioned in 2 news articles.

Article 2. *Environmental impact of Emergency Services in Public Health: an assessment tool.*

The article Environmental Impact of Emergency Services in Public Health: An Assessment Tool was published in the Revista Española de Salud Pública, which is indexed in the Journal Citation Report (JCR) under the category Public, Environmental, and Occupational Health in the Social Sciences Citation Index (SSCI). In the year of its publication, the article achieved an Impact Factor of 0.9 and a Journal Citation Indicator of 0.16. It ranks 346th out of 403, placing it in the fourth quartile (Q4). Its impact within its category is moderate, with a 14.3 impact percentile and an Article Influence Score of 0.182.

In the Scimago Journal & Country Rank (SJR), the journal had an SJR index of 0.291 and an H-index of 42 in the year of publication. It is classified in the Medicine (Miscellaneous) category, ranking 1,730th out of 2,494, and in the Public Health, Environmental, and Occupational Health category, ranking 447th out of 656. In both categories, it falls within the third quartile (Q3). Its citation rate per document was 0.779.

The article has gained attention within the scientific community. According to the Web of Science (WOS), it has been cited by 2 articles. When compared to articles in both its category (Public, Environmental & Occupational Health) and the same journal, WOS has classified it as above average in both cases. According to the journal's website, the full-text article has been downloaded 73 times.

Article 3. *The Emergency Department carbon footprint calculator: design and validation*.

This article has been accepted for publication in the Medicine journal, which is included in the Journal Citation Report (JCR), under the Medicine, General & Internal category of the Science Citation Index Expanded (SCIE). According to 2023 records, it holds Impact Factor of 1.4 and a Journal Citation Indicator of 0.35. It ranked 141st out of 329, placing it in the second quartile (Q2). It is a very influencing journal in its category, with an impact percentile of 57.3, and one of the most influential, with an Article Influence Score of 0.396.

In the Scimago Journal & Country Rank (SJR), the journal is classified in the Medicine (miscellaneous) category. In 2023, its SJR index was 0.44 and the H-index was 174. It ranked 6th out of 172, placing it in the first quartile (Q3). It is a journal of high relevance, with a citation per document index of 1.672.

This article is in the process of being published, so impact and dissemination metrics are not yet available.

Appendix II. Awards.

Appendix III. Articles.

Received: 18 October 2022 | Revised: 1 March 2023 | Accepted: 7 April 2023

DOI: 10.1111/jan.15671

REVIEW

JAN Leading Global Nursing Research WILEY

The carbon footprint of healthcare settings: A systematic review

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Abstract

Healthcare systems are responsible for 4%–5% of the emissions of greenhouse gases worldwide. The Greenhouse Gas Protocol divides carbon emissions into three scopes: scope 1 or direct emissions secondary to energy use; scope 2 or indirect emissions secondary to purchased electricity; and scope 3 for the rest of indirect emissions.

Aim: To describe the environmental impact of health services.

Design: A systematic review was conducted in the Medline, Web of Science, CINAHL, and Cochrane databases. Studies that focused their analysis on a functional healthcare unit and which included. This review was conducted from August to October 2022.

Results: The initial electronic search yielded a total of 4368 records. After the screening process according to the inclusion criteria, 13 studies were included in this review. The reviewed studies found that between 15% and 50% of the total emissions corresponded to scopes 1 and 2 emissions, whereas scope 3 emissions ranged between 50% and 75% of the total emissions. Disposables, equipment (medical and non-medical) and pharmaceuticals represented the higher percentage of emissions in scope 3.

Conclusion: Most of the emissions corresponded to scope 3, which includes the indirect emission occurring as a consequence of the healthcare activity, as this scope includes a wider range of emission sources than the other scopes.

Implications for the profession and/or patient care: Interventions should be carried out by the healthcare organizations responsible of Greenhouse Gas emissions, and also every single individual that integrates them should make changes. The use of evidence-based approaches to identify carbon hotspots and implement the most effective interventions in the healthcare setting could lead to a significant reduction of carbon emissions.

Impact: This literature review highlights the impact that healthcare systems have on climate change and the importance of adopting and carrying out interventions to prevent its fast development.

Protocol Registration: PORSPERO ID CRD42022365121.

Reporting Method: This review adhered to PRISMA guideline. PRISMA 2020 is a guideline designed for systematic reviews of studies that analyse the effects of heath interventions, and aim is to help authors improve the reporting of systematic review and meta-analyses.

Patient or Public Contribution: No Patient or Public Contribution.

KEYWORDS

carbon footprint, environmental impact, greenhouse gases emissions, healthcare settings, life cycle assessment

1 | INTRODUCTION

Climate change has forced many countries and institutions to declare a climate emergency and carry out changes in different sectors of society in an attempt to reduce Greenhouse Gases (GHGs) (Intergovernmental Panel on Climate Change, 2018). Romanello et al. (2021) described climate change as one of the worst healthcare threats of the 21st century. Climate change can be defined as the alteration of the climate patterns provoked by changes in the environment and the variability of its characteristics and that keeps happening for a long period of time (Intergovernmental Panel on Climate Change, 2018). Climate change can be caused by natural internal and/or external processes, as well as human activity. GHGs emitted by human activity intensify global warming, increasing the chances of heatwaves, floods, droughts and/or air pollution, among others. These variations in the climate are directly related to an increase in pathologies such as cardiovascular, respiratory and/or infectious diseases, as well as malnutrition or mental health issues secondary to the lack of resources and the growth of situations of high emotional distress (Chua et al., 2019). The Intergovernmental Panel on Climate Change (IPCC) report (2018) analysed data from different models of projected risks and found that exposure to climate change could increase heat-related morbidity and mortality up to 16 times. Diseases such as malaria or dengue are expected to be intensified due to climate change, which could potentially put 2.25 billion people at risk (IPCC, 2018). The food industry may also be affected by climate change, posing a risk of malnutrition. Furthermore, climate change could lead to conditions of severe poverty affecting more than 100 million people worldwide and, therefore, to a significant increase in migration processes (Hallegatte et al., 2016). This increased migration along with the intensification of natural disasters could result in a significantly greater number of healthcare demands, thus having an especially significant impact on those countries in which healthcare systems are already fragile (Watts et al., 2018). The COVID-19 pandemic has showed the vulnerability of healthcare systems worldwide and the difficulties experienced when dealing with situations of extreme emergency, so prevention, adaptation and preparation are key to reduce and slow down the consequences of climate change (Fournier et al., 2022).

Carbon footprint can be defined as the best possible estimation of the impact that something has on climate change (Spruell et al., 2021). Carbon footprint is the sum of direct and indirect emissions of GHGs secondary to a process, a product or an organization and is calculated in Carbon Dioxide equivalent (CO_2e). This concept entitles the seven GHGs established by the United Nations Framework Convention on Climate Change (The Paris Agreement, 2015): carbon dioxide (CO_2); methane (CH_4); nitrous oxide (N_2O); hydrofluorocarbons (HFCs); perfluorocarbons (PFCs); sulphur hexafluoride (SF_6); and nitrogen trifluoride (NF_3). CO_2 represents 86.0% of the GHGs emissions, hence why GHGs emissions, carbon emissions and carbon footprint are often used interchangeably. The Greenhouse Gas Protocol (2022) classifies carbon emissions in three scopes; scope 1 or direct emissions are those related to the use of energy (without including purchased electricity) and on which the organization has direct control, for example the use of fuel for heating; scope 2 or indirect emissions are those related to purchased electricity or the use of electricity that has been produced somewhere else; and scope 3, which encompasses the rest of indirect emissions emitted by an organization and of which production is not controlled by the organization. There are three main methodologies for measuring the carbon footprint or Life Cycle Assessment (LCA): bottom-up life cycle assessment; top-down cycle assessment or economic input–output analysis; and the combination of both or hybrid model. Bottom-up LCAs measure all the materials used to produce an item or a process and multiply each material or item by a conversion factor. Top-down cycle assessment or economic input–output analysis uses the money spent in a product or a process, and this is multiplied by a conversion factor. Finally, the hybrid model is a combination or both (Lin et al., 2013).

Over the last years, there has been a surge of interventions aimed at reducing the effects of climate change (Spruell et al., 2021). The Sustainable Development Unit (SDU) carried out a survey of NHS

What does this paper contribute to the wider global clinical community?

- Awareness of the carbon emission caused by the healthcare activity.
- Identification of the hotspots carbon emission within the healthcare system.
- Guidance for more effective interventions aimed at reducing carbon emissions.

workers between 2017 and 2019 and found that 98% of them believed in the importance of building a sustainable healthcare service (NHS England, 2017). As different situations serve as evidence of necessary interventions, laws change, as can be seen in the Climate Change Act passed in the UK, which aims to reduce carbon emissions to zero by 2050 (UK Government, 2008). On their part, healthcare systems are responsible of 4%–5.0% of the emissions of GHGs worldwide (Pichler et al., 2019), so health services have a responsibility in fighting climate change not just to reduce their own carbon footprint but also to decrease the consequences of healthcare activity on health and to act as a role model for the society (SDU, 2018). The IPCC report (2018) stated that climate resilience could have a strong potential for ameliorating climate change impact on health and that transformational changes would be more effective if they are responsive to regional and local knowledge, considering the many dimensions of vulnerability. The development and implementation of programmes and policies in health systems has followed an evidence-based model over the last years (Hess et al., 2014). The use of evidence-based approaches to identify carbon hotspots and implement the most effective interventions in healthcare could bring about a significant reduction of carbon emissions (Hess et al., 2014). Therefore, the analysis of healthcare settings emissions is essential to decrease the impact of health services on the environment. The contribution and novelty of this literature review lies on collecting the most recent evidence available regarding the carbon footprint of healthcare systems. The results of this study will help to analyse the carbon footprint of the healthcare systems and identify those areas of higher greenhouse gases intensity.

1.1 | Aim

This review aims to describe the environmental impact of healthcare services by answering the following questions: What is the carbon footprint of healthcare settings? How much greenhouse gas emissions do healthcare services emit? Which are the hotspots of carbon emissions in the healthcare sector?

1.2 | Methodology

To give answer to the study questions, a systematic review was conducted in accordance with the PRISMA 2020 Statement (Page et al., 2021). The review was registered at PORSPERO ID CRD42022365121.

1.3 | Eligibility criteria

The eligibility criteria were structured according to the components of the Population, Intervention, Comparator, Outcome (PICO) framework (Booth et al., 2019), in which health care units were considered the population, care activity the intervention, absence of care activity the comparator, carbon footprint and outcome.

Regarding the population, studies that focused their analysis on a functional healthcare unit, that is a complete patient care service, from admission to discharge, were included. Analyses of a single procedure or device were excluded for not performing a holistic assessment of user care. In relation to the intervention, studies carried out in the healthcare field, which analyse patient care, were included, and studies carried out in other fields, such as industrial, economic, waste management or studies not centred on the patient, were excluded. As for the outcome, cross-sectional studies that measured the carbon footprint, life cycle assessment or GHG emissions of healthcare functional units and which incorporated the three scopes recommended in the Greenhouse Gas Protocol (2022) were included. Reviews, opinion or popularization articles, research projects or other reports that did not provide results of an environmental impact assessment were excluded. Studies published between 2012 and 2022 were included so as to identify the latest evidence, and which were written in English and Spanish, as they are the most frequent languages in the scientific literature.

1.4 | Information sources

The Medline, Web of Science, CINAHL and Cochrane databases were searched. Furthermore, a snowball search was performed to retrieve studies not identified in the database search. Reference lists of publications which were eligible for full-text review and references from systematic review reports on a similar topic were reviewed. The initial search was conducted between February and April 2022, and updated in July 2022 after incorporating the results obtained from the snowball process.

1.5 | Search strategy

The search terms were identified by consulting the titles, abstracts and keywords of relevant reviews and articles. Several combinations of search terms were tested in the databases beforehand to select the strategy that could identify relevant studies in the most focused way. This process was agreed upon by two of the researchers. The search strategy used was ("carbon footprint" OR "greenhouse gas emission" OR "life cycle assessment") AND (health*). The filters used were year of publication and language.

1.6 | Selection and data collection process

The retrieved records were downloaded into a Microsoft Excel spreadsheet that allowed for the identification and elimination of duplicate records. The records were blindly screened by two independent researchers. The titles were reviewed, and the records were pooled to discuss inconsistencies and unify criteria. Then, the abstracts were screened and those that met the inclusion criteria were selected. Discrepancies in the selection were resolved by consensus. In case of doubt, it was agreed upon to include them for full-text review. The same researchers independently reviewed the full text of the selected studies, and discrepancies were resolved by consensus, resorting to a third researcher when necessary.

Data collection was carried out by one of the researchers and verified by two others. A form was designed to extract the data, including country, year of publication, functional unit, methodology, categories analysed, carbon emissions, data collection (including data source and data type) and emissions factors (Table 2).

Once the data were extracted, they were analysed and grouped according to the dimensions described by the Greenhouse Gas Protocol (2022): scope 1 (gases directly emitted by the institution, such as anaesthetic gases); scope 2 (indirect cause of gases derived from primary resources, such as electricity); and scope 3 (indirect cause of gases derived from products used by the institution in its production chain, such as medical devices).

1.7 | Study risk of bias assessment

Two main sources of biases were considered in this review. On the one hand, biases arising from methodological quality, and on the other hand, biases arising from inaccuracies in the measurements made by the reviewed studies. These inaccuracies may lie in the calculation method employed (top-down or bottom-up), the inventory boundaries and the accuracy of data and assumptions made by the reviewed studies. Therefore, the risk of bias assessment was carried out through an ad hoc tool with elements drawn from the most relevant critical appraisal tools for assessing methodological quality (Pussegoda et al., 2017; Zeng et al., 2015) and elements from the reference guidelines (Greenhouse Gas Protocol, 2022). This assessing method has been used by Rizan et al. (2020) in a previous similar review. The assessment was conducted independently by two researchers who agreed on the discrepancies.

2 | RESULTS

The initial electronic search yielded a total of 4368 records. Duplicated articles were excluded, and, after carrying out a title screening, 90 met the inclusion criteria. The abstract review further reduced the number of records to 41, and a full-text reading was carried out. Finally, 13 studies were selected for this literature review (Figure 1). Regarding the quality assessment of the studies, all of them scored over 17 out of 24. All the articles were accepted as the magnitude of their analysis and the methodological quality were considered appropriate (Table 1).

The chosen studies were all written in English and conducted in different locations between 2012 and 2022: one in Morocco; one in Japan; two in the United States; three in Australia; two in Switzerland; one in the UK; one in China; and two in Canada. This literature review included studies that calculated the carbon footprint of a functional unit in a healthcare setting using one of the following methods: bottom-up life cycle assessment (Keller et al., 2021; Lim et al., 2013;

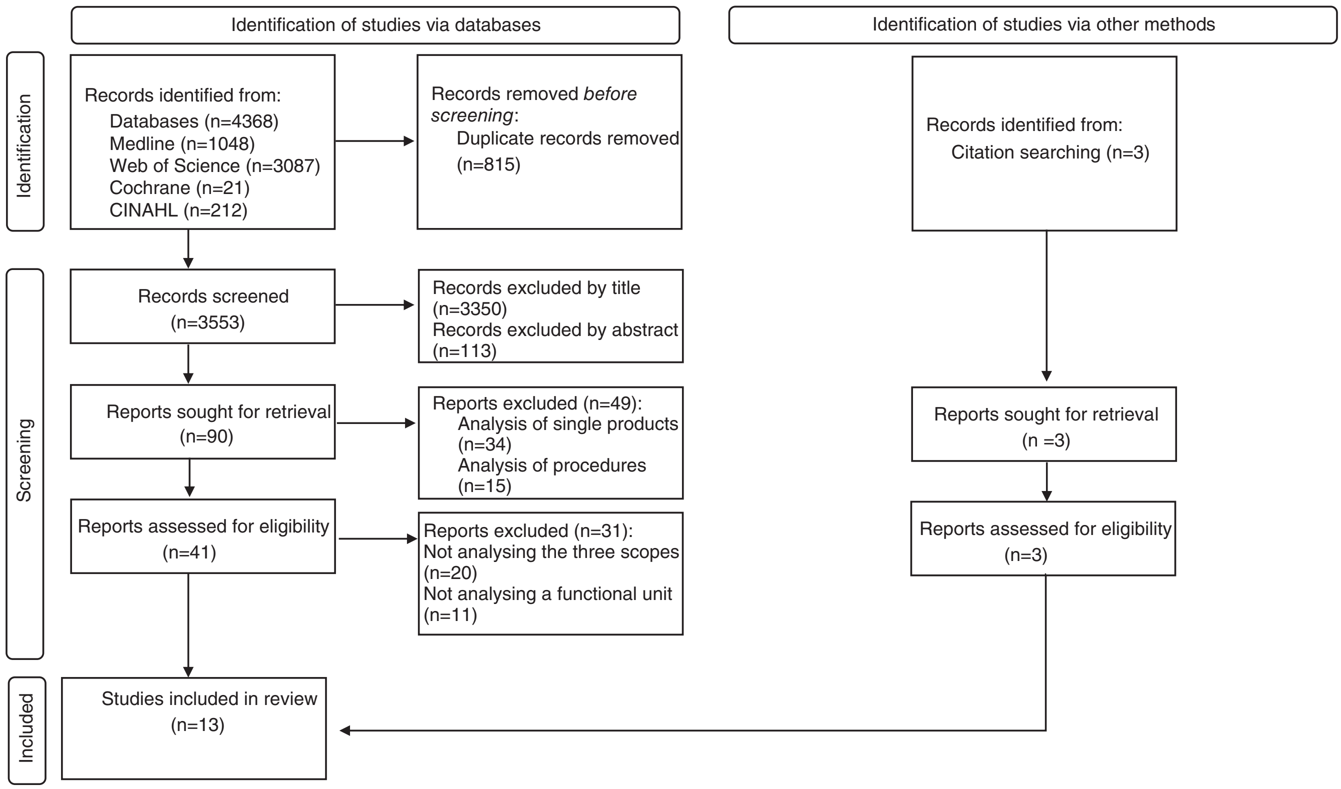

FIGURE 1 Article selection flowchart.

TABLE 1 Quality assessment results.

Category	Scoring system	Mtioui et al. (2021)	Nansai et al. (2020)	Prasad et al. (2022)	Malik et al. (2021)
Completeness	(a) To what extent are study inventory boundaries complete for a given functional unit? *Includes all reasonable factors* (2) *Includes limited/ambiguous factors* (1) *Narrow focus* (0)	2	2	2	2
	(b) Does the study account for all 3 scopes of GHG associated with the functional unit? *All 3 scopes measured* (2) *2 scopes measured* (1) *scopes limited to 1* (0)	2	2	2	2
Consistency	(a) To what extent is the study consistent with a recognized carbon footprinting guideline? *Stated and referenced* (2) *Stated, not referenced* (1) *No guideline stated* (0)	2	2	2	1
	(b) For comparative studies, how consistently are methods applied? *Consistently applied throughout* (2) *Limited consistency* (1) *Poor consistency* (0)	2	2	2	2
Transparency	(a) Are the hypothesis(/es) and study objectives clearly stated? *Both clearly stated* (2) *Either hypothesis or study objectives stated* (1) *Neither stated* (0)	1	2	1	2
	(b) To what extent are the GHGs included clearly stated? *Number of GHGs included clearly stated* (2) *Number of GHGs deducible* (1) *Number of GHGs not deducible* (0)	1	2	1	1
	(c) To what extent are study assumptions and exclusions clearly stated? *Both assumptions and exclusions stated* (2) *Limited* (1) *Neither stated* (0)	1	2	2	2
	(d) To what extent are the number of data points collected per process clearly stated? *Clear for all processes* (2) *Clear for limited processes* (1) *Not stated for any processes* (0)	2	2	2	2
	(e) How transparent are reported GHG results? *Numerical data for all sub-processes* (2) *Limited numerical data for some sub-processes* (1) *Descriptive or graphical data only* (0)	2	2	2	2°
Accuracy	(a) What is the specificity of the data sources to the study site? *1° data only* (2) *Both 1° & 2° data* (1) *2° data only* (0)[a]	1	1	1	0
	(b) Does the study determine parameter uncertainty? *Clear statistical plan with CI reported* (2) *CI reported, no clear plan* (1) *No CI or plan* (0)	2	0	0	0
	(c) Does the study determine scenario uncertainty? *Yes, demonstrating minimal uncertainty* (2) *Yes, demonstrating large uncertainty* (1) *No* (0)	2	0	1	1
Total	Scores out of 24	20	19	18	17

[a]1° = primary, 2° = secondary, CI = confidence interval, GHG = greenhouse gas.

MacNeill et al., 2017; Mtioui et al., 2021); top-down cycle assessment or economic input–output analysis (Eckelman et al., 2018; Eckelman & Sherman, 2016; Malik et al., 2018; Nansai et al., 2020; Wu, 2019); or a combination of both, also known as hybrid model (Malik et al., 2021; Nicolet et al., 2022; Prasad et al., 2022; Tennison et al., 2021).

The functional unit for analysis was stablished by the author/s of each study. Seven studies took the healthcare system of a whole country or a large state within a country as functional unit (Eckelman et al., 2018; Eckelman & Sherman, 2016; Malik et al., 2018, 2021; Nansai et al., 2020; Tennison et al., 2021). Three studies were multicentred: one of them in thirty-three hospitals (Keller et al., 2021); another one in three hospitals (MacNeill et al., 2017); and the third one in ten private primary care settings (Nicolet et al., 2022). The other three studies were carried out in units within a hospital: two of them in haemodialysis units (Lim et al., 2013; Mtioui et al., 2021) and one in an intensive care unit (Prasad et al., 2022).

Not all the studies analysed the same categories and that might be due to the complexity of such analysis. For example, those articles that analysed the entire healthcare system distributed their data in different areas of healthcare (such as public hospitals, primary

Keller et al. (2021)	Tennison et al. (2021)	Lim et al. (2013)	Malik et al. (2018)	MacNeill et al. (2017)	Nicolet et al. (2022)	Wu (2019)	Eckelman et al. (2018)	Eckelman and Sherman (2016)
2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2
2	2	2	2	2	1	2	2	1
1	2	0	1	1	1	2	2	2
2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2
2	2	1	2	2	2	2	2	2
2	2	2	1	2	2	0	0	0
2	0	0	2	0	1	2	2	2
2	2	0	2	0	0	2	2	2
23	22	17	20	19	19	23	22	21

healthcare, pharmaceutical industry), whereas those studies carried out in smaller functional units divided the data in more specific categories (such as water, waste, medical equipment, etc.). The main findings of the reviewed studies are summarized in Table 2.

2.1 | Scope 1 emissions

Scope 1 emissions ranged between 10% and 30% in the analysed studies. Studies that assessed healthcare systems found that scope 1 emissions were around 10% (Eckelman et al., 2018; Eckelman & Sherman, 2016; Malik et al., 2018, 2021; Nansai et al., 2020; Tennison et al., 2021), whereas in those analysing hospital settings or primary healthcare centres, these were around 20% (Keller et al., 2021; Lim et al., 2013; MacNeill et al., 2017 and Nicolet et al., 2022).

There were two exceptions of studies that found disparate results: one that found low levels of emissions, 0.4% (Mtioui et al., 2021) and another one which found high levels, 25.2% (Prasad et al., 2022). Only three of the studies assessed the use of medical gases, that ranged between 1.9% (Prasad et al., 2022) and 83.7%

(MacNeill et al., 2017). Transport freight or transport of goods by the organization was also part of the direct emissions and they accounted for less than 5% in the studies that looked into them (Mtioui et al., 2021; Nansai et al., 2020; Nicolet et al., 2022).

2.2 | Scope 2 emissions

Emissions secondary to purchased electricity differs between the studies analysed. Nicolet et al. (2022) found very low levels of emissions due to electricity (0.3%); however, their scope 1 emissions were higher than those of other studies. Three studies analysed energy and electricity together, thus hindering the individual analysis. Two of them showed higher percentages of emissions for energy and electricity (MacNeill et al., 2017; Prasad et al., 2022). On the other hand, Lim et al. (Lim et al., 2013) found relatively low levels, compared to the other two.

2.3 | Scope 3 emissions

Scope 3 emissions ranged between 50% and 75%. The largest emissions in scope 3 were found to be due to disposables or consumables, equipment (medical and non-medical) and pharmaceuticals. Disposables or consumables were analysed in different ways, yet most of the studies found that the carbon footprint related to them was greater than 20.0%. Studies that analysed healthcare systems found pharmaceuticals to account for between 7.6% (Wu, 2019) and 35.7% (Lim et al., 2013) of the emissions. Carbon emissions derived from medical equipment were generally high, ranging between 0.4% (Nicolet et al., 2022) and 32.2% (Prasad et al., 2022). Although there were some studies that calculated medical equipment, disposables and infrastructure together, this was still a significant percentage of the carbon footprint. Only two studies (Lim et al., 2013; Nicolet et al., 2022) found relatively low levels of emissions secondary to disposables. Two other categories, staff travel and building infrastructure, represented around 3.0% (Lim et al., 2013) and 16.6% of the total emissions each (Mtioui et al., 2021). Water, waste and patient travel generally represented less than 10.0%. The results for catering differed, ranging from 1.9% (Wu, 2019) to 30.3% (Prasad et al., 2022). The two studies that calculated the emissions secondary to food consumption for the whole national healthcare system found the levels relatively low, 3.6% (Nansai et al., 2020) and 6.1% (Tennison et al., 2021), respectively. However, the other two studies calculating catering carbon footprint found higher percentages, of 17.0% (Keller et al., 2021) and 30.3% (Prasad et al., 2022), and this might be so because these studies were carried out in hospital settings, where the provision of food to patients is expected to be high. Furthermore, Prasad et al. (Prasad et al., 2022) found higher percentages of emissions due to catering, and that is likely to be related to the fact that both staff and patient food consumption were calculated together.

3 | DISCUSSION

The aim of this systematic review was to analyse studies measuring the carbon footprint of healthcare settings and identify hotspots of carbon emissions. Overall, the studies reviewed showed that scopes 1 and 2 emissions were between 15% and 50% of the total emissions. Scope 3 emissions accounted for the rest, ranging between 50% and 75%, in which disposables, equipment (medical and non-medical) and pharmaceuticals represented the highest percentage of emissions. Staff travel and building infrastructure were also found to have a significant impact on the emissions, ranging between 10% and 15%. Water, waste and patient travel represented low levels of emissions. Data regarding carbon emissions secondary to catering were limited.

Regarding scopes 1 and 2, the geographic location of the analysed functional unit might influence the results. For instance, Mtioui et al. (2021) measured the carbon footprint in a dialysis unit in Casablanca (Morocco) and found energy only being responsible of 0.2% of carbon emissions; however, electricity represented a 27.7%. The authors explained this finding as due to the little use of heating and air conditioner in this functional unit because of the specific weather conditions in Casablanca (Mtioui et al., 2021). Another factor that could influence scopes 1 and 2 emissions was the age of the buildings. When analysing three different hospitals, MacNeill et al. (2017) noticed that two new hospitals produced less carbon emissions derived from energy and electricity than an old one. Overall, scopes 1 and 2 emissions proved to be linked, as those studies that found higher levels of emissions in scope 1 had lower emissions in scope 2, and vice versa. Reducing scopes 1 and 2 emissions can be achieved by introducing renewable energy in healthcare units as well as the use of insulation materials in the renovation and construction of new buildings (Campion et al., 2016). Furthermore, optimized electrical installations by improving air conditioning and heating systems could lead to a further reduction in energy use (García-Sanz-Calcedo et al., 2018). Montiel-Santiago et al. (2020) carried out a simulation of a digital system to model new systems of lighting and found that energy efficiency improvements could lead to a 47.0% reduction in energy use.

The use of certain anaesthetic gases can have a significant impact on the environment. The study conducted by MacNeill et al. (2017) in three hospitals of different countries (Canada, United States and United Kingdom) identified that the use of anaesthetic gases such as desflurane versus isoflurane and/or sevoflurane could lead to a 46.0% increase. Vollmer et al. (2015) suggested that the use of anaesthetic gases with low global warming potential, as well as limiting their use when possible, could reduce the carbon footprint. Hence, healthcare professionals and organizations should support and demand the use of anaesthetic gases that have a minimal impact on the environment.

The reviewed studies revealed that scope 3 emissions represented between 50% and 75% of the total emissions in healthcare. A previous study carried out in England found that the two largest contributors of scope 3 carbon emissions were medical equipment

TABLE 2 Main results from the reviewed studies.

Authors' year Functional unit Methodology	Categories analysed	Data collection: Carbon emissions CO_2e (%)	Data source	Data type	Emission factor	Comments
Mtioui et al. (2021) Haemodialysis Unit Bottom-up LCA	Energy/heating	0.86 t CO_2e (0.2%)	Invoice and billing	P	IPCC, Base Carbone, ADEME	No use of heating as per location of the study High carbon footprint electricity due to large proportion of fossil energy used for its production. Medical equipment and/or non-medical equipment and building infrastructure were measured together. It included building infrastructure, IT, biomedical equipment, and furniture.
	Freight transport	0.74 t CO_2e (0.2%)	Invoice and billing	P		
	Electricity	113.5 t CO_2e (27.7%)	Daily measurement	P		
	Water	0.5 t CO_2e (0.1%)	Source of water supply	P		
	Waste	25.34 t CO_2e (6.1%)	Company providing the service	S		
	Staff travel	36.67 t CO_2e (8.9%)	Survey (distance/transport)	P		
	Patient travel	54.86 t CO_2e (13.4%)	Survey (distance/transport)	P		
	Disposable	109 t CO_2e (26.6%)	Service's accounting register	P		
	Equipment	68 t CO_2e (16.6%)	Service's accounting register	P		
	TOTAL	408.98 tons of CO_2e				

Authors' year Functional unit Methodology	Categories analysed	Medical Services[a]	Health & hygiene[a]	Nursing services[a]	Fixed Capital[a]	Data source	Data type	Emission factor	Comments
Nansai et al. (2020) National healthcare system Economic input–output analysis	On-site emissions	5.4 (13.0)	0.08 (9.3)	2.83 (28.1)	0.25 (2.7)	National report of GHGs inventory	S	IPCC, National report of GHGs inventory	Medical services included hospitalization, non-hospitalization, dentistry and miscellaneous medical services. Health and hygiene included non-profit and for-profit. Nursing services included facility services and excluding facility. Fixed capital formation included private and public for all the previous categories. Total emissions 62.5 (4.69%) of the total national GHG emissions
	Freight transport	1.3 (3.1)	0.17 (1.6)		0.12 (1.3)				
	Electricity	7.5 (18.1)	0.22 (27.2)	2.66 (26.4)					
	Waste	1.0 (2.4)	0.04 (5.4)	0.28 (2.7)					
	Staff/Patient travel	1.0 (2.4)	0.02 (3.1)	0.38 (3.7)					
	Disposables	2.1 (5.1)	0.02 (2.5)	0.18 (1.7)	0.36 (4.0)				
	Equipment	1.2 (2.8)			0.94 (10.5)				
	Pharmaceuticals	11.3 (27.2)	0.03 (3.4)						
	Building infrastructure	1.0 (2.4)			4.98 (55.6)				
	Catering			0.37 (3.6)					
	TOTAL	41.5 (66.4)	0.81	10.07	8.95				

Authors' year Functional unit Methodology	Categories analysed	ICU[b]	ACU[b]	Data source	Data type	Emission factor	Comments
Prasad et al. (2022) Intensive care unit and Acute Care Unit Hybrid model	Energy/electricity	30.5 (25.2)	30.8 (67.6)	Invoice and billing	P	Ecoinvent 3.4 unit process database	Carbon footprint calculated by floor area and by staff allocation. This table only shows by floor area. ACU produces the largest portion of the hospital's Non-RCRA Hazardous Pharmaceutical Wastes, 743 kg per year or 15%.
	Medical gases	2.4 (1.9)	2.4 (5.3)				
	Water	0.3 (0.2)	0.3 (0.6)				
	Waste	4.3 (3.5)	3.4 (7.4)	Auditing over 5 days.	P		
	Staff travel	10.4 (8.6)	4.9 (10.7)	Working days/distance/transport	S		
	Disposables	44.4 (36.7)	12.0 (26.3)	Inventory of the products and the expenditure	P	2013 US EEIO LCA model v1.1	
	Equipment	30.5 (32.2)	6.5 (14.2)				
	Catering	13.8 (11.4)	13.8 (30.3)	Assumption of 3 meals/patient/year.	S		
	TOTAL	120.8 per bed day	45.5 per bed day				

TABLE 2 Continued

Malik et al. (2021) Largest state in Australia Hybrid model	GHG emissions	7908 kt CO_2e (6.6%)	Expenditure on the health system in New South Wales (Australia). Customized MRIO table using a government computer platform.	S	Leontief framework	Coal 63%, gas 21%, hydroelectricity 5%, and wind 4% of national energy sources. No conversion to carbon emissions was done for this study.
	Water	246 gigalitres of water use per year				
	Waste	1624 kt of waste per year				
Keller et al. (2021) 33 Swiss hospitals Bottom-up LCA	Energy/heating	26.0%	Invoice and billing of annual demand	P	IPCC, USEtox 2.02	The GWP per hospital changes from 3.2 to 4.9 t CO_2-eq which increases the share of electricity on total impact from 9% to 42%. Wastewater was the same as water use. Five areas contribute more than 10% in some categories on waste assessment. Nitrile gloves are responsible for 45% of medical products and plastics contribute around 70% of housekeeping
	Electricity	9.0%.	Electricity provider	P		
	Water	0.5%.		P		
	Waste	4.5%.	Inventory data from 2 hospitals.	P		
	Medical equipment	3.0% – medical products 4% – housekeeping	Auditing	P		
	Pharmaceuticals	12.0%	Invoice and billing.	P		
	Building infrastructure	15.0%	Energy reference area. Average from three hospitals.	P		
	Catering	17.0%	Meals for patients, staff, visitors.	P		
	TOTAL	3.2 tonnes CO_2eq per FU average/year				
Tennison et al. (2021) National healthcare system Hybrid model	Energy and heating	2520 Kt CO_2-e (10.0%)	Inventory (ERIC)	P	From UK Government energy ministry publications, IPCC AR5, BEIS and UK MRIO satellite	Travel emissions include fleet travel (Scope 1), business and staff commuting (scope 3), and personal patient and visitors. Acute services are the largest contributors of total emissions (56%) or 125Kg CO_2-e/bed-day. 76 Kg CO_2-e/outpatient appointment in acute care. 66 Kg CO_2-e/GP visit. 75 Kg CO_2-e/ambulance emergency response.
	Medical gases	1290 Kt CO_2-e (5.1)	NHS pharmacy electronic data.	P		
	Electricity	0.70 Kt CO_2-e (2.8%)	Inventory (ERIC)	P		
	Water and waste	1300 Kt CO_2-e (5.1%)				
	Staff travel	2400 Kt CO_2-e _ (9.5%)	Fleet travel was from expenditure. Staff travelling from the department of transport: 2015–2019.	P		
	Patient travel	123 Kt CO_2-e (4.9%)		S		
	Visitors travel	29 Kt CO_2-e (1.1%)				
	Disposables	6030 Kt CO_2-e (24.0%)	From UK MRIO and Public Expenditure Statistical Analysis Supply and Use tables from HM Treasury	S		
	Medical equipment	2520 Kt CO_2-e (10%)				
	Non-medical equipment	1960 Kt CO_2-e (7.8)				
	Pharmaceuticals	5060 Kt CO_2-e or (20.2%)				
	Building infrastructure	80 Kt CO_2-e or (5.0%)				
	Catering	154 Kt CO_2-e (6.1%)				
	TOTAL	25,040 Kt CO_2-				

TABLE 2 Continued

Lim et al. (2013) Haemodialysis unit Bottom-up LCA	Energy and heating	22,716 Kt CO_2-e (18.6%)			Activity data/auditing.	P	From Australian government publications, individual providers	Electricity and energy were calculated together. Electricity use alone was 18,313 Kt CO_2-e or 15%. Water treatment and supply was 1470 Kt CO_2-e or 1.2% and sewerage treatment and management was 7773 Kt CO_2-e or 6.4%. Landfill was 1375 Kt CO_2-e or 1.1%, incinerated 3780 Kt CO_2-e or 3.1% and recycled – 992 Kt CO_2-e or −0.8%.
	Water	9243 Kt CO_2-e (7.6%)			Estimation from haemodialysis machines			
	Waste	4163 Kt CO_2-e (3.4%)			Auditing/measurement over one week			
	Staff travel	3369 Kt CO_2-e (3%)			Survey (distance/transport)	P		
	Patient travel	7043 Kt CO_2-e (5.8%)						
	Equipment	28,490 Kt CO_2-e (23.4%)				P		
	Pharmaceuticals	5060 Kt CO_2-e (35.7%)						
	Aids and appliances	1054 Kt CO_2-e (2.9%)						
	TOTAL	121.9 t CO_2-e/year or 10.2 t CO_2 e/year/patient						
		VGH[b]	**UMMC**[b]	**JRH**[b]				
MacNeill et al. (2017) 3 hospitals (Canada, US and UK) Bottom-up LCA	Energy and heating/Electricity	2,034,277 (63.2)	2,129,841 (50.9)	211,212 (4.1)	Invoice and billing.	P	DEFRA	Energy, heating and electricity were considered to be scope 2 as the energy is not produced within the operating theatre. The difference among medical gases can be due to the use of desflurane.
	Medical gases	534,194 (16.5)	1,515,763 (36.2)	4,344,150 (83.7)	Invoice and billing (pharmacy purchasing records)	P		
	Waste	650,436 (20.2)	536,260 (12.8)	632,574 (12.1)	Auditing over 3 weeks.	P		
	TOTAL	3,218,907 year	4,181,864 year	5,187,936 year				
Malik et al. (2018) National healthcare system Economic input–output analysis	Public hospitals	12,295 Kt CO_2-e (34.3%)			Health expenditure Australia report (Australian Institute of Health and Welfare) that includes all government and non-government costs. Private and public services were included. Expenditure collected for 16 different categories.	S	Leontief framework. Input–output mathematical equations.	Scope 2 and 3 emissions shown together. Healthcare in Australia contributes 7.2% of the total emissions. The four largest financial cost categories were: public and private hospitals (39%), pharmaceuticals (12%), specialist medical services (12%) and unreferred medical services (7%)
	Private hospitals	3635 Kt CO_2-e (10.2%)						
	All other medications	3347 Kt CO_2-e (9.3%)						
	Pharmaceuticals	3257 Kt CO_2-e (9.1%)						
	Building infrastructure	2776 Kt CO_2-e (7.7%)						
	Patient transport	427 Kt CO_2-e (1.2%)						
	TOTAL	35,772 Kt CO_2-e						
Nicolet et al. (2022) 10 private primary care practices Hybrid model	Energy and heating	9106 kg CO_2-e/year (29.8%)			Invoicing and billing.	P	COINVENT	Energy included electric solar, gas and oil. Electricity included energy consumption of in-house computer server and x-ray device. General waste 321 kg CO_2-e/year, special waste (radioactive) was 164 kg CO_2-e/year and paper waste 6 kg CO_2-e/year. Equipment was divided into medical equipment (such as stethoscope, examination bed, saturometer, ECG, Xray devices, etcetera) and non-medical (such as computer, printer, desk, chair, table)
	Electricity	95 kg CO_2-e/year (0.3%)			Invoicing and billing.	P		
	Waste	491 kg CO_2-e/year (1.6%)			Invoicing billing and staff observation	P		
	Staff travel	3816 kg CO_2-e/year (12.5%)			Survey	P		
	Patient travel	10,145 kg CO_2-e/year (33.2%)			Survey	P		
	Medical consumables	1678 kg CO_2-e/year (5.5%)			Invoicing and billing.	P		
	Non-medical consumables	338 kg CO_2-e/year (1.1%)						
	Equipment	110 kg CO_2-e/year (0.4%)			Inventory	P		
	Building infrastructure	1239 kg CO_2-e/year (4.1%)			Invoicing and billing	P		
	Total	30.5 tons of CO_2-e/year						

TABLE 2 Continued

Wu (2019) National Healthcare system Economic input–output analysis	Electricity and steam	33 mt CO_2-e (10.6%)	Data sources for health expenditure include the national input–output table, China Health and Family Planning Statistics, China Construction Statistics, and China Science and Technology Statistics yearbooks.	S	Leontief framework. Input–output mathematical equations.	
	Agriculture	25 mt CO_2-e (7.9%)				
	Pharmaceuticals	24 mt CO_2-e (7.6%)				
	Medical equipment	13 mt CO_2-e (4.1%)				
	Catering	6 mt CO_2-e (1.9%)				
	TOTAL	315 mt CO_2-e				
Eckelman et al. (2018) National healthcare system Economic input–output analysis	Public Hospitals	7.1 mt CO_2-e (21.5%)	Data obtained from Statistics Canada Environmental Accounts, the Canadian National Pollutant Release Inventory and then creation of an environmentally extended input–output (EEIO) tables and the National Health Expenditures database maintained by the Canadian Institute for Health Information.	S	Open IO – Canada model b IMPACT2002 + LCA model	
	Physicians	4.4 mt CO_2-e (13.3%)				
	Dental Services	1.8 mt CO_2-e (5.4%)				
	Prescribed Drugs	7.0 mt CO_2-e (21.2%)				
	Capital	2.4 mt CO_2-e (7.3%)				
	Public Health	1.9 mt CO_2-e (5.7%)				
	TOTAL	33.0 mt CO_2-e (4.6% of the national emissions)				
Eckelman and Sherman (2016) National healthcare system Economic input–output analysis	Hospital care	238 Mt CO_2-e (36%)	US National Health Expenditure Accounts for the decade 2003–2013.	S	IMPACT2002 + LCA model	Total: Suppliers of energy, goods, and services: power generation (36%), government services (8%), non-residential commercial and health care construction (4%) and basic organic chemicals manufacturing (3%)
	Clinical Services	77 Mt CO_2-e (11.7%)				
	Nursing Care Facilities	41 Mt CO_2-e (6.2%)				
	Prescribed drugs	68 Mt CO_2-e (10.3%)				
	Public Health Activities	29 Mt CO_2-e (4.4%)				
	Structures and equipment	71 Mt CO_2-e (10.8%)				
	TOTAL	655 Mt CO_2-e in 2013 (9.8% of the national total)				

Abbreviations: ACU, acute care unit; ADEME, Agence de l'environnement et de la maîtrise de l'énergie (the French Environment and Energy Management Agency); BEIS, Department for Business, Energy and Industrial Strategy; EEIO, environmentally extended input–output; ERIC, Estates Return Information Collection; FU, functional unit; GHG, greenhouse gas; GWP, global warming potential; HM, high majesty; ICU, intensive care unit; IPCC, Intergovernmental Panel on Climate Change; JRH, John Radcliffe Hospital; LCA, life cycle assessment; MRIO, multi-regional input output modelling; P, primary; S, secondary; VGH, Vancouver General Hospital; UMMC, University of Minnesota Medical Center.

[a]mt CO_2e (%).

[b]Kg CO_2e (%).

(13.1%) and pharmaceuticals (12.1%), and that is mainly due to the emissions caused by manufacturing, packaging and transport of goods (NHS England, 2008). For example, the carbon footprint of pharmaceuticals without including the energy used to produce them has been estimated at 5.0%, showing that most of the emissions come from the energy used in their production and distribution (Karliner et al., 2020). It is important to understand that the carbon footprint of an item represents indirect emissions for the user; however, its production will require energy and electricity (scopes 1 and 2); thus, most carbon emissions come from energy that might be direct or indirect depending on where it is used.

Interventions such as the installation of solar panels in roofs and parking lots in hospitals, changing to a vegetable-based hospital menu, replacing telemedicine for face-to-face appointments when possible, promoting active transport and/or introducing effective lighting and energy appliances, have shown to have a significant impact in the reduction of carbon footprint (Bozoudis & Sebos, 2021; Bozoudis et al., 2022). Nansai et al. (2020) stated that the carbon footprint of a hospital supply chain could be minimized by reducing the demand of goods and services. This can be achieved by restricting unnecessary patient attendance and diagnostic testing, minimizing human error and/or avoiding duplication of processes, such as previous consultations or testing in different services (Malhotra et al., 2016). Ouslander et al. (2016) found that 23% of the emergency visits, hospital admissions and/or readmissions were preventable. Freund et al. (2013) carried out semi-structured interviews with 12 primary care physicians from 10 primary care clinics in Germany regarding 104 hospitalizations of 81 patients and found that 41% of those hospitalizations were avoidable and could have been managed in ambulatory services. However, this raises the question whether admissions versus ambulatory patients would increase or decrease carbon emissions as, for example, the use of transport-related emissions would be greater. The COVID-19 pandemic has shown how telemedicine can be used as a feasible, acceptable and effective way of healthcare practice (Hong et al., 2020). Studies such as the one carried out by Purohit et al. (2021) found that telemedicine could significantly reduce the carbon emissions secondary to travelling as well as the demand in healthcare settings. The use of telemedicine could mean an opportunity to reduce attendances in settings such as primary healthcare, where the carbon emissions secondary to patient and staff travelling are much higher than in other healthcare settings (Nicolet et al., 2022).

McAlister et al. (2022) carried out a prospective life cycle assessment of five imaging modalities: chest X-Ray, mobile chest X-ray, computerized tomography (CT), magnetic resonance imaging (MRI) and ultrasound (US). They found that CT and MRI produced 17 and 9 times more carbon emissions than X-rays and US. They recommended using low-impact imaging when appropriate and limiting unnecessary testing in order to reduce the carbon footprint. Human errors such as incidents related to drugs or treatments may also lead to an increase in the carbon footprint. Panagioti et al. (2019) in their metanalysis found that one in twenty hospitals admissions some kind of preventable error was made. For example, the wrong administration of a drug can lead to anaphylaxis and, therefore, to an increase in the items and resources used. Another example could be a surgery that is not properly performed, and, as a result, another surgery needs to be carried out, leading to the utilization of more resources as well as longer hospital stay of the patient. Consequently, it is important to put in place measures to reduce human errors not only to improve patient's care but also to reduce the carbon footprint.

The promotion of a healthy lifestyle may also help to reduce the carbon footprint as well as improving physical health. Several studies have shown that shifting towards a healthy diet could contribute to minimizing the carbon footprint by adopting diets with low calories or reducing animal-based food (Scarborough et al., 2014; Tukker et al., 2011). Furthermore, the promotion and maintenance of physical activity such as walking or cycling will reduce the carbon emissions secondary to transport and also improve health by decreasing the incidence of cardiovascular diseases, among others (Lindsay et al., 2011; Woodcock et al., 2009). In addition to this, the reduced incidence of certain diseases after adopting healthy lifestyles could diminish the demand for health services, thus reducing the carbon footprint of healthcare settings (Lee et al., 2017).

However, sustainable practice can only be achieved with the commitment of all healthcare professionals and their organizations (IPCC, 2018). As mentioned by NHS England (2022) recommendations, advanced health professionals and their teams should reduce the environmental impact of equipment and resources by, for example, applying the 5 R's: reduce, reuse, reprocessed, renewable and recycle. In this sense, healthcare professionals should demand manufacturers of healthcare equipment ways of reducing the carbon footprint of their products whenever possible (Chiarini et al., 2017). Furthermore, the move from a linear economy to a circular one, where items are not wasted or replaced by new ones, but fixed or used for different purposes, is also a way of reducing the carbon footprint, so these approaches should be further explored (NHS England, 2020).

The limitations of the present study include those inherent to the systematic review methodology. It is possible that some relevant studies were not identified, although the search strategy was broad and targeted, and measures were taken to retrieve studies such as the review of reference lists. A possible interpretation bias is also acknowledged, yet the data were analysed and peer-reviewed. In addition, possible biases are recognized when comparing the results of the articles reviewed, due to differences in the assessment methodology employed by the researchers or the scope of the study in terms of the service assessed or the level of detail.

4 | CONCLUSION

The studies analysed in this literature review found that scopes 1 and 2 emissions were between 15% and 50% of the total, whereas scope 3 emissions ranged between 50% and 75%. Disposables, equipment (medical and non-medical) and pharmaceuticals represented the higher percentage of scope 3 emissions. Other variables such as transport and building infrastructure were also significant contributors of carbon emissions.

This literature review highlights the effect that healthcare systems have on climate change and the importance of adopting and carrying out interventions to reduce the impact of healthcare on the development of climate change. Interventions must be carried out by the organizations responsible for those emissions, but also every single individual that integrates them should make changes. In fact, scope 3 emissions represent a high percentage of the total, and individuals in the organizations could have a significant impact on reducing these, or demanding manufacturers to do so, whereas scopes 1 and 2 emissions are more likely to be managed at organizational level. Current healthcare practice should be assessed at all levels, for example by creating or reviewing pathways and policies to not only reduce the carbon footprint but also improve patient's care and the service provided.

To effectively reduce carbon emissions secondary to healthcare activities, in-depth analysis of individual units is recommended. Evidence-based approaches may facilitate the identification of carbon hotspots, thus achieving a more effective development and application of interventions aimed at reducing carbon emissions. Further research in healthcare's carbon footprint is recommended, as well as the development of tools to measure carbon emissions and identify carbon hotspots, so as to reduce the impact of healthcare activity on the environment.

AUTHOR CONTRIBUTIONS

Lucas Rodriguez-Jimenez: Conceptualization, Methodology, Project administration. Macarena Romero-Mrtín: Methodology, Data curation, Writing – Original draft preparation. James Chan: Visualization, Investigation. Timothy Spruell: Investigation, Data curation. Zoe Steley: Software, Validation, Formal analysis. Juan Gómez-Salgado: Writing – Reviewing and Editing.

FUNDING INFORMATION

No fundings were received for this paper.

CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to declare that are relevant to the content of this article.

PEER REVIEW

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/jan.15671.

DATA AVAILABILITY STATEMENT

Data sharing not applicable.

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How to cite this article: Rodríguez-Jiménez, L., Romero-Martín, M., Spruell, T., Steley, Z., & Gómez-Salgado, J. (2023). The carbon footprint of healthcare settings: A systematic review. *Journal of Advanced Nursing*, *79*, 2830–2844. https://doi.org/10.1111/jan.15671

REVISTA ESPAÑOLA DE SALUD PÚBLICA

RESP

Issue
97
6/2/2023

Environmental impact of Emergency Services in Public Health: an assessment tool

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ORIGINAL

Received: 4/12/2023
Accepted: 5/7/2023
Published: 6/2/2023

e202306044

e1-e10

Impacto medioambiental de los servicios de Urgencias en la Salud Pública: una herramienta de valoración

Authors declare that there is no conflict of interests.

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SUGGESTED CITATION

Rodríguez-Jiménez L, Romero-Martín M, Gómez-Salgado J. Environmental impact of Emergency Services in Public Health: an assessment tool. Rev Esp Salud Pública. 2023; 97: June 2nd e202306044.

ABSTRACT

BACKGROUND // Climate change is directly related to increasing medical conditions such as cardiovascular, respiratory and/or infectious diseases, as well as malnutrition and mental illness caused by the reduction of available food and the growth of situations with significant emotional impact, respectively. Evidence showed that healthcare services are responsible for 4-5% of the greenhouse gas emissions worldwide. The aim of this study is the development of an assessment tool to evaluate the carbon footprint of emergency departments.

METHODS // The development of the proposed assessment tool followed five stages. Firstly, the categories of GHGs to be included in the assessment tool were determined through a literature review. This was followed by the establishment of scopes and boundaries, selection of conversion factors, data collection from the Emergency Department at the Royal Free Hospital in London as a pilot site, and finally, the development of methodology to assess the carbon footprint.

RESULTS // The assessment tool was divided in three scopes and each scope included one or more categories containing several items. Data was collected from different sources such as meters invoicing and billing, auditing, and surveys. The tool is presented in a *Microsoft Excel* document.

CONCLUSIONS // This carbon assessment tool offers an opportunity to monitor carbon emissions in emergency departments, aiming to proliferate environmental strategies. The assessment tool seeks to provide a baseline carbon footprint assessment, identifying carbon hotspots within the department. The identification of these areas of intensive carbon emissions can help guide and focus local environmental initiatives that can later be monitored with a follow-up assessment to evaluate their effectiveness.

KEYWORDS // Carbon footprint; Greenhouse gases emissions; Emergency departments; Life cycle assessment; Environmental impact.

RESUMEN

FUNDAMENTOS // El cambio climático está directamente relacionado con el aumento de ciertas patologías como enfermedades cardiovasculares, respiratorias y/o infecciosas, así como con la desnutrición, provocada por la reducción de los alimentos disponibles, y el deterioro de la salud mental. La evidencia ha señalado que los servicios sanitarios son responsables del 4%-5% de las emisiones de gases efecto invernadero en todo el mundo. El objetivo de este estudio fue diseñar una herramienta de evaluación de la huella de carbono de los servicios de Urgencias.

MÉTODOS // Se diseñó la herramienta a través de cinco etapas. En primer lugar, se seleccionaron las categorías a incluir en la herramienta desde una revisión de la literatura. Posteriormente, se determinaron el alcance y límites, se seleccionaron los factores de conversión, se recopilaron datos del servicio de Urgencias del *Royal Free Hospital* de Londres como sitio piloto y se seleccionó el método de cálculo de la huella de carbono.

RESULTADOS // La herramienta resultante se dividió en tres ámbitos, y cada ámbito en una o más categorías que contienen varios elementos. Los datos se recopilaron de diferentes fuentes, como facturación, medidores, auditorías y encuestas. La herramienta se presentó en un documento de *Microsoft Excel*.

CONCLUSIONES // Esta herramienta de evaluación de carbono ofrece una oportunidad para monitorear las emisiones de carbono en los servicios de Urgencias. Pretende proporcionar una valoración de la huella de carbono de referencia, identificando puntos críticos de emisión dentro del servicio, que puede dar lugar a iniciativas ambientales locales.

PALABRAS CLAVE // Huella de carbono; Emisiones de gases efecto invernadero; Servicios de Urgencias; Evaluación del ciclo de vida; Impacto medioambiental.

INTRODUCTION

CLIMATE CHANGE CAN BE DEFINED AS THE shift in temperatures and weather patterns secondary to increasing greenhouse gas emissions released into the atmosphere by human activity (1). Greenhouse gases (GHGs) are gases that retain the heat within the earth's atmosphere causing what is called the greenhouse effect, thereby increasing global warming, and changing the Earth's climate (2). Increasing temperature leads to extreme weather conditions such as heatwaves, floods, droughts, and/or environmental hazards (3). Furthermore, climate change is directly related to increasing medical conditions such as cardiovascular, respiratory and/or infectious diseases, as well as malnutrition and mental health caused by the reduction of available food and the growth of situations with significant emotional impact, respectively (4). In 2022 alone, 7.6 million people were displaced in Pakistan due to floods (5). An increase of 68% of heat-related deaths caused by heatwaves was also observed between 2000 and 2021 (6). Climate change does also favour the proliferation and propagation of infectious diseases such as dengue, whose favourable conditions for its propagation have increased a 30% in Europe compare to data from the 1950s. Rising temperatures are also provoking earlier floral seasons compared to data from the last 40 years and this is related to an increase of allergens and allergies, currently affecting 40 per cent of the global population. The impact of climate change on people's health is already noticeable and is expected to increase in following years.

According to the 2015 *Paris Agreement*, the greenhouse gases are: carbon dioxide (CO_2); methane (CH_4); nitrous oxide (N_2O); hydrofluorocarbons (HFCs); perfluorocarbons (PFCs); sulphur hexafluoride (SF_6); and nitrogen trifluoride (NF_3). Carbon dioxide represents 86% of GHGs and it is for this reason that often the literature, including this document, refers to carbon footprint when referring to greenhouse gas emissions although they include the rest of all GHGs (7). *Carbon footprint* can be defined as the best possible estimation of GHG emissions produced by human activity (8). GHGs are classified into direct emissions -those in which an individual or organisation has direct control-, and indirect emissions -those related to the activity of the individual or organization but over which there is not control of the source-. According to the *Greenhouse Protocol* (9), GHG emissions can be divided into three scopes:

- Scope 1: includes direct emissions produced by the organisation, for example emissions secondary to fuel use for heating, use of anaesthetic gases and/or freight of transport.
- Scope 2: includes indirect emissions produced from purchased electricity, and therefore electricity that has been produced elsewhere is beyond the organisation's control.
- Scope 3: includes the rest of indirect emissions that are mainly related to the chain-supply, and in which the organisation has not direct control over.

Carbon footprint analysis can be divided mainly into three different methodologies: bottom-up cycle assessment; top-down cycle assessment or economic input-output analysis; and the combination of the two previous methods, also known as the hybrid model (10). Bottom-up cycle assessment consists of the analysis of the carbon emissions attributed to each element of an item, which are converted into carbon equivalent using a conversion factor. Top-down cycle assessment or the economic model uses the money spent on each item and multiplies it by a carbon conversion factor. The hybrid model combines both models. Estimations are used to calculate the carbon footprint of organisations. It is necessary to quantify the activity that generates carbon emissions and multiply it by a conversion factor, which represents the amount of GHGs emitted by that activity. The unit to measure carbon footprint is CO_2eq, using this gas as reference, being the most influential in global warming (11).

Evidence has revealed that healthcare services are responsible for 4-5% of GHG emissions worldwide (12). In 2015, the state members of the United Nations, due to the crisis of the planet as a sustainable space to be home to everyone in a fair and equal manner, established *17 Sustainable Development Goals* to preserve the planet and improve everyone's lives and anticipated to be achieved by 2030 (13). These Sustainable Development Goals include, amongst others: zero hunger, good health and well-being, clean water and sanitation, affordable and clean energy, sustainable cities and communities and climate action. The Sustainable Development Goals are interrelated and configured as a global strategy, since for instance, the goals of reducing tropical diseases or reducing deaths and illness from hazardous chemicals, and air, water and soil pollution and contamination, are directed related to climate action. Climate action targets aim to strengthen climate resilience, integrate climate change measures into national policies, strategies, and planning, improve education and raise awareness, create a Green Climate Fund and promote climate related changes.

The National Health Service (NHS) in the UK was the first health system to introduce net zero policies into legislation, with the objective to reduce their carbon emissions to zero by 2040 (14). The Intergovernmental Panel on Climate Change (IPCC) 2022 report highlights the importance of regional and local initiatives to reduce carbon emissions (15). Local sustainability initiatives in the healthcare field can have a significant impact in reducing carbon emissions and produce a snowball effect in other health services, however evidence is necessary to make a case of these initiatives (8). The *Green Emergency Department* (GreenED) project is an initiative led by the Royal College of Emergency Medicine (RCEM), which aims to reduce the environmental impacts, including greenhouse gases emissions, resulting from activity in the delivery of emergency healthcare services in NHS hospitals.

The development of tools to evaluate the carbon footprint of healthcare services can be a way to provide evidence of the environmental impact of a given activity, and an opportunity to identify carbon hotspots, and to quantify and reduce carbon emissions. The aim of this study is the development of an assessment tool to evaluate the carbon footprint of EDs in the UK.

MATERIAL & METHODS

THE METHODOLOGY TO DEVELOP THE ED carbon assessment tool followed the following steps:

- Selection of the categories included in the assessment tool, through a literature review.
- Determination of scope and boundaries.
- Selection of conversion factors.
- Data collection.
- Evaluation method of the carbon footprint.

Categories selection. To begin with, the research team conducted a literature review to identify the most common categories previously analysed in carbon footprint assessments papers in the healthcare field. The literature review was carried out using the Medline, Web of Science, CINAHL and Cochrane databases with the key words: *carbon footprint, greenhouse gases, life cycle assessment* and *health*. This literature review revealed that the categories analysed in the selected studies were: energy and heating, anaesthetic gases, freight transport, purchased electricity, catering and food, disposables and consumables, medical and non-medical equipment, pharmaceuticals, transport, waste, and water. The research team considered that all these categories could provide a comprehensive carbon footprint assessment and all of them were included in this study. However, anaesthetic gases and freight transport were adapted for the emergency services context.

Scope and boundaries. The assessment tool has been designed for the period of time that the user considers appropriate. The ED premises for this tool include all areas in which emergency care is provided (such as Minors, Majors, Resus and Same Day Emergency Care (SDEC) ambulatory units) for adults and/or paediatrics. Radiology departments that are shared or exclusively used by the ED are also included. In addition, administration offices that are within the ED premises and that are part of its management and functionality are included. This study does not include building infrastructure, support services (such as financial or other administrative services) and other diagnostic services (such as laboratories or imaging departments such as nuclear medicine or ultrasound departments). Other services such as ambulance services are included as a form of transport, however the carbon footprint originating from activities whilst the patient is in the ambulance (*e.g.*, disposables use) is not included. Laundry services are also not included due to this being a process external to an ED; also there are not specific conversion factors for this activity, making the data inaccessible **(16,17)**.

Conversion factors selection. The emissions factors used for this tool are based on the publication made by the Department for Environment, Food & Rural Affairs (DEFRA). DEFRA provides annual conversion factors for organisations reporting GHG emissions. The data provided by DEFRA offers easy access, most up to date conversion factors and has an international recognition. The only exception was in the category of waste, as DEFRA does not provide specific data for the waste streams of health services; in this case conversion factors provided by Rizan *et al.* were used **(18)**.

Data collection. Data sources were identified in the literature review and the research team carried out a key data collection, creating an inventory of items for each category. The ED at the Royal Free Hospital in London was selected as a pilot site for the identification and collection of data between November 2022 and February 2023. Data were collected by observation and hospital records. *Microsoft Excel* for *Mac* Version 16.25 was used for the organisation of collected data and calculations.

– Energy, heating, purchased electricity and water. Data regarding energy, heating, electricity, and water are usually obtained from meters, however specific submeters for EDs are rarely available. For this assessment tool, the approach used by Prasad *et al.* **(19)** was adopted, according to which the total consumption of the site is multiplied by the department's surface and divided by the total surface of the site. This formula can provide an estimation of the department's consumption and subsequently its carbon footprint. This data can be obtained from supplier companies or the administration team through billing records. Specific use of green energies sources was not included in the calculator; however, the use of green energies is applied in the conversion factors provided by DEFRA, hence the increase of green energy use will decrease the conversion factor.

– Anaesthetic gases. It was observed that anaesthetic gases are rarely used in ED and, when used, are normally managed and ordered by the anaesthetics team rather than emergency practitioners. Hence, this category only included nitrous oxide and methoxyflurane that are often used as short-acting anaesthetsic agents in EDs.

– Freight transport. Freight transport was excluded from our assessment tool. Freight transport is often controlled by the organisation rather than individual departments, hence the analysis of specific freight transport for EDs is not accessible and feasible for this study. However, the transport of patients to different sites within a trust are included in this category, as they represent direct emissions controlled by the department. Interhospital transport can be defined in this study as the transport of patients between different sites in or different trust due to, for example, requiring specialist input or diagnostic tests that are not available on site. However, ambulance services as a method of transport for patients to go from their house or place of incident to the hospital are categorised as indirect emissions and are analysed in another category.

- Disposables/consumables and pharmaceuticals. The data for disposables or consumables and pharmaceuticals can be obtained from the department's ordering records. Departmental records should include the prices of each item and the number of items ordered either monthly or annually. Due to the large number of items for these two categories, the authors applied a top-down approach for these two categories. Furthermore, medicines that were rarely used and for which the price was less than £1 were excluded since their contribution to the carbon footprint would be negligible; to expedite the calculation, it was decided to exclude them.

- Medical and non-medical equipment. Medical equipment includes a comprehensive list of equipment utilised in ED, such as observation machines, thermometers and ultrasounds. Medical equipment lists can be obtained from the medical devices department. All the medical items provided by the medical devices department were included in this assessment tool. Furthermore, information from manufacturers regarding life expectancy for each item was included.

  Non-medical equipment included were paper, pens, computers, and printers. An audit carried out showed that these items were the most used in ED and therefore were selected for this category.

- Patient and staff transport. Data regarding patient and staff transport can be collected through a survey. The survey must offer a comprehensive list of methods of transport and calculate the distance per return journey from the individual's house to ED. The list of methods of transport includes active transport, cars of different sizes (small, regular and large) and fuel (petrol, diesel, hybrids and electrics), motorcycles, and public transport (bus, tube and train). The survey is anonymous and its participation voluntary and includes the miles between the patient's house or place of incident per journey and the method of transport. The survey will be carried out over a two weeks period and estimations will be made for a year period. Regarding staff, an audit will be carried out including the number of full and part time staff, the mileage per journey and the method of transport. DEFRA provides a comprehensive list of conversion factors for each mile travelled in different methods of transport, such as travel by train, bus, motorcycle, regular diesel or petrol car, amongst others.

- Food and catering. Numbers of meals served in ED can be calculated through auditing. DEFRA provides conversion factors for food and drinks based on weight and cost. Our assessment tool provides calculations based on weight per meal served. Furthermore, several items of catering are included. This assessment tool does not differentiate between vegetarian and non-vegetarian meals and is considered one of our limitations.

– Waste. Waste calculations include recycled waste, domestic waste, non-infectious offensive waste, infectious waste, clinical waste, medicinal contaminated sharps, anatomical waste, medicinal waste, reusable surgical instruments, and batteries. Data can be collected through auditing over a period of time, obtaining the weight of each type of waste. As previously mentioned, DEFRA does not provide these specific conversion factors, hence the conversion factors provided by Rizan et al. are used (18). Rizan *et al.* carried out a carbon footprint assessment of the waste in three different hospitals of the UK, producing a list of conversion factors for healthcare waste through the obtained data. The NHS database provides the expenses secondary to hospital waste and hence, allows the calculation of each type of waste, which Rizan *et al.* used in their study. Rizan *et al.* included in their study the transportation of waste between the hospital and the waste plant, the energy and water used to process waste, and direct emissions. The method for waste disposal was carried out in three groups: autoclave, heat waste or incineration and recycling.

Evaluation method of the carbon footprint. Our assessment tool uses a hybrid method to quantify the ED carbon footprint, combining bottom-up and top-down life cycle assessments depending on the availability and accessibility of the data collected. The assessment of energy and heating, anaesthetic gases, electricity, catering and food, transport, waste, and water related carbon emissions are calculated through a bottom-up approach, whereas the rest apply a top-down or financial model.

RESULTS

OUR PROPOSED CARBON FOOTPRINT assessment tool for EDs is divided in three scopes and each scope contains one or more categories containing several items [TABLE 1]. The categories selected are energy and heating, anaesthetic gases, interhospital patient transport, purchased electricity, catering and food, disposables and consumables, medical and non-medical equipment, pharmaceuticals, transport, waste, and water. Data is collected through four different sources: meters (*e.g.*, energy meter or water meters), invoicing and billing, auditing, and survey. Key data is obtained from each category over a period of a year. Assumptions are made in the categories of energy/heating, electricity, and water when submeters are not available, however the user is able to introduce exact values if submeters are present. Furthermore, the categories of catering and food, and waste are audited over a week and values extrapolated from that calculation.

The tool is presented in a *Microsoft Excel* document. The user can navigate the Excel and introduce the amount required for each item when available. The amount introduced is multiply by a conversion factor that originates the amount of carbon emissions. Most of the data can be obtained directly from the service, however, there is some data regarding energy, electricity and water use that will likely need to be obtained from the Estates Management team or ERIC database.

DISCUSSION

THIS CARBON ASSESSMENT TOOL OFFERS an opportunity to monitor carbon emissions in EDs, with the aim to develop environmental strategies to reduce carbon emissions. The assessment tool seeks to provide a baseline carbon footprint, identifying carbon hotspots within the department. The identification of carbon hotspots or areas of high carbon emissions can lead to local environmental initiatives that later can be monitored with a follow-up assessment to evaluate their effectiveness. The development of the tool is not only beneficial for the Emergency Department but can also incentivise the development of similar tools in other healthcare fields (20).

Our study is similar to the calculator previously made by Sawyer, who developed a calculator for GP practices in the UK **(21)**. The GP calculator divides the carbon footprint into three areas: operational (including energy use, travel, professional services, and other activities such as procurement, office and medical consumables, water and waste), investigations and pharmaceuticals. Sawyer highlighted the importance of deve-

Table 1
Contents of the ED carbon footprint asessment tool.

Scope	Categories	Data sources	Key data collected	Example of items	Conversion factor	Unit
1	Energy and heating	Invoicing and billing, Energy meters	Annual consumption(*)	Natural gas, burning oil, green energies, etc.	DEFRA database(**)	Litres, kWh
	Anaesthetic gases	Invoicing and billing	Annual consumption	Nitrous oxide and methoxyflurane	DEFRA database	£
	Freight transport	Practice inventory/ auditing		Patients transport between different sites	DEFRA database	
2	Electricity	Invoicing and billing, Electricity meters	Annual consumption(*)	Electricity consumption	DEFRA database	kWh
3	Catering and food	Practice inventory/ auditing	Number of meals per patient	Meals, sandwitches, milk, fruits, biscuits, etc.	DEFRA database	Kg
	Disposables and consumables	Practice inventory/ auditing	Inventory of disposables and consumables	Office consumables such as tones, paper, batteries, clothing, etc. Medical consumables such as couch rolls, aprons, gloves, blood sample tubes, cannulas, catheter, disposable incontinence, etc.	DEFRA database	£
	Medical equipment	Practice inventory/ auditing	Inventory of medical equipment	Miscellaneous medical equipment (stethoscopes, thermometer, pentorch, electrical equipment and machinery, electrical items)	DEFRA database	£
	Non-medical equipment	Practice inventory/ auditing	Inventory of non-medical equipment	Computers, trolleys, beds, metal equipment, pillows, etc.	DEFRA database	£
	Pharmaceuticals	Practice inventory/ auditing	Annual consumption	Injectables, fluids, tablets, creams, nebulizers, inhalers, eyedrops, etc.	DEFRA database	£
	Transport	Survey	Survey to patients, relatives, and staff. Mean of transport and distance	Transport of patients, relatives and staff. Includes means of transport such as active transport, carrs by size (small, medium and large) and combustible (petrol, diesel, LPG, hybrids and electrics), motorbikes and public transport (bus, tube and train)	DEFRA database	Km
	Waste	Invoicing and billing, Practice inventory/ auditing	Inventory of waste	Recycling, domestic, non-infectious offensive, infectious, clinical, anatomical, and medicinal waste	Rizan *et al.*(16)	Kg
	Water	Practice inventory/ auditing, Water meters	Annual consumption(*)	Water consumption	DEFRA database	m^3

(*) If data not available specifically (sub-metered) for the department, total use for the hospital will be divided by the sqm of the department; **(**)** Department for Environment, Food & Rural Affairs (DEFRA).

loping these assessment tools to meet national reduction targets. Furthermore, carbon footprint calculators could lead to positive actions such as establishing key priorities, changing behaviours, recognising the benefit of action, and influencing others to carry out green initiatives. Health service for the climate (*Sanidad por el clima* in Spanish) is a platform that was created as a result of COP25 in 2019 and that has recently developed a free carbon footprint assessment tool for healthcare organisations in Spain (22). Their assessment tool incorporates similar categories that our assessment too, however, leaves out some other categories such as medical equipment and consumables that we considered important in our study. Nevertheless, their assessment tool is designed to help organisations as a whole and hence, it is not adapted to a more detailed service such as Accident and Emergency. Other calculators such as the one proposed by the Ecologic Transition and Demographic Challenge ministry (Spain) facilitate the calculation of scope 1 and 2 emissions, however it does not calculate scope 3, which it is considered of great relevance in the development of local initiatives within healthcare professionals (23).

Local initiatives have proven the potential of significant impact in the reduction of carbon emissions in EDs. A multidisciplinary team carried out a project to reduce unnecessary cannulation in an ED at Charing Cross Hospital in London (24). A baseline audit revealed that 86 per cent of the patients attending ED were cannulated and 40 per cent of those were not used. The team led a project to educate, raise awareness and encourage staff to change behaviour towards unnecessary cannulation, highlighting the cost and environmental impact of those actions. A follow-up audit showed a 25 per cent reduction of cannulation in ED, suggesting a potential reduction of 19,000 kg/CO_2 per year and saving around £95,000. Furthermore, Manchester University NHS Foundation Trust, which sees about 2 million visitors per year and employs over 20,000 staff, carried out a sustainable travel programme to encourage people to use more sustainable and active travel options (25). The programme focused on increasing bus use, reducing single-occupancy car journeys, and increasing walking and cycling as method of active transport. To accomplish these targets, the trust improved their infrastructure with more cycle parking spaces and extra electric vehicles charging points and offered discount schemes for travelling amongst other initiatives. These measures resulted in a 40 per cent increase of more sustainable transport use amongst the staff in the trust.

Similar initiatives have also been developed in Spain. Infanta Elena hospital in Huelva reduced their GHG emissions 36 per cent, from 3,070 tonnes of CO_2eq in 2019 to 1,130 CO_2eq in 2020, thanks to a campaign to improve the management of fuels. Petrol boilers were replaced by natural gas, which has a coefficient of less than 40 per cent. Furthermore, there was a 13 per cent reduction in natural gas consumption for heating and hot water as consequence of responsible use, adapted to the time of the day and needs of the service, and the isolation of windows and doors to preserve better the temperature (26). In 2021, Gregorio Maranon hospital in Madrid launched a sustainable management plan to reduced single use plastics, eliminating the purchase of plastic tableware and replacing it with biodegradable materials. This resulted in a reduction of 217,000 straws, 21,700 trays, 668,200 spoons, 102,300 knives, 139,900 forks, 229,300 plates and 256,550 cups. Furthermore, the bin bags wereare made from 100 per cent recycled material (27).

The limitations of the current study include, first of all, the estimations in the calculation of carbon emissions in some of the categories that could influence the obtained results. The consumption of energy and heating, electricity or water could not be collected through direct meter readings, which might affect the calculated carbon footprint. Furthermore, the research team acknowledged that the bottom up LCA approach would provide more accurate data, especially for categories such as consumables and pharmaceuticals, however, this methodology is not feasible for some of the categories in this study. Equally, there is possible uncertainty associated with the reliability of the conversion factors. In relation to the data regarding transportation of patient, since it is collected through a survey completed by the users, it must be recognised that there is bias associated with the representativeness of the sample, and the information provided.

As a conclusion, our research team proposes a comprehensive carbon footprint assessment tool for EDs. This initiative highlights the importance of assessing carbon emissions in healthcare units in order to carry out environmental initiatives in line with the UN sustainability goals and national net zero policies. This tool is the first carbon footprint assessment tool specifically for EDs, available for free access. Its use will allow EDs to calculate their carbon footprint in a standardised and efficient manner. Furthermore, the use of this tool can lead to raised awareness, increase climate resilience, and promote climate action by patients and staff. This study facilitates the production of robust evidence to back up environmental initiatives and presents an opportunity for further research.

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REVISTA ESPAÑOLA DE SALUD PÚBLICA

Volumen 97
2/6/2023

Impacto medioambiental de los servicios de Urgencias en la Salud Pública: una herramienta de valoración

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ORIGINAL

Recibido: 12/4/2023
Aceptado: 7/5/2023
Publicado: 2/6/2023

e202306044es

e1-e11

Carbon footprinting the Emergency Departments in the United Kingdom: an assessment tool

Los autores declaran que no existe ningún conflicto de intereses

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CITA SUGERIDA

Rodríguez-Jiménez L, Romero-Martín M, Gómez-Salgado J. Impacto medioambiental de los servicios de Urgencias en la Salud Pública: una herramienta de valoración. Rev Esp Salud Pública. 2023; 97: 2 de junio e202306044es.

RESUMEN

FUNDAMENTOS // El cambio climático está directamente relacionado con el aumento de ciertas patologías como enfermedades cardiovasculares, respiratorias y/o infecciosas, así como con la desnutrición, provocada por la reducción de los alimentos disponibles, y el deterioro de la salud mental. La evidencia ha señalado que los servicios sanitarios son responsables del 4%-5% de las emisiones de gases efecto invernadero en todo el mundo. El objetivo de este estudio fue diseñar una herramienta de evaluación de la huella de carbono de los servicios de Urgencias.

MÉTODOS // Se diseñó la herramienta a través de cinco etapas. En primer lugar, se seleccionaron las categorías a incluir en la herramienta desde una revisión de la literatura. Posteriormente, se determinaron el alcance y límites, se seleccionaron los factores de conversión, se recopilaron datos del servicio de Urgencias del *Royal Free Hospital* de Londres como sitio piloto y se seleccionó el método de cálculo de la huella de carbono.

RESULTADOS // La herramienta resultante se dividió en tres ámbitos, y cada ámbito en una o más categorías que contienen varios elementos. Los datos se recopilaron de diferentes fuentes, como facturación, medidores, auditorías y encuestas. La herramienta se presentó en un documento de *Microsoft Excel*.

CONCLUSIONES // Esta herramienta de evaluación de carbono ofrece una oportunidad para monitorear las emisiones de carbono en los servicios de Urgencias. Pretende proporcionar una valoración de la huella de carbono de referencia, identificando puntos críticos de emisión dentro del servicio, que puede dar lugar a iniciativas ambientales locales.

PALABRAS CLAVE // Huella de carbono; Emisiones de gases efecto invernadero; Servicios de Urgencias; Evaluación del ciclo de vida; Impacto medioambiental.

ABSTRACT

BACKGROUND // Climate change is directly related to increasing medical conditions such as cardiovascular, respiratory and/or infectious diseases, as well as malnutrition and mental illness caused by the reduction of available food and the growth of situations with significant emotional impact, respectively. Evidence showed that healthcare services are responsible for 4-5% of the greenhouse gas emissions worldwide. The aim of this study is the development of an assessment tool to evaluate the carbon footprint of emergency departments.

METHODS // The development of the proposed assessment tool followed five stages. Firstly, the categories of GHGs to be included in the assessment tool were determined through a literature review. This was followed by establishment of scopes and boundaries, selection of conversion factors, collection of data from the Emergency Department at the Royal Free Hospital in London as a pilot site, and finally, the development of methodology to assess the carbon footprint.

RESULTS // The assessment tool was divided in three scopes and each scope included one or more categories containing several items. Data was collected from different sources such as meters invoicing and billing, auditing, and surveys. The tool is presented in a *Microsoft Excel* document.

CONCLUSIONS // This carbon assessment tool offers an opportunity to monitor carbon emissions in emergency departments, aiming to proliferate environmental strategies. The assessment tool seeks to provide a baseline carbon footprint assessment, identifying carbon hotspots within the department. The identification of these areas of intensive carbon emissions can help guide and focus local environmental initiatives that later can be monitored with a follow-up assessment to evaluate their effectiveness.

KEYWORDS // Carbon footprint; Greenhouse gases emissions; Emergency departments; Life cycle assessment; Environmental impact.

INTRODUCCIÓN

EL CAMBIO CLIMÁTICO SE PUEDE DEFINIR como el cambio en las temperaturas y los patrones climáticos consecuencia del aumento de las emisiones de gases de efecto invernadero liberadas por la actividad humana a la atmósfera **(1)**. Los Gases de Efecto Invernadero (GEI) son aquellos que contribuyen a retener el calor dentro de la atmósfera terrestre provocando el calentamiento global y cambiando el clima de la Tierra, lo que se denomina efecto invernadero **(2)**. El aumento de la temperatura global conduce a condiciones climáticas extremas, como olas de calor, inundaciones, sequías y/o desastres naturales **(3)**. Además, el cambio climático está directamente relacionado con el aumento de ciertas patologías como enfermedades cardiovasculares, respiratorias y/o infecciosas, así como con la desnutrición, provocada por la reducción de los alimentos disponibles, y el deterioro de la salud mental, como consecuencia del aumento de situaciones de impacto emocional significativo **(4)**. Solo en 2022, 7,6 millones de personas fueron desplazadas en Pakistán a causa de las inundaciones **(5)**. También se observó un aumento del 68% de las muertes relacionadas directamente con el calor, causadas por olas de calor entre 2000 y 2021. El cambio climático favorece también la proliferación y propagación de enfermedades infecciosas como, por ejemplo, el dengue, cuyas condiciones favorables para su propagación han aumentado un 30% en Europa en comparación con datos de la década de 1950. El aumento de las temperaturas también está causando el adelanto de la época floral, comparado con datos de hace cuarenta años, y, por tanto, aumentando los alérgenos y las alergias, lo cual afecta actualmente a un 40% de la población mundial **(6)**. El impacto del cambio climático en la salud de las personas ya es perceptible y se espera que aumente en los próximos años.

Según el *Acuerdo de París* de 2015, los GEI son: dióxido de carbono (CO_2); metano (CH_4); óxido nitroso (N_2O); hidrofluorocarbonos (HFC); perfluorocarbonos (PFC); hexafluoruro de azufre (SF_6); y trifluoruro de nitrógeno (NF_3). El CO_2 representa el 86% de los GEI; por eso, en la literatura, incluido este documento, el término *huella de carbono* hace referencia a las emisiones de gases de efecto invernadero, aunque incluye al resto de todos los GEI **(7)**. La huella de carbono se puede definir como la mejor estimación posible de las emisiones de GEI producidas por la actividad humana **(8)**. Los GEI se clasifican en emisiones directas (aquellas sobre las que una persona u organización tiene el control directo) y emisiones indirectas (aquellas relacionadas con la actividad de la persona u organización, pero en las que no se tiene control de la fuente). Según el *Greenhouse Protocol* **(9)**, las emisiones de GEI se pueden dividir en tres alcances:

– Alcance 1: incluye las emisiones directas producidas por la organización, por ejemplo, las emisiones consecuencia del uso de combustible para calefacción, del uso de gases anestésicos y/o del transporte de mercancías.

– Alcance 2: incluye las emisiones indirectas producidas por la electricidad que se ha producido en otro lugar y que están fuera del control de la organización.

– Alcance 3: incluye el resto de las emisiones indirectas, que son principalmente las relacionadas con la cadena de suministro, y sobre las que la organización no tiene control directo.

El análisis de la huella de carbono puede seguir principalmente tres metodologías: evaluación del ciclo de abajo hacia arriba; evaluación del ciclo de arriba hacia abajo (o análisis económico de entradas y salidas); y la combinación de los dos métodos anteriores, también conocido como modelo híbrido **(10)**. La evaluación del ciclo de abajo hacia arriba consiste en el análisis de las emisiones de carbono atribuidas a cada elemento de un artículo, y se convierten en equivalente de carbono utilizando un factor de conversión. La evaluación del ciclo de arriba hacia abajo o el modelo económico utiliza el dinero gastado en cada artículo, y esto se multiplica por un factor de conversión. Y el modelo híbrido combina ambos modelos. Para el cálculo de la huella de carbono de una organización se realiza una estimación aproximada. Es preciso cuantificar la actividad generadora de las emisiones y multiplicar por un factor de conversión, que representa la cantidad de GEI emitidos por cada unidad de actividad. La unidad de medida de la huella de carbono es el CO_2eq (equivalente de CO_2), tomándose este gas como referencia por ser el que más influye en el calentamiento global **(11)**.

La evidencia ha revelado que los sistemas sanitarios son responsables del 4%-5% de las emisiones de GEI en todo el mundo **(12)**. En 2015, los Estados miembros de las Naciones Unidas, ante la crisis del planeta como espacio sostenible para albergar a todas las personas de forma justa e igualitaria, establecieron *17 Objetivos de Desarrollo Sostenible* en 2015 para preservar el planeta y mejorar la vida de todas las personas, y anticiparon alcanzarlos para 2030 **(13)**. Estos Objetivos de Desarrollo Sostenible incluyen, entre otros: hambre cero; buena salud y bienestar; agua limpia y saneamiento; energía limpia y asequible; ciudades y comunidades sostenibles; y acción climática. Los Objetivos de Desarrollo Sostenible están interrelacionados y configuran una estrategia global, ya que, por ejemplo, los objetivos de reducir las enfermedades tropicales o reducir las muertes y enfermedades debidas a productos químicos peligrosos y a la contaminación, así como la contaminación del aire, el agua y el suelo, están relacionados con la acción climática. Los objetivos de la acción climática tienen como meta fortalecer la resiliencia climática, integrar las medidas contra el cambio climático en las políticas, estrategias y planificaciones nacionales, mejorar la educación y crear conciencia, crear un Fondo Verde para el Clima y promover el cambio relacionado con el clima.

El Servicio Nacional de Salud (NHS) del Reino Unido fue el primer sistema de salud en introducir políticas de emisiones de CO_2 en la legislación, con el objetivo de reducir sus emisiones netas de carbono a cero para 2040 **(14)**. Además, los informes del Panel Intergubernamental sobre el Cambio Climático (IPCC) destacan la importancia de las iniciativas regionales y locales para reducir las emisiones de carbono **(15)**. Las iniciativas sostenibles locales en materia de salud pueden tener un impacto significativo en la reducción de las emisiones de carbono y producir un efecto de bola de nieve en otros servicios de salud; sin embargo, se necesita evidencia para respaldar esas iniciativas **(8)**. El proyecto *Green Emergency Department* (Green ED) es una iniciativa liderada por el *Royal College of Emergency Medicine* (RCEM) con el objetivo de reducir las emisiones de gases de efecto invernadero derivadas de la actividad asistencial en los servicios de Urgencias.

El desarrollo de herramientas para evaluar la huella de carbono de los servicios sanitarios ayuda a proporcionar evidencia del impacto ambiental de su actividad y facilita la identificación de áreas de emisiones crítica para reducir la huella de carbono. El objetivo de este estudio fue diseñar una herramienta de evaluación de la huella de carbono de los servicios de Urgencias.

MATERIAL Y MÉTODOS

LA METODOLOGÍA PARA DESARROLLAR LA herramienta de evaluación de la huella de carbono de los servicios de Urgencias siguió los siguientes pasos:

– Selección de las categorías incluidas en la herramienta de valoración, a través de una revisión de la literatura.

– Determinación de alcances y límites.

– Selección de factores de conversión.

– Recogida de datos.

– Método de evaluación de la huella de carbono.

Selección de categorías. En primer lugar, el equipo de investigación realizó una revisión de la literatura para identificar las categorías más comunes analizadas previamente en los documentos de evaluación de la huella de carbono en el campo de la salud. La revisión bibliográfica se condujo utilizando las bases de datos de *Medline*, *Web of Science*, *CINAHL* y *Cochrane*, con las palabras claves: *huella de carbono, gases de efecto invernadero, evaluaciones de ciclo de vida* y *salud*. Dicha revisión reveló que las categorías analizadas en los estudios seleccionados fueron: energía y calefacción; gases anestésicos; transporte de mercancía; consumo eléctrico; *catering* y alimentos; desechables y consumibles; equipos médicos y no médicos; productos farmacéuticos; transporte; desechos; y agua. El equipo de investigación consideró que todas estas categorías podrían proporcionar una evaluación integral de la huella de carbono y todas ellas se incluyeron en este estudio, aunque los gases anestésicos y el transporte de mercancías se adaptaron para la realidad de los servicios de Urgencias.

Alcance y límites. La herramienta fue diseñada para el periodo de tiempo que el usuario considere oportuno para su medición. Las premisas para el empleo de esta herramienta en un servicio de Urgencias incluyen todas las áreas en las que se brinde atención de emergencia (como sala de espera, zona de *boxes* y/o *box* de críticos) para adultos y/o pacientes pediátricos. También se incluyó el departamento de radiología compartido o utilizado exclusivamente por el servicio de Urgencias. Además, se incluyeron las oficinas de administración que se encuentran dentro de las instalaciones de Urgencias y que forman parte de su gestión y funcionalidad. Este estudio no incluyó la infraestructura de edificios, los servicios de apoyo (como servicios financieros u otros servicios administrativos) y otros servicios de diagnóstico (como laboratorios o departamentos de imágenes, los departamentos de medicina nuclear o ultrasonido). Otros servicios, como los servicios de ambulancia, se incluyeron como método de transporte; sin embargo, no se incluyó la huella de carbono originada por la actividad mientras el paciente está en la ambulancia (por ejemplo, el uso de desechables). Los servicios de lavandería tampoco fueron incluidos por ser un servicio externo de Urgencias y no disponerse de factores específicos de conversión, lo que hace que los datos sean inaccesibles **(16,17)**.

Selección de factores de conversión. Los factores de emisión utilizados para esta herramienta se basaron en los datos proporcionados por el Departamento de Medio Ambiente, Alimentos y Asuntos Rurales (*DEFRA* en inglés). *DEFRA* proporciona factores de conversión anuales para las organizaciones que informan sobre sus emisiones de GEI. Los datos proporcionados por *DEFRA* son de fácil acceso, los factores de conversión están actualizados y tienen un reconocimiento internacional. La única excepción fue la categoría de residuos, ya que *DEFRA* no proporciona datos específicos para los residuos de los servicios de salud; en este caso, se utilizaron los factores de conversión proporcionados por Rizan *et al.* **(18)**.

Recogida de datos. Las fuentes de datos se identificaron en la revisión bibliográfica previa y el equipo de investigación llevó a cabo una recopilación de datos clave, creando un inventario detallado de todos los artículos incluidos en cada categoría. Se seleccionó el servicio de urgencias del *Royal Free Hospital* de Londres como sitio piloto para la búsqueda y recopilación de datos, la cual fue llevada a cabo entre noviembre de 2022 y febrero del2023. Los datos se recopilaron a través de la observación y los registros hospitalarios. Se utilizó *Microsoft Excel* para *Mac*, Versión 16.25 para la organización de los datos recopilados y los cálculos.

- Energía, calefacción, consumo eléctrico y agua. Los datos sobre energía, calefacción, electricidad y agua generalmente se obtienen de los contadores; sin embargo, los contadores específicos para los servicios de Urgencias rara vez están disponibles. Para esta herramienta de evaluación se siguió el enfoque utilizado por Prasad *et al.* **(19)**, según el cual se multiplica el consumo total del Centro por la superficie del servicio de Urgencias y se divide por la superficie total del Centro. Esta fórmula puede proporcionar una estimación del consumo concreto del servicio y, posteriormente, su huella de carbono. Estos datos se pueden obtener de la empresa proveedora o del equipo de administración gracias a la facturación. El uso específico de energías verdes no se incluyó en la calculadora; sin embargo, el uso de energías verdes se incluye en los factores de conversión proporcionados por *DEFRA*, por lo que el aumento del uso de energías verdes disminuirá el factor de conversión.

- Gases anestésicos. Se observó que los gases anestésicos rara vez se usan en el servicio de Urgencias y, cuando se usan, normalmente los gestiona el equipo de anestesistas en lugar de los médicos de Urgencias. Por lo tanto, esta categoría solo incluía el óxido nitroso y el metoxiflurano, que a menudo se utilizan como anestesia de acción breve.

- Transporte de mercancías. El transporte de mercancías se excluyó de nuestra herramienta de evaluación. Este transporte a menudo está controlado por el Centro en lugar de los departamentos, por lo que el análisis del transporte de mercancías específico para el servicio de Urgencias no fue accesible ni factible para este estudio. Sin embargo, el transporte de pacientes a diferentes servicios dentro de la misma institución si se incluyeron en esta categoría, ya que representan emisiones directas controladas por el propio servicio. El transporte interhospitalario se puede definir en este estudio como el transporte de pacientes entre diferentes centros sanitarios institucionales, por ejemplo, a quienes requieren consultas de especialistas o pruebas diagnósticas que no están disponibles en el Centro propio. Sin embargo, los servicios de ambulancia como medio de transporte para que los pacientes vayan desde su casa o lugar del incidente al hospital se categorizaron como emisiones indirectas y se analizaron en otra categoría.

- Desechables/consumibles y productos farmacéuticos. Los datos de material desechable o fungible y de productos farmacéuticos se pueden obtener de los registros de pedidos del servicio. Los registros del servicio deben incluir los precios de cada artículo y la cantidad de artículos pedidos, ya sea mensual o anualmente. Debido a la gran cantidad de elementos para estas dos categorías, los autores aplicaron un enfoque de arriba hacia abajo para estas dos categorías. Además, se excluyeron los medicamentos de escaso uso y cuyo precio fuera inferior a una libra esterlina. Dado que su contribución a la huella de carbono sería poco relevante, para agilizar el cálculo se decidió rechazar su contribución y excluirlos.

- Equipamiento médico y no médico. El equipamiento médico incluyó una lista completa de equipamientos utilizados en la sala de Urgencias, como monitores, termómetros o ultrasonidos. La lista de equipamientos médicos se puede obtener del inventario del servicio o por observación directa. En el diseño de la herramienta se incluyeron todos los artículos médicos inventariados por el departamento de dispositivos médicos. Además, se incluyó información del fabricante sobre la vida media de cada artículo.

Los equipamientos no médicos incluidos en esta herramienta de evaluación fueron papel, bolígrafos, computadoras e impresoras. Una auditoría realizada mostró que ▶

estos artículos eran los más utilizados en Urgencias y, por lo tanto, fueron seleccionados para esta categoría.

– Transporte de pacientes y personal. Los datos sobre el transporte de pacientes se pueden recopilar a través de una encuesta. La encuesta debe ofrecer una lista completa de métodos de transporte y la distancia recorrida por el paciente por viaje desde el punto de origen del individuo hasta el servicio de Urgencias, el cual el paciente debe rellenar. La lista de métodos de transporte incluyó transporte activo, coches de diferente tamaño (pequeño, mediano y grande) y combustible (petróleo, diésel, gas natural, híbridos y eléctricos), motocicletas y transporte público (autobús, metro y tren). La encuesta es anónima y de participación voluntaria e incluye las millas entre la casa del paciente o el lugar del incidente por viaje y el medio de transporte. Se recogerán datos durante un período de dos semanas y se hacen estimaciones para un período de un año. En cuanto al personal, se lleva a cabo una auditoría que incluye el número de personal a tiempo completo y parcial, el kilometraje por viaje y el método de transporte. *DEFRA* proporciona una lista completa de factores de conversión para cada milla recorrida en diferentes métodos de transporte, tales como viaje en tren, autobús, motocicleta, coche diésel regular o de gasolina entre otros.

– Comida y *catering*. El número de comidas servidas en el servicio de Urgencias se puede calcular a través de la observación directa. *DEFRA* proporciona factores de conversión para alimentos y bebidas según el peso y el costo. Nuestra herramienta de evaluación proporciona cálculos basados en el peso por comida servida. Además, se incluyeron varios elementos de *catering*. Esta herramienta de evaluación no diferencia entre comidas vegetarianas y no vegetarianas, y esta se considera una de las limitaciones.

– Residuos. Los cálculos de desechos incluyeron residuos reciclables, domésticos, biosanitarios sin riesgo de infección, biosanitatios con riesgo de infección, de medicamentos, de instrumental sanitario y baterías. Se pueden recolectar datos a través de la auditoría en un período de tiempo, obteniendo el peso de cada tipo de residuo. Como se mencionó anteriormente, *DEFRA* no proporciona estos factores de conversión específicos; por lo tanto, se utilizaron los factores de conversión proporcionados por Rizan *et al.* **(18)**. Estos autores llevaron a cabo una evaluación de la huella de carbono causada por los residuos de tres hospitales del Reino Unido, elaborando a través de los datos obtenidos una lista de factores de conversión para residuos producidos por la actividad sanitaria. Incluyeron en su estudio el transporte de residuos del hospital a la planta de manejo de residuos, la energía y agua empleada para el procesamiento de residuos, así como las emisiones directas. El procesamiento de residuos fue dividido en tres grupos: autoclaves esterilizadores a vapor; tratamiento térmico; de incineración y reciclaje.

Método de evaluación de la huella de carbono. Nuestra herramienta de evaluación utilizó el método híbrido para cuantificar la huella de carbono de los servicios de Urgencias, combinando evaluaciones de ciclo de vida de abajo hacia arriba y de arriba hacia abajo, según la disponibilidad y accesibilidad a los datos recopilados. La evaluación de las emisiones de carbono relacionadas con la energía y la calefacción, los gases anestésicos, la electricidad, la restauración y la alimentación, el transporte, los residuos y el agua se calcularon mediante un enfoque ascendente, mientras que para el resto se aplicó un modelo financiero o descendente.

RESULTADOS

NUESTRA PROPUESTA DE HERRAMIENTA de evaluación de la huella de carbono para los servicios de urgencias se dividió en tres alcances, y cada alcance en una o más categorías que contienen varios elementos **[Tabla 1]**. Las categorías seleccionadas fueron: energía y calefacción; gases anestésicos; transporte interhospitalario de pacientes; consumo eléctrico; restauración y alimentación; residuos; consumibles; equipamiento médico y no médico; fármacos; transporte; residuos; y consumo de agua.

Tabla 1
Contenidos de la Herramienta de valoración de la huella de carbono para los servicios de Urgencias.

Alcance	Categorías	Fuente de datos	Datos clave	Ejemplos de datos recogidos	Factores de conversión	Unidad
1	Energía y calefacción	Facturación, Contadores	Consumo anual(*)	Gas natural, queroseno, gas propano y carbón	Base de datos *DEFRA*(**)	Litros, kWh
	Gases anestésicos	Facturación	Consumo anual	Óxido nitroso y metoxiflurano	Base de datos *DEFRA*	£
	Transporte de mercancías	Auditoría		Transporte de pacientes entre diferentes centros sanitarios institucionales	Base de datos *DEFRA*	
2	Electricidad	Facturación, Contadores	Consumo anual(*)	Uso o gasto de electricidad	Base de datos *DEFRA*	kWh
3	Comida y *catering*	Auditoría	Número de menús servido por paciente	Menús, sándwiches, leche, fruta, galletas, etc.	Base de datos *DEFRA*	Kg
	Fungibles y consumibles	Auditoría	Inventario de desechables y consumibles	Consumibles de oficina como cartuchos, papel, baterías, etc. Consumibles médicos como rollos de papel, delantales, guantes, tubos de analítica, vías, sondas vesicales, escupideras, etc.	Base de datos *DEFRA*	£
	Equipamiento médico	Auditoría	Inventario de equipo médico	Fonendoscopio, termómetro, linternas, equipo eléctrico, etc.	Base de datos *DEFRA*	£
	Equipamiento no médico	Auditoría	Inventario de equipo no médico	Ordenadores, camas, camillas, bandejas, almohadas, etc.	Base de datos *DEFRA*	£
	Productos farmacéuticos	Auditoría	Consumo anual	Inyectables, fluidos, pastillas cremas, nebulizadores, inhaladores, gotas, etc.	Base de datos *DEFRA*	£
	Transporte de pacientes y personal	Encuesta	Encuesta a pacientes, familiares y personal, incluyendo medio de transporte y distancia recorrida	Transporte de pacientes, familiares y personal. Métodos de transporte incluye transporte activo, coches de diferente tamaño (pequeño, mediano y grande) y combustible (petróleo, diésel, gas natural, híbridos y eléctricos), motocicletas, y transporte público (autobús, metro y tren)	Base de datos *DEFRA*	Km
	Residuos	Facturación, Auditoría	Inventario de residuos	Residuos reciclables, domésticos, biosanitarios sin riesgo de infección, biosanitatios con riesgo de infección, de medicamentos, de instrumental sanitario y baterías	Rizan *et al.*[16]	Kg
	Agua	Auditoría Contadores	Consumo anual(*)	Consumo de agua	Base de datos *DEFRA*	m^3

(*) Si no hay contadores específicos para el departamento de Urgencias, se calcula el uso del departamento dividiéndolo por el uso total del hospital; **(**)** *Department for Environment, Food & Rural Affairs (DEFRA).*

Los datos se recopilan a través de cuatro fuentes diferentes: medidores (por ejemplo, contador eléctrico o de agua); facturación; auditoría; y encuesta. La recopilación de datos clave se obtiene de cada categoría durante un período de un año. Se hacen estimaciones en las categorías de energía, calefacción, electricidad y agua cuando los medidores específicos no están disponibles; sin embargo, el usuario de la herramienta puede introducir valores exactos, en caso de estar disponibles. Además, se propone auditar las categorías de restauración y alimentación, y los residuos se auditan durante una semana y se estiman los valores anuales de ese cálculo.

La herramienta se presenta en un documento de *Microsoft Excel*. El usuario puede navegar por el documento e introducir la cantidad requerida para cada artículo cuando esté disponible. La cantidad introducida se multiplica por un factor de conversión que origina la cantidad de emisiones de carbono. La mayoría de los datos se pueden obtener directamente del servicio; sin embargo, hay algunos datos sobre el uso de energía, electricidad y agua que probablemente deban obtenerse del departamento de gestión.

DISCUSIÓN

ESTA HERRAMIENTA DE EVALUACIÓN DE carbono ofrece la oportunidad de monitorear las emisiones de carbono en los servicios de Urgencias, con el objetivo de desarrollar estrategias ambientales de reducción de emisiones. La herramienta pretende proporcionar una evaluación de la huella de carbono de referencia, identificando puntos críticos de emisiones dentro del servicio. La identificación de áreas de altas emisiones de carbono puede dar lugar a iniciativas ambientales locales que luego se pueden monitorear con una evaluación de seguimiento para evaluar su efectividad. El desarrollo de dicha herramienta no solo es beneficioso para los servicios de Urgencias, sino que puede incentivar la creación de herramientas similares en otros ámbitos de los servicios sanitarios. De este modo, se fomenta la perspectiva verde, entendida como un enfoque transversal que considera todos los factores ambientales de las organizaciones en favor del desarrollo sostenible (20).

Nuestro estudio es similar al realizado previamente por Sawyer, quien desarrolló una calculadora para valorar las emisiones de GEI asociadas a la práctica asistencial de los médicos de familia en el Reino Unido (21). Esta herramienta dividió la huella de carbono en tres áreas: operativa (incluido el uso de energía, viajes, servicios profesionales y otras actividades como compras, consumibles médicos y de oficina, agua y residuos); investigaciones; y huella farmacéutica. Sawyer destacó la importancia de desarrollar estas herramientas de evaluación para cumplir con los objetivos nacionales de reducción de emisiones de carbono. Además, las calculadoras de huella de carbono podrían conducir a acciones positivas, como establecer prioridades clave, cambiar comportamientos, reconocer el beneficio de la acción e influir en otros para llevar a cabo iniciativas ecológicas. *Sanidad por el clima* es una plataforma que nació a raíz de la *Conferencia de las Naciones Unidas sobre Cambio Climático de 2019* (COP25) y que recientemente ha desarrollado una herramienta gratuita de evaluación de la huella de carbono para las organizaciones sanitarias en España (22). Esta herramienta de evaluación incorpora categorías similares a las del presente estudio; sin embargo, omite otras categorías, como equipamientos médicos y consumibles. Además, está diseñada para ayudar a las organizaciones en su conjunto y, por lo tanto, no se adapta a los datos más detallados de un servicio especializado como el de Urgencias. Otras calculadoras, como las propuestas por el Ministerio para la Transición Ecológica y el Reto Demográfico, han sido diseñadas para otros ámbitos diferentes del sanitario, por lo que no son sensibles a las particularidades de esta área. Además, facilitan el cálculo de emisiones de alcance uno y dos, pero no calcula el alcance tres, el cual es considerado de gran relevancia a la hora de proponer iniciativas locales por parte de los profesionales sanitarios (23).

Las iniciativas locales han demostrado el potencial de impacto significativo en la reducción de las emisiones de carbono en los servicios de Urgencias. Un equipo multidisciplinario llevó a cabo un proyecto para reducir el número de canulaciones venosas periféricas innecesarias en el servicio de Urgencias del *Charing Cross Hospital* de Londres (24). Una auditoría interna de referencia reveló que el 86% de los pacientes que acudían al servicio de Urgencias fueron canulados y el 40% de estos no fueron usados. El equipo dirigió un proyecto para educar, concienciar y alentar al personal a cambiar el comportamiento hacia la canulación innecesaria, destacando el costo y el impacto ambiental de esas acciones. Una auditoría de seguimiento mostró una reducción del 25% en la canulación en el servicio de Urgencias, lo que sugiere una reducción potencial de 19.000 kg de CO_2 al año y un ahorro de alrededor de 95.000 libras esterlinas. Por otro lado, el complejo hospitalario *Manchester University NHS Foundation Trust*, que recibe alrededor de dos millones de visitantes por año y emplea a más de 20.000 empleados, llevó a cabo un programa de viajes sostenibles para alentar a las personas a utilizar opciones de viaje con menor impacto medioambiental (25). El programa se centró en aumentar el uso de autobuses, reducir los viajes en automóviles de un solo ocupante y aumentar los desplazamientos a pie y en bicicleta como método de transporte activo. Para lograr estos objetivos se mejoró la infraestructura con más estacionamientos para bicicletas y puntos de carga adicionales para vehículos eléctricos, y se ofrecieron descuentos para el transporte, entre otras iniciativas. Estas medidas dieron como resultado un aumento del 40% en el uso de un transporte más sostenible entre el personal sanitario.

En España también se han desarrollado iniciativas similares. El Hospital Infanta Elena de Huelva consiguió reducir un 36% las emisiones de GEI, pasando de 3.070 toneladas de CO_2eq en 2019 a 1.130 toneladas de CO_2eq en 2020, gracias a una campaña de mejora de la gestión de combustibles. Se renovaron las calderas para sustituir el gasóleo C como fuente energética por gas natural, con un coeficiente de emisión 40% menor. Además, se redujo el consumo de gas natural empleado en la calefacción y agua caliente en un 13% como consecuencia de un uso responsable, adaptándola al momento del día y a las necesidades reales del Centro, así como al aislamiento de las ventanas y cierres para conservar mejor la temperatura (26). En 2021 el hospital Gregorio Marañón de Madrid puso en marcha un plan de gestión sostenible de plásticos de un solo uso, eliminando la compra de menaje de plástico y sustituyéndolo por menaje de material compostable. Esto supuso una reducción de 217.000 pajitas, 21.700 bandejas, 668.200 cucharas, 102.300 cuchillos, 139.900 tenedores, 229.300 platos y 256.550 vasos. Además, las bolsas de residuos son de material 100% recicladas (27).

Las limitaciones del presente estudio incluyen, en primer lugar, que la estimación en el cálculo de las emisiones en algunas categorías puede influir en los resultados obtenidos. El consumo de energía y de calefacción, electricidad o agua no se pudieron recoger mediante lecturas directas de contadores, lo que podría afectar a la huella de carbono calculada. Además, el equipo de investigación reconoce que el enfoque de abajo hacia arriba proporcionaría datos más precisos, especialmente para categorías como consumibles y productos farmacéuticos; sin embargo, esta metodología no fue factible para algunas de las categorías de este estudio. Igualmente, se deben reconocer las posibles imprecisiones asociadas a la fiabilidad de los factores de conversión. En relación con los datos relacionados con el transporte de pacientes, al ser recogidos mediante consulta directa con una encuesta autocompletada, se deben reconocer también los sesgos asociados a la representatividad de la muestra y el sesgo de información.

A modo de conclusión, nuestro equipo de investigación propone una herramienta integral de evaluación de la huella de carbono para los servicios de Urgencias. Esta iniciativa destaca la importancia de evaluar las emisiones de carbono de las unidades asistenciales sanitarias para llevar a cabo iniciativas ambientales en línea con los objetivos sostenibles de la ONU y las políticas nacionales de cero emisiones. Esta herramienta es la primera herramienta de evaluación de la huella de carbono específicamente adaptada a la realidad de los servicios de Urgencias disponible de acceso gratuito. Su empleo permitirá a dichos servicios calcular su huella de carbono de forma estándar y más eficiente. Además, el uso de esta herramienta puede generar conciencia, aumentar la resiliencia climática y promover la acción climática entre los pacientes y el personal. Este estudio facilita la producción de la evidencia sólida requerida para respaldar las iniciativas ambientales y representa una oportunidad para futuras investigaciones.

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Para : Macarena Romero-Martin <macarena.romero@denf.uhu.es>
Responder a : Medicine <medicine@wolterskluwer.com>

CC: "Lucas Rodríguez-Jiménez" lucas.rodriguezjimenez@nhs.net, "Juan Gómez-Salgado" jgsalgad@gmail.com

ACCEPTANCE NOTIFICATION

RE: MD-D-24-09488R1, entitled "The Emergency Department carbon footprint calculator: design and validation."

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Appendix IV. Permissions.

Royal Free London
NHS Foundation Trust

Royal Free Hospital
Pond Street
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NW3 2QG

Tel: 020 3758 2000

12 June 2024

To whom it may concern,

This is to certify that Mr. Lucas Rodriguez Jimenez is authorised by me in the capacity of Clinical Lead for the Emergency Department, to carry out research activities whilst working at the Royal Free Hospital.

These research activities included the design and validation of the carbon footprint calculator between October 2022 and November 2023 (inclusive).

This document should serve as a record and take timely effect where appropriate.

Yours sincerely,

Mr Nishal P. Amin *BSc, MRCS, FRCEM*

Consultant in Emergency Medicine.
ED Service Line Lead & Trust Trauma Director
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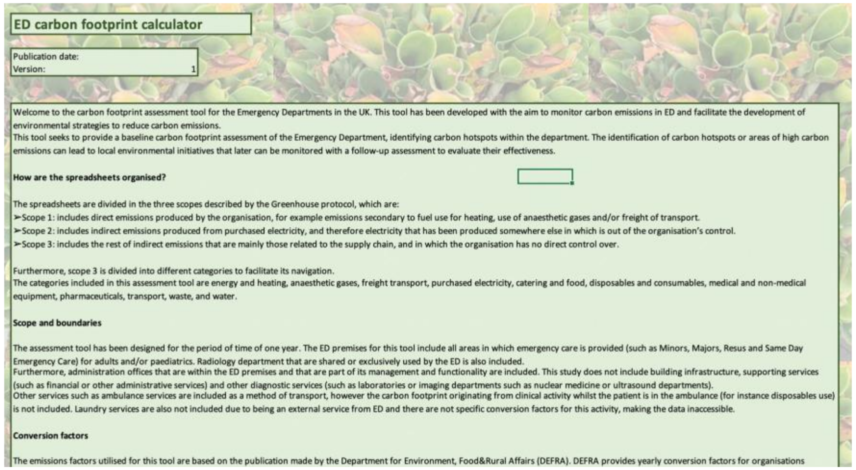
London 12 June 2024

Appendix V. ED Carbon Footprint Calculator. Demo.



ED carbon footprint calculator

Publication date:
Version: 1

Welcome to the carbon footprint assessment tool for the Emergency Departments in the UK. This tool has been developed with the aim to monitor carbon emissions in ED and facilitate the development of environmental strategies to reduce carbon emissions.
This tool seeks to provide a baseline carbon footprint assessment of the Emergency Department, identifying carbon hotspots within the department. The identification of carbon hotspots or areas of high carbon emissions can lead to local environmental initiatives that later can be monitored with a follow-up assessment to evaluate their effectiveness.

How are the spreadsheets organised?

The spreadsheets are divided in the three scopes described by the Greenhouse protocol, which are:
➢Scope 1: includes direct emissions produced by the organisation, for example emissions secondary to fuel use for heating, use of anaesthetic gases and/or freight of transport.
➢Scope 2: includes indirect emissions produced from purchased electricity, and therefore electricity that has been produced somewhere else in which is out of the organisation's control.
➢Scope 3: includes the rest of indirect emissions that are mainly those related to the supply chain, and in which the organisation has no direct control over.

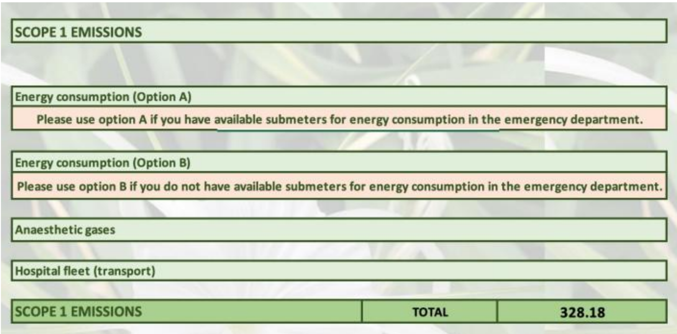
Furthermore, scope 3 is divided into different categories to facilitate its navigation.
The categories included in this assessment tool are energy and heating, anaesthetic gases, freight transport, purchased electricity, catering and food, disposables and consumables, medical and non-medical equipment, pharmaceuticals, transport, waste, and water.

Scope and boundaries

The assessment tool has been designed for the period of time of one year. The ED premises for this tool include all areas in which emergency care is provided (such as Minors, Majors, Resus and Same Day Emergency Care) for adults and/or paediatrics. Radiology department that are shared or exclusively used by the ED is also included.
Furthermore, administration offices that are within the ED premises and that are part of its management and functionality are included. This study does not include building infrastructure, supporting services (such as financial or other administrative services) and other diagnostic services (such as laboratories or imaging departments such as nuclear medicine or ultrasound departments).
Other services such as ambulance services are included as a method of transport, however the carbon footprint originating from clinical activity whilst the patient is in the ambulance (for instance disposables use) is not included. Laundry services are also not included due to being an external service from ED and there are not specific conversion factors for this activity, making the data inaccessible.

Conversion factors

The emissions factors utilised for this tool are based on the publication made by the Department for Environment, Food&Rural Affairs (DEFRA). DEFRA provides yearly conversion factors for organisations



SCOPE 1 EMISSIONS

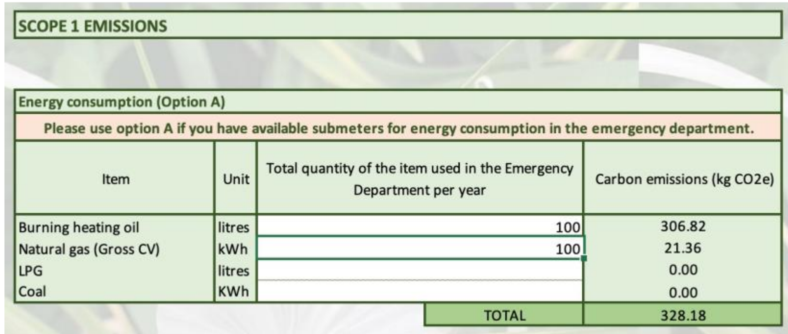
Energy consumption (Option A)
Please use option A if you have available submeters for energy consumption in the emergency department.

Energy consumption (Option B)
Please use option B if you do not have available submeters for energy consumption in the emergency department.

Anaesthetic gases

Hospital fleet (transport)

SCOPE 1 EMISSIONS	TOTAL	328.18



SCOPE 1 EMISSIONS

Energy consumption (Option A)
Please use option A if you have available submeters for energy consumption in the emergency department.

Item	Unit	Total quantity of the item used in the Emergency Department per year	Carbon emissions (kg CO2e)
Burning heating oil	litres	100	306.82
Natural gas (Gross CV)	kWh	100	21.36
LPG	litres		0.00
Coal	KWh		0.00
		TOTAL	328.18

SCOPE 3 EMISSIONS - DISPOSABLES/ CONSUMABLES		
Disposables/consumables (Option A)		
Please use option A if you would like to measure this category item by item.		
Disposables/consumables (Option B)		
Please use option B if you would like to measure this category based on the total expenditure.		
SCOPE 3 EMISSIONS - DISPOSABLES/ CONSUMABLES	TOTAL	0.00

SCOPE 3 EMISSIONS - DISPOSABLES/ CONSUMABLES
Disposables/consumables (Option A)
Please use option A if you would like to measure this category item by item.
Airway (Includes all ventilators materials, intubation tools, airway management and suction)
Breathing
Circulation
Disability (temperature, insulin needles)
Gloves and PPI
Gynae
Hygiene and cleaning
Housekeeping
Immobilisation
Others
Specimens
Surgical instruments
Urology: catheterisation, pads, urinary incontinence
Wound care, dressings, tape.
Blank items

SCOPE 3 EMISSIONS - DISPOSABLES/ CONSUMABLES

Disposables/consumables (Option A)

Please use option A if you would like to measure this category item by item.

Airway (Includes all ventilators materials, intubation tools, airway management and suction)

Item	Quantity used in the Emergency Department per year	Carbon emissions (kg CO2e)	Items per pack	Product code
Adult bougie. Tracheal tube bougie vented 14 ch × 750 mm sterile single use box of 10		0.00	10	FTC494
Airway nasopharyngeal sterile rounded. 6mm ID transparent 8mm OD, 7.5mm ID transparent 10mm OD, 7mm ID transparent 9.3mm OD, 8mm ID transparent 10.7mm OD.	20	34.32	10	FDB216,FDB219, FDB218, FDB221
Airway oropharyngeal guedel dispasable. One piece size 3 ISO 9.0 yellow		0.00	10	FDB317
Airway oropharyngeal guedel disposable (Intersurgical Ltd). One piece size 2 ISO 8.0 green, One piece size 4 ISO 10.0 red	2	0.95	10	FDB316,FDB318
Airway supraglottic (I-Gel). Resus pack for medium adults 50 kg - 90kg ~ includes a size 4 1-GEL 02. Resus pack for medium adults 30 kg - 60kg - includes a size 31-GEL 02, Resus pack for large adults 90kg+ ~ includes a size 5 I-GEL 02 with orange		0.00	6	FDD2841, FDD2840, FDD2842
Catheter mount (Venticalre). Double swivel elbow with elastomeric cap 22 male/15 female and 22 fema		0.00	50	EDE190
Catheter suction two small relieving eyes (Tender Tip). (10FG x 53cm, 12FG x 53cm, 14FG x 53cm, 6FG x 53cm, 8FG x 53cm)	80	3.52	1	FSQ575
Catheter suction with Vacuum Control (Bicakcilar). Standard open suction catheter PVC sterile size 8fg length 50cm with at		0.00	100	FSQ1165
Connecting suction tube with vacuum control- pennine (green bag and clear bag)		0.00	1	CT4025
Cricothyroidotomy emergency kit. Melker (ID 4.0 mm)	100	2,125.20	1	FDG1307
Endotracheal Stylet. 5mm od x 365mm adult malleable aluminium with ivory PVC outer sleeving		0.00	10	FDG043
Endotracheal tube guide 5ch 50cm paediatric disposable guide (5)		0.00	10	FDF490
Guedel airway size 0, 1 and 4	2345	928.62	10	FDB313, FDB314, FDB318
Guedel airway size 2 and 3		0.00	10	FDB316, FDB317
Heat Moisture Exchanger Mechanical Filter with Sampling Port Adult. 22 Fentale 22 Male/15 Female Connections 99.999percent efficiency		0.00	1	FTC029
Intubating Introducer Set. Frova (bougie) 14Fr		0.00	10	FDG1642
Laryngoscope Blade and Handle Disposable (Marshall). Fibre optic led single use laryngoscope fitted set - blade adult plastic hand	60	784.08	10	FSM1662
Laryngoscope Blade and Handle Disposable (Marshall). Fibre optic led single use laryngoscope fitted set blade adult plastic handle		0.00	20	FSM3555
Laryngoscope Handle & Blade Combination. Callisto blade macintosh 4 & callisto led pre-loaded		0.00	10	FSM1750
Liners Soft with Lids. 2 litre standard (for individual or cascade use)		0.00	64	FSE133
Oral endotracheal tube cuffed with murphy eye performed 6mm		0.00	1	FDH061
Reinforced Endotracheal Tube Cuffed with murphy eye. Clear PVC oral/nasal sterile 7mm id ETT		0.00	5	FDG098
Standard endotracheal tube cuffed with murphy eye oral/nasal intermidiate with large diameter low pressure cuff clear pvc (3mm id, 3.5mm id, 4mm id)		0.00	10	FDF1505
Standard endotracheal tube cuffed with murphy eye oral/nasal intermidiate with large diameter low pressure cuff clear pvc (5mm id, 5.5mm id)		0.00	10	FDF1877
Standard Endotracheal Tube cuffed with. Clear blue line soft seal cuff sterile single use (6mm, 6.5mm, 7mm , 7.5mm,8mm, 8.5mm, 9mm)		0.00	1	FDF603
Standard Endotracheal Tube Cuffed without. Oral/nasal long term profile cuff magill plain tip sterile blue line x-ray opaque		0.00	1	FDF063, FDF010, FDF345, FDF349, FDF147
Suction handle (CareTip). Tube Yankauer Suction High Capacity Flexible No Vacuum Control		0.00	1	FWP415
Suction liner (Serres). Blue 1000ml		0.00	36	FDR625
Superset catheter mount patient connection 22m/15f swivel elbow with double flip to cap (port and sealaround cap)		0.00	75	FDE152
Tube yankauer suction short mini with vacuum control por paediatric use		0.00	1	FWP118
Ventimask		0.00	1	FDD551
	TOTAL	3,876.69		

SCOPE 3 EMISSIONS - TRANSPORT		
Transport		
Item	Total distance (Km)	Carbon emissions (kg CO2e)
Active travelling (walking, cycling)		0.00
Bus (average local)	300	36.00
Bus (local London)		0.00
Bus (local, not London)		0.00
Car Battery Electric (average) *	100	7.00
Car Battery Electric (large)*		0.00
Car Battery Electric (medium) *	100	7.00
Car Battery Electric (small)*		0.00
Car CNG (average) *		0.00
Car CNG (large)*	100	29.00
Car CNG (medium)*		0.00
Car diesel (average)*		0.00
Car diesel (large)*		0.00
Car diesel (small)*		0.00

SCOPE 3 EMISSIONS - CATERING AND FOOD		
Meals		
Beverages		
Breakfast		
Others		
Tableware		
Paediatrics food		
SCOPE 3 EMISSIONS - CATERING AND FOOD	TOTAL	0.00

	TOTAL Carbon emissions (kg CO2e)
SCOPE 1 EMISSIONS	328.18
SCOPE 2 EMISSIONS	26.16
SCOPE 3 EMISSIONS	4,818.12
DISPOSABLES/ CONSUMABLES	3,876.69
MEDICAL EQUIPMENT	0.00
NON-MEDICAL EQUIPMENT	0.00
PHARMACEUTICALS	0.00
TRANSPORT	79.00
WASTE	0.00
WATER	0.00
CATERING AND FOOD	862.43