The Environmental Sustainability of Health Care Systems

A literature review on the environmental footprint of health care systems and interventions aiming to reduce it – towards a framework for action for France

Anna-Veera Seppänen, *IRDES*
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La soutenabilité environnementale des systèmes de santé

Une revue de littérature sur l'empreinte écologique des systèmes de santé et les mesures visant à réduire son impact : vers un cadre d'action en France

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Abbreviations

CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
EEA	European Environmental Agency
EU	European Union
IPCC	Intergovernmental Panel on Climate Change
GHG	Greenhouse gas
GP	General practitioner
Kg	Kilograms
Kt	Kilotonnes (1,000 tonnes)
LTC	Long-term care
MDI	Metered-dose inhaler
Mt	Megatonnes (one million tonnes)
NHS	National Health Service
OECD	Organization for Economic Cooperation and Development
OR	Operation room
PM	Particulate matter
PPE	Personal protective equipment
Ppm	Parts per million
WHO	World Health Organization

French summary

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Contexte

Le réchauffement climatique constitue une menace majeure pour la santé des populations et les systèmes de santé en général (Romanello *et al.*, 2022). Les températures ont augmenté significativement depuis le début du siècle à l'échelle mondiale, et ce phénomène ne cesse de s'accentuer en affectant l'écosystème, l'eau, la production alimentaire, la santé et le bien-être, ainsi que les infrastructures (IPCC, 2022). Les changements de température et les inondations plus nombreuses risquent également de modifier l'environnement et de favoriser de nouvelles maladies infectieuses. D'après les scientifiques, une augmentation globale de 1,5 °C au-dessus de la moyenne préindustrielle, ainsi que la perte continue de biodiversité, risquent à terme d'avoir des conséquences catastrophiques et irréversibles sur la santé humaine (Atwoli *et al.*, 2021).

Les activités du système de santé, qui représentent une part importante de l'économie, ont des effets non négligeables sur l'environnement et contribuent à l'empreinte écologique. Leur impact carbone, notamment les émissions dans la chaîne d'approvisionnement, est comparable dans de nombreux pays industrialisés à celui du secteur alimentaire dans son ensemble (Pichler *et al.*, 2019). Le *Green Deal* européen de 2019 a fixé l'objectif de neutralité climatique en Europe d'ici à 2050 dans tous les secteurs, notamment celui de la santé. Néanmoins, jusqu'à présent, le rôle joué par les soins dans le réchauffement climatique est resté largement sous-estimé dans les politiques publiques – il apparaît donc urgent d'identifier les modes d'action susceptibles de réduire l'impact environnemental du système de santé, et de développer des stratégies visant à garantir sa soutenabilité.

Cette étude menée par l'Irdes, en partenariat avec le secrétariat général du Haut conseil pour l'avenir de l'Assurance maladie (Hcaam) – dont elle n'engage pas les membres – porte sur l'empreinte écologique des systèmes de santé et les différentes stratégies susceptibles d'atténuer celle-ci. Cette question ayant été peu documentée à ce jour, il est apparu nécessaire d'élaborer une synthèse de la littérature existante, de plus en plus abondante, concernant les différentes stratégies envisageables et leur efficacité. L'objectif ici est de proposer un cadre d'action fondé sur des preuves, visant à assurer la soutenabilité environnementale du système de santé français. Nous avons réalisé pour cela deux revues de littérature, à la fois distinctes et complémentaires : la première présente un panorama des principales sources de pollution et des principaux domaines du système de santé qui contribuent à l'empreinte écologique ; la seconde identifie un échantillon représentatif des mesures mises en œuvre dans les pays industrialisés – et leur impact estimé – pour réduire l'empreinte écologique des activités de soins. Nous nous sommes appuyés sur les résultats de ces deux revues et sur l'analyse des principaux acteurs impliqués dans la surveillance et la réduction de l'impact environnemental des soins en France pour proposer un cadre d'action holistique visant à améliorer la soutenabilité environnementale du système de santé.

L'impact environnemental des systèmes de santé est de plus en plus mesuré

Les systèmes de santé sont responsables de 3 % (Mexique) à 10 % (États-Unis) des émissions nationales de carbone selon les pays (Pichler *et al.*, 2019). En France, les émissions de gaz à effet de serre (GES) du secteur de la santé ont été estimées à environ 8 % des émissions nationales, atteignant entre 39 et 61 mégatonnes d'équivalents CO2 (MtCO2e) [Sénéchal, 2023]. Les secteurs hospitalier et pharmaceutique sont systématiquement identifiés dans la littérature comme étant les principaux responsables du réchauffement climatique au sein des systèmes de santé (voir tableau 1 pour la contribution des autres secteurs). On estime que les soins hospitaliers sont responsables, selon les systèmes de santé, de 22 % (Canada) à 44 % (Australie) des émissions, principalement liées aux soins aigus et aux opérations chirurgicales, à d'autres traitements énergivores tels que l'hémodialyse, ainsi qu'à l'utilisation de gaz médicaux (Eckelman *et al.*, 2018 ; Malik *et al.*, 2018). Le secteur hospitalier est également une source importante d'émissions liées aux produits alimentaires, à la consommation d'énergie et à des quantités élevées de déchets matériels. A titre de comparaison, les soins ambulatoires représentent entre 10 % et 23 % (Malik *et al.*, 2018 ; Tennison *et al.*, 2021) des émissions au sein des systèmes de santé, et les soins infirmiers et aux personnes âgées entre 6 % et 16 % (Eckelman et Sherman, 2016; Nansai *et al.,* 2020). Les produits pharmaceutiques représentent à eux seuls 10 % des émissions aux États-Unis et environ un tiers des émissions en France, selon des estimations préliminaires, dont la plupart sont liées à la chaîne d'approvisionnement, c'est-à-dire à la production de produits pharmaceutiques à l'étranger (Eckelman et Sherman, 2016 ; Shift *et al.*, 2021). Le transport des patients, du personnel de santé, des visiteurs et des produits médicaux constitue un autre facteur important du réchauffement de la planète, représentant entre 10 % (Angleterre) et 13 % (France) des émissions liées aux soins (Sénéchal, 2023 ; Tennison *et al.*, 2021), avec la consommation d'énergie (13 % à 39 %) [Shift *et al.*, 2021 ; Eckelman *et al.*, 2018], les bâtiments du secteur de la santé (8 % à 9 %) [Malik *et al.*, 2018 ; Shift *et al.*, 2021], les produits alimentaires (11 %) [Sénéchal, 2023] et leur production (5 %) [Eckelman *et al.*, 2018].

Les interventions visant à réduire l'impact des soins sur l'environnement se multiplient

La revue des différents modes d'action visant à réduire l'empreinte écologique des systèmes de santé a porté sur la littérature scientifique et grise publiée entre 2010 et 2022. Parmi les 4 442 titres et 216 abstracts examinés, 43 publications ont fourni des preuves concernant l'efficacité de ces initiatives. Tous les articles ainsi que leurs principaux résultats peuvent être consultés page 81.

Initiatives ciblant les hôpitaux, la chirurgie et les salles d'opération

Les données probantes sur la manière d'améliorer la soutenabilité environnementale des hôpitaux sont nombreuses, dans plusieurs domaines : l'architecture hospitalière, la télémédecine, les mesures visant à économiser l'eau (telles que l'audit de l'usage de l'eau, la vérification et la réparation des fuites et la récupération de l'eau), le remplacement des équipements jetables par des équipements réutilisables dans les salles d'opération, l'amélioration de la gestion des déchets hospitaliers, le recyclage et la prévention de la création de déchets (McGain et Naylor, 2014). Les études les plus récentes fournissent des preuves supplémentaires sur les mesures concernant, par exemple, les pratiques anesthésiques, de la dialyse, le recyclage, ainsi que la réutilisation et le retraitement des matériaux en dehors de la salle d'opération.

De nombreuses études suggèrent par ailleurs que les émissions liées aux opérations chirurgicales et aux salles d'opération peuvent être réduites grâce à un ensemble de mesures technologiques, organisationnelles, comportementales et préventives. Une grande partie des émissions liées aux salles d'opération est due à une forte consommation d'énergie. Par conséquent, les mesures visant à baisser celle-ci, telles que l'installation de capteurs d'occupation qui réduisent le renouvellement de l'air dans les salles d'opération inutilisées, la diminution du chauffage et de la climatisation, ainsi que l'alimentation des salles d'opération en énergie propre, peuvent avoir un impact significatif (Pradere *et al.*, 2022 ; Thiel *et al.*, 2018).

Les protocoles et les pratiques écologiques peuvent également permettre d'obtenir d'importantes réductions de CO2e. Un protocole d'économie d'électricité dans un hôpital australien a contribué à réduire la consommation d'électricité de quatre stérilisateurs à vapeur de 26 % (79 tCO2 par an), simplement en les éteignant lorsqu'ils n'étaient pas utilisés (McGain *et al.*, 2016).

Développer la réutilisation et la stérilisation

L'impact environnemental des matériaux à usage unique est devenu particulièrement visible lors de la pandémie de Covid-19. En Angleterre, l'utilisation d'équipements de protection individuelle (EPI), tels que des masques chirurgicaux et des gants en plastique, a généré au cours des six premiers mois de la pandémie des émissions équivalentes à près de 1 % de l'empreinte carbone totale du secteur de la santé en activité normale (Rizan *et al.*, 2021a). Les émissions liées aux EPI auraient pu être réduites de 12 % si les équipements avaient été fabriqués au niveau national, et jusqu'à 45 % si les gants avaient été remplacés par le lavage des mains. En outre, selon certaines estimations, le fait de remplacer dans les hôpitaux américains les conteneurs à objets tranchants jetables par des conteneurs réutilisables permet de réduire de 84 % le potentiel réchauffement climatique annuel de ces conteneurs, et éviter la mise en décharge de tonnes de déchets en plastique et en carton (Grimmond et Reiner, 2012). Cependant, l'impact d'actions isolées fondées sur le recours à du matériel réutilisable est relativement faible par rapport à d'autres émissions liées aux soins de santé.

Gestion et réduction des déchets

L'empreinte carbone liée à la gestion des déchets hospitaliers (notamment le traitement et le transport des déchets) peut être efficacement réduite par le recyclage. Bien que le traitement des déchets génère une part proportionnellement faible des émissions de GES au Royaume-Uni, il a été démontré que le choix du flux de déchets, par exemple l'incinération à haute température versus recyclage, peut avoir un impact multiplié par 50 sur l'empreinte carbone liée aux déchets, ce qui signifie que la séparation des déchets est importante pour éviter un traitement inutile des déchets à haute teneur en carbone (Rizan *et al.*, 2021b). De nombreuses actions permettent également de réduire le gaspillage alimentaire et les émissions liées à l'alimentation, qui ciblent différentes parties de la chaîne alimentaire, notamment l'approvisionnement, la préparation, la consommation et l'élimination des déchets (Carino *et al.*, 2020). Plusieurs études ont montré que des changements, même modérés, dans la gestion des déchets au sein des cuisines des hôpitaux peuvent réduire les émissions liées aux déchets alimentaires (de 64 % à 90 % avec un recyclage et un compostage maximal) [Thiel *et al.*, 2021]. Les modifications apportées au modèle de système alimentaire se sont également avérées efficaces, par exemple la livraison de nourriture par chariot en remplacement de repas servis individuellement, l'utilisation de chariots isothermes, l'amélioration de la présentation des repas et le choix laissé au patient du menu et de la quantité de nourriture, etc. (Carino *et al.*, 2020). Les mesures prises en matière d'approvisionnement alimentaire regroupent diverses initiatives : ventes directes de producteurs locaux à des hôpitaux, consommation d'aliments biologiques, approvisionnement en viande durable, etc. Néanmoins, l'impact de ces mesures a donné lieu, dans l'ensemble, à un nombre limité d'évaluations.

Réduire les déplacements et développer les transports plus écologiques

Selon les estimations du National Health Service (NHS) britannique, les émissions annuelles liées aux transports doivent être réduites de 3 402 ktCO2e pour parvenir à un système de santé à taux zéro. Certaines des mesures susceptibles de réduire significativement ces émissions se situent en dehors du secteur de la santé. Par exemple, l'amélioration de l'efficacité des véhicules au niveau national peut réduire les émissions liées aux véhicules utilisés dans le NHS (transport médical) et par le personnel, les patients, etc. (-1 463 ktCO2e). D'autres mesures visent à réduire l'utilisation de véhicules dans le NHS, en encourageant le personnel de santé, les patients et les visiteurs à privilégier des modes de déplacement actif (marche, vélo) et les transports publics (-461 ktCO2e) [NHS England, 2020].

Les solutions de télésanté présentent également de grands avantages potentiels en termes de diminution des émissions de GES, en contribuant à réduire à la fois le transport des patients et du personnel. La littérature suggère que les émissions produites par les systèmes de télémédecine sont beaucoup plus faibles que celles qui permettent d'être évitées (Blenkinsop *et al.*, 2021). Cependant, le niveau de réduction des émissions de carbone dépend des distances moyennes de déplacement vers les soins qui ont été remplacés par la télémédecine, de la distance vers les sites de télémédecine, ainsi que de facteurs techniques, tels que la technologie utilisée (Holmner *et al.*, 2014). La télémédecine est plus efficace lorsqu'elle remplace des visites de soins à longue distance (plus de 7 km) et lorsqu'elle ne donne pas lieu à une double consultation (c'est-à-dire suivie d'une consultation en face à face) [Purohit *et al.*, 2021].

Réduire la pollution pharmaceutique et améliorer les pratiques de prescription

En termes de progrès médical ayant permis de réduire les émissions de GES, on peut citer le remplacement des gaz propulseurs des inhalateurs (qui détruisent la couche d'ozone) et des gaz d'anesthésie par des alternatives non gazeuses ou bas-carbone. En Angleterre, on estime qu'une grande majorité de leurs émissions pourraient être atténuées, sans affecter les patients, en augmentant l'utilisation des inhalateurs à poudre sèche (-374 ktCO2e par an), en réduisant l'utilisation des inhalateurs à gaz par l'innovation et l'adoption des nouveaux alternatifs à bas-carbone (-403 ktCO2e par an), et en transformant la pratique de l'anesthésie (-195 ktCO2e) [NHS England, 2020]. Le NHS soutient également les entreprises pharmaceutiques qui développent un programme encourageant les patients à retourner les dispositifs d'inhalation aux pharmacies, pour une mise au rebut écologique.

Très peu d'études ont évalué l'impact de la modification des pratiques de prescription sur la réduction des émissions de GES. Une seule étude a estimé, pour le traitement du reflux, l'impact du passage d'un traitement exclusivement médicamenteux à un traitement chirurgical ; les résultats ont suggéré que, neuf ans après l'intervention, pour un résultat de santé équivalent, la chirurgie était plus efficace en termes d'émissions de carbone que le traitement médicamenteux, les médicaments étant souvent prescrits à vie (Gatenby, 2011).

Si l'amélioration de la chaîne d'approvisionnement médicale est identifiée comme un élément majeur pour atteindre les objectifs de zéro émission nette, il existe néanmoins peu d'actions dont l'impact a été quantifié. Selon NHS England, si tous les fournisseurs de produits pharmaceutiques répondaient aux exigences environnementales du NHS sur leurs propres processus de production (ce qui n'est pas obligatoire en ce moment), cela permettrait de réduire les émissions de 4 203 ktCO2e par an ; de même, les innovations vertes en matière de processus et de produits pourraient réduire encore ces émissions de 1 488 ktCO2e (NHS England, 2020).

Approches au niveau du système de santé

Un consensus émerge sur la nécessité de mettre en place simultanément un large éventail d'actions pour réduire significativement les émissions liées au secteur de la santé et ralentir le changement climatique. La stratégie la plus exhaustive a été mise en œuvre par le NHS England, qui a publié en 2010 une *Route Map for Sustainable Health* (Feuille de route pour une santé durable). Celle-ci propose des mesures détaillées dans tous les domaines et pour tous les acteurs impliqués, tant au niveau de la gouvernance (par exemple, mise en place de conseils consultatifs nationaux, de réseaux locaux, de plans de gestion, etc.) qu'à l'échelle du système d'accompagnement (par exemple, élaboration d'indicateurs, évaluation des progrès réalisés, soutien à la recherche, mise en œuvre de directives sectorielles et industrielles, etc.). Entre 2007 et 2015, le NHS a réduit son empreinte carbone de 11 % malgré une activité globale en hausse de 18 % (Roschnik *et al.*, 2017). De la même manière, en Suède, l'expérimentation d'un changement systémique à plus petite échelle – sous la forme d'un protocole environnemental pour le secteur de la santé dans une région – a permis de réduire les émissions de CO2 jusqu'à 40 % par patient (Wanegård et Fagerberg, 2019).

Dans l'ensemble, la littérature suggère qu'il existe de nombreuses mesures susceptibles de réduire avec succès l'empreinte écologique du système de santé dans toute une série de domaines, en particulier dans le secteur hospitalier, et notamment dans les salles d'opération. La plupart des études se sont concentrées sur les mesures écologiques intervenant au niveau micro ou méso. Les preuves restent néanmoins insuffisantes, ou limitées, en ce qui concerne les coûts et les avantages des stratégies visant à réduire le « gaspillage » dans l'offre de soins, en renforçant notamment l'adéquation des soins et la prévention primaire. Néanmoins, les modélisations suggèrent que des mesures isolées au niveau micro auraient un impact limité et que l'obtention de réductions significatives nécessiterait des changements majeurs au niveau organisationnel, en combinant différentes actions environnementales à des mesures plus structurelles.

Un cadre d'action pour un système de santé écologiquement durable

En France, de nombreux acteurs prennent en charge les questions liées à l'environnement et la santé, notamment les institutions gouvernementales, les associations professionnelles, les établissements de santé, les ONG et l'industrie (voir tableau 4 pour la liste des acteurs). La France ne disposait pas à ce jour d'une organisation globale spécifique ayant pour mission de développer une stratégie globale et de coordonner les efforts entrepris par ces multiples acteurs pour améliorer la soutenabilité environnementale du système de santé. Toutefois, un comité stratégique sur la transition écologique en santé vient d'être créé au ministère de la Santé en mars 2023. Les expériences étrangères montrent l'importance de disposer d'une instance dédiée, qui s'attache à mesurer l'ampleur du problème dans différents secteurs, ainsi qu'à conceptualiser et à suivre les changements à mettre en œuvre.

La soutenabilité est définie comme « la satisfaction des besoins des générations présentes sans compromettre la capacité des générations futures à satisfaire leurs propres besoins » (Brundtland, 1987). En règle générale, la soutenabilité financière fait référence à la capacité d'un gouvernement à maintenir les finances publiques dans une position crédible et efficace à long terme, tandis que la soutenabilité environnementale désigne le fait de générer une quantité minimale de pollution et de GES, en alignant l'offre de soins sur les objectifs climatiques mondiaux (OECD, 2013 ; World Bank, 2017). Dans le secteur de la santé, assurer la soutenabilité économique à long terme exige que les financeurs publics s'engagent dans une prévision stratégique continue des besoins et des revenus futurs, en tenant compte des facteurs environnementaux et des tendances socio-économiques afin d'adapter le système de santé en conséquence. Investir dans la soutenabilité environnementale des systèmes de santé est une responsabilité mais peut-être également une opportunité, puisque les stratégies de mitigation peuvent permettre de générer des bénéfices mesurables en termes de promotion de la santé, de qualité et pertinence des soins, d'efficience économique, et de communautés résilientes. Par conséquent, la soutenabilité environnementale et économique des systèmes de santé sont étroitement liées.

Ainsi, notre cadre conceptuel (accessible ici), indique qu'il existe de nombreuses mesures « vertes » susceptibles de réduire efficacement l'empreinte écologique des soins de santé dans plusieurs domaines, mais celles-ci resteront insuffisantes tant qu'elles ne seront pas accompagnées de stratégies de soutenabilité pour transformer l'offre et la consommation de soins. Ces stratégies se fondent sur un certain nombre de mesures organisationnelles visant à redéfinir l'offre de soins, tout en réduisant le besoin et la demande de soins. Pour cela, il convient d'identifier les processus de transformation nécessaires et les différents leviers d'action. En ce sens, notre cadre d'action identifie divers types de mesures à mettre en œuvre simultanément afin de réduire les sources directes et indirectes de pollution dans le secteur de la santé.

En premier lieu, il est essentiel d'encourager auprès des fournisseurs de soins les innovations techniques et organisationnelles visant à réduire l'utilisation des ressources, et de soutenir la diffusion d'« actions vertes » efficaces, telles que la réduction et le recyclage des déchets, le retraitement, le passage à des anesthésiques moins polluants et à des sources d'énergie propres... Mais ces actions resteront insuffisantes tant qu'elles ne seront pas accompagnées de « mesures de soutenabilité » impliquant un changement dans la manière dont les soins sont dispensés et consommés. La réduction du gaspillage dans l'offre et l'utilisation des soins implique des interventions systémiques pour atténuer les besoins en matière de santé, garantir la pertinence des soins et favoriser leur efficience. La prévention primaire, qui repose notamment sur le changement des attitudes individuelles et sociales pour soutenir une consommation de soins plus durable, apparaît également comme un moyen de réduire le besoin et la demande de services de santé (Pichler *et al.*, 2019 ; Taylor et Mackie, 2017).

Il est tout aussi essentiel de réinvestir, voire de réinventer, la question de l'offre de soins, notamment en définissant mieux quels sont les soins pertinents selon les contextes et le profil des patients, en améliorant les parcours de soins, en renforçant l'offre de soins de proximité et la formation des professionnels de santé à de nouvelles technologies et aux consultations à distance, etc., afin de favoriser une gestion des soins par la stratification des risques (Wong *et al.*, 2021).

Enfin, les mesures visant à réduire l'empreinte écologique des soins de santé peuvent avoir des co-bénéfices positifs sur les plans sanitaire, économique et organisationnel. Des soins durables sur le plan environnemental renforceront les systèmes de santé ainsi que la santé des populations en assurant un meilleur accès à l'eau potable, une meilleure qualité de l'air, des transports propres, etc., mais aussi en garantissant une meilleure prévention et des soins de proximité, tout en réduisant le gaspillage dans le système et en augmentant la sécurité et la qualité, en s'appuyant sur de meilleurs protocoles de soins. Les politiques climatiques sont aussi susceptibles d'avoir des retombées positives, par exemple au sein des personnels de santé en favorisant l'esprit d'équipe (contribuant ainsi à améliorer l'environnement de travail) [Blum et al., 2021], ainsi qu'au sein de la population, en termes d'amélioration de l'état de santé – ces facteurs étant des corollaires importants à la mise en œuvre de ces politiques. Dans ces domaines, la dynamique de changement proviendra à la fois de facteurs « push » tels que le respect de la législation environnementale, et de facteurs « pull » centrés sur les changements comportementaux et les avantages potentiels que représente la soutenabilité des soins pour les patients. D'autres travaux de recherche sont nécessaires afin d'étudier la façon dont la conception et le financement des soins influencent leur empreinte écologique, et d'identifier les leviers et les obstacles à la mise en œuvre des changements.

English summary

The Environmental Sustainability of Health Care Systems

A literature review on the environmental footprint of health care systems and interventions aiming to reduce it: towards a framework for action for France

Context

Global warming is an undisputable threat to populational health and health care systems (Romanello et al., 2022). The temperature of Earth has risen significantly since the beginning of the century and continues to do so with an accelerating speed. Climate change has already affected the ecosystem, water, food production, health and wellbeing and infrastructure in Europe (IPCC, 2022). Changes in temperature, and more frequent floods will alter the environment in favor of new infectious diseases. According to scientists, an increase of the Earth's mean temperature of 1.5°C above pre-industrial values and a continued loss of biodiversity may cause catastrophic and irreversible damage on human health (Atwoli et al., 2021).

Health care systems make up a large part of economies and the size of their environmental footprint is non-negligible. Their carbon footprint, including emissions from their supply chain, is comparable to that of the food sector in many industrialized countries (Pichler et al., 2019). The 2019 European Green Deal sets the objective of climate neutrality in Europe by 2050 across all sectors in society – including the health care sector. Yet, the contribution of health care to global warming is largely overlooked in policy and there is an urgent need to identify interventions that could reduce the environmental impact of health care systems and develop strategies to assure their environmental sustainability.

This study is carried out by the Institute for Research and Information in Health Economics (IRDES) in collaboration with the *Haut conseil pour l'avenir de l'Assurance maladie* (HCAAM) –with no involvement of its members– and focuses on the environmental impact of health care systems and strategies aiming to reduce it. The interventions that could reduce the environmental impact of health care and their effectiveness is still poorly documented, calling for the need for a synthesis of the increasingly rich literature on this subject. The objective of this work was to develop an evidence-based framework for action for assuring environmental sustainability of the French health care system. For this, we carried out two distinct but complementary literature reviews: the first provides an overview of the environmental impact of major health care sectors and main sources of pollution, and the second –a scoping review– identifies a representative sample of interventions used in high-income countries to reduce the environmental footprint of health care and their estimated impact. We pooled the results from two reviews and examined the main stakeholders involved in monitoring and reducing the environmental impact of the health care sector in France to propose a holistic framework for action for improving environmental sustainability of the health care system.

Growing evidence on the environmental impact of health care systems

Health care systems are responsible for between 3% (Mexico) and 10% (USA) of national carbon emissions around the globe (Pichler et al., 2019). In France, greenhouse gas (GHG) emissions from the health care sector have been estimated to stand for approximately 8% of national emissions, reaching between 39 and 61 megatonnes of CO2 equivalents (Mt-

CO_2e) [Sénéchal, 2023]. The hospital and pharmaceutical sectors are systematically identified in the literature as the main contributors to global warming within health care systems (see Table 1 for the contribution of other sectors). Hospital care is estimated to be responsible for between 22% (Canada) and 44% (Australia) of emissions, depending on the health care system, mainly due to emissions linked to acute care and surgical operations, other energy-intensive treatments, such as hemodialysis and the use of medical gases (Eckelman et al., 2018; Malik et al., 2018). The hospital sector is also an important source of emissions from food products, energy use and high amounts of material waste. As a comparison, ambulatory care stands for between 10% and 23% (Malik et al., 2018; Tennison et al., 2021), and elderly care and nursing between 6% and 16% (Eckelman and Sherman, 2016; Nansai et al., 2020) of health care-related emissions. Across all health care sectors, pharmaceuticals alone stand for between 10% of health care-related emissions in the USA, and for approximately one-third of emissions in France according to preliminary estimations, of which most are linked to the supply chain, i.e., production of pharmaceuticals abroad (Eckelman and Sherman, 2016; Shift et al., 2021). Transportation of patients, staff, visitors and medical products is another major contributor to global warming, standing for between 10% (England) and 13% (France) of health care-related emissions (Tennison et al., 2021; Sénéchal, 2023), together with energy use (13%–39%) [Shift et al., 2021; Eckelman et al., 2018], health sector buildings (8%–9%) [Malik et al., 2018; Shift et al., 2021] and food products (11%) [Sénéchal, 2023] and their production (5%) [Eckelman et al., 2018].

An increasing number of interventions aiming to reduce the environmental impact of health care

The scoping review of interventions aiming to reduce the environmental impact of health care systems covered the scientific and grey literature published between 2010 and 2022. Out of 4,442 titles and 216 abstracts reviewed, 43 publications provided evidence on interventions aiming to reduce the environmental impact of health care. All articles included in the review can be found page 77, and their principal results page 81.

Interventions targeting hospital, surgery and operating rooms

The evidence-base on how to improve hospitals' environmental sustainability is extensive on several areas: hospital architecture, telemedicine, water-saving interventions (such as water use auditing and checking and repairing leaks), replacing disposable with reusable equipment in operating rooms (OR), improved hospital waste management, recycling, and avoiding creating waste in the first place (McGain and Naylor, 2014). The most recent studies provide additional evidence on interventions concerning, for instance, anesthetic and dialysis practices, recycling, and reusing and reprocessing materials also outside of ORs.

Many studies suggest that emissions related to surgical operations and ORs can be reduced with a set of technological, organizational, behavioral, and preventive interventions. A large part of OR-related emissions is caused by their high energy consumption. Hence, interventions reducing energy consumption, such as occupancy sensors that reduce air turnover of unused ORs, reduced heating and air conditioning, and powering ORs with clean energy, can have significant impact (Pradere et al., 2022; Thiel et al., 2018).

Green protocols and practices can also achieve significant CO_2e reductions. An electricity-saving protocol in an Australian hospital reduced the electricity consumption of four steam sterilizers by 26% (79 tCO_2 per year) just by switching them off when not in use (McGain et al., 2016).

Increasing reusing and sterilizing

The environmental impact of single-use materials became evident during the Covid-19 pandemic. In England, the use of personal protective equipment (PPE), such as surgical masks and plastic gloves, during the first 6 months of the pandemic, generated emissions equivalent to almost 1% of the entire carbon footprint of health sector during normal activity (Rizan et al., 2021a). The PPE-related emissions could have been reduced by 12% if the equipment had been manufactured nationally, and up to 45% if gloves had been replaced by hand washing. Estimations from US hospitals also suggest that converting to reusable instead of disposable sharps containers can reduce the containers' annual global warming potential by 84% and avoid tonnes of plastic and cardboard landfill waste (Grimmond and Reiner, 2012). However, the impact of isolated actions of shifting to reusable material is relatively low in relation to other health care emissions.

Waste management and reduction

The carbon footprint of hospital waste treatment streams (including waste processing and transportation of waste) can be effectively reduced by recycling. Although waste management generates a proportionally small part of the GHG emissions in the UK, it is shown that the choice of waste stream, for instance high temperature incineration versus recycling, can have a 50-fold impact on the waste carbon footprint, showing the importance of waste segregation to avoid unnecessary, highly polluting wase treatment (Rizan et al., 2021b). There are many interventions for reducing food waste and food-related emissions targeting different parts of the food-chain, including procurement, preparation, consumption, waste disposal (Carino et al., 2020). Several studies show that even moderate changes to waste management in hospital kitchens can reduce food waste-related GHG emissions (from 64% up to 90% with maximal recycling and composting) [Thiel et al., 2021]. Food-system model changes such as bulk trolley food delivery instead of individually served meals, isothermal trolleys, improved meal presentation, and patient choice of meal size and meal selection are also shown to be effective (Carino et al., 2020). Food procurement interventions include farm to hospital initiatives, organic food, and sustainable meat procurement, but with few reports on their impact.

Reducing travel and greening transport

The National Health Service (NHS) of England has estimated that annual transportation-related emissions need to be reduced by 3,402 ktCO2e to achieve a net-zero health care system. Some of the interventions that could reduce these emissions significantly are outside the health care sector. For instance, national vehicle efficiency improvements could reduce the emissions of vehicles used within the NHS (medical transport) and by staff and visitors (-1,463 ktCO2e). Other measures could reduce the use of private vehicles for transport, by encouraging health care staff, patients and visitors to engage in active travel (walking, biking) and taking public transport (-461 ktCO2e) |NHS England, 2020].

Telehealth solutions also have great potential benefits for reducing GHG emissions, reducing both patient and staff transport. The literature suggests that the emissions produced from telemedicine systems are much lower compared to the emissions they prevent (Blenkinsop et al., 2021). However, the level of carbon reductions are dependent on the average travel distances to the care being replaced by telemedicine, and distance to telemedicine sites, as well as on several technical factors, such as the technology used (Holmner et al., 2014). Telemedicine is more efficient when replacing long distance health care visits (over 7 km) and when not resulting in double-consulting (i.e. followed by a face-to-face consultation) [Purohit et al., 2021].

Reducing pharmaceutical pollution and green prescription practices

One medical improvement allowing to reduce emissions is the replacement of gas-based inhaler propellants (ozone depleting) and anesthetic gases with non-gas or low-carbon alternatives. In England it has been estimated that a large part of their emissions could be eliminated without clinical impact on patients, by increasing the use of dry powder inhalers (-374 ktCO2e per year), reducing the use of gas-based inhalers by replacing them with innovative and low-carbon alternatives (-403 ktCO2e per year), and by transforming anesthetic practices (-195 ktCO2e per year) [NHS England, 2020]. The NHS also supports the initiative of pharmaceutical companies to develop a program encouraging patients to return inhaler devices to pharmacies for green disposal.

Very few studies assess the impact of changed prescription practices for reducing GHG emissions. One study assessed the impact of shifting from medication only-treatment to surgery for treating reflux and showed that, for similar health outcomes, surgery became more carbon efficient than medicine-only treatment after 9 years post-surgery, because the need for medication is often life-long (Gatenby, 2011).

While improving the medical supply chain is identified as one major area of intervention to meet net-zero goals, there are not many interventions for which the impact is quantified. NHS England estimates that making pharmaceutical suppliers meet the NHS environmental requirements (which are currently not obligatory) could reduce emissions by 4,203 ktCO2e annually, and green process and product innovations could reduce emissions further by 1,488 ktCO2e (NHS England, 2020).

Health system-level approaches

There is an emerging consensus that a wide range of interventions are needed to reduce the contribution of health care activities to climate change. The most comprehensive climate strategy has been implemented by NHS England which published a Route Map for Sustainable Health in 2010. The Route Map provides detailed measures in all areas and for all stakeholders from governance (e.g. setting up national advisory boards, local networks, management plans etc.) to system support (e.g. developing metrics, evaluating progress, supporting research, developing sector and industry guidelines, etc.). Between 2007 and 2015, the NHS reduced its carbon footprint by 11%, despite activity levels rising by 18% (Roschnik et al., 2017). A more small-scale systemic change implemented in one region in Sweden, a comprehensive environmental protocol for the health care sector, allowed reducing CO2e emissions up to 40% per patient (Wanegård and Fagerberg, 2019).

Overall, the literature suggests that there are many interventions that can successfully reduce the environmental impact of health care across a range of domains, especially in the hospital sector, and in ORs. Most studies focus on green interventions at the micro or meso-level. Evidence is lacking or is limited on the costs and benefits of mitigation strategies which can reduce health care consumption by reducing "waste" in care provision, assuring appropriateness of care and strengthening primary prevention. Modelling exercises suggest that single micro-level measures would have limited impact and achieving meaningful reductions would require major changes at the organizational level, combining different environmental interventions and innovation with more structural measures.

A framework for action for an environmentally sustainable healthcare system

A large variety of stakeholders manage and monitor environmental and health-related issues in France, including governmental institutions, professional associations, health care facilities, NGOs and the industry (see Table 4 here for the full list of stakeholders). France has been missing until recently an overarching organization which develops a coherent strategy and coordinates efforts across multiple stakeholders for improving the environmental sustainability of the health care system. In March 2023, the Ministry of Health created a strategic committee on ecological transition in health. Experiences from other countries show that it is important to have a dedicated instance that is responsible for assessing the extent of emissions in different sectors and conceptualizing and monitoring changes required for improvement.

Sustainability is defined as "fulfilling the needs of current generations without compromising the needs of future generations" (Brundtland, 1987). Generally, fiscal sustainability refers to the ability of a government to maintain public finances at a credible and efficient position over the long term, while environmental sustainability means generating a minimal amount of pollution and GHG, aligning health delivery with global climate goals (OECD, 2013; World Bank, 2017). In the health sector ensuring long-term fiscal sustainability requires public payers engage in continual strategic forecasting of future needs and revenues, considering environmental factors and socio-economic trends in order to adapt healthcare system accordingly. Investing in environmental sustainability in health systems is a responsibility but also can be an opportunity, because promoting environmental sustainability in health systems can provide measurable benefits and opportunities in terms of health protection and promotion, financial savings, improved care efficiency and quality and resilient communities. Thus, environmental and economic sustainability of health care systems are closely linked.

Our conceptual framework (accessible here) recognizes that there are numerous “green” interventions that can successfully reduce the environmental impact of health care across a range of domains, but they are insufficient if not accompanied by sustainability strategies which modify how health care is provided and consumed via organizational-level interventions targeting to redesign health care provision and to reduce the need and demand for health care. This requires identifying necessary transformative processes and multiple levers of action. The framework outlines different types of actions which should be developed simultaneously for reducing both direct and indirect sources of pollution in the health care sector.

Encouraging technical and organizational innovations for reducing resource use and supporting the diffusion of effective “green interventions” such as waste reduction and recycling, reprocessing, shifting to less polluting anesthetics, and clean energy sources, across care providers is essential. Nevertheless, such interventions are not enough unless accompanied by “sustainability” measures changing the way health care is provided and consumed. Reducing wasteful health care provision and consumption would involve systemic interventions for mitigating health care need, assuring appropriateness of health care use (pertinence) and making health care more efficient. Prevention, which also includes changing individual and social attitudes to support more environmentally sustainable care consumption, is identified as one way of reducing the need and demand for health care services (Pichler et al., 2019; Taylor and Mackie, 2017).

It is equally fundamental to reinvest and reimagine how to provide care, everything from defining which care is pertinent for which patient and in which setting, to enhancing referral pathways, strengthening proximal care provision, and training care professionals to use new technologies including teleconsultations for better care management through patient risk stratification and triage (Wong et al., 2021).

Interventions aiming to reduce the environmental footprint of health care may have positive health, economic and organizational co-benefits. Environmentally sustainable health care will strengthen health systems and population health by ensuring better access to safe water, better air quality, clean transport, etc. but also by warranting better prevention and proximal care, while reducing waste in the system and increasing the security and quality with better care protocols. Climate policies can also have positive spillover effects, such as a sense of teamwork among health care staff which could contribute to a better work environment (Blum et al., 2021) as well as populational-level benefits of better health, which are important biproducts motivating implementation. The impetus to change across different areas will come both from 'push' factors such as compliance with environmental legislation, and 'pull' factors centered on behavioral change and the potential patient benefits of sustainable health care. More research is called for to understand how the design and funding of health care influences its environmental footprint, and what facilitators and barriers exist for implementing changes.

1. Introduction

1.1. Global warming poses an increasing threat to health and health care systems

Global warming is an undisputable threat to populational health and health care systems (Romanello et al., 2022). The temperature of Earth has risen significantly since the beginning of the century and continues to do so with an accelerating speed. In 2020, the Earth's global mean temperature was 0.6°C higher compared to the period 1981-2010 and 1.25°C higher compared to pre-industrial times (Copernicus, 2021).

Climate change has already affected the ecosystem, waters, food production, health and wellbeing and infrastructure in Europe (IPCC, 2022). More frequent and persistent droughts will pose a greater risk for safe food and water supply, and wildfires will increase air pollution, provoking respiratory diseases and premature deaths (European Environment Agency, 2020). Changes in climate and warmer sea temperatures will alter the environment in favor of new vectors of infectious diseases, such as ticks and tiger mosquitos. Floods will become more frequent, increasing the risk infectious diseases through, for instance, flood water contaminated by sewage overflows or chemicals from flooded landfills (European Environment Agency, 2020). These events will occur more frequently, and often simultaneously. Especially extreme weather events are likely to pose a high threat to European cities (European Environment Agency, 2020), damaging important infrastructure and impacting both physical and mental health. There is a scientific consensus that an increase of the global mean temperature of 1.5 °C above pre-industrial values and continued loss of biodiversity may cause catastrophic and irreversible impact on human health (Atwoli et al., 2021).

Global warming will put a strain on health systems and the economy, leading to increased costs related to excess mortality and morbidity. It has been estimated that greenhouse gases (GHG) and toxic air pollutants produced by USA's health care system caused the loss of 388,000 disability-adjusted life-years in 2018 (Eckelman et al., 2020). Mitigating global warming is not only a priority for population health - but also for economic sustainability. The economic cost of measures limiting global warming can be outweighed, or at least to a large part compensated, by the economic savings made from improved populational health (Markandya et al., 2018). Reducing CO_2 emissions from electricity use by 50% could gain 100 life-years per million people in the EU in 2030 (Markandya et al., 2009).

1.2. The health care system is a major contributor to global warming

Health care systems make up a large part of economies: 9.6 % of GDP on average among OECD countries, and 12.4% of the GDP in France in 2021 (OECD, 2023). Representing a large share of economic activity, the size of its footprint (including emissions occurring in supply-chain) is non-negligible and comparable to that of the food sector, and is only smaller than the energy, transport, and construction sectors in many countries (Pichler et al., 2017). The footprint varies largely across models of health care systems in different countries, generally with a larger footprint per capita in high-income compared to low-income countries. Annual carbon emissions are estimated to vary between 6 tCO_2 per 100 persons in India to 151 tCO_2 per 100 person in the USA (Pichler et al., 2017). The health care system stands for approximately 3% of the total carbon footprint in Mexico and 4% in the UK (the

National Health Service; NHS) [Pichler et al., 2017], 5% in Canada (Eckelman et al., 2018), 7% in Australia (Malik et al., 2018), around 8% in the Netherlands (Pichler et al., 2017) and 10% in the USA (Eckelman and Sherman, 2016). In France, GHG emissions from the health care sector have been estimated to stand for about 8% of all national emissions; reaching between 39 and 61 MtCO2e according to the Shift Project (Sénéchal, 2023). Furthermore, the health care system is a major source of other environmental pollutants. In Canada, the health care system is estimated to be responsible for, in addition to 33 MtCO2 equivalents (CO2e) annually, over 200,000 tonnes of other pollutants such as ammonia, carbon monoxide, methanol, nitrogen oxides and particulate matter (PM) [Eckelman et al., 2018].

1.3. Increasing focus on transforming health care systems

Creating environmentally sustainable societies is crucial for the world population. The 2019 European Green Deal set the objective of climate neutrality in Europe by 2050 across all sectors in society, supported by the European climate law (European Commission, 2019). Environmental objectives were also integrated to the WHO's Geneva chart for well-being, for achieving socially and environmentally responsible health policies. Nevertheless, until recently, the contribution of health care systems to global warming was largely overlooked in environmental and health policies (Romanello et al., 2021), with insufficient stakeholder involvement (especially of health authorities) and poor consideration of co-benefits (European Environment Agency and the Lancet Countdown, 2021). The European Commission acknowledges that the EU states need to look more systematically at all policies and regulations aiming to reduce emissions contributing to global warming (European Commission, 2019). The Covid-19 crisis in 2020 and 2021 revealed the importance of improving the sustainability and resilience of health care systems, including through reducing the environmental impact of health care. The large amounts of extra waste produced by the health care system, from single-use personal protective equipment (PPE; such as surgical masks and Covid-19 test kits) to chemical waste, and the poor capacity to handle the waste, were some of the notable issues during the pandemic (WHO, 2022). The EU Resilience Fund supports efforts to create more sustainable health care systems, requiring health sector transformation with objectives of environmental performance. France received €2.5 billion from the EU Resilience Fund for making "green investments" in the health care sector (European Commission, 2021). However, in France, the political interest in environmental sustainability of health care systems and measurement of health care-related emissions is still in its infancy. Environmental efforts have mainly focused on legislations over a wide variety of domains, including water and air quality, biodiversity, transportation, urban development, and industrial pollution.

The health care sector's environmental footprint has become an important question since the pandemic, partly because the EU Resilience Funding. The Shift project pointed out in 2021 that there is a need for more evidence-based, and more long-term strategies for reducing the environmental footprint of the health care system and stressed the importance of focusing on more transversal strategies which are largely prevention-centered (Shift et al., 2021).

1.4. Objectives of the study

This study was driven by the lack of information on strategies for reducing the environmental impact of the health care sector in France, and the need for a synthesis on the increasingly rich literature on interventions that could be efficient. It aims to contribute to developing an evidence-based framework for action for reducing the environmental impact of the health care system. For this, it proposes two distinct but complementary literature reviews. The two reviews together aim to identify the most problematic areas of environmental impact in the health care sector and effective interventions that can support the ecological transformation of health care systems while assuring sustainability at the long term. This evidence is used for developing a holistic framework for identifying the main domains and types of actions for reducing the environmental footprint of the health care system in France.

For this, we adopted the following iterative strategy:

- First, we performed a rapid review of international literature **on the environmental impact of health care systems** to identify major health sectors and sources of pollution where interventions should focus.
- Secondly, we performed a scoping review to identify **interventions** that are **used for reducing the environmental impact** across different health care systems. More specifically, we provide an overview of interventions, their characteristics, and estimated impact when the information is available.
- Finally, we synthesized the information from the two reviews, and identified main stakeholders in France, with the objective of **developing a holistic framework for action** for reducing the environmental footprint of the health care system in a sustainable way. The framework is not intended to be prescriptive nor provide a list of required actions, but rather to provide policymakers and major stakeholders with ideas on how to contextualize environmental sustainability of the health care system, commit to implementing coherent strategies and support cross-sectoral collaboration with national and regional partners, health workers and users.

2. Evidence on the environmental impact of health care systems

2.1. Different sources of emissions and pollution

Box 1. Definitions

Direct emissions: Emissions from sources that are owned or controlled by care providers, such as on-site use of fossil fuel for heating, gases from anesthesia and metered-dose inhalers (MDIs), and emissions from hospital vehicles (ambulances etc.). Direct emissions are also referred to as **Scope 1** emissions. The level of on-site water consumption, medication use, and waste generation are also sources of pollution which can be controlled by the care providers.

Indirect emissions: Off-site emissions linked to, for instance, water use (such as wastewater treatment and off-site provision of hot water), waste production (such as waste treatment through incineration), use of purchased electricity (emissions related to producing the electricity for heating, cooling, lighting etc.), staff commute, patient and visitor travel, commissioned services, as well as supply-chain emissions related to producing and procuring products such as pharmaceuticals, medical equipment and foods. These are also referred to as **Scopes 2 and 3**.

Source: Tennison et al., 2021.

Global warming and pollution of the environment are linked to a range of emissions, pollution and actions, including GHG emissions, water and air pollution, landfill waste and deforestation, etc. Emissions can be both direct and indirect (see Box 1), and direct emissions represent only a small part of the contribution of health care activities. CO2 emissions, for instance, are mainly indirect, as the majority comes from fuel combustion and land use in the supply chain (Lenzen et al., 2020). Similarly, Nitrous Oxide (N2O) and methane emissions in the health care system mainly originate from indirect emissions, for instance from agriculture and fluorinated gases from industrial processes in the supply chain (Lenzen et al., 2020).

In France, approximately 85% of CO2e in the health care sector come from indirect emissions, mainly from procurement of pharmaceuticals and medical devices (Shift et al., 2021). In Canada, only 6.4% of health care and social assistance-related emissions, 3.1% of hospital-related emissions, and 0.4% of nursing and residential care emissions are direct (Eckelman et al., 2018). In Australia, 90% of the health care carbon footprint comes from indirect CO2 emissions (Malik et al., 2018).

The majority (62%) of all CO2e emissions associated with the National Health Services (NHS) in England came from the supply chain of pharmaceuticals and chemicals, medical and non-medical equipment, business services, food and catering and other procurement (Scope 3) in 2019. This is a much larger share than the emissions of care delivery (24%) including on-site use of fossil fuels, anesthetic gases, NHS vehicles (Scope 1), purchased energy (Scope 2) and emissions related to water, waste, metered-dose inhalers (MDIs), and business travel (Scope 3) in England (Tennison et al., 2021). The supply chain emissions come to a lesser extent from construction-related supply-chain emissions (5%) and freight transport (6%), which are often targeted when aiming to reduce health-care related emissions (Tennison et al., 2021).

The management and reduction of GHG emissions is complex due to the large part of supply-chain emissions happening abroad, especially in high-income countries, which are harder to control. Less than one-fourth of emissions in countries such as Sweden, Luxembourg and Switzerland occur within the country, in contrast to China for instance, where 94% of emissions are domestic (Pichler et al., 2017).

2.2. Emissions across health care sectors and domains

There is a growing body of literature on emissions across different health care sectors. However, both health care systems and population demographics differ largely across countries, and methods used for categorizing and measuring emissions are heterogeneous. Nevertheless, studies consistently come to similar conclusions on which health care sectors are the main contributors to global warming.

Hospital care

Studies consistently suggest that the **hospital sector** is one of the main contributors to global warming. In Australia, **public and private hospital activity**, related to all diagnosis and treatment of pathologies, radiology, physiotherapy, labor, construction, food, paper, plastics, and medical equipment, stood for 44% of all health care-related CO2e emissions in 2014–2015, while excluding hospital-associated pharmaceuticals, research, patient transport, and aids and appliances (Malik et al., 2018). In Canada, **public hospitals** stood for 22% of health care life cycle GHG emissions in 2015 (Eckelman et al., 2018), whereas in the USA, 36% of all health-care related GHG emissions were estimated to comes from the **hospital sector** in 2013 (Eckelman and Sherman, 2016).

For activities within the hospital sector, **acute care and hospitalizations** have the highest environmental footprint regardless of pathology (Nansai et al., 2020). **Acute services** are the most resource intensive within the NHS England, responsible for 56% of all emissions stemming from clinical activities (Tennison et al., 2021). In Japan, medical services with **hospitalization** are over five times more carbon intensive than medical services without hospitalization (including outpatient care in hospital, preventive health activities and health consultations) [Nansai et al., 2020].

Treatment of cardiovascular diseases are leading in terms of emissions, followed by neoplasms, respiratory diseases, musculoskeletal and connective tissue diseases (Nansai et al., 2020). For specific hospital-based treatments, **hemodialysis** has been identified as one of the most energy-consuming treatments, with high water and electricity consumption, a high number of patients and a high intensity and frequency of the treatment (Wieliczko et al., 2020). Estimations from the USA show that each treatment emits around 59 kgCO2e, through patient and staff transportation, electricity use and use of natural gas (Sehgal et al., 2022).

Surgical operations and related activities have been identified as amongst the most resource intensive hospital activities (Alshqaqeeq et al., 2020) – up to six times more energy-intensive than other hospital services (Rizan et al., 2020). In three surgical suites (including operating rooms (OR), corridors, sterile core, anesthetic and equipment rooms, but excluding pre- and post-operative holding and recovery areas, administrative offices, and medical device reprocessing departments) in the UK, USA and Canada, emissions were estimated between 3 and 5 million kg of CO2e per surgical suite per year, of which the main source of GHG emission was anesthetic gases (desflurane, isoflurane, and sevoflurane) in the USA and Canada, and electricity use in the UK (MacNeill et al., 2017). The majority

(90–99%) of all energy consumption in all three surgical suites came from heating, ventilation and air conditioning of the ORs (MacNeill et al., 2017). A systematic review found that carbon emissions of one single surgical operation can range between 6 and 814 kgCO2e, depending on the estimation methods but also the type of operation, the level of invasiveness, level of electricity use and procurement of consumables (Rizan et al., 2020).

The average carbon footprint **of cataract surgery,** the most common surgical operation in New Zealand, has been estimated at 152 kgCO2e per surgical operation, which corresponds to approximately 62 liters of petrol (Latta et al., 2021). Out of the emission sources studied (energy consumption, procurement of disposable materials and pharmaceuticals, waste disposal and travel), the majority of emissions came from procurement of disposable materials and travel (Latta et al., 2021).

An intensive care unit has been estimated to generate 7.1 kg of solid waste and 138 kgCO2 per hospitalization day compared to 5.5 kg and 45 kgCO2 for acute care units in the USA (Prasad et al., 2022). A review assessed that 45–59% of **OR waste** is general waste, 23–32% is clinical waste and 17–25% is recyclable waste produced primarily from a high use of single-packaged disposable sterile instruments (and unused but opened equipment) and anesthetics (glass, plastics, drug ampoules and volatile gasses) [Wyssusek et al., 2019]. An assessment of 17 neuro-interventional procedures found instead that the majority (63%) was clinical waste, followed by general waste (21%), recyclable paper (11%) and plastics (4%) and sharps (1%) [Shum et al., 2020].

Gases used in medical procedures (mainly **anesthetic gases**) stand for less than 1% of GHG emissions in the health care sector in France (0.2 MtCO2e annually) [Shift et al., 2021]. However, they have been identified as an important aspect of emissions, as anesthetic gases are directly emitted to the atmosphere, are replaceable by products without direct emissions, and are additionally subject to large amounts of waste (unused NO2, for instance) [Shift et al., 2021].

Pharmaceutical and medical products

Medical and pharmaceutical products stand out as one of the domains that pollute the most (Eckelman et al., 2018; Lenzen et al., 2020) in all health care systems. In Australia, pharmaceuticals stood for 19% of all health care-related CO2e emissions in 2014/2015, where medical aids and appliances associated with rehabilitation, orthopedics, glasses, and hearing aids added another 3% (Malik et al., 2018). **Pharmaceuticals** (both prescribed and non-prescribed) represented 25% of health care life cycle GHG emissions in Canada in 2015 (Eckelman et al., 2018), and 10% of health-care related GHG emissions in the USA in 2013, without taking into account anesthetic gases (Eckelman and Sherman, 2016). In the USA, 5% of GHG emissions were related to medical equipment (3% from durable equipment and 2% from non-durable) [Eckelman and Sherman, 2016]. In France, **procurement of pharmaceuticals** (indirect emissions) has been estimated to stand for up to a third of total health care-related emissions (15.6 MtCO2e annually), followed by **procurement of medical aids and appliances** (21% or 10.0 MtCO2e annually); together they are likely to account for between 35% and 50% of health care-related emissions in France (Sénéchal, 2023).

The emissions related to **pharmaceuticals** in the medical sector in Japan (excluding long-term care (LTC) and public health services) exceeded the emissions related to hospitals' energy consumption in 2011 (Nansai et al., 2020).

Metered-dose inhalers (MDI) contain very potent GHGs to transport medication to the lung and are one of the medicines that contribute the most to global warming. The chlorofluorocarbons in inhalers have progressively been replaced with hydrofluorocarbons, which are not ozone-depleting but still potent GHGs, as well as dry-powder inhalers, which have drastically lower environmental impact (Janson et al., 2020). In the UK, MDIs are still amongst the main drivers of primary care emissions (Tennison et al., 2021). Depending on the inhaler, emissions vary; for instance, tetrafluoroethane inhalers emit less than 10 kgCO2e per inhaler, reliever inhalers (e.g., Ventolin) emit about 25 kgCO2e and heptafluoropropane inhalers emit over 36 kgCO2e per inhaler (Wilkinson et al., 2019).

Furthermore, an ecological risk assessment of the **presence of pharmaceuticals in waters** identified that several common pharmaceuticals are posing an environmental risk in France due to their high presence, including acetaminophen, ibuprofen, diclofenac, oxazepam and carbamazepine (Bouissou-Schurtz et al., 2014). A study assessing pharmaceutical products in the marine waters and sediments of Augusta Bay in the central Mediterranean sea estimated the amounts to range between 2,426 to 67,155 ng per liter for untreated wastewaters, 550 to 27,889 ng per liter for marine receiving waters (amounts representing a high risk of impact on aquatic organisms) and 12 to 281 ng per liter for seawaters (non-hazardous levels) [Feo et al., 2020]. The main pharmaceutic polluters were antibiotics, anti-inflammatory drugs, and medications for cardiovascular and hypertensive disorders (Feo et al., 2020).

Energy (electricity, gas and oil)

Studies show that **fossil fueled electricity and gas** used by health care services (approximately 137.4 MtCO2e in 2015, globally) are two main sources of emissions across health care sectors (Lenzen et al., 2020). In Japan, electricity use in the supply-chain is consistently the largest contributor to emissions across all health care sectors (Nansai et al., 2020) and in Canada, electricity alone contributes to 22% of the life-cycle emissions of the health care sector, and oil and gas contribute with another 17% (Eckelman et al., 2018).

In France, energy use in the form of **fuel and gas usage** is the largest source of direct emissions, standing for 10% of all health care-related emissions (4.5 MtCO2e per year). This energy is mainly used for heating, hot water and meal preparation in health care facilities (Shift et al., 2021). Electricity use stands for 3% of all GHG emissions (1.5 MtCO2e per year) [Shift et al., 2021].

Transportation

Different sources of emissions related to transportation, including **freight and patient transportation,** are among the top five sources of emissions for both direct and supply chain-related sources, in medical, nursing and public health and sanitary services in Japan (Nansai et al., 2020). In England, patient, visitor and staff transport to and from NHS sites stood for 10% of all NHS emissions in 2019 (Tennison et al., 2021).

Ambulance transport in Australia, where distances travelled can be very long in rural areas, is estimated to generate 22 kgCO2e per ground ambulance response, mainly stemming from fuels (58%), followed by electricity consumption. One **air ambulance** response has an impact estimated to be 200 times higher than a ground ambulance response, and generates, together with ground ambulance transportation, between 110,000 and 120,000 tCO2e annually in Australia (Brown et al., 2012).

Higher travel-related emissions are also associated with **highly specialized care**, often centralized to highly specialized units, increasing travel distances for patients. The carbon emissions related to a modernized ST-myocardial infarction treatment in the UK was three times higher – 11.2 $kgCO_2$ compared to 3.7 $kgCO_2$ for traditional care – due to ambulance travel increasing from 13 km to 42 km (Zander et al., 2011).

In France, transportation related to patients, visitors, and health care professionals stands for 13% of national health care-related GHG emissions (Sénéchal, 2023).

Buildings

The global emissions from 189 countries related to **buildings and vehicles** of health care providers have been estimated to 63.1 $MtCO_2e$ globally in 2015 (Lenzen et al., 2020). **Buildings** (capital expenditure principally consisting of building and renovating hospitals) stood for 8% of all health care related CO_2e emissions in Australia in 2014–2015 (Malik et al., 2018). In Japan, a large part of emissions related to **buildings** are directly related to the construction of hospitals, followed by supply chain emissions, including electricity use and extraction of raw materials needed for construction (Nansai et al., 2020). In France, it is estimated that buildings in the health care sector stand for 9% of the national health care-related GHG emissions (4.3 $MtCO_2e$ in 2020) [Shift et al., 2021].

Food products

Crop and animal production (mainly fertilizer and animals) stand for 5.2% of the health care sector's life cycle emissions in Canada, due to the link between the food industry and hospital sector (Eckelman et al., 2018). **Food products** are estimated to contribute with up to 11% to the total GHG emissions in the health care sector in France (Sénéchal, 2023).

Apart from food production, **food waste** is a major contributor to emissions related to meals in the health care sector. In the USA, one large hospital kitchen (in a hospital of 750 beds, 9,575 on-site staff, and 212,574 patient-days annually) was estimated to produce 862 kg of solid organic or compostable food waste daily, when providing 1,900 inpatient and 3,400 retail meals (Thiel et al., 2021). The environmental footprint of food waste in terms of GHG emissions (kg CO_2e per kg of food waste) and land use (m^2 per kg food waste) in the health care sector has been assessed as higher (2.9 kg CO_2e and 1.9 m^2 per kg food waste) compared to the food waste in the business sector (up to 2.3 kg CO_2e and 1.4 m^2 per kg food waste) [Meier et al., 2021].

Elderly care and nursing

Japan, with one of the oldest populations on Earth, has seen an increasing rate of emissions related to **nursing services**; 16% of total health care-induced emissions can be directly or indirectly related to nursing services (Nansai et al., 2020). In the USA, 6% of all health-care related GHG emissions came from **nursing care facilities and "continuing care retirement communities"** in 2013 (Eckelman and Sherman, 2016). The **elderly care and nursing sector** is likely to grow and become a larger contributor to the environmental footprint also in France, considering the ageing of the population.

Ambulatory care

The **ambulatory care** sector, including primary care providers and outpatient specialist care, accounts for varying proportions of health care emissions around the world. All **specialist care and related services** provided outside hospital in Australia accounted for 6% and general practice for 4% of health care-related CO2e emissions in 2014–2015 (based on life-cycle assessments of these economic sectors including both direct and indirect emissions, but excluding the impact of pharmaceuticals, aids and appliances and patient travel) [Malik et al., 2018]. **Non-hospital "Physician and Clinical Services"** (without specifying the scope) contributed to 12% of health-care related GHG emissions in the USA in 2013 (Eckelman and Sherman, 2016). In the UK, **primary care** (including Scope 1, 2 and 3 emissions of care delivery including buildings, energy use, water, waste and anesthetic gases and business travel, supply chain including medical and non-medical products, other procurement, plus personal travel) stood for 23% (5,770 ktCO2e) of all CO2e emissions within the NHS in 2019, primarily driven by supply chain emissions and prescriptions of MDIs (Tennison et al., 2021). It was the second largest contributor in the NHS, after acute care (12,960 ktCO2e from the same type of emission sources).

A study assessing emissions in 10 **primary care practices** in Switzerland found that more than half (55.5%) of the total CO2e emissions in primary care were caused by patient (33.2%), staff (12.5%) and courier transportation (9.8%) [Nicolet et al., 2022]. The heating system was responsible for 29.8% of emissions, medical consumables for 5.5%, non-medical equipment for 4.1% and medical equipment for 0.4%. Waste disposal and external laboratory analyses contributed with less than 2% of emissions respectively, and electricity consumption only 0.3%. For medical consumables, bandages and compresses accounted for 62.6% of emissions, blood sampling material for 12.6%, medical bed paper sheets for 8.8% and gloves for 4.3%. Examination beds accounted for the majority (78.8%) of medical equipment-related emissions and electronic devices accounted for the majority of non-medical equipment emissions (81.1%) [Nicolet et al., 2022].

Public health and community care

Public health, community care and equivalent services are amongst the smallest sources of emissions in the health care sector, between 4% and 6%, partly because of the relatively small provision of such services.

Services classified as **"health and hygiene"** services in Japan was the smallest health care sector in the country in 2011, with emissions of 0.8 MtCO2e per year, compared to, for instance, nursing services at 10.1 MtCO2e and medical services (hospital, ambulatory, dentistry and other services) at 41.5 MtCO2e in total (Nansai et al., 2020). In the USA, 4% of all health-care related GHG emissions came from **governmental public health activities** in 2013, whereas 4% come from **"other health, residential and personal care"** (Eckelman and Sherman, 2016). In the UK, **community care** stood for 5% (1,280 ktCO2e) of all CO2e emissions within the NHS in 2019, which is less than both mental health care-related emissions (1,520 ktCO2e) and primary care-related emissions (5,770 ktCO2e) [Tennison et al., 2021]. In Australia, **community care** (such as clinics for maternal and child health, mental health care or minorities' health) **and public health services** (screening, disease control, immunization, food and hygiene) accounted for 6% of health care-related CO2e emissions in 2014–2015, which is similar to the ambulatory specialist care sector (Malik et al., 2018).

Raw materials and manufacturing

Manufacturing of petroleum products and primary metal contribute with 4% and 3% to the life cycle GHG emissions in the Canadian health care system, respectively (Eckelman et al., 2018). **Raw materials**, in particular pig iron and cement, also make up a large part of supply chain emissions related to the fixed capital of all health sectors in Japan (Nansai et al., 2020).

Dentistry

Dentistry only accounts for 3% of all health care-related CO2e emissions in Australia (Malik et al., 2018), and 2% in the USA in 2013 (Eckelman and Sherman, 2016). According to estimations of the NHS **primary dental services**, which emit approximately 675 ktCO2e annually (April 2013 to March 2014), the dental services that emit the most are examinations (27%), tooth restorations (amalgam or composite; 19%) and scaling and polishing (13%) [Duane et al., 2017]. The majority of emissions were related to staff and patient travel (65%), procurement of goods and services (19%) and energy use (15%) [Duane et al., 2017].

Health care and hospitalization at home

One study has estimated the emissions from health care at patients' homes, including **home hospitalizations**, which stood for 3% of all health care-related GHG emissions in the USA in 2013 (Eckelman and Sherman, 2016).

Material and medical waste

Material waste such as single-use plastics (e.g. gloves and packaging), metal and plastic from consumables as well as food waste stand for 2% of GHG emissions in France (0.7 MtCO2e in 2020) [Shift et al., 2021]. A part of waste stems from **unused medical products**. Out of 116 pharmaceuticals assessed in four hospital sites performing cataract surgery in the USA, on average 45% (83,070 ml monthly) of pharmaceuticals remained unused, corresponding to a total of 5,762 kg of unnecessary CO2e emissions per month for the four centers, with additional unnecessary air and water pollution (Tauber et al., 2019). Especially eyedrops remained unused (66%) compared to 60% of systemic medications and 25% of injections. Non-use of medications were highest in the ambulatory (66%) and outpatient (57%) care centers, and lowest in the tertiary care center (21%) [Tauber et al., 2019].

A survey aimed at pharmacists in New Zealand revealed that up to 80% of solid waste drugs are appropriately removed by contractors, whereas most of Class B controlled liquid drugs are disposed down the pharmacy sink, posing an environmental risk for aquatic environments (Tong et al., 2011). Medical waste treated through incineration is the third (direct emissions) and fourth (supply chain) largest source of GHG emissions in the health and hygiene sector (public health included), the fifth (direct) and sixth (supply chain) largest source in the LTC and nursing sector, and the eighth largest source (both for direct and supply chain sources) in the medical care sector in Japan (Nansai et al., 2020).

Diagnostic testing

The environmental impact of common **pathology testing in hospitals** is relatively small. Emissions, mainly resulting from sample collection, have been estimated at 116 gCO2e per test for full blood examinations, 99 g per test for urea and electrolyte assessments, 82 g per coagulation profile for hematology tests, 49 g per arterial blood gas assessment and 0.5 g per test for C-reactive protein levels (McAlister et al., 2020). Yet, pathology testing is an important source to address due to the large amounts of tests performed on a daily basis (McAlister et al., 2020).

Magnetic resonance imaging (MRI) has a significantly larger environmental impact; 22 kgCO2e per case, when counting the emissions for the entire service (Esmaeili et al., 2018). The in-hospital (direct) energy use for performing an MRI (including energy consumption of the MRI machine, lighting, the facilities etc.) is lower (29 kWh per patient) than the indirect energy consumption (75 kWh per patient) [related to generating and transmitting electricity to the hospital and to the manufacturing of consumables]. The MRI

Table 1 Estimations of environmental impact of health care sectors and domains

Sector/domain	Country	Impact as % of all health care-related CO_2e emissions unless otherwise stated
Hospital care	CA, AUS	Between 22% (CA) and 44% (AUS) of emissions in the health care system
Surgery	CA, ENG, AUS	Between 3.2 ktCO_2e (CA) and 5.2 ktCO_2e (ENG) per surgical suite per year. One single surgical operation can emit between 6 and 814 kgCO_2e (AUS)
Acute care	ENG	56% of all emissions from clinical activities
Hospitalization	JP	Is five times more carbon intensive than medical care without hospitalization
Medical gases	FR	<1% of emissions (0.2 MtCO_2e annually) in the health care system
Hemodialysis	USA	59 kgCO_2e per treatment
Pharmaceuticals and medical aids	FR	Procurement of pharmaceuticals and medical aids and appliances account for between 35% and 50% of emissions in the health care system (FR)
Pharmaceuticals	USA, FR	Between 10% (USA) and up to 33% (FR) of emissions in the health care system
Medical aids and appliances	AUS, FR	Between 3% (AUS) and up to 21% (FR) of emissions in the health care system
Inhalers	ENG	Emissions from inhalers include for instance: • Tetrafluoroethane: <10 kgCO_2e per inhaler • Reliever inhalers (e.g. Ventolin): 25 kgCO_2e per inhaler • Heptafluoropropane: >36 kgCO2e per inhaler
Energy	FR, CA	Between 13% (FR) and 39% (CA)
Fossil fueled electricity and gas	FR	Emit 137.4 MtCO_2e per year (globally, world-wide), or 6 MtCO_2e per year in France
Electricity	FR, CA, CH	Stands for between 3% (FR) to 22% (CA) of emissions in the health care system. In primary care, electricity consumption stands for <1% of emissions (CH)
Fuel or oil and gas	FR, CA	Between 10% (FR) and 17% (CA) of emissions in the health care system
Transportation		
Patient, visitor and staff	ENG, FR, CH	Between 10% (ENG) and 13% (FR) of emissions in the health care system. Just within primary care, 33% of emissions are caused by patient and 13% by staff transportation (CH)
Freight/courier	CH	In primary care, courier transportation stands for almost 10% of emissions
Buildings	CA, FR	Between 8% (CA) and 9% (FR) of emissions in the health care system
Food products		
Food products	FR	11% of all health care-related emissions
Crop and animal production	CA	5% of emissions in the health care system
Food waste	DE	3 kgCO_2e per kilo food waste and 2 m^2 land use per kg food waste
Ambulatory care	AUS, ENG	Between 10% (AUS; 6% specialist and 4% generalist care) and 23% (ENG, mainly driven by MDIs) of emissions in the health care system
Primary care practices	ENG, CH	Emit 5,770 ktCO_2e per year (ENG). Emissions in primary care practices stem from (CH): • Transportation (56%) • Heating (30%) • Medical consumables (6%, of which 63% from bandages and compresses, 13% from sampling material, 9% from bed paper sheets and 4% from gloves) • Non-medical equipment (4%, of which 81% from electronic devices) • Waste disposal (<2%) • External laboratory analyses (<2%) • Medical equipment for (<1%, of which 79% due to examination beds) • Electricity consumption (<1%)

.../...

Table 1 (continued) Estimations of environmental impact of health care sectors and domains

Sector/domain	Country	Impact as % of all health care-related CO_2e emissions unless otherwise stated
Elderly care and nursing	USA, JP	Between 6% (USA) and 16% (JP) of emissions in the health care system
Mental health care	ENG	1,520 ktCO_2e per year
Public health, community care and hygiene	USA, AUS	Between 4% (USA) and 6% (AUS) of emissions in the health care system depending on definition and country
Community care and public health services	AUS	6% of emissions in the health care system (such as clinics for maternal and child health, mental health, minorities' health, screening, disease control, immunization, food and hygiene)
Community care	ENG	5% (1,280 ktCO_2e per year) of emissions in the health care system
Governmental public health activities	USA	4% of emissions in the health care system
Health and hygiene	JP	0.8 MtCO_2e per year
Raw materials and manufacturing		
Manufacturing petroleum products	CA	4% of emissions in the health care system
Manufacturing primary metal	CA	3% of emissions in the health care system
Dentistry	USA, AUS	Between 2% (USA) and 3% (AUS) of emissions in the health care system
Primary dental care	UK	Services contributing to emissions in primary dental care are: • Examinations (27%) • Tooth restorations (19%) • Scaling and polishing (13%) • Emissions from these services stem from • Staff and patient travel (65%) • Procurement of goods and services (19%) • Energy use (15%)
Material waste	FR	2% of emissions in total in the health care system (0.7 MtCO_2e per year)
Primary care	CH	<2% of emissions in the primary care sector come from material waste
Health and hygiene	JP	Third (direct) and fourth (supply chain) largest emission source in the health and hygiene sector
Nursing	JP	Fifth (direct) and sixth (supply chain) source in the long-term care and nursing sector
Medical (hospital) care	JP	Eighth (both for direct and supply chain sources) in the medical care sector
Research	USA	2% of emissions in the health care system
Diagnostic testing		
Biological samples	AUS	• 116 gCO_2e per full blood examination • 99 gCO_2e per urea and electrolyte assessment • 82 gCO_2e per coagulation profile for hematology tests • 49 gCO_2e per arterial blood gas assessment • 0.5 gCO_2e per test for C-reactive protein levels
Magnetic resonance imaging	USA	• 22 kgCO_2e per imaging case, counting emissions for the entire service • 29 kWh per patient or the in-hospital energy use for performing an MRI • 75 kWh per patient in indirect energy consumption and manufacturing of consumables

Notes: Figures are not comparable across countries, as the level of dependence of fossil fuels differs. Domains may not be generalizable; there is large variation in definitions, sources of emissions included in the calculations (e.g. direct versus indirect emissions) as well as sample sizes used as a base for estimations (e.g. one hospital only). Abbreviations: AUS – Australia; CA – Canada; CH – Switzerland; DE – Germany; ENG – England; FR – France; JP – Japan; MDI – Metered dose inhalers; MRI – Magnetic resonance imaging; UK – United Kingdom; USA – the United States of America. Units: Mt – megatonne (or one million tonnes); kt – kilotonne (or 1,000 tonnes); t – tonne (or 1,000 kilograms); kg – kilograms (or 1,000 grams).

imaging and the standby energy of the machine make up 38% of the total life cycle energy consumption (Esmaeili et al., 2018).

Research

Few studies take into account the GHG contribution of the **medical research sector**. In the USA, it was estimated that 2% of health-care related GHG came from research activities in 2013 (Eckelman and Sherman, 2016).

2.3. Conclusions

The hospital and pharmaceutical sectors are consistently identified as the main health care-related contributors to global warming. Treatment of the most common chronic diseases such as cardiovascular and respiratory diseases, and energy-intensive treatments, including hemodialysis, surgery, and intensive care are to a large part responsible for these elevated emissions. The factors that drive these emissions include patient and visitor transportation, high fossil energy use due to the need for heating, cooling, hot water, meal preparations and operating and sterilizing equipment, and high amounts of waste generated. Most importantly, overall, hospitalizations have a higher environmental impact compared to medical services without hospitalization. Ambulatory care and public health activities are currently among the least polluting health care activities.

High emissions from pharmaceuticals come from their entire life-chain: production, use and disposal. Procurement of pharmaceuticals and medical appliances are estimated to account for up to half of all health care-related emissions in France, with the majority coming from the supply-chain, often in foreign countries where the pharmaceutical production sites are held. France has also one of the highest pharmaceutical prescription and consumption rates across OECD countries.

Finally, although studies are still limited, the example of Japan shows how LTC will represent a growingly larger part of energy consumption due to an ageing population and increasing prevalence of chronic disease.

3. Interventions aiming to improve the environmental sustainability of health care systems: a scoping review

While there is an increasing attention on actions to reduce the environmental footprint of health care systems, there is currently, to our knowledge, no overview of evaluations of such interventions nor a synthesis of evidence-based methods to reduce the environmental impact of health care systems, especially at the organizational level.

This review aims to provide an overview of interventions that are used in industrialized countries to reduce the environmental impact of health care systems, focusing on both « green interventions » that aim to improve care processes at the micro or meso-level and sustainability strategies that aim to shift health care organization and demand for care (Box 2). We synthesize the evidence available on interventions, their characteristics, and estimated impact on reducing the environmental impact of health care systems.

Box 2. Definitions

In this document we regularly refer to two different types of interventions

"Green interventions" refer to micro or meso-level interventions aiming to reduce emissions stemming from specific health care activities, for example by replacing disposable with reusable medical equipment, reducing electricity use, increasing recycling or improving procurement protocols to reduce emissions in the supply chain.

Sustainability strategies are mainly macro- or organizational-level interventions aiming to restructure health care activities to reduce the demand, and utilization of carbon-intensive care by transforming care provision. Sustainability strategies include avoiding excessive hospital use, improving disease prevention, reducing wasteful care (such as unnecessary medical acts or prescription of antibiotics), etc. These strategies can reinforce both economic and environmental sustainability of the health care system.

3.1. Methods

The scoping review is a well-established methodology suitable for assessing the range of literature available on a certain topic in order to synthesize the evidence available (Davis et al., 2009). The method is well suited to give an indication of the volume and types of literature and studies available as well as an overview of the emerging evidence in a given field (Munn et al., 2018). We followed the Joanna Briggs Institute (JBI) guidelines for scoping reviews (Peters et al., 2020), and the PRISMA Extension for Scoping Reviews guidelines (Tricco et al., 2018).

3.1.1. Search strategy

We searched for peer-reviewed scientific articles published in English, French or Swedish, between 2010 and May 2022 in Medline (via PubMed) and Web of Science. The search in peer-review repositories was conducted in four steps between 23 February and 17 May, while refining the search strategy to target publications that may have been missed in the previous searches. Reference lists of relevant peer-reviewed articles were assessed to retrieve additional publications with a snowballing method, and an additional hand search was performed for areas where results were lacking in the automated searches. The main search strategy used in PubMed is described in the box below (for the full search, see Appendix 1). Grey literature and non-peer reviewed articles were hand searched via Google and official websites of relevant institutions, such as the WHO, the World Bank and the Intergovernmental Panel for Climate Change (IPCC).

((((((((((((((((«climate smart»[Title/Abstract]) OR («ecological»[Title/Abstract])) OR («green health care»[Title/Abstract])) OR («green healthcare»[Title/Abstract])) OR («carbon neutral»[Title/Abstract])) OR («decarbonized»[Title/Abstract])) OR (decarbon*[Title/Abstract])) OR («climate objectives»[Title/Abstract])) OR («climate change»[Title/Abstract])) OR («global warning»[Title/Abstract])) OR («carbon emission»[Title/Abstract])) OR («pollution»[Title/Abstract])) OR («greenhouse gases»[Title/Abstract])) OR («environmental impact»[Title/Abstract])) OR («environmental footprint»[Title/Abstract])) OR («environmental footprints»[Title/Abstract])) OR («environmental impacts»[Title/Abstract])) OR («environmental friendly»[Title/Abstract])) OR («sustainable development»[Title/Abstract]) AND ((((((((((((((((((((((((((«health care»[Title/Abstract]) OR («healthcare»[Title/Abstract])) OR («care sector»[Title/Abstract])) OR («healthcare services»[Title/Abstract])) OR («health care services»[Title/Abstract])) OR («primary care»[Title/Abstract])) OR («hospital»[Title/Abstract])) OR («hospitals»[Title/Abstract])) OR («doctors»[Title/Abstract])) OR («surgery»[Title/Abstract])) OR («outpatient»[Title/Abstract])) OR («inpatient»[Title/Abstract])) OR («pathways»[Title/Abstract])) OR («medical practice»[Title/Abstract])) OR («care organization»[Title/Abstract])) OR («care organizations»[Title/Abstract])) OR («long term care»[Title/Abstract])) OR («nursing»[Title/Abstract])) OR («pharmaceuticals»[Title/Abstract])) OR («healthcare waste»[Title/Abstract])) OR («health care waste»[Title/Abstract])) OR («healthcare wastes»[Title/Abstract])) OR («health care wastes»[Title/Abstract])) OR (medical equipment[Title/Abstract])) OR («medical transport»[Title/Abstract])) OR («healthcare supply chain»[Title/Abstract])) OR («health care supply chain»[Title/Abstract])) OR («care delivery»[Title/Abstract])) OR («drugs»[Title/Abstract]) AND ((((((((((((((«reduction»[Title/Abstract]) OR (mitigation[Title/Abstract])) OR (intervention[Title/Abstract])) OR (interventions[Title/Abstract])) OR (policy[Title/Abstract])) OR (policies[Title/Abstract])) OR (INTERVENTION[Title/Abstract])) OR (INTERVENTIONS[Title/Abstract])) OR (strategy[Title/Abstract])) OR (strategies[Title/Abstract])) OR («plans»[Title/Abstract])) OR (PLAN[Title/Abstract])) OR (waste reduction[Title/Abstract])) OR (avoidable[Title/Abstract])) OR («care grade»[Title/Abstract])) OR (prevention[Title/Abstract]) OR «community care»[Title/Abstract] OR ((((EVALUATION[Title/Abstract]) OR (EVALUATIONS[Title/Abstract])) OR (ASSESSMENT[Title/Abstract])) OR (ASSESSMENTS[Title/Abstract])) OR (IMPACTS[Title/Abstract])

Combined with specifications for three groups of countries (France, European OECD, non-European OECD):

AND ((FRANCE[MeSH Terms]) OR FRANCE[Title/Abstract]) OR «french»[Title/Abstract]

AND (((((((((((((((((((((((((((((((((((((«european union»[MeSH Terms]) OR «european union»[Title]) OR «europe»[MeSH Terms]) OR «europe»[Title]) OR «europe, eastern»[MeSH Terms]) OR «austria»[MeSH Terms]) OR «austria»[Title]) OR «belgium»[MeSH Terms]) OR «belgium»[Title]) OR «finland»[MeSH Terms]) OR «finland»[Title]) OR «germany»[MeSH Terms]) OR «germany»[Title]) OR great britain[MeSH Terms]) OR «great britain»[Title]) OR «united kingdom»[MeSH Terms]) OR «united kingdom»[Title]) OR «greece»[MeSH Terms]) OR «greece»[Title]) OR «iceland»[MeSH Terms]) OR «iceland»[Title]) OR «ireland»[MeSH Terms]) OR ireland[MeSH Terms]) OR «italy»[Title]) OR «italy»[MeSH Terms]) OR «portugal»[MeSH Terms]) OR portugal[Title]) OR («scandinavian and nordic countries»[MeSH Terms])) OR «denmark»[MeSH Terms]) OR «denmark»[Title]) OR «norway»[MeSH Terms]) OR «norway»[Title]) OR «sweden»[MeSH Terms]) OR «sweden»[Title]) OR «spain»[MeSH Terms]) OR «spain»[Title]) OR «netherlands»[MeSH Terms]) OR «netherlands»[Title]) OR «switzerland»[MeSH Terms]) OR «swizerland»[Title]

AND ((((((((«australia»[MeSH Terms]) OR «australia»[Title]) OR «canada»[MeSH Terms]) OR «canada»[Title]) OR «japan»[MeSH Terms]) OR «japan»[Title]) OR «united states»[MeSH Terms]) OR united states]) OR «new zealand»[MeSH Terms]) OR «new zealand»[Title])

3.1.2. Study selection

The objective of the review was to provide **a representative sample of peer-reviewed and grey literature** assessing the impact of interventions (both micro- and macro-level) aiming to reduce the environmental footprint of the health care system or parts of it. We focused on the health care domains with the largest environmental impact, aiming to give an overview of the potential effects of interventions targeting these domains across different measures, such as reduced CO2 emissions, water use or food waste.

We primarily aimed at including publications that provide a quantified effect measure of an implemented intervention, or that estimate the quantified effect of a theoretical intervention (i.e. that has not been implemented in practice). However, as such evaluations may be scarce, we also sought to complete our search with results from systematic reviews, when relevant. As we strived to identify interventions, measures, and actions potentially applicable to the French health care system, we excluded studies in low-income countries and studies conducted in other settings than the health care sector. We did not apply limitations on study design.

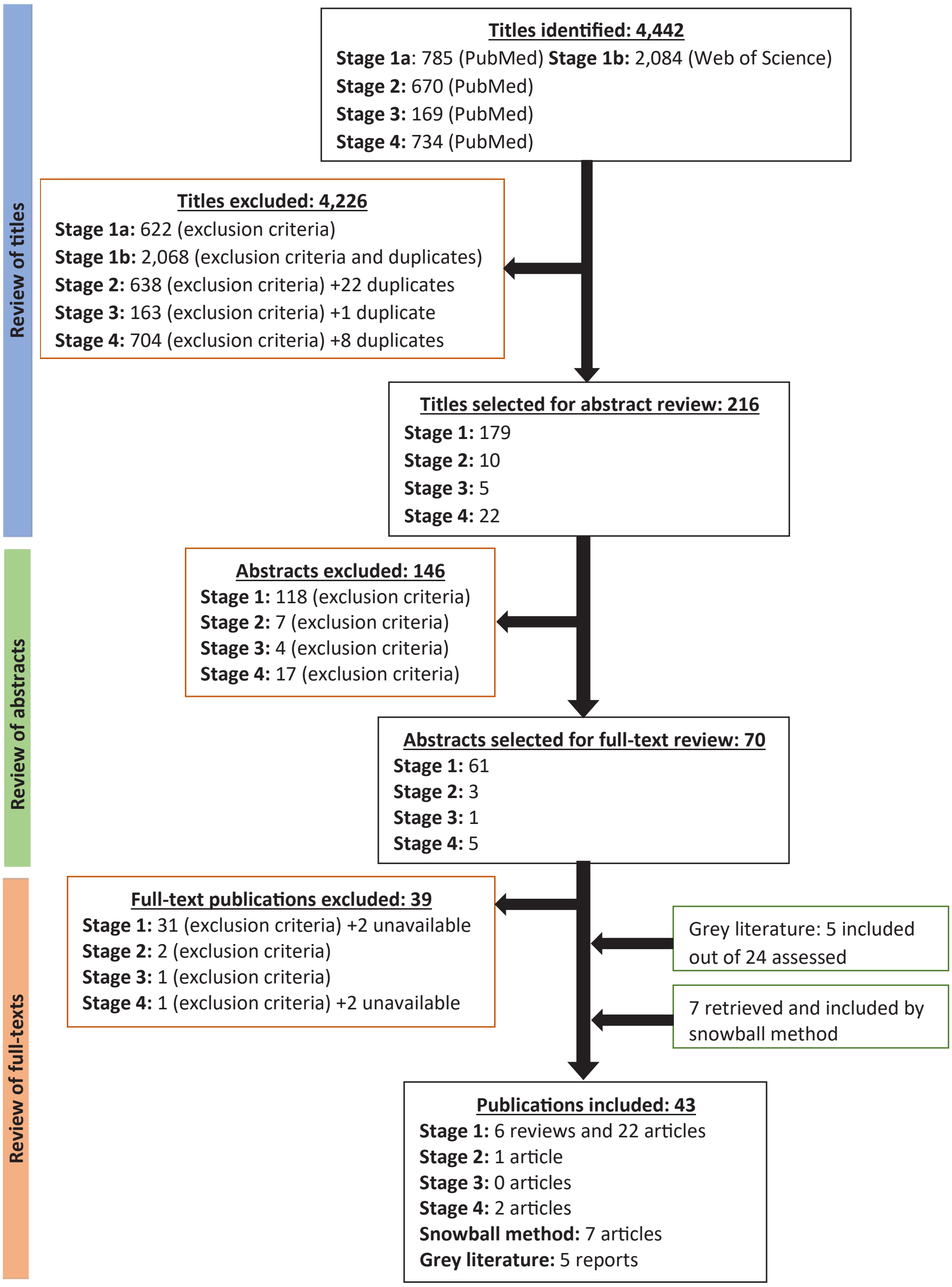
All titles retrieved were first screened by a documentalist (MOS) for relevance and duplicates were removed by MOS for an initial selection. Two researchers (AVS and ZO) then screened the titles and abstracts of the selected articles for a second selection, followed by a review of full-texts of the selected articles, using the inclusion and exclusion criteria (see Table 2). Articles for which there were doubts about inclusion were discussed until agreement was reached between AVS and ZO at each step. A list of publications retrieved from grey literature was compiled by MOS as an initial selection. AVS and ZO screened the titles, abstracts and full-texts of the selected articles and conducted additional hand searches and selections using the same inclusion and exclusion criteria as described in Table 2. Publications retrieved through the snowball method and hand searching were assessed full-text by AVS and reassessed by ZO.

Table 2 Inclusion and exclusion criteria for scoping review

Inclusion criteria
Publications from high-income countries
Publications published in 2010 or later
Publications in English, French, or Swedish (spoken in the research team)
Publications that describe and estimate the effect of an intervention (implemented or theoretical) that aims to reduce the environmental footprint of the health care system or parts of it (as primary or secondary effect)
Systematic reviews on the impact of specific interventions
Exclusion criteria
Publications not concerning the health care sector directly, such as interventions in industries or studies on vehicles or buildings in general
Publications not providing any quantified measure or estimate of the intervention's environmental impact, such as reduced CO_2 emissions, water use or food waste
Publications providing only a description of interventions without any evaluation or impact estimate
Publications which do not report all data extraction items

A data extraction sheet was developed to extract data on the publication type (peer-reviewed article, grey literature etc.), study design (study type, country, setting, intervention, outcome, etc.), study results (impact assessment, effect size, recommendation) and meta data (authors, year, etc.). We did not appraise the methodology, nor the strength of evidence provided in each study, as the aim was to get an overall understanding of interventions used and collect information on their potential impact for mitigating environmental impact of health care.

Figure 1 Flow diagram of study selection



3.2. Results

The searches yielded 4,442 publications for which titles were screened by MOS, removing 2,127 publications not meeting the inclusion criteria and 31 duplicates from PubMed and 2,068 publications not meeting the inclusion criteria and/or duplicates from Web of Science (see Figure 1. Flow diagram of study selection). Abstracts of the 216 selected publications were retrieved, which were assessed by AVS and ZO for full-text assessments. Out of the 216 abstracts, 146 were excluded and 70 were assessed in full-text. Thirty-one of the full-text publications met the inclusion criteria and were included in the review. Out of 24 documents in the grey literature, five met the inclusion criteria and were included in the review. Seven additional full-text publications were retrieved through the snowball method, of which all were peer-reviewed research articles. In total, 43 publications were included: 32 peer-reviewed research articles, six peer-reviewed literature reviews, and five reports from grey literature. For all articles included, see Appendix 2.

3.2.1. Study characteristics

We found 43 publications fulfilling the inclusion criteria. Over half of these (n=22) were published in 2020, 2021 and the first months of 2022 (see Appendix 3: Data extracted – synthesized table). The peer-reviewed research articles and grey reports had been conducted in the UK (n=17 in England, 1 in Scotland), the USA (n=5), Australia (n=3), Sweden (n=3), Canada (n=2), Germany (n=2), Switzerland (n=2), France (n=1), and Portugal (n=1). The six systematic reviews had an international scope. Out of the 32 peer-reviewed research articles, 13 assessed the impact of interventions that had been implemented in a real-life setting, whereas 19 estimated the impact of theoretical interventions (primarily mathematical modelling studies). All peer-reviewed research articles and reports from grey literature reported quantitative effect measures. None of the systematic reviews conducted meta-analysis of quantitative effect measures but reported some quantified measures from individual studies.

Most publications concerned the hospital sector (n=30): 11 concerned the hospital sector in general, seven focused on ORs or surgeries, three on hospital outpatient care, one on hospital in-patient and outpatient care, and two on hospital food services. Several of these 30 publications concerned the hospital sector as well as the primary care sector (n=4), specialist rehabilitation (n=1) or the pharmaceutical sector (n=1). Seven publications targeted all sectors in the health care system, of which one focused on food services. Few publications focused specifically on primary care (n=1), secondary care (n=1), primary and secondary care combined (n=1), dental care (n=1) and pharmaceuticals (n=2).

3.2.2. Description of interventions

Most commonly reported interventions were health system-level approaches (n=8), such as health system-level climate goals and strategies (of which most concerned the NHS climate strategy) or health system reconfiguration (modelling studies), as well as green protocols/practices/procedures (n=8) such as climate audit and intervention protocols, or modified procedures to reduce energy consumption. Six publications reported on telemedicine interventions, and another six publications reported on interventions aiming to replace disposable (single-use) material with reusable materials (for instance, reusable surgical equipment). Three publications reported on food or solid waste management measures or waste disposal/recycling interventions and three reported on changing prescription practices (for mitigating resource-intensive care or less carbon-intensive treatments). Remaining publi-

Table 3 Interventions targeting main health care sectors and domains

Sector or source of emission[a]	Type of intervention (n publications) Note that one publication can concern several sectors and interventions
Hospital sector	30 publications
Hospital care (in general)	Green protocols/practices procedures (n=3) Any/multiple interventions (n=3) Replacing disposable with reusable material (n=2) Telemedicine (n=2) Solid waste management/recycling (n=1) Proximal care (n=1) Disease prevention (n=2) Wastewater treatment (n=1)
Specific inpatient care	Replacing disposable with reusable material (n=1) Prescription practices (less carbon-intensive treatments) [n=1]
Specific surgery	Green protocols/practices/procedures (n=5) Replacing disposable with reusable material (n=2)
Anesthetic gases	Green protocols/practices/procedures (n=2)
Food services specifically	Any/multiple interventions (n=1) Food and solid waste management/recycling (n=1)
Hemodialysis specifically	Green protocols/practices/procedures and behavioral (n=1) Any/multiple interventions (n=1)
Outpatient care	Telemedicine (n=4) Replacing disposable with reusable material (n=1) Prescription practices (less carbon-intensive treatments) [n=1]
Energy (electricity) consumption within hospital[b]	Green protocols/practices/procedures and behavioral (n=5) Any/multiple interventions targeting energy consumption (n=1)
Solid waste[b]	Green protocols/practices/procedures (n=1) Replacing disposable with reusable material (n=3) Solid waste management/recycling (n=1) Any/multiple interventions targeting solid waste (n=2)
Pharmaceuticals (all sectors)	**3 publications** Policy-innovation mix (n=1) Prescription practices (treatment for mitigating resource-intensive care) [n=1] Wastewater treatment (n=1)
Transportation (all sectors)	**8 publications**
Patients, visitors and/or staff	Telemedicine (n=6) Proximal care (n=1) Health system-level approach (n=1)
Primary care sector	**6 publications** Prescription practices (treatment for mitigating resource-intensive care) [n=1] Health system-level approach (n=1) Disease prevention (mitigation) [n=2] Replacing disposable with reusable material (n=1) Telemedicine (n=1)
Other secondary/ specialist health care sector	**3 publications** Prescription practices (treatment for mitigating resource-intensive care) [n=1] Health system-level approach (n=1) Telemedicine (n=1)
Dentistry sector	**1 publication** Health system-level approach (n=1)
Health care systems as a whole	**7 publications** Health system-level approach (n=5) Replacing disposable with reusable material (n=1)
Food services specifically (catering different services in the health care sector)	Food waste management scheme (n=1)

[a] Categories are not mutually exclusive, for instance, a publication on solid waste from surgery is reported under both "Hospital (surgery)" and "Solid waste".
[b] Many studies take into account electricity and solid waste in estimations of CO_2e. Here, we refer to interventions that specifically target reducing energy consumption (related to the use of machines, heating, etc.) or solid waste generation.

cations reported on disease prevention-measures (n=2), policy-innovation-mixed interventions (n=1), wastewater treatment (n=1) and proximal care provision (n=1). Finally, four publications (systematic reviews) assessed multiple interventions, or any intervention, aiming to reduce the environmental impact in a certain health care area or domain.

Interventions targeting surgery and operating rooms

Hospital activities, and especially surgeries, have been identified as being amongst the most polluting activities in the health care sector. Numerous studies investigate how emissions related to surgical operations and ORs can be reduced, which include a set of technological, organizational, behavioral, and preventive interventions. A review concluded that the evidence-base on how to improve hospitals' environmental sustainability is extensive in several areas: **hospital architecture, telemedicine, water-saving interventions** (such as water use auditing, checking and fixing leaks, installing flow restrictors and dual-flush toilets and reclaiming water from dialysis units and sterilizers), **replacing disposable with reusable equipment in ORs, improved hospital waste management, recycling, and avoiding creating waste in the first place** (McGain and Naylor, 2014). More recent studies acknowledge the wide evidence base available concerning certain interventions, such as changing anesthetic practices, telehealth, dialysis practices (Alshqaqeeq et al., 2020), waste sorting, recycling, reuse and reprocessing (Alshqaqeeq et al., 2020; Pradere et al., 2022).

A large part of **OR-related emissions** is caused by their high energy consumption. A recent review (2022) concluded that the most important reductions in the environmental footprint of ORs could be made by **reducing energy consumption** through **reduced heating, ventilation, and air conditioning and through powering ORs with clean energy** (Pradere et al., 2022). Interventions aimed at reducing energy use, such as occupancy sensors that reduce air turnover of unused ORs, can reduce annual electricity use by one-third per OR (Thiel et al., 2018). Switching to renewable energy sources could reduce GHG emissions of ORs further, while increasing GHG savings from other hospital activities as well (Thiel et al., 2018). Some studies also target staff practices, such as turning off steam sterilizations when not in use (McGain et al., 2016).

The Shift project has estimated that 50% (-0.08 MtCO2e) of emissions stemming from **anesthetic gases** in France can be reduced by **prohibiting the use of anesthetics with high environmental impact** (Shift et al., 2021). Anesthetic gases, such as desflurane, have high GHG impact, but are also substitutable by alternatives with lower GHG emissions, such as intravenous anesthetics (e.g. propofol) [Thiel et al., 2018]. Several studies have identified better anesthetic gas choice and management as actions that can drastically reduce emissions related to surgeries (Hu et al., 2021; Pradere et al., 2022; Thiel et al., 2018). For instance, replacing desflurane with a lower GHG alternative can reduce GHG emissions by 25% for laparoscopic surgical operations, and using propofol when clinically appropriate can reduce GHG emissions related to anesthetics up to 28% (Thiel et al., 2018). **Vapor-capturing technology can recycle 70% of anesthetic gases**, which would make sevoflurane gas less carbon intensive than propofol (Hu et al., 2021). The carbon intensity of propofol, in turn, can be reduced by procuring propofol manufactured with green energy (Hu et al., 2021).

In contrast, a study found that differences in total GHG emissions between **different anesthetic practices** during knee surgery (29 patients) in Australia**,** comparing spinal (propofol), general (almost exclusively sevoflurane) and combined anesthesia, were negligible (McGain et al., 2021). This is explained by the fact that total emissions related to anesthetic practices are dependent on multiple factors related to surgery, such as the duration of the operation (which is 20% longer for spinal anesthesia), use of single-use plastics, number of consumables and equipment used (and sterilized), high versus low oxygen flows, more or less need for heating, and the type of electricity source (fossil versus renewable). In this example, regardless of the higher environmental impact of anesthetic gases compared to intravenous alternatives, the higher need for sterilizing reusable equipment, the higher use of liquid oxygen, and the higher electricity use (primarily fossil fueled in this case) associated with intravenous anesthetic procedures resulted in similar total GHG impacts for the different practices (McGain et al., 2021).

One study in Sweden targeted all sources of emissions related **to two surgical departments**, evaluating a comprehensive environmental protocol for the health care sector – the **"Climate friendly health and care (CLIRE)" protocol** (Wanegård and Fagerberg 2019). The protocol helps to identify all emission sources (e.g. materials, energy use, transport, food products, water use and laundry) and their magnitude for a specific health care service, to determine which domains to prioritize, and provides guided steps for reducing the emissions in each domain (e.g. changing work protocols or resource use). The study showed that by implementing the protocol, the two surgical departments and their related services (outpatient diagnosis, examination and rehabilitation and inpatient services) were able to reduce CO2e emissions over a five-year period by up to 40% per patient, through a range of changes in practices, such as replacement of single-use materials and a reduction in energy use (Wanegård and Fagerberg, 2019).

Reduced use of single-use materials

Interventions aimed at recycling, reusing and sterilizing medical materials have been frequently studied, with the rationale that these practices can reduce the environmental impact of health care through reduced waste generation (Pradere et al., 2022). The environmental impact of single-use materials became evident during the Covid-19 pandemic in 2020. In England, the use of personal protective equipment (PPE), such as surgical masks and plastic gloves, during the first six months of the pandemic generated emissions equivalent to almost 1% of the entire carbon footprint of health and LTC sectors during normal activity (Rizan et al., 2021a). The PPE-related emissions could have been reduced by 12% if the equipment was manufactured nationally, by 10% if gowns and gloves had been reused, by 45% if gloves had not been used at all (replaced by hand washing), and by 35% with maximal recycling of PPE. All actions combined, 75% of these emissions could have been avoided, but the authors acknowledge that implementing all these actions fully may not be feasible (Rizan et al., 2021a).

Grimmond et al. (2012) showed that when a hospital converted to **reusable instead of disposable** sharps containers, it reduced the annual global warming potential (GWP) of their sharps containers by 83.5% and avoided 31 tonnes of plastic and 5 tonnes of cardboard landfill waste (Grimmond and Reiner, 2012). Although this reduction only represented a fraction of the hospital's GWP, changing sharps containers at a national scale would result in significant reductions (Grimmond and Reiner, 2012). Another study assessed the environmental impact of replacing single-use with **reusable anesthetic equipment** in one Australian hospital with six ORs during one year (McGain et al., 2017). The estimations showed that the switch would have increased the environmental footprint related to anesthetic equipment by 9%, mainly driven by the energy used for washing, drying and packing the reusable equipment, due to the highly coal-based energy mix in Australia. Had the hospital instead been supplied with the energy-mix of the USA (dominated by natural gas), the switch to reusable equipment would have lowered the environmental footprint by 48%. Had a European energy-mix (mainly renewable energy) been used, the reduction would have been 84% (McGain et al., 2017). Manufacturing all single-use equipment in Europe instead of in Asia would have resulted in a marginal reduction in the environmental footprint, because two of the main manufacturing processes are dependent on non-renewable energy sources (steel and plastic manufacturing) [McGain et al., 2017].

Donahue et al. (2020) estimated that if the annual use of disposable vaginal specula (n=5,875) at certain clinics were replaced by reusable stainless steel specula, their life cycle GHG emissions could be reduced by up to 75%, and the end-of-life waste generation caused by the use of specula could be reduced by 64 kg per year (Donahue et al., 2020). Carbon emissions of surgical instruments can further be decreased by packing instruments in sets instead of individually, by optimizing the loading of decontamination machines, and by using low-carbon energy sources and recycling (Rizan et al., 2021b). For instance, the total carbon footprint of decontaminating and packaging instruments is 77 gCO2e per instrument when packed in aluminium containers, 66 gCO2e when packed in a tray wrap, and 189 gCO2e when instruments are individually wrapped (Rizan et al., 2021b). At the same time, it is better to open an individually packed instrument instead of a multi-pack of instruments during surgical operations that require few (10 or less) instruments, to avoid wasting unused equipment (Rizan et al., 2021b).

Furthermore, a study showed that **repairing reusable material,** in this case, surgical scissors, would result in further reductions in environmental impact across numerous environmental indicators (including global warming, ozone layer depletion, fine PM formation, freshwater and terrestrial damage, human carcinogenicity, resource scarcity and water consumption), with reductions between 2% (for marine eutrophication) and 73% (for mineral resource scarcity) [Rizan et al., 2022]. The carbon footprint of reusable scissors was 70 gCO2e/use, which was reduced by 19% when repairing the scissors off-site after 40 uses instead of replacing them (57 gCO2e/use) and by 20% when repaired on-site (56 gCO2e/use). The repair itself had a relatively low environmental impact (up to 1.5% of the total carbon footprint of scissors), but all reusable scissors were associated with an environmental impact of sterilization (causing up to 97% of the footprint of reusable scissors), compared to disposable scissors. This impact could be counteracted by preparing instruments in sets instead of individually packed scissors, optimizing number of scissors in decontamination machine, and recycling packaging (Rizan et al., 2022).

However, the impact of isolated actions of shifting to reusable material is relatively low in relation to other health care emissions. The impact of replacing single-use material represents only a fraction of total hospital global warming potential and is one of many steps necessary in a larger climate strategy (Grimmond and Reiner, 2012). For instance, sterilization and reuse of surgical instruments results in a GHG reduction of approximately 10% per surgical operation for laparoscopic hysterectomy (Thiel et al., 2018), and **should be part of wider strategies aiming at reducing surgery-related emissions**. If a hospital performed all its laparoscopic hysterectomies via the ideal combination of anesthetic gas, material waste and energy reduction, GHG emissions could be reduced by 47% for hysterectomies alone; a combination of approaches is needed to achieve significant GHG reductions.

Waste management

Modelling the carbon footprint of hospital waste treatment streams (including waste processing and transportation of waste) in three NHS hospitals showed that recycling had the lowest carbon footprint per ton waste (21–65 kgCO2e/t) compared to low temperature incineration (172–249 kgCO2e, or 569 kgCO2e with prior decontamination via autoclave steam sterilization) and high temperature incineration (1,074 kgCO2e/t) [Rizan et al., 2021c]. High temperature incineration was used for clinical waste, sharps, anatomical and medicinal waste, according to regulations in the UK. Although waste management generates a proportionally small part of the GHG emissions in the UK, the choice of waste stream, for instance high temperature incineration instead of recycling, can have a 50-fold impact on the waste-related carbon footprint, and the authors recommend waste segregation to avoid unnecessary high-carbon waste treatment, and research focusing on **designing products and systems enabling recycling of medical products** (Rizan et al., 2021c).

The Shift project has estimated that waste-related emissions in the health sector can be reduced with additional benefits for the environment by better **recycling** of single-use materials, promoting wider use of reusable medical equipment and materials produced in France, **reducing the generation of hazardous waste, and better monitoring to make sure that biowaste is systematically composted** (Shift et al., 2021).

Reducing food-related emissions and food waste

A systematic literature review by Carino et al (2020) summarizes the evidence on interventions aiming to reduce the environmental impact of hospital food services. The study identified **interventions across different parts of the food-chain, including procurement, preparation, consumption, waste disposal** and approaches addressing several aspects of the food chain, however with varying quality of evidence on their effectiveness.

Food procurement interventions include **farm to hospital initiatives**, organic food, and sustainable meat procurement, frequently reported to be implemented with various toolkits or guides, but with few reports on their impact. Signing up to one intervention, the "Balanced Menu Challenge" was reported to reduce hospital meat purchasing by 10% to 20%, through, for instance, increasing the amount of vegetarian meals and smaller meat portion sizes (Carino et al., 2020). There is a paucity of evidence on methods that can successfully reduce energy use and food waste in the food preparation phase, but an efficiency protocol, aiming to improve housekeeping in kitchens through less wasteful practices and changed portioning procedures, has shown promising results (Carino et al., 2020).

A larger number of studies evaluate interventions aiming to reduce waste in food consumption, mainly through **food-system model changes.** Methods that show reduced food waste include room service, bulk trolley food delivery instead of individually served meals, isothermal trolleys and improved meal presentation, and patient choice of portion size and meal selection (Carino et al., 2020). For instance, improving (generally reducing) portion sizes or letting patients select their meals has shown to avoid food waste between 5% to 30%, and using isothermal trolleys to keep meals warm can reduce food waste by 14% per meal served, while better presentation of meals can reduce it by 19% per meal (Carino et al., 2020). **Food waste measurement methods** for monitoring, staff training and using **reusable instead of single-use** service ware were other possible measures pointed out to help reduce waste of food services (Carino et al., 2020).

Several studies report on methods to avoid **sending food waste to landfills (such as composting and recycling, and reusing leftovers for new recipes)**, but few provide quantitative estimations of their environmental benefit (Carino et al., 2020). One recent study estimated that increasing recycling in the hospital food service and composting could reduce food service waste going to landfills by 55% and reduce its GHG emissions by 64% in one hospital in the USA (Thiel et al., 2021).

Some studies have evaluated interventions **addressing multiple aspects of the food supply chain**, redesigning the whole hospital food system from procurement to waste and involving stakeholders outside of the care sector (Carino et al., 2020). This type of sustainability approaches has shown positive results on food-related waste in nursing homes, rehabilitation and long-term medical care (Carino et al., 2020). A **robust waste-management** intervention (including waste monitoring, hotspot identification and management) in three catering companies delivering to hospitals in Germany resulted in a reduction in food waste by 17% overall (-1.8% for breakfast, -14.9% for supper and -17.9% for lunch), with reductions also in land use, and to some extent water use (Meier et al., 2021).

The Shift project has estimated that 40% (-1.1 MtCO2e) of emissions related to **food procurement** in the health care sector in France can be reduced through better food quality (reducing food waste), promoting local food production as well as replacing a part of animal proteins (especially beef) with vegetal proteins (Shift et al., 2021).

Telehealth solutions

There is a large evidence-base on the potential benefits of telehealth solutions (video and telephone consultations) for reducing emissions, both from staff and patient transport (Alshqaqeeq et al., 2020; Blenkinsop et al., 2021; Dullet et al., 2017; Holmner et al., 2012; Masino et al., 2010; Oliveira et al., 2013; Purohit et al., 2021). According to a recent systematic review, research unanimously reports that **telemedicine reduces health care-related emissions**, between approximately 1 and 372 kgCO2e per consultation (depending on the location of services replaced), principally **through reduced emissions from patient transport** (Purohit et al., 2021). The emissions produced from telemedicine systems are much lower compared to the emissions they prevent and are therefore a viable option for reducing health care-related emissions (Blenkinsop et al., 2021; Masino et al., 2010; Purohit et al., 2021), and with few adverse effects reported (Blenkinsop et al., 2021).

However, the level of carbon reductions reached for teleconsultations are **dependent on several technical factors, such as the technology used and the internet connection** (Holmner et al., 2014). Reductions are also strongly related to the average travel distances to the care that is being replaced by telemedicine, as well as the travel distance to telemedicine sites. Telemedicine is more efficient when replacing long distance health care visits (over 7 km) and when **not resulting in double-consulting** (i.e. followed by a face-to-face consultation) [Purohit et al., 2021]. Video consultations for two rehabilitation clinics in rural Sweden, where travel distances are very long, resulted in carbon reductions ranging between 15–250 times compared to traditional care (Holmner et al., 2014). Teleconsultations also have the potential to significantly reduce carbon emissions in urban areas if their use is expanded, especially for shorter consultations (Holmner et al., 2014), and for more specialized services, for which travel distances tend to be longer (specialized centers serve a wider geographic area) [Purohit et al., 2021].

Reducing travel and greening transportation

According to estimations made by the NHS, annual **transportation-related emissions** need to be reduced by 3,402 ktCO2e to reach the net-zero goals of the NHS. Some of the interventions that could reduce emissions significantly are those outside the health care sector such as national vehicle efficiency improvements through better standards, which would reduce the impact of all vehicles used by care providers, staff and patients (-1,463 ktCO2e), and active travel (walking, biking) and using public transport by staff, patients and visitors which would reduce the amount of vehicle use (-461 ktCO2e) [NHS England, 2020]. Reduced travel from digital care pathway redesign could reduce emissions by 159 ktCO2e, whereas preventive medicine (mainly primary prevention, e.g. through interventions targeting lifestyle factors and wider determinants of health) could reduce travel-related emissions by 62 ktCO2e by avoiding journeys to care (NHS England, 2020).

One study from Canada on **cancer treatment outreach clinics** has shown that drastic reductions in GHG emissions from patient travel can be achieved thanks to implementation of three surgical cancer outreach clinics. The median travel distance reduced by 318 km with outreach clinics (compared to the regional cancer center), with a mean difference of 118 kgCO2 per patient treated in the outreach clinic. Yearly, the savings would amount to almost 47,000 kgCO2, for treating approximately 400 patients (Forner et al., 2021).

The Shift project has estimated that 99% (-7.1 MtCO2e) of the emissions caused by health-care related **transportation** in France can be reduced through a number of actions: replacing fossil fueled vehicles (e.g. ambulances) with electric vehicles, promoting and facilitating walking, biking, carpooling and the use of collective transportation, encouraging administrative personnel and researchers to telework, prioritizing e-learning and local conferences to reduce distances travelled for professional training, and developing and expanding telemedicine (Shift et al., 2021).

Health system-level approaches

One of the most comprehensive and ambitious climate strategies has been implemented in the publicly funded national health care system (NHS) in the UK. An ambitious ecological transformation program for the health care sector was adopted at the creation of the **NHS Sustainable Development Unit (SDU)** in 2008 to respond to the Climate Change Act adopted in the same year. This was followed by a **Route Map for Sustainable Health in 2010** (Roschnik et al., 2017) focusing on five main areas:

- Governance (setting up national advisory boards, local networks, sustainable management plans etc.).
- Stakeholder engagement (involvement of health workforce, top management, local leaders, general public and industry).
- Carbon measurement and reduction.
- Building resilience and adaptation to climate change (undertake risk assessments and prepare for and adjust to the expected effects of climate change with the aim to moderate harm.
- System support (developing metrics and guidelines, evaluating the progress and uptake of processes, supporting research and supporting workforce through factsheets, guidelines, climate awards and communication campaigns) [Roschnik et al., 2017].

The principles of the reform included a shift from curative medicine to early intervention and prevention, from sickness to health and wellbeing, from an isolated and segregated system to more integration and partnership, and from waste and overuse of resources to a balanced use (Roschnik et al., 2017).

The decarbonization of the NHS is monitored and regularly evaluated as part of the objectives of the Route Map, resulting in numerous publications related to the greening of the NHS. Multiple publications report on progress across different time spans and measures:

- Between **2007 and 2015 the NHS reduced its carbon footprint by 11% (from 25.7 to 22.8 MtCO2), despite the activity levels rising by 18%.** Thus, the carbon intensity (emissions per health care act) decreased by 22% per capita. The carbon footprint from buildings decreased by 4.3%, water consumption by 4.2%, whereas non-recycled waste decreased by one-third (from 0.3 to 0.2 million tonnes) [Roschnik et al., 2017].

- Between **2007 and 2017, the NHS reduced GHG emissions by 18.5%,** its carbon intensity by 35% and emissions related to energy consumption, work travel and medical gases by 18.5%, while the NHS health care trusts had made cumulative savings of 1.85 billion pounds (Roschnik et al., 2019).
- Between **2010 and 2017, total water consumption in the NHS decreased by 21%** (Roschnik et al., 2019).
- **Between 1990 and 2019, carbon emissions were reduced by 26%, regardless of an increase in population and care provision**. The initial reduction in the 1990s (about 45% of the decrease) is mainly linked to a general shift in energy sources **away from coal and oil for heating in England as well as a reduction in building energy use (better insulation)** [Tennison et al., 2021].

Tennison et al. (2021) acknowledge that further action is needed to reduce the environmental impact of the NHS, including green interventions at the provider level such as water use efficiency, waste reduction and recycling of unused medications, as well as sustainable changes, including optimizing care delivery, and investing in health promotion and disease prevention to reduce resource intensive care use. It is estimated that energy use in the NHS could be further reduced by 40% through technological interventions (such as insulation and efficient appliances) and with on-site solar and wind generated power sources (Tennison et al., 2021). Another important goal identified by the authors, but more difficult to achieve, is to reduce supply-chain emissions. The main actions that could reduce these emissions include reducing the overall care demand and shifting to low-carbon goods and services (e.g. shifting to plant-based diets) [Tennison et al., 2021].

A more small-scale systemic change was evaluated in Sweden, where the **CLIRE protocol** was implemented in the hand and urology surgical departments (with related outpatient and post-surgery services) in the city of Malmö in 2010. The protocol required identifying emission sources and their magnitude, assessing the domains to be prioritized for reducing emissions, and provided guidelines for reducing the emissions. This resulted in a replacement of single-use materials, a change in working protocols to improve patient flows and resource use, a reduction in patient, material and staff transport and a reduction in heating, lighting and electricity use. In terms of CO_2e emissions, reductions were made up to 40% per patient over a period of five years (Wanegård and Fagerberg, 2019). Emissions were reduced by 4.0 $kgCO_2e$ per hand surgery operation and 10.5 $kgCO_2e$ per hand surgery inpatient care episode, whereas emissions decreased by 5.8 $kgCO_2e$ per urology surgery operation and 3.9 $kgCO_2e$ per urology inpatient care episode (Wanegård and Fagerberg, 2019). The only increase in emissions was observed for the outpatient activities in one of the clinics (+0.3 $kgCO_2e$ per examination visit). However, the number of patient trips to this clinic reduced significantly during the same period, by changing inpatient registration procedures and by using home visit nurses to a larger extent (Wanegård and Fagerberg, 2019).

The effects of large-scale systemic changes have mostly been estimated using mathematical modelling exercises, which is an alternative when larger interventions, such as **care provision redesign**, are not feasible for experimental purposes. Nicolet et al. (2022) performed a retrospective carbon footprint estimation and modelling exercise on theoretical worst- and best-case scenarios in primary care practice in Switzerland. They found that domains which are not directly linked to medical activities were responsible for the largest share of the carbon footprint in primary care; more than half of emissions were related to staff, patient and courier transport, which can be mitigated through organizational interventions, without an impact on care quality (Nicolet et al., 2022). A ten-fold reduction in CO_2e emissions could be achieved by **transforming the worst-performing primary care**

practices to best-performing practices, which would involve developing local primary care networks and telehealth options, which would reduce travel distances for patients and staff, and by increasing capacity for urgent laboratory testing within primary care practices, which would reduce the need for courier transport (Nicolet et al., 2022). Optimizing the use of primary care facilities could reduce the footprint of heating and energy, by providing more consultations simultaneously and not leaving facilities heated but unused (Nicolet et al., 2022).

A bottom-up approach for decision-making in health system redesign – the Pollard model – has been used in several studies to assess the carbon implications of health care policies (and/or service reconfiguration) aiming to improve resource use, such as better staff deployment and reduced patient travel. Pollard et al. used this method to model different configurations of NHS **care pathways, and their impact on direct GHG emissions**, indirect electricity emissions, and patient transport (excluding medicines and equipment, waste, procurement and administration-related emissions) [Pollard et al., 2013]. The models showed that rationalizing, i.e. **closing smaller outpatient clinics,** reduced the internal carbon footprint of the health care services by 4%. However, **rationalizing services increased emissions external to the services, i.e. the patient carbon footprint**, by 35%. This increase is greater than the reduction from rationalization, even when combined with other actions, such as better scheduling of operating theater use (i.e. theaters are not run beyond operations) and lowering hot water storage temperatures (which in turn had an increased risk of bacterial proliferation) [Pollard et al., 2013]. The emissions saved by the initiatives and operational changes tested in this study were not sufficient for reaching the target of 80% reduction before 2050 in the UK; health care delivery requires additional redesign for these targets to be met (Pollard et al., 2013).

The Pollard model has also been applied to **reconfigure dental services**. Duane et al found that energy use due to patient and staff travel was estimated to represent 45% (22% patient, 23% staff) of the carbon footprint of dental care. The facilities contributed to the footprint with another 18% of dental care provided under "business as usual". The modelling showed that rationalization of dental services could halve patient travel, which could reduce the carbon emissions from 317 tCO2e to 158 tCO2e. **Reconfiguring over-utilized dental services could reduce emissions** further to 107 tCO2e – again, showing the importance of reducing patient travel distances (Duane et al., 2014). Finally, the authors stressed that it can often be possible to allow patients to choose care at a closer location, if the staff pool is large enough, and if the services are provided close to public transport hubs.

Reducing pharmacological pollution and greening prescription practices

One of the major technological improvements allowing to reduce emissions reported in literature is the replacement of gas-based inhaler propellants with non-gas alternatives. In the NHS England, the significant GHG reductions that occurred between 1990 to 2000 were partly driven by the phase-out of chlorofluorocarbon propellants in inhalers (Tennison et al., 2021). These were replaced by hydrofluoroalkane propellants, that are not ozone-depleting but still have a large GHG impact. Changing 10% of currently used metered-dose inhalers (MDIs) to dry powder inhalers (which do not contain hydrofluoroalkane) would reduce emissions with 58 ktCO2e per year in England (Wilkinson et al., 2019). If 50% of inhalers were substituted with dry powder and other low carbon-inhalers, 288 ktCO2e would be saved each year in England, and if reduced by 90%, 519 ktCO2e would be saved (Wilkinson et al., 2019).

In 2020, the NHS England estimated that if the use of inhalers and anesthetic gases **were reduced to the largest extent possible**, a vast majority of their emissions could be mitigated while results are clinically equivalent for patients (-403 ktCO2e annually by reducing the use of MDIs combined with innovation allowing low-carbon alternatives, and -195 ktCO2e annually by reducing anesthetic gases) when combined with a shift towards dry-powder inhalers, for the remaining use (-374 ktCO2e annually) [NHS England, 2020]. The NHS also supports the initiative of pharmaceutical companies to develop a program encouraging patients to return inhaler devices to pharmacies for green disposal (NHS England, 2020).

Moreover, NHS England (2020) estimates that one of the major areas where interventions are required to meet the net-zero goal of the NHS is the **medical supply-chain**. In England, an annual reduction of 16,531 ktCO2e, is required to meet the net-zero goals. Making pharmaceutical and non-pharmaceutical suppliers meet the NHS environmental requirements (which is currently voluntary) could reduce emissions by 4,203 and 4,458 ktCO2e respectively and process and product innovation could reduce emissions further by 1,488 ktCO2e (NHS England, 2020). A pilot study of the NHS Supplier Engagement Program encouraging carbon transparency reporting has shown promising results in increasing suppliers' voluntary sharing of carbon reduction plans; an initiative that was extended to 500 NHS suppliers in 2021 (NHS England, 2020).

A part of the literature on pharmaceuticals focuses on pollution in wastewater, which eventually end up in the aquatic environment. However, many wastewater interventions do not target the hospital sector, and we found only one study proposing water treatment interventions at hospitals, with limited impact on reducing pharmaceutical impact on the aquatic environment (Chèvre et al., 2013). However, due to the pathogens existing and being evacuated through hospital wastewater, water treatment at the source remains an important issue, in combination with wastewater treatment plants (Chèvre et al., 2013).

Few recent studies have assessed the impact of changed prescription practices for reducing GHG emissions. We found one study that assessed the shift from medication only-treatment to surgery for treating reflux. Although surgery is known to be very resource intensive, medicine-only treatment had a higher environmental footprint than surgery in the long term, for similar health outcomes, because the need for medication is often lifelong. Surgery became more carbon efficient than medicine-only treatment after nine years post-surgery (Gatenby, 2011).

One study assessed the GHG impact of **shifting from traditional mental health treatments to social support-based interventions,** with the objective of mitigating more resource intensive care in the future (Maughan et al., 2016). The study assessed the environmental impact of a primary care-based social prescribing program for mental health patients which consisted of group-based community interventions such as creative leisure activities, support with skills and employment, and administrative advice, and was hypothesized to reduce the need for secondary care and medication, and thus result in lower GHG emissions compared to cognitive behavioral therapy or antidepressants (Maughan et al., 2016). The social prescribing intervention was estimated to reduce future secondary health care use while having co-benefits for health and wellbeing of the patients, but when the emissions of the service itself were taken into account, the intervention was associated with an increased carbon footprint per patient. The authors concluded that **larger reductions in secondary care needs** are required for compensating for the environmental footprint of the service and for achieving a sustainable reduction in GHG emissions (Maughan et al., 2016).

Our literature search did not yield evaluations of interventions that reduced the GHG emissions of pharmaceuticals, for instance in pharmaceutical manufacturing, prescription and waste in terms of unused pharmaceuticals, apart from some reports of case studies in the grey literature, however with incomplete data reporting.

Reducing and greening electricity and water consumption

The NHS England has estimated that from 2020 base levels, a reduction of 2,351 kt-CO2e annually is needed in emissions related to **hospital facilities** to be able to reach a net-zero health care system by 2040. This reduction can primarily be achieved through interventions targeting on-site generation of renewable energy and heat (-580 ktCO2e, e.g. installing solar power), optimization of building usage (-572 ktCO2e, involving energy monitoring), upgrading buildings (-473 ktCO2e, involving new lighting, cooling and heating systems etc.), national electricity decarbonization (-342 ktCO2e) and hospital improvements (-205 ktCO2e) [NHS England, 2020].

For **primary care facilities** in the NHS, **achieving net-zero goals** require an annual reduction of 167 ktCO2e, through upgrading buildings (-59 ktCO2e), national electricity decarbonization (-47 ktCO2e), optimizing building usage (-34 ktCO2e), new buildings (-11 ktCO2e) and on-site generation of renewable energy and heat (-7 ktCO2e) [NHS England, 2020].

The Shift project has estimated that 75% (-4.3 MtCO2e annually) of emissions stemming from the heath care-**building** sector in France can be reduced, through interventions such as better insulation, shift from fossil-fueled heating to low-carbon energy sources, using bio-materials for new constructions, refer to an "energy referent/expert" in health care facilities and train health care staff in the matter of sustainable consumption habits (Shift et al., 2021).

One scientific study assessed the effects of **water and energy conserving interventions** in hospitals, and found that switching off four steam sterilizers when not in use in one hospital would reduce CO2 emissions by approximately 78.7 tCO2 annually, saving 26% of electricity and 13% of water use compared to their usual use, where the machines would be kept on but in an idle state (McGain et al., 2016).

One impact report conducted in one NHS hemodialysis unit replaced two out of three disinfection cycles per 24 hours with a rinsing process of the dialysis machines, and also kept the machines in standby mode in between patients. These changes saved a total of 1,905 kg-CO2e per year. Electricity savings amounted to 1,672 kgCO2e/year (5,741 kWh/year), water savings to 42 kgCO2e/year (114 m3/year) and acid savings to 190 kgCO2e/year (3,509 l/year) [Hardy et al., 2022].

Policy mixed with innovation

Globally, it is recognized that single measures would have limited impact on reducing the environmental footprint of health care. A Bayesian network-based socio-ecological study assessed the impact of public health measures and drug design for reducing pharmaceuticals in wastewaters (Brandmayr et al., 2015). The study concluded that achieving a meaningful impact would require a combination of environmental policies and drug innovation, together with public health (disease prevention) measures reducing the need for pharmaceutical treatments. Such measures include early prevention of disease, regulations such as tobacco bans and sugar taxation, and a shift from curative to preventive care with the help of eHealth, improved patient-provider communication and payment models incentivizing prevention

(Brandmayr et al., 2015). The authors also stressed that different drugs will be concerned to different extent by any one intervention, which is why a broad range of integrated public health and environmental interventions are needed as well as drug innovation.

Secondary and tertiary prevention

The Shift project has estimated that, regardless of large reductions made in the transportation, building, food and waste sectors, attaining the goal of an 80% reduction from 2020-levels in France would require large investments in **prevention** of care needs, i.e. primary, secondary and tertiary prevention, as well as reducing unnecessary care acts and adverse medical events (Shift et al., 2021).

Evidence on the impact of preventive strategies is rare in literature. We identified one case report (Gadegaard and Penny, 2015) and one study (Fordham et al., 2020) that assessed CO2e emissions associated **with poor versus good management of type 2 diabetes** and related complications. Comparing differences in health care use (GP visits, ER visits, surgical procedures, use of pharmaceuticals, blood sugar testing), patient travel and inpatient care related to good versus poor adherence to diabetes treatment, Gadegaard and Penny showed that **good management of type 2 diabetes can lower the CO2e impact by 7% per year or by 3% over the lifetime of the patient (despite their longer lifetime), compared to poor management**. This corresponds to a reduction from 155 kgCO2e to 144 kgCO2e per year. When extrapolated to 5 million diabetes patients (the expected number for 2025 in the UK), good management could reduce emissions by 720,000 tCO2e per year, whereas with poor management, emissions would increase by 56 tCO2e per year. **The main contributor to emissions related to diabetes management come from pharmaceutical consumption, patient travel and inpatient admissions,** of which the latter largely explains the higher emissions related to poor management (Gadegaard and Penny, 2015).

In terms of carbon emissions due to diabetes-related complications, Fordham et al. (2020) report that the greatest carbon reductions through good disease management (keeping blood glucose at 7% or 53 mmol/mol) can be achieved by decreasing the risk of renal complications, followed by ophthalmological and cardiovascular diseases (Fordham et al., 2020). The least **carbon-intensive treatment is the one where patients' diabetes can be controlled early with less aggressive treatment**, due to the drastic reduction in the risk of developing these complications (Fordham et al., 2020).

3.3. Discussion

3.3.1. Strength and limitations of the scoping review

We used a systematic search strategy based on established scoping review methods, refined the search terms throughout the search process, and targeted literature in three languages (English, French and Swedish). Nevertheless, it is possible that publications were missed in our search. We found large heterogeneity in definitions and terms used, resulting in both a large number of publications outside the scope of our review, as well as a possibility that publications using more narrow terminology were missed. Our language restrictions may have impacted especially the chances of finding reports on national policy –and organizational– level interventions, often published in local languages. Nevertheless, our review did not aim to provide an exhaustive list of interventions, but to present an overview of the types of interventions that have been evaluated to reduce the environmental impact of health care.

We did not conduct critical appraisal, nor assess the quality of the studies included in our review, as our objective was to identify the variety of interventions for which evidence is available. While we excluded publications which do not report all data extraction items, to assure the reliability of results, there are important variations in methods and assumptions across studies included in our review, and the results should be interpreted with caution. The evaluation of measures aiming to reduce the environmental impact of health care systems is largely in its infancy, and remains complex due to the multiple outcomes to be considered and the reliance on observational studies, which present drawbacks, such as their inability to isolate an intervention from external influences and thus determine the causality between an intervention and an outcome. Nevertheless, these studies allow identifying interventions that have great potential for reducing the environmental impact of health care and can contribute to understanding the margins for progress compared to status quo. In addition to observational studies, a large pool of literature is based on modelling exercises. Theoretical calculation models such as the Pollard model can inform decision making, although they do not consider possible variations in implementation and issues in practice.

Finally, our research was limited to studies conducted in high-income countries, as our aim was to provide an overview of evidence that could be applied to the French context. Nevertheless, the effectiveness of climate measures are highly context and time dependent and require case-by-case assessment for their generalizability (European Environment Agency, 2020). For instance, replacing single use anesthetic equipment with reusable equipment would reduce their CO2e emissions with 48% when using the energy source-mix of the USA, and with 84% with a European energy source-mix, but would instead increase emissions with 9% in Australia, due to their higher reliance on fossil-fueled energy (McGain et al., 2017). Similarly, the impact of electric cars would vary depending on the local energy source used for producing electricity (green versus fossil-fueled electricity) and for fabrication of the cars. Therefore, the size of effects reported here may not be the same for France. However, our results show that a large range of interventions have been evaluated with consistent findings over a large range of settings, suggesting that a reduction in the environmental impact is possible even if the magnitude of the effect may vary, or contextual adaptations are needed.

3.3.2. Discussion of results

There is increasing evidence on how to combat climate change through interventions in the health care sector. The scoping review yielded 43 publications published since 2010, assessing the impact of interventions aiming to reduce the environmental footprint of health care systems.

Overall, the literature suggests that there are numerous interventions that can successfully reduce the environmental impact across a range of domains, especially in the hospital sector, and in particular in ORs. The majority of studies focus on micro-level interventions aiming to reduce the environmental impact of limited aspects of care, such as reducing patient travel-related emissions through telehealth solutions or shifting from single-use to reusable equipment, improved hospital waste management and recycling and reducing the use of the most polluting anesthetic gases.

Many studies stress that single micro-level measures would only have limited impact on reducing the environmental footprint of health care, and that there is a need for strategies going beyond micro-level interventions to meet climate goals. Achieving meaningful impact would require major changes at the organizational level, combining environmental policies and innovation, with public health measures reducing the need for treatments, and a shift of care to the community setting while preventing highly polluting inpatient care (Brandmayr et al., 2015).

Public health interventions are frequently suggested as a necessary part of strategies aiming to reduce the environmental impact of health care systems, due to their environmental-health co-benefits and potential to reduce hospital admissions, especially as populations are getting older and requiring more health care (Malik et al., 2018). The Sustainability Unit of the NHS has acknowledged that sustainable development must refocus on prevention **to be able to face the rise in non-communicable diseases,** as well as constrained financial resources (Pencheon, 2015). Public health strategies are now, together with disease prevention, an essential part of the NHS climate strategy.

Although the importance of reducing care need through public health measures and disease prevention is acknowledged in the literature, **the evidence on its impact is limited**, and the details of such measures are still unclear. The currently available evidence is limited to **disease prevention measures** and their impact on non-communicable diseases, such as increasing physical activity, reducing sugar and salt intake, reducing consumption of meat, alcohol and tobacco, as well as reducing the prevalence of childhood obesity, which **could have environmental co-benefits** (Vineis et al., 2021).

There are also wide opportunities for increasing the evidence base on how the **primary, auxiliary and LTC sectors** could contribute to the reduction of GHG emissions and other environmental impacts; these sectors were poorly represented in the literature, apart from interventions aiming to improve proximal care provision through telemedicine. Improving the coordination between the primary, secondary and tertiary care sectors could help creating more innovative (and sustainable) models of care, but evidence on the benefits for patients and practitioners are still lacking (WHO Regional Office for Europe, 2017). The existing research may also need to expand beyond assessing the impact within isolated health-care sectors, as sectors within the health care system affect each other. For instance, although the environmental footprint of primary care facilities can be reduced by decreasing their number and optimizing the use of facilities, such measures could result in travel-related emissions when patients need to travel further in the lack of proximal after-hours care. Nicolet et al. (2022) suggest that a dense and local network of primary care practices could reduce travel distances and encourage patients to come by foot. They also suggest that the ability to perform urgent laboratory tests within the practice would significantly reduce their carbon footprint, by less utilization of the on-call courier. Although studies on proximal care provision were scarce in our review, more evidence is likely to be available in earlier studies.

Evidence is also lacking or is limited for large-scale interventions to guide decision-making, including financial and tax incentives to reduce emissions, for instance trough changed travel patterns (such as public transport services and hospital bicycle facilities) and reducing demand for hospital services and avoiding unnecessary procedures – areas identified as needing more research (McGain and Naylor, 2014). Very few studies evaluate organizational-level interventions aiming to reduce health care demand or change care provision.

Although evidence based on modelling exercises suggest that large-scale organizational interventions, and carbon-reduction strategies can have significant benefits and improve the sustainability of health care systems, these studies remain to be confirmed in real-life settings, and the effects of such interventions might be counteracted by different barriers for implementation. Barriers and enablers for practical implementation of interventions were rarely assessed or taken into account in the literature. In France, interviews with self-employed primary care providers have revealed **several barriers for reducing the**

environmental footprint of their practice, including financial costs, lack of interest and information, as well as barriers related to team work and the geographic location of the office (Bouraly and Bonnefond, 2022). Scarce resources and funding, lack of knowledge among staff and a belief that there is no economic benefit to purchasing sustainable food have also been identified as barriers for reducing food waste in hospitals (Carino et al., 2020).

Education of health care professionals has been identified as an important action to increase awareness of the health care sector's impact on global warming (Parker et al., 2020) and to successfully implement environmental reforms in the health care sector (Crowther et al., 2022; Pradere et al., 2022). Carbon reduction interventions are more likely to be implemented if the there is sufficient staff pressure for change (Husain and Sidhu, 2021) which in turn requires staff education and awareness (Pradere et al., 2022) and behavioral changes (Vaccari et al., 2017). Staff and patient involvement in **co-designing climate interventions** have also been shown to facilitate sustainable and long-term change (Crowther et al., 2022). At hospital level, having a **strategic plan** and a **sustainability coordinator** can help developing environmental sustainability plans and change practice with **a bottom-up approach** (Langstaff and Brzozowski, 2017).

Carbon reduction measures are also more likely to be implemented if there is **sufficient practical/logistical support** (Husain and Sidhu, 2021). This can be new technology or practical guidelines that prevent any negative co-effects that interventions could cause on patient outcomes (Alshqaqeeq et al., 2020) as well as toolkits and other methodological support measures. The Life Cycle Assessment is an established tool to support decision-makers in implementing organizational changes to improve their services' environmental performance. The method helps identifying environmental hotspots and comparing methods to address them through both upstream and downstream activities (Seifert et al., 2021). Establishing **gold standards for practices and** real-time data **monitoring and reporting of metrics** are other key practices for successful and long-term change (Crowther et al., 2022; Vaccari et al., 2017). **Greater national guidance and continuous evaluations** have also been called for in order to support de-carbonization of health care systems (Husain and Sidhu, 2021).

3.4. Conclusions

The published literature revealed a vast range of targeted micro-level interventions that can reduce the environmental impact of care without compromising health care quality. Waste generation and energy use in hospitals and patient transport are common examples of where reductions can be made, through for instance recycling and proximal care provision and telemedicine. Comprehensive assessments exist also on the magnitude of change needed.

Although micro-level green interventions have shown to be effective, they are insufficient if not accompanied by health care restructuring, and research systematically acknowledges the need for environmental sustainability strategies at the organizational and sectorial levels targeting a reduction in health care need, demand and use. There is an emerging consensus that holistic, comprehensive systems approaches are needed, where primary care providers and public health strategies are key in mitigating health care use, and where barriers for change are addressed. However, evaluations of interventions focusing on reducing health care demand, and avoiding care need and use, are scarce.

4. Perspectives for the French health system

4.1. Overview of the principal stakeholders in France

Environmental and health-related issues concern a large variety of stakeholders in France, including governmental institutions (at national and local levels), non-governmental organizations, associations, research institutions, health care providers and industry (Table 4).

Governmental stakeholders: national and local

Most governmental stakeholders have responsibilities related to **actions targeting indirect emissions of the health care system,** such as shifting to green energy sources, transformation of the transport, infrastructure and building sectors, and wastewater treatment. Two ministries are entirely dedicated to environmental issues: the ministries of Ecological transition and Territorial cohesion and Energy transition.

The Ministry of Health and national agencies in **the health sector** have traditionally focused on environmental hazards and populational health, through surveillance and monitoring and assuring the safety of health care products and services. While each of them may attend to environmental issues, none of them have the responsibility to develop and implement climate change mitigation strategies in the health care sector. For instance, the National public health agency (*Santé publique France*; SPF), which is the main agency for public health expertise under the Ministry of Health in France and responsible for executing national public health policies, has missions related to **climate adaptation from a public health perspective**, but is not concerned by the environmental impact of the health care system. Similarly, the National Agency for Food Safety and Hygiene, the Environment and Work (*Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail*; ANSES) focuses on the environmental impact on health and climate adaptation, rather than mitigation strategies.

Although there is no single agency in charge of decarbonizing the health care sector, environmental responsibility has been increasingly incorporated into the missions of national agencies over the past years. Some **agencies have missions linked to improving the environmental sustainability of the health care sector**. For instance, the National health authority (*Haute autorité de santé*; HAS), in charge of the certification of hospitals, introduced sustainable development, environmental risk and sustainable procurement as criteria in the certification in 2011. The National performance support agency (*Agence nationale d'appui à la performance*, ANAP) also provides operational tools, guidance and training on sustainable development for hospital and LTC providers. In March 2022, the Senate outlined 48 propositions for developing a more environmentally sustainable health and social security system, acknowledging the need to develop more transversal sustainability efforts across the health and social security system and to address the lack of funding and coordination in the matter (Chevrollier and Vogel, 2022). In this report, a new cross-ministerial commission is proposed to coordinate the environmental transition. There is also a proposition to link some of the public health insurance funding for care providers to environmental objectives.

Table 4 Main stakeholders in France

STAKEHOLDER	DESCRIPTION/OVERALL MISSION	ENVIRONMENTAL AND/OR HEATLH MISSIONS	REFERENCE/LINK
Governmental - national and local			
Agence de l'environnement et de la maîtrise de l'énergie (ADEME)	The National Agency for Ecological Transition is a public agency of an industrial and commercial nature (EPIC) placed under the ministries of Environmental Transition and territorial cohesion, Energy transition and Higher education and research.	ADEME's aims are to support innovation, develop good practices and advance knowledge to reach France's carbon neutrality objectives. ADEME conducts research and training, funds research, defines and implements national policy directions, provides expertise and support to the state, public, financial and regional actors, and collects and publishes environmental data. They have several national and local directories across the country, and they also provide support for measuring the carbon impact of, for instance, hospitals.	https://www.ademe.fr/lagence/
Agence nationale d'appui à la performance (ANAP)	The National Performance Support Agency is a public administrative agency of experts that supports health and LTC providers through actions (including tools, guidance, events, interventions and expertise) to improve their services while controlling spending. This can involve, for instance, improving administration, or managing real estate assets.	One of ANAP's main aims is to provide operational tools and recommendations, as well as guidance and training, for sustainable development for hospital and LTC, for instance, actions to reduce energy use in hospitals, and guidance in the transition from petrol to electric vehicles in the health care sector.	https://anap.fr/accueil
Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail (ANSES)	The National Agency for Food Safety and Hygiene, the Environment and Work is a public scientific and administrative agency under the ministries of Health, Environment, Agriculture, Work and Consumption	The agency works on improving knowledge about and anticipating health and ecosystem-related challenges and develops benchmarks regarding food, environmental and work safety for human and animal health and nature. ANSES monitors and assesses health risks, to support public decision-makers (for instance regarding the spread of tiger mosquitos, the exposure to carcinogenic substances and antibiotic-resistant bacteria). Their environmental work thus focuses on estimating future risks for humans, animals and plants that stem from climate change to support adaptation strategies.	https://www.anses.fr/fr https://www.anses.fr/fr/content/changement-climatique-et-sant%C3%A9
Agence nationale de sécurité du médicament et des produits de santé (ANSM)	The National Agency for the Safety of Medical and Health Products is a governmental agency that manages the entry of medical products on the French market, surveils their safety, accessibility and utilization	The ANSM do not have missions related to the environmental impact of medicines and medical products on the French market.	https://ansm.sante.fr/

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Table 4 (cont'd) Main stakeholders in France

STAKEHOLDER	DESCRIPTION/OVERALL MISSION	ENVIRONMENTAL AND/OR HEATLH MISSIONS	REFERENCE/LINK
Agence régionale de santé (ARS)	The Regional Health Agencies were created in 2010 to coordinate all health-related agencies and care providers in their region and implement national public health policies	Since 2011, the ARS have the mission to work both on preventing environmental risks on human health (such as water safety), and the impact of human activities on the environment (such as air quality and toxic waste from health care). They coordinate cross-sectional environmental health policies through Regional Environmental health plans (PRSE), which mainly focus on protecting populations from environmental health hazards. The ARS also promote and finance regional health-environmental projects, such as projects promoting active transport or education of health care professionals on the environmental impact of pharmaceuticals in water. Not until 2021, as part of the Ségur reform, did the ARS become responsible for coordinating new investment plans for assuring sustainable development.	https://www.ars.sante.fr/les-actions-de-prevention-des-ars-en-sante-environnement-0?parent=4787 https://www.paca.ars.sante.fr/media/90735/download?inline https://elaboration.prse4-iledefrance.fr/blog/1275/quest-ce-que-le-prse4
Conseil économique, social et environnemental (CESE)	The Economic, Social and Environmental Council is an institution that supports and advices the government and parliament in public policy, conducts dialogue with civil society representatives and debates petitions, evaluates public policies and brings together the regional CESE branches	The CESE has a permanent environmental committee that focuses on climate change, biodiversity, water, ecological and energy transitions, as well as prevention of and adaptation to environmental risks. They produce recommendations, for instance, on the management of the ecological transition in France. Their work is overarching and does not address the health care sector directly.	www.lecese.fr https://www.lecese.fr/decouvrir-cese/commissions/commission-environnement
Commissariat général du développement durable (CGDD)	The General Commission for Sustainable Development was created in 2008 under the Ministry of Environmental transition and Territorial cohesion	The CGDD produces and delivers data and savoir faire to the ministries to support their actions related to the environment. It hosts the National council for ecological transition (Conseil national de la transition écologique - CNTE), a body of consultation for developing national strategies concerning energy, climate and sustainable for the National health environment plan (Le plan national santé environnement; PNSE). The work largely focuses on transport, infrastructure, food production and the building sector, and from the health perspective, climate adaptation and the impact of climate change on health.	https://www.ecologie.gouv.fr/commissariat-general-au-developpement-durable-cgdd https://www.ecologie.gouv.fr/cnte https://www.ecologie.gouv.fr/plan-national-sante-environnement-pnse

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Table 4 (cont'd) Main stakeholders in France

STAKEHOLDER	DESCRIPTION/OVERALL MISSION	ENVIRONMENTAL AND/OR HEATLH MISSIONS	REFERENCE/LINK
Caisse nationale de l'assurance maladie (CNAM)	The National statutory health insurance fund, CNAM, is a public administrative body that executes the national statutory health insurance strategy under the ministries of Health and Economy and Finance. CNAM also has certain responsibilities related to regulating the health care system.	The CNAM is engaged in reducing the environmental footprint of its own activities since 2007, through actions such as recycling, and reducing water and energy use. Recent propositions by the government include an increased responsibility of the CNAM in terms of developing a more environmentally sustainable social security system; a part of the government funding for this transition will be distributed through the CNAM.	http://www.senat.fr/rap/r21-594/r21-594-syn.pdf https://assurance-maladie.ameli.fr/qui-sommes-nous/engagements/demarche-rso-rse
Conseil national de l'investissement en santé (CNIS)	The National council for investments in health and its Scientific council (SC) were created in 2021 under the Ministry of Health, to develop strategic orientations and priorities for investments in the health care sector, and monitor and assess investments in health across health, medical, LTC and primary care as well as the digitalization thereof.	With the Ministry of Health, the SC of CNIS recently published a reference document to prepare the health care sector for the environmental transition that soon will apply also to all buildings in the health care sector. The document provides guidance to health care providers on how to live up to and report actions taken to meet hospitals' obligations towards sustainable development and societal responsibility.	https://solidarites-sante.gouv.fr/IMG/pdf/210409_-_cp_-_communique_de_presse_-_segur_de_la_sante_-_olivier_veran_et_brigitte_bourguignon_installent_le_conseil_national_pour_les_investissements_en_sa.pdf https://solidarites-sante.gouv.fr/IMG/pdf/csis_guide_dd_vf-2.pdf
Direction régionale et interdépartementale de l'environnement, de l'aménagement et des transports (DRIEAT)	The Regional and interdepartmental directorate of the environment, development, and transports is a decentralized department of the Ministry of Environmental Transition and territorial cohesion	DRIEAT implements the Ministry's policies on transport, planning and sustainable development, environment, energy and urban planning. DRIEAT develops and implements national and European policies protecting and preserving resources, natural spaces and species. They also surveil and prevent environmental hazards and pollution, and co-develop the Regional health environment plans (Le plan regional santé environnement; PRSE).	https://www.drieat.ile-de-france.developpement-durable.gouv.fr/spip.php?page=sommaire
Haute autorité de santé (HAS)	The National health authority is an independent, scientific administrative authority that oversees the development of guidelines of good practice for medical care. The HAS oversees the certification of hospitals, and support improving care quality in France.	The certification of hospitals includes one criterion regarding actions in place that ensure sustainable (social, economic and environmental) development in hospitals and preparedness to adapt to environmental risks.	www.has-sante.fr https://www.has-sante.fr/jcms/c_916883/fr/contexte-et-enjeux-du-developpement-durable

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Table 4 (cont'd) Main stakeholders in France

STAKEHOLDER	DESCRIPTION/OVERALL MISSION	ENVIRONMENTAL AND/OR HEATLH MISSIONS	REFERENCE/LINK
Haut Conseil pour le climat (HCC)	The High Council of Climate was created in 2018 as an independent organization that evaluates the government's climate policies and develops recommendations and objectives for further action for the government. The HCC also assesses the socio-economic impact of climate policies.	The health-related work of the HCC is limited and has mainly focused on resilience against future pandemics provoked by climate change through accelerating a socially fair (equitable) ecological transition. A report was published on the subject by the HCC in 2020, laying out recommendations for a fair transition.	https://www.hautconseilclimat.fr/ https://www.hautconseilclimat.fr/publications/climat-sante-mieux-prevenir-mieux-guerir/
Ministère de la Santé et de la Prévention	The Ministry of Health and prevention develops and implements the government's public health and care organization policies mainly at the Directorate general of health (DGS) which is concerned by overall public health policy, and the Directorate general of care offer (DGOS) that plans care provision.	The ministry mainly oversees prevention, monitoring and management of health risks related to the environment, water and air pollution. The impact of climate change on health which is a recognized area of concern together with the impact of heat and cold waves, but the main focus lies on managing environmental pollutants and risks to human health.	https://sante.gouv.fr/sante-et-environnement/risques-climatiques/article/changement-climatique-et-sante
Ministère de la transition écologique et de la cohésion des territoires et la Ministère de la transition énergétique	The Ministry of Environmental transition and Territorial cohesion and the Ministry of Energy transition develop and implement policy in all areas related to ecology, energy transition and the protection of biodiversity.	Develops and implements climate change mitigation and adaptation policies regarding the energy market and production of energy (Directorate general of energy and climate, DGEC), infrastructure projects for personal and commercial land and sea travel (Directorate general of infrastructure, transport and the sea, DGITM), urbanization, biodiversity and waters (Directorate general of planning, housing and nature, DGALN), climate risk assessment and prevention (Directorate general of risk prevention, DGPR) and the safety and sustainability of flight travel (Directorate general of civil aviation, DGAC).	https://www.ecologie.gouv.fr
Observatoire national sur les effets du réchauffement climatique (ONERC)	The National Observatory on the Effects of Global Warming was created in 2001 and was attached to the Directorate general of energy and climate in 2008.	ONERC collects and disseminates information on risks associated with global warming and makes recommendations for climate adaptation in order integrate climate change into public environmental policies. The ONERC coordinates national climate adaptation policies and cooperates with the Intergovernmental group of experts on climate change (IPCC). ONERC's health-related work is limited and focuses mainly on climate change adaptation, rather than mitigation.	https://www.ecologie.gouv.fr/observatoire-national-sur-effets-du-rechauffement-climatique-onerc

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Table 4 (cont'd) Main stakeholders in France

STAKEHOLDER	DESCRIPTION/OVERALL MISSION	ENVIRONMENTAL AND/OR HEATLH MISSIONS	REFERENCE/LINK
Conseils départementaux	The departments (local authorities) in France are in charge of the development at the local level in agriculture, health and environmental safety, digital development (providing high speed internet networks, for instance) and public accessibility of services. The départements are also involved in environmental management and planning, including water provision, waste treatment, protection of nature, etc.	The responsibilities of departments are mostly limited to assuring direct protection of the environment, such as natural zones and water sources. The Departmental councils can also implement voluntary actions such as supporting greener infrastructure, recycling campaigns, wider environmental protection, sports events etc. Such actions could have indirect impact of emissions in the health care system, for instance, through encouraging active transport or telehealth solutions.	www.departements.fr https://www.senat.fr/questions/base/2016/qSEQ160320554.html#:~:text=Les%20d%C3%A9partements%20sont%20nombreux%20%C3%A0,des%20%C3%A9tiages%2C%20gestion%20des%20d%C3%A9chets.
Santé publique France (SPF)	The National Public Health Agency is responsible for public health policy and expertise in France. Their missions include health promotion and education, public health surveillance, disease prevention and monitoring as well as alert and response to disease outbreaks and other public health emergencies.	Their environment-related work is principally associated with the public health effects of global warming, for instance through the spread of new infectious diseases, and the impact of extreme high and low temperatures on health. SPF is increasingly (2020 onwards) publishing articles and organizing events related to the environment, public health and health equity, as well as their co-benefits. In 2020, SPF published a reflection on the indicators for assessing and reacting to climate change from a public health perspective, however, focusing on adaptation rather than mitigation.	www.santepubliquefrance.fr
Non-governmental organizations (NGO) and associations			
Association des ingénieurs hospitaliers de France (IHF)	IHF is an association that organizes seminars for hospital administrative, technical and managerial staff as well as hospital construction companies and engineers.	Offers training on decarbonizing health care, energy management, digitalization in the health care sector and sustainable development in the hospital and LTC sectors	https://www.ihf.fr/
Associations des professionnels en conseil climat energie et environnement (APCC)	APCC is a non-profit association gathering representatives of companies that support and advice public establishments, institutions and companies on their ecological transformation. They actively participate in the development of environmental policies. They organize working groups, seminars and groups of reflection on the ecological transition of all types of organizations.	Although few, the APCC offers reflections on the theme of health care providers' impact on the environment from the perspective of materials and products used in the health care sector; how to assess as well as reduce their impact.	www.apc-climat.fr https://apc-climat.fr/wp-content/uploads/2022/07/Note-climat-et-sante.pdf
Collectif eco-responsabilité en santé (CERES)	Eco-responsibility in Health Collective (CERES) groups together health professional associations with the aim to increase awareness on the role of health care professionals in the fight against global warming.	CERES promotes eco-responsibility in the health care sector, collaboration across health care sectors in issues concerning sustainable development and supports the implementation of environmentally friendly practices in the health care sector, for instance through sharing recommendations and tools.	https://ceres-sante.fr/

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Table 4 (cont'd) Main stakeholders in France

STAKEHOLDER	DESCRIPTION/OVERALL MISSION	ENVIRONMENTAL AND/OR HEATLH MISSIONS	REFERENCE/LINK
Comité 21	Committee 21, also called the Committee for the Environment and Sustainable Development, is an association created by the Ministry of Environment in 1995 in response to Agenda 21. It works as a network for French actors in sustainable development (businesses, NGOs, public and educational institutions). Its main aims are to implement sustainable development in organizations, companies and territories. They conduct thematic working groups, training sessions and offer technical and methodological tools.	Committee 21 gathers and shares documentation related to the health and/or health care system and global warming and support aimed at organizations regardless of domain but does not have specific missions related to health and the health care system.	http://www.comite21.org/
Comité pour le Développement durable en Santé (C2DS)	The Committee for Sustainable Development in Health is a non-profit association bringing together 805 hospitals and LTC providers that want to develop more environmentally sustainable services.	The C2DS provides a toolbox for developing the sustainability of services, tools for auto-assessment, training of health professionals and practical knowledge for reducing the environmental impact of health care services through experiences in the network; as an example, they have produced a practical guide for hospitals on how to reduce material waste. Their work also consists of identifying priority actions to decarbonize the health care sector, organizing educative events to support care providers in the transition, and monitor and document the progress of decarbonization in the health care sector	https://www.c2ds.eu/ https://www.has-sante.fr/upload/docs/application/pdf/2013-07/reduction_dechets_hospi.pdf
Hospital federations	The Hospital Federations are non-profit associations grouping public hospitals and long-term care providers (*Fédération hospitalière de France*, FHF), private non-profit hospitals (*Fédération des établissements hospitaliers et d'aide à la personne*, FEHAP) and private for-profit hospitals (*Fédération de l'hôspitalisation privée*, FHP) as well as specialized cancer clinics (Fédération nationale des centres de lutte contre le cancer) and home hospitalization providers (Fédération nationale des établissements d'hospitalisation à domicile), and others. The main aims are to promote, support and represent hospitals and long-term care providers.	The federation members have signed a chart for sustainable development, accompanied by a range of actions and initiatives. For instance, Tthe FHF engages in the development of propositions for supporting the environmental transition of hospitals and long-term care providers. They also organize webinars, publish documentation on sustainable development and encourage environmental initiatives in the sector. Within the FHF, a committee for the environmental transition in health (*Comité sur la transition écologique en santé*) has been created to accelerate the transition process within the health care sector. The committee is responsible for producing proposals for public authorities and support the transition of health care providers. The FHP has been engaging in environmental issues for the past decade and has an Observatory for sustainable development performance since 2015 and a Working Group on sustainable development group since 2016.	https://www.fhf.fr/ https://www.fhf.fr/sites/default/files/2022-12/Note_Trans_Eco_Mobilite5.pdf https://www.fhp.fr/1-fhp/3-la-fhp/1010-/2-1010-article.aspx

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Table 4 (cont'd) Main stakeholders in France

STAKEHOLDER	DESCRIPTION/OVERALL MISSION	ENVIRONMENTAL AND/OR HEATLH MISSIONS	REFERENCE/LINK
Health care providers			
Hospitals : Centre hospitalier universitaire (CHU), Centre hospitalier régionale (CHR) and Centre hospitalier (CH), Etablissement de santé intérêt publique (ESPIC), and private clinics.	University and teaching hospitals, regional hospitals and public hospitals, nonprofit private hospitals and private clinics	Many bottom-up environmental initiatives stem from individual hospitals. For instance, the University Hospital in Tours has initiated actions to reduce travel-related emissions and increase recycling. The ESPIC in Midi-Pyrenees is collaborating with the C2DS to establish an organization within the hospital that can reduce its carbon footprint. The CH in Niort has engaged in an ambitious carbon neutrality program, and has been performing a climate audit with regular carbon monitoring since 2012. It has reduced food waste and supported environmental procurement using new software.	https://www.has-sante.fr/jcms/c_916964/fr/des-initiatives-dans-le-champ-hospitalier https://www.ch-niort.fr/nous-demain/developpement-durable
Health care practitioners	Health care practitioners are organized through professional councils (for instance the Medical council and the Nursing council). Professional councils mainly work on issues concerning medical practice and deontology, which currently does not include sustainable health care provision.	The Medical council has organized events where physicians engage in reflections regarding the impact of the environment on health, and how to reduce that impact (e.g. through reduced pollution) and the nursing council treat issues around sustainable health care. However, environmental issues are not among the priorities of professional councils.	https://www.conseil-national.medecin.fr/publications/communiques-presse/medecins-face-changement-climatique-energies-fossiles
Health professional associations (sociétés savants)	Health professional associations promote the roles of their profession and contribute with research and reflections concerning the professional community, their roles and other topics of importance.	Health professional associations increasingly engage in reflections and initiatives concerning the environment. For instance, the Francophone Health and Environmental Association (Société francophone de santé et environnement; SFSE) engages in informing and reflecting on global warming adaptation and mitigation from a health professional and research perspective. The French society of anesthesia and intensive care medicine has elaborated and published recommendations for reducing the environmental impact of general anesthesia.	https://www.sfse.org/presentation/quisommesnous https://sfar.org/download/reduction-de-limpact-environnemental-de-lanesthesie-generale/?wpdmdl=37890&refresh=6389f19e7d25e1669984670
Industry			
Les entreprises de médicament (LEEM)	The Association of drug companies (les entreprises de médicament; LEEM) represents actors in the pharmaceutical industry in policy and market-related negotiations with the state, and promotes and defends ethics in the industry.	As a bottom-up initiative, LEEM has established a Social responsibility plan for pharmaceutical companies that include an engagement to reduce the carbon emissions of the companies' activities. Adopting the plan is voluntary and requires auto-evaluation of the progress.	https://www.leem.org/responsabilite-societale-des-entreprises-du-medicament
Syndicat National de l'Industrie des Technologies Médicales (SNITEM)	The National association of the medical technology industry represents and promotes actors in the industry of medical technology and devices.	SNITEM produces and disseminates information on innovation in medical technology, of which the environmental impact is increasingly being incorporated. Members of the SNITEM also sign a Chart of Ethics, including a clause of adhering to the national legislation on environmental responsibility. However, the SNITEM does not have specific missions focusing on environmental issues.	https://www.snitem.fr/le-snitem/missions-et-services/ https://www.calameo.com/snitem/read/0006105421948b36ffdfb

In 2021, following the major investment plan made for the health care sector as part of the "*Ségur de la santé*" reform, a new instance, the National council for investments in health (*Conseil national de l'investissement en santé*, CNIS) was created under the Ministry of Health. It is in charge of developing strategic priorities and monitors investments in medical facilities, LTC and primary care as well as their digitalization. The Scientific council of CNIS announced that "greening" investments in the health care sector will soon be an obligation, and provided a guide on how to report sustainable development and societal responsibility actions (e.g. energy efficiency) in the hospital sector. In 2021, the Ministry of Health, the CNSA and ANAP also announced an investment of €10 million per year until 2024 to finance up to 150 advisors to support energy and ecological transition in hospital and LTC facilities (*Conseillers en transition énergétique et écologique en santé*, CTEES).

At the regional level, since 2011, Regional health agencies *(Agence régionale de santé*, ARS) work on both preventing environmental risks on human health (such as water safety), and the impact of human activities on the environment (such as air quality and infectious waste from health care activities).

Health care providers

Health care providers are at the forefront meeting the health consequences of climate change, and they are amongst the main stakeholders when it comes to mitigating such consequences. Many **bottom-up environmental initiatives** stem from health care providers, such as hospitals. For instance, the University Hospital in Tours has initiated actions to reduce travel-related emissions and increase recycling in the hospital. A hospital in the Midi-Pyrenees region is collaborating with the C2DS to establish an organization within the hospital that can reduce its carbon footprint. A hospital in Niort has also engaged in a comprehensive environmental transition program aiming at carbon neutrality by 2030.

Health care practitioners, both in the hospital and outpatient settings, are mainly brought together through professional councils, such as the Medical council (*Ordre des Médecins*). Professional councils are mainly concerned with promoting good medical practice and professional deontology, of which environmental issues are currently not part of. Nevertheless, the Medical council has organized events in the past (e.g. 2015 and 2017) to engage physicians in reflections regarding the impact of the environment on health, and how to reduce that impact (e.g. through reduced pollution). Other councils, such as the Nursing council, do treat subjects like sustainable health care, which could be further expanded to environmental sustainability. Furthermore, some health professional associations (*sociétés savantes*) engage actively in reflections and initiatives concerning the environment and the role of their profession in environmental issues in the health care sector.

Non-governmental organizations and associations

Numerous non-governmental organizations and associations have missions more focused on implementing decarbonization actions in the health sector, as well as monitoring and reporting on their implementation. For example, the Eco-responsibility in health collective (*Collectif écoresponsabilité en santé*, CERES), the Committee for sustainable health development (*Comité pour le développement durable en santé*, C2DS), Committee 21 (also called the Committee for the environment and sustainable development) provide technical and methodological aid to health care providers, including auto-assessment tools and training of health professionals for reducing the environmental impact of health care.

Industry

The pharmaceutical industry and pharmaceuticals are amongst the major contributors to the environmental footprint of the health care sector. Although **bottom-up initiatives** have created charts of responsible production and guidelines for environmental responsibility, actions in the pharmaceutical sector **are voluntary**. Authorization and surveillance of pharmaceuticals on the French market is conducted by the National agency for the safety of medical and health products (*Agence nationale de sécurité du médicament et des produits de santé*, ANSM), but they do not have any missions related to the environmental impact of medicines and medical products on the French market.

4.2. Need for strengthening coordinated actions in the health sector

Our review shows that there is a large range of stakeholders involved in issues concerning the climate and the health care sector in France. Most stakeholders focus on specific environmental issues in sectors such as agriculture, buildings and air pollution. In the health sector, most public agencies have been concerned by limiting the adverse effect of environment on health rather than mitigating the impact of health care until recently.

While there is no paucity of stakeholders in the fields of environment and health care, **France has been missing until recently an overarching organization which develops a coherent strategy for improving environmental sustainability of its health care system and for coordinating efforts across multiple stakeholders.** In March 2023, the Ministry of Health created a strategic committee on ecological transition in health. The experience from other countries shows that having a dedicated instance that works on identifying the size of the problem in different sectors and conceptualizing and monitoring change is important. For instance, the creation of a Sustainable Development Unit in the NHS England was instrumental for improving the environmental sustainability of the NHS over the past 15 years, and continues to be so through the Greener NHS program committing to and setting out the pathway for reaching a net-zero health system (NHS England, 2022).

France also needs stakeholders to cultivate systematic measurement of the environmental footprints of health care providers (hospital buildings, primary care centers, etc.), considering energy, water use and transport, the life cycle of procured items as well as an evaluation of care processes. There is need for national, regional and provider-level data on emission trends to develop effective strategies for improving the environmental sustainability of the health care sector.

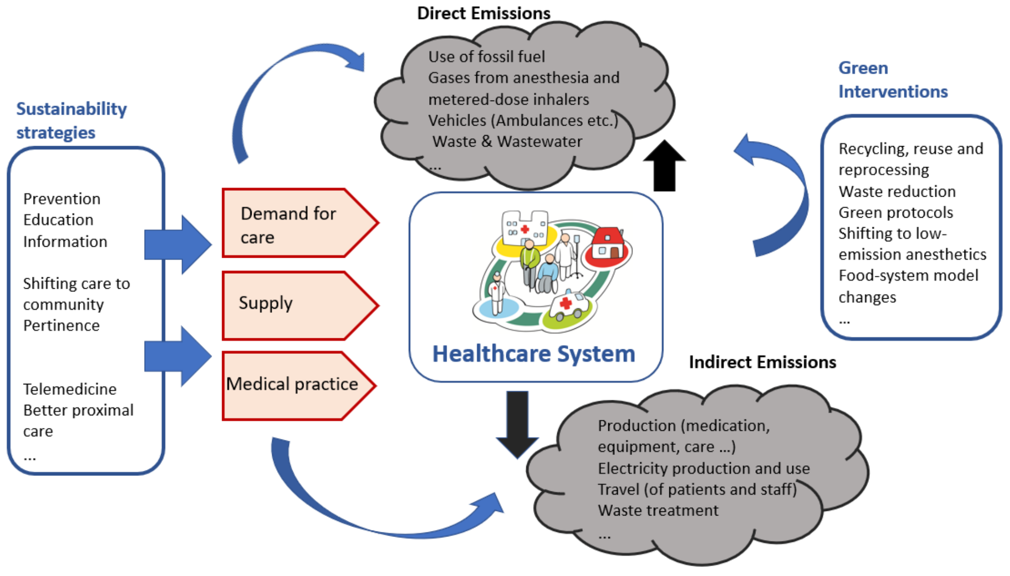
Few stakeholders have expertise in or are concerned by environmentally sustainable health care and related issues simultaneously although several of the stakeholders would be suitable for this mission. For instance, medical and nursing associations as well as educational institutions have great potential to create bottom-up engagement in the health care work force; these stakeholders consist of both the hospital and primary care sectors and could serve as a platform to promote action across sectors. The environmental aspects of heath care could also be further integrated into care quality and good clinical practice guidance and evaluations.

4.3. A framework for action

Generally, sustainability is defined as "fulfilling the needs of current generations without compromising the needs of future generations" (Brundtland, 1987), and ensuring a balance between economic, environmental, and social well-being. Generally, fiscal sustainability refers to the ability of a government to maintain public finances at a credible and efficient position over the long term, while environmental sustainability means generating a minimal amount of pollution and GHG, aligning health delivery with global climate goals (OECD, 2013; World Bank, 2017). In the health sector, ensuring long-term fiscal sustainability requires public payers to engage in continual strategic forecasting of future needs and revenues, considering environmental factors and socio-economic trends in order to adapt healthcare system accordingly. Investing in environmental sustainability in health systems is both a responsibility and an opportunity (WHO, 2017), because promoting environmental sustainability in health systems can provide measurable benefits and opportunities in terms of health protection and promotion, financial savings, improved efficiency, and resilient communities. Therefore, economic sustainability of health care systems is closely linked to their environmental sustainability.

The literature shows that there are numerous "green interventions" that can successfully reduce the environmental impact of health care across a range of domains, but they are insufficient if not accompanied by sustainability strategies which modify how health care is provided and consumed via large-scale, organizational-level interventions targeting to redesign health care provision and reduce the need and demand for health care. This requires a broad approach for identifying the necessary transformative process and multiple levers for action. Figure 2 presents a conceptual framework which outlines different types of actions which should be developed simultaneously for reducing both direct and indirect sources of pollution in the health care sector. There are numerous effective interventions which can reduce direct and indirect impact of health care by modifying or reducing use of resources, including energy sources, natural resources, medical products, water and travel. Waste seg-

Figure 2 A framework for action to improve the environmental sustainability of the health system



regation and recycling, reuse and reprocessing of materials, use of less polluting anesthetic gases and shifting to cleaner energy sources have been shown successful interventions to improve the sustainability of surgical activities. Innovation in care processes and medical technology can also support the transition to a sustainable health system. Products and technologies with minimal environmental impact and recyclable materials or materials that can be reused as a form of further resource (e.g. clinical waste reused as building boards) need to be generalized.

Encouraging technical and organizational innovations for reducing resource use and supporting the diffusion of effective "green interventions" across care providers is essential. Nevertheless, such interventions are not enough unless accompanied by mitigation or "sustainability" measures which requires to change the way health care provided and consumed. The most effective way of reducing the impact of health care is reducing health care demand. **Reducing wasteful health care provision and use** would involve systemic interventions for mitigating health care need, assuring appropriateness of health care use (pertinence) and making health care more efficient. Prevention, which also includes changing individual and social attitudes to supporting more environmentally sustainable care consumption, is identified as one way of reducing the need and demand for health care services (Pichler et al., 2017; Taylor and Mackie, 2017). For instance, reducing waste and unnecessary medication use has a potential to reach a similar effect to reducing energy consumption in hospitals (Nansai et al., 2020).

It is equally fundamental to reinvest in and reimagine how to provide care, everything from defining which care is pertinent in which setting to refining referral pathways and upskilling health care professionals for better proximal care provision, teleconsultations and use of artificial intelligence for patient risk stratification, triage and reinforced consultations in outpatient settings (Wong et al., 2021). While not all hospital care can be replaced, avoiding hospitalizations, reducing length of hospital stay and promoting less carbon intensive services in the community could help to reduce health-care related emissions. Ultimately, as stated in the NHS strategy of sustainable health care, the overarching aim is **doing less, but better.** This would involve smaller and more resource efficient hospitals, reconsidering hospitals as part of a larger, patient centered care system instead of the default care provider, more prevention, and care at home, fewer unnecessary (and harmful) care procedures, more sparse use of pharmaceuticals, more rapid implementation of research and technology, and a more integrated organization of health care system including public health (Pencheon, 2015).

Interventions aiming to reduce the environmental footprint of health care may have positive health, economic and organizational co-benefits. Vice versa, public health measures such as promoting healthy lifestyles can have benefits for the environment. Climate policies can also have positive spillover effects, such as a sense of teamwork among health care staff which could contribute to a better work environment (Blum et al., 2021) as well as populational-level benefits of better health, which are important biproducts motivating implementation. The impetus to change across different areas will come both from "push" factors such as compliance with environmental legislation, and "pull" factors centered on behavioral change and the potential patient benefits of sustainable health care. The effects of preventive or demand management measures which avoid unnecessary health care utilization are likely to be much greater than incremental changes to how these procedures are performed.

5. Conclusions

The health sector contributes significantly to global warming through energy and transport it relies on as well as the products it manufactures and consumes. It is also directly impacted by and must face the consequences of global warming for preventing and responding to health causalities. Health care mitigation and environmentally sustainable health care provision strategies can reduce the negative impact of health care on the environment and can provide significant economic, organizational and health benefits for attaining a resilient and sustainable health care system.

Environmentally sustainable greener health care will strengthen health systems and populational health by ensuring better access to safe water, clean transport and clean waste disposal as well as better prevention and proximal care, while reducing waste in the system and increasing the security and quality with better care protocols. There is increasing evidence on effective strategies for improving environmental sustainability of health care systems, including strategies for better public information and training of health care professionals, but the first step in all instances is the measurement of the environmental footprint of health care in different settings. A significant part of the footprint of health care providers relates to clinical practice, that is, decisions regarding the use (or non-use) of technologies, pharmaceuticals, and medical devices. Life cycle assessment studies can help understand the full financial and environmental costs of different health care activities.

While encouraging innovation (technological, clinical, organizational, etc.) that will reduce emissions from health care is essential, the effects of preventive or demand management measures which avoid unnecessary health care utilization are likely to have much greater incremental changes. More research is called for to understand how the design and funding of health care influences the uptake of sustainable behaviors and innovations. Research is also needed to better comprehend attitudes and cultures within the health care system and in wider society that can facilitate, or hinder, improving the environmental sustainability of health care.

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Appendix 1.
Full list of search terms for scoping review

Stage 1. Preliminary search

PubMed

((("primary health care"[MeSH Terms]) OR ("practice patterns"[Title/Abstract])) OR (((((primary health care[MeSH Terms]) OR ("practice patterns, physicians"[MeSH Terms])) OR (practice patterns, nurses[MeSH Terms])) OR (practice patterns, pharmacists[MeSH Terms])) OR ("practice patterns, dentists"[MeSH Terms])) OR (primary prevention[MeSH Terms]) AND ((((((((("climate change"[Title/Abstract]) OR ("environmental impacts"[Title/Abstract])) OR ("environmental impact"[Title/Abstract])) OR ("environmental footprints"[Title/Abstract])) OR ("carbon emissions"[Title/Abstract])) OR ("carbon footprints"[Title/Abstract])) OR ("carbon dioxide/analysis"[MeSH Terms])) OR ("pollution"[Title/Abstract])) or ("particles"[Title/Abstract])) OR ("greenhouse gas emissions"[Title/Abstract])) OR ("greenhouse gases/analysis"[MeSH Terms]).

Performed four times with specifications for reviews only and for three groups of countries (France, European OECD, non-European OECD)

AND ((("systematic review"[Title]) OR "literature review"[Title]) OR "scoping review"[Title]) OR "metaanalysis"[Title].

AND ((FRANCE[MeSH Terms]) OR FRANCE[Title/Abstract]) OR "french"[Title/Abstract].

AND ((((((((((((((((((((((((((((((((((("european union"[MeSH Terms]) OR "european union"[Title]) OR "europe"[MeSH Terms]) OR "europe"[Title]) OR "europe, eastern"[MeSH Terms]) OR "austria"[MeSH Terms]) OR "austria"[Title]) OR "belgium"[MeSH Terms]) OR "belgium"[Title]) OR "finland"[MeSH Terms]) OR "finland"[Title]) OR "germany"[MeSH Terms]) OR "germany"[Title]) OR great britain[MeSH Terms]) OR "great britain"[Title]) OR "united kingdom"[MeSH Terms]) OR "united kingdom"[Title]) OR "greece"[MeSH Terms]) OR "greece"[Title]) OR "iceland"[MeSH Terms]) OR "iceland"[Title]) OR "ireland"[MeSH Terms]) OR ireland[MeSH Terms]) OR "italy"[Title]) OR "italy"[MeSH Terms]) OR "portugal"[MeSH Terms]) OR portugal[Title]) OR ("scandinavian and nordic countries"[MeSH Terms])) OR "denmark"[MeSH Terms]) OR "denmark"[Title]) OR "norway"[MeSH Terms]) OR "norway"[Title]) OR "sweden"[MeSH Terms]) OR "sweden"[Title]) OR "spain"[MeSH Terms]) OR "spain"[Title]) OR "netherlands"[MeSH Terms]) OR "netherlands"[Title]) OR "switzerland"[MeSH Terms]) OR "swizerland"[Title].

AND (((((((("australia"[MeSH Terms]) OR "australia"[Title]) OR "canada"[MeSH Terms]) OR "canada"[Title]) OR "japan"[MeSH Terms]) OR "japan"[Title]) OR "united states"[MeSH Terms]) OR united states]) OR "new zealand"[MeSH Terms]) OR "new zealand"[Title]).

Web of Science

TS=(Healthcare or health care systems) and TS=(climate change or environmental impact or footprint or ecological transition or environmental friendly or greenhouse gasses emissions or sustainable development or smart healthcare).

Ti=(mitigation* or strateg* or intervention* or action* or policy or policies).

TS=(primary prevention or practice patterns or primary health care).

Stage 2. Extended to all care sectors and interventions – main search strategy

PubMed
(((((((((((((((((“climate smart"[Title/Abstract]) OR (“ecological"[Title/Abstract])) OR (“green health care"[Title/Abstract])) OR (“green healthcare"[Title/Abstract])) OR (“carbon neutral"[Title/Abstract])) OR (“decarbonized"[Title/Abstract])) OR (decarbon*[Title/Abstract])) OR (“climate objectives"[Title/Abstract])) OR (“climate change"[Title/Abstract])) OR (“global warning"[Title/Abstract])) OR (“carbon emission"[Title/Abstract])) OR (“pollution"[Title/Abstract])) OR (“greenhouse gases"[Title/Abstract])) OR (“environmental impact"[Title/Abstract])) OR (“environmental footprint"[Title/Abstract])) OR (“environmental footprints"[Title/Abstract])) OR (“environmental impacts"[Title/Abstract])) OR (“environmental friendly"[Title/Abstract])) OR (“sustainable development"[Title/Abstract]) AND ((((((((((((((((((((((((((“he alth care"[Title/Abstract]) OR (“healthcare"[Title/Abstract])) OR (“care sector"[Title/Abstract])) OR (“healthcare services"[Title/Abstract])) OR (“health care services"[Title/Abstract])) OR (“primary care"[Title/Abstract])) OR (“hospital"[Title/Abstract])) OR (“hospitals"[Title/Abstract])) OR (“doctors"[Title/Abstract])) OR (“surgery"[Title/Abstract])) OR (“outpatient"[Title/Abstract])) OR (“inpatient"[Title/Abstract])) OR (“pathways"[Title/Abstract])) OR (“medical practice"[Title/Abstract])) OR (“care organization"[Title/Abstract])) OR (“care organizations"[Title/Abstract])) OR (“long term care"[Title/Abstract])) OR (“nursing"[Title/Abstract])) OR (“pharmaceuticals"[Title/Abstract])) OR (“healthcare waste"[Title/Abstract])) OR (“health care waste"[Title/Abstract])) OR (“healthcare wastes"[Title/Abstract])) OR (“health care wastes"[Title/Abstract])) OR (medical equipment[Title/Abstract])) OR (“medical transport"[Title/Abstract])) OR (“healthcare supply chain"[Title/Abstract])) OR (“health care supply chain"[Title/Abstract])) OR (“care delivery"[Title/Abstract])) OR (“drugs"[Title/Abstract]) AND ((((((((((((((“reduction"[Title/Abstract]) OR (mitigation[Title/Abstract])) OR (intervention[Title/Abstract])) OR (interventions[Title/Abstract])) OR (policy[Title/Abstract])) OR (policies[Title/Abstract])) OR (INTERVENTION[Title/Abstract])) OR (INTERVENTIONS[Title/Abstract])) OR (strategy[Title/Abstract])) OR (strategies[Title/Abstract])) OR (“plans"[Title/Abstract])) OR (PLAN[Title/Abstract])) OR (waste reduction[Title/Abstract])) OR (avoidable[Title/Abstract])) OR (“care grade"[Title/Abstract])) OR (prevention[Title/Abstract]) OR “community care"[Title/Abstract] OR ((((EVALUATION[Title/Abstract]) OR (EVALUATIONS[Title/Abstract])) OR (ASSESSMENT[Title/Abstract])) OR (ASSESSMENTS[Title/Abstract])) OR (IMPACTS[Title/Abstract]).
Combined with specifications for three groups of countries (France, European OECD, non-European OECD)
AND ((FRANCE[MeSH Terms]) OR FRANCE[Title/Abstract]) OR “french"[Title/Abstract].
AND ((((((((((((((((((((((((((((((((((((“european union"[MeSH Terms]) OR “european union"[Title]) OR “europe"[MeSH Terms]) OR “europe"[Title]) OR “europe, eastern"[MeSH Terms]) OR “austria"[MeSH Terms]) OR “austria"[Title]) OR “belgium"[MeSH Terms]) OR “belgium"[Title]) OR “finland"[MeSH Terms]) OR “finland"[Title]) OR “germany"[MeSH Terms]) OR “germany"[Title]) OR great britain[MeSH Terms]) OR “great britain"[Title]) OR “united kingdom"[MeSH Terms]) OR “united kingdom"[Title]) OR “greece"[MeSH Terms]) OR “greece"[Title]) OR “iceland"[MeSH Terms]) OR “iceland"[Title]) OR “ireland"[MeSH Terms]) OR ireland[MeSH Terms]) OR “italy"[Title]) OR “italy"[MeSH Terms]) OR “portugal"[MeSH Terms]) OR portugal[Title]) OR (“scandinavian and nordic countries"[MeSH Terms])) OR “denmark"[MeSH Terms]) OR “denmark"[Title]) OR “norway"[MeSH Terms]) OR “norway"[Title]) OR “sweden"[MeSH Terms]) OR “sweden"[Title]) OR “spain"[MeSH Terms]) OR “spain"[Title]) OR “netherlands"[MeSH Terms]) OR “netherlands"[Title]) OR “switzerland"[MeSH Terms]) OR “swizerland"[Title].
AND ((((((((“australia"[MeSH Terms]) OR “australia"[Title]) OR “canada"[MeSH Terms]) OR “canada"[Title]) OR “japan"[MeSH Terms]) OR “japan"[Title]) OR “united states"[MeSH Terms]) OR united states]) OR “new zealand"[MeSH Terms]) OR “new zealand"[Title]).

Stage 3. Complementary search focused on health care systems

PubMed
((((((((((((((((((((((((((("health care"[Title/Abstract]) OR ("healthcare"[Title/Abstract])) OR ("care sector"[Title/Abstract])) OR ("healthcare services"[Title/Abstract])) OR ("health care services"[Title/Abstract])) OR ("primary care"[Title/Abstract])) OR ("hospital"[Title/Abstract])) OR ("hospitals"[Title/Abstract])) OR ("doctors"[Title/Abstract])) OR ("surgery"[Title/Abstract])) OR ("outpatient"[Title/Abstract])) OR ("inpatient"[Title/Abstract])) OR ("pathways"[Title/Abstract])) OR ("medical practice"[Title/Abstract])) OR ("care organization"[Title/Abstract])) OR ("care organizations"[Title/Abstract])) OR ("long term care"[Title/Abstract])) OR ("nursing"[Title/Abstract])) OR ("pharmaceuticals"[Title/Abstract])) OR ("healthcare waste"[Title/Abstract])) OR ("health care waste"[Title/Abstract])) OR ("healthcare wastes"[Title/Abstract])) OR ("health care wastes"[Title/Abstract])) OR (medical equipment[Title/Abstract])) OR ("medical transport"[Title/Abstract])) OR ("healthcare supply chain"[Title/Abstract])) OR ("health care supply chain"[Title/Abstract])) OR ("care delivery"[Title/Abstract])) OR ("drugs"[Title/Abstract]) AND (((((((((environmental mitigation strategies[Title]) OR (environmental mitigation strategy[Title])) OR (environmental mitigation measures[Title])) OR (environmental mitigation intervention[Title])) OR (environmental mitigation interventions[Title])) OR (environmental mitigation policies[Title])) OR (environmental mitigation policy[Title])) OR ("carbon reduction policies"[Title])) OR ("carbon reduction strategies"[Title])) OR ("carbon reduction strategy"[Title])) OR ("high wastewater treatment"[Title]).

Stage 4. Verifications: update of literature since 2020 and refined searches

PubMed
Update for literature since 2020
(((((((((«climate change»[Title/Abstract]) OR («environmental impacts»[Title/Abstract])) OR («environmental impact»[Title/Abstract])) OR («environmental footprints»[Title/Abstract])) OR («carbon emissions»[Title/Abstract])) OR («carbon footprints»[Title/Abstract])) OR («carbon dioxide/analysis»[MeSH Terms])) OR («pollution»[Title/Abstract])) or («particles»[Title/Abstract])) OR («greenhouse gas emissions»[Title/Abstract])) OR («greenhouse gases/analysis»[MeSH Terms]) AND (((((((((((((((«healthcare»[Title]) OR («health care system»[Title])) OR («health care systems»[Title])) OR («delivery of health care»[MeSH Terms])) OR (health care sectors[MeSH Terms])) OR («nursing»[MeSH Terms])) OR («hospitals»[MeSH Terms])) OR (surgery department, hospital[MeSH Terms])) OR (emergencies[MeSH Terms])) OR (primary health care[MeSH Terms])) OR (long term care[MeSH Terms])) OR («drugs»[Title/Abstract])) OR («pharmaceuticals»[Title/Abstract])) OR («medical devices»[Title/Abstract])) OR («disposable equipment»[MeSH Terms])) OR (transportation of patients[MeSH Terms])) OR («e health»[Title/Abstract]) AND («mitigations»[Title/Abstract])) OR (mitigation[Title/Abstract])) OR («intervention»[Title/Abstract])) OR (interventions[Title/Abstract])) OR (action[Title/Abstract])) OR (actions[Title/Abstract])) OR (strategy[Title/Abstract])) OR (strategies[Title/Abstract])) OR (policy[Title/Abstract])) OR (policies[Title/Abstract]).
Refined search 1 (2010 onwards)
(((((((environmental impact[Title/Abstract]) OR (environmental footprints[Title/Abstract])) OR («carbon emissions»[Title/Abstract])) OR («carbon footprints»[Title/Abstract])) OR («carbon dioxide/analysis»[MeSH Terms])) OR (pollution[Title/Abstract])) OR («greenhouse gas emissions»[Title/Abstract])) OR («greenhouse gases/analysis»[MeSH Terms]) AND (((((((((((((((«healthcare»[Title]) OR («health care system»[Title])) OR («health care systems»[Title])) OR («delivery of health care»[MeSH Terms])) OR (health care sectors[MeSH Terms])) OR («nursing»[MeSH Terms])) OR («hospitals»[MeSH Terms])) OR (surgery department, hospital[MeSH Terms])) OR (emergencies[MeSH Terms])) OR (primary health care[MeSH Terms])) OR (long term care[MeSH Terms])) OR («drugs»[Title/Abstract])) OR («pharmaceuticals»[Title/Abstract])) OR («medical devices»[Title/Abstract])) OR («disposable equipment»[MeSH Terms])) OR (transportation of patients[MeSH Terms])) OR («e health»[Title/Abstract]) AND ((((«mitigations»[Title]) OR («mitigation»[Title])) OR («reduce»[Title])) OR («reduction»[Title])) OR («reductions»[Title]) AND (((((((Intervention[Title]) OR (interventions[Title])) OR (action[Title])) OR («actions»[Title])) OR (strategy[Title])) OR (strategies[Title])) OR (policy[Title])) OR (policies[Title]).

Refined search 2 (2010 onwards)
(((((((environmental impact[Title/Abstract]) OR (environmental footprints[Title/Abstract])) OR («carbon emissions»[Title/Abstract])) OR («carbon footprints»[Title/Abstract])) OR («carbon dioxide/analysis»[MeSH Terms])) OR (pollution[Title/Abstract])) OR («greenhouse gas emissions»[Title/Abstract])) OR («greenhouse gases/analysis»[MeSH Terms]) AND (((((((((((((((«healthcare»[Title]) OR («health care system»[Title])) OR («health care systems»[Title])) OR («delivery of health care»[MeSH Terms])) OR (health care sectors[MeSH Terms])) OR («nursing»[MeSH Terms])) OR («hospitals»[MeSH Terms])) OR (surgery department, hospital[MeSH Terms])) OR (emergencies[MeSH Terms])) OR (primary health care[MeSH Terms])) OR (long term care[MeSH Terms])) OR («drugs»[Title/Abstract])) OR («pharmaceuticals»[Title/Abstract])) OR («medical devices»[Title/Abstract])) OR («disposable equipment»[MeSH Terms])) OR (transportation of patients[MeSH Terms])) OR («e health»[Title/Abstract]) AND (((((((Intervention[Title]) OR (interventions[Title])) OR (action[Title])) OR («actions»[Title])) OR (strategy[Title])) OR (strategies[Title])) OR (policy[Title])) OR (policies[Title]) AND ((«outcome and process assessment, health care»[MeSH Terms]) OR («health care evaluation mechanisms»[MeSH Terms])) OR («program evaluation»[MeSH Terms]).

Appendix 2.
List of articles included in scoping review

Alshqaqeeq F., et al. (2020). "Quantifying Hospital Services by Carbon Footprint: A Systematic Literature Review of Patient Care Alternatives", *Resources Conservation and Recycling,* 154.

Blenkinsop S., et al. (2021). "Carbon Emission Savings and Short-Term Health Care Impacts from Telemedicine: An Evaluation in Epilepsy", *Epilepsia,* 62 (11), 2732-40.

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Appendix 3.
Data extracted – synthesized table

First author, year, coutry	Health care sector concerned	Intervention type / Aim	Description of intervention	Results
(Alshqaqeeq et al., 2020)* International	Hospital	Multiple areas/any intervention in the hospital sector Reduce the environmental impact of health care	Any interventions reported in the literature, such as waste reduction and management, water and energy use habits, improved anesthetic practices, use of reusable equipment, solar power, choice of dialysis machines, telemedicine, and policies	- There is evidence on how to reduce emissions from hospitals, operating rooms, anesthesia, patient transport, dialysis machines, medical equipment, and emergency and outpatient services (but mainly transportation-related emissions associated with the latter) - There are reports of successful strategies and actions for reducing waste, disposable equipment, energy consumption and water use, emissions from anesthesia and travel-related emissions (from both private and medical transportation) - Telemedicine approaches have high potential for reducing the carbon footprint of various health care services - This review found no reports on interventions concerning research activities, diagnostic services, oncology, respiratory care, or laboratory services
(Blenkinsop et al., 2021)** England	Hospital (outpatient)	Telemedicine Reduce GHG emissions related to patient travel	An enforced telemedicine service at one clinic: Remotely held consultations (due to the Covid-19 pandemic) for 1,277 epilepsy patients using teleconference software and telephone at patients' homes over a 6,5-month period	- Compared to a scenario where the telemedicine practice had not existed, the telemedicine service resulted in considerable savings in CO_2e emissions with minimal adverse clinical outcomes in the short term - 1,567 face-to-face consultations were "avoided" - 224,000 km of travel and 35,000–40,000 kgCO_2e were avoided - Emissions from the teleservice itself were <200 kgCO_2e (ranging from 2 kgCO_2e for a telephone call to up to 167 kgCO_2e for a video call)
(Brandmayr et al., 2015)*** Germany	Pharmaceutical	Policy-innovation mix Reduce pharmaceuticals in wastewaters due to consumption of medicines	A mix of policy and innovation, including different public health market, drug design and environmental policy configurations regarding: - Performance incentive scheme for disease prevention - Doctor–patient communication - Training of doctors - eHealth - Reducing obesity prevalence - Changing drug prescriptions - Improved drug design Two scenarios were compared to status quo (no intervention): 1) The likely scenario in Germany in 2030 where policy-innovation measures concerning drug innovation and environmental regulations are implemented non-systematically 2) A sustainability scenario where comprehensive, integrated management strategies are implemented with the different policy-innovation measures	- Scenario 1 was estimated to have ~80% the PEC value of status-quo for Metformin ~60% of the Predicted Environmental Concentration (PEC) value of status-quo for Metoprolol - Scenario 2 was estimated to have ~35% the PEC value of status-quo for Metformin ~25% of the PEC value of status-quo for Metoprolol - Although both scenarios resulted in a lower PEC compared to status quo, Scenario 2 was estimated to have 50% lower PEC compared to Scenario 1 - The measures will have different efficiency depending on the drug targeted (Metformin or Metoprolol). Thus, there is a need for a comprehensive set of initiatives addressing different sections of the lifecycle of a pharmaceutical - Single public health measures are likely to have limited impact, and a combination of the proposed measures reducing the need for pharmaceutical treatments are needed to reduce pharmaceuticals in wastewaters

First author, year, coutry	Health care sector concerned	Intervention type / Aim	Description of intervention	Results
(Carino et al., 2020)* International	Hospital (food service)	Multiple areas/any intervention in the health care food sector Reduce food waste, waste sent to landfills, and emissions related to production, preparation and distribution	Any intervention reported in the literature aiming to reduce the environmental impact of food services in the health care sector, such as sustainable food procurement, food system redesign and toolkits	- There are a range of interventions across different parts of the food chain, including procurement, preparation, consumption, waste disposal and approaches addressing several aspects of the food chain, however with varying quality of the evidence of their effectiveness - Food procurement interventions, such as farm-to-hospital initiatives, organic food, and sustainable meat procurement, are frequently reported in the literature, but with few reports on their impact. One study reported a 10-20% reduction in meat purchasing. - The most effective strategies to reduce food waste increase patients' food intake or reduce the portion size, such as the room service model, bulk trolley food delivery instead of individually served meals, isothermal trolleys and improved meal presentation, and patient choice of portion size and meal selection. Reducing portion sizes or letting patients select their meals has shown to avoid food waste between 5% to 30%. The amount of food eaten per meal served can be increased by 14% when served from isothermal trolleys and by 19% when improving the presentation of meals. - The evidence on different food waste disposal measures (e.g. recycling and composting) had insufficient quality to give any conclusive results on impact. One study estimated that increasing recycling in the hospital food service and composting could reduce waste going to landfills by 55% and reduce its GHG emissions by 64% in one hospital - Several studies addressed multiple aspects of the food supply chain using a holistic approach to sustainability. Redesigning the whole food system, can reduce food-related waste, as shown in nursing homes, rehabilitation and long-term medical care - Evidence-based toolkits helping hospitals to implement sustainable food procurement strategies and evidenced-based guidelines on environmentally sustainable foodservice system models can help bridge the gap between research and practice
(Chèvre et al., 2013)*** Swizerland	Hospital and pharmaceutical	Wastewater treatment Reduce substance flow (pharmaceutical waste pollution) from hospital wastewater	Seven different technical water treatment scenarios to avoid pharmaceuticals (ciprofloxacin, carbamazepine, diclofenac and gabapentin) reaching the environment in the city of Lausane and Lake Geneva were modelled. One scenario concerned the hospital sector, treating hospital wastewater with O_3 at the outputs of hospitals. This intervention was also combined with wastewater inlet and outlet treatment.	- Compared to estimated business as usual (BAU) flow of pharmaceutical substances in the water, best practice treatment with the best available techniques to eliminate chemicals at both the source (hospitals) and at the wastewater treatment plant reduces the risk of pharmaceuticals reaching the surface waters drastically: . From 33.7 to 7.2 kg/year for Ciprofloxacin . From 2.0 to 0.2 kg/year for Carbamazepine . From 30.1 to 3.3 kg/year for Diclofenac . From 116 to 12.7 kg/year for Gabapentin - For the compounds studied, hospitals are minor sources of water contamination. However, water treatment at hospitals contributes to reducing the aquatic environmental risk caused by ciprofloxacin by a factor of one-third - Hospital waste-water treatment can also reduce the risk of pharmaceuticals being flushed out in the environment when rainwater overflows sewers, which wastewater treatment plants do not have an impact on

First author, year, coutry	Health care sector concerned	Intervention type / Aim	Description of intervention	Results
(Donahue et al., 2020)*** USA	Hospital and primary care	Replacing disposable with reusable material Reduce solid waste and supply chain GHG emissions related to the use of disposable vaginal specula	The study estimated the environmental impact of replacing the 5,875 disposable acrylic vaginal specula used during one year in Michigan Medicine hospitals and clinics by two types of reusable stainless steel vaginal specula (grade 304 and grade 316).	- The use of disposable vaginal specula is associated with increased GHG emissions, without clinical advantage - Compared to the disposable speculum, the grade 304 speculum produces less life cycle CO_2e after two exams completed, and the grade 316 speculum after three exams - After 500 exams, the emissions would have been: . 107.52 $kgCO_2e$ for Speculum 316 . 101.31 $kgCO_2e$ for Speculum 304 . 438.55 $kgCO_2e$ for the disposable speculum - Had reusable specula been used (100 uses on average per specula) instead of the 5,875 disposable specula used during one year, GHG emissions could have been reduced by up to 75%, and end-life solid waste by 64 kg
(Duane et al., 2014)*** Scotland	Dental	Health system-level approach Reduce GHG emissions from dental care provision resulting from patient travel and energy use	Different dental care reconfigurations: A) Assuming all patients travel to their closest site (no other changes) B) Geographically reconfiguring over-utilized sites (thus retaining all sites) C) Closing sites with less than 40% utilization and geographically reconfiguring remaining sites D) Rationalizing services i.e. closing sites with less than 60% utilization even after reconfiguration, and reconfiguring remaining sites. These interventions were simulated using a tool to help health care managers balance economic viability, patient outcomes and climate change mitigation, through finding a "best-fit" solution to enhance indicators for carbon reduction, patient travel, resource utilization and costs.	Compared to BAU, which generates 317 tCO_2e, the scenarios had the following effects: - Scenario A rendered one clinic redundant and reduced patient travel from 1,544 km to 523 km and GHG emissions to 107 tCO_2e - Scenario B) reduced GHG emissions and patient travel to the same extent as Scenario A, but reduced energy consumption to 177,740 kWH (182,584 kWh at baseline) - Scenario C) GHG emissions were reduced to 112 tCO_2e through lower patient travel and energy consumption - Scenario D) GHG emissions were reduced to 158 tCO_2e by halving patient travel
(Dullet et al., 2017)** USA	Hospital (outpatient)	Telemedicine Reduce CO_2 and NO_x emissions related distances travelled by patients	The University of California Davis Health System's telemedicine program providing interactive, video-based consultations at 157 telemedicine sites, was compared to in-person care. The program primarily provides subspecialty consultations in more than 30 clinical specialties normally provided face-to-face at more than 120 locations across California.	Between 1996 and 2013, the telemedicine visits resulted in total travel distance savings of 5,345,602 miles and emission savings of 1,969 tCO_2, 50 tCO, 3.7 tNO_x, and 5.5 t of volatile organic compounds.

First author, year, coutry	Health care sector concerned	Intervention type Aim	Description of intervention	Results
(Fordham et al., 2020)*** UK	Hospital and primary care	Disease prevention (primary/secondary) Reduce all relevant CO_2e emissions associated with management of type 2 diabetes, including emissions associated with complications arising from treatment	Good and poor management of type 2 diabetes-related complications were compared represented in three scenarios: 1) Untreated persons with diabetes 2) Keeping blood glucose at 7% or 53 mmol/mol 3) Reducing the blood glucose level by 1% These scenarios were simulated for two groups of people: A) Persons with diabetes on first-line medical therapy, i.e., diabetes not adequately controlled by diet and exercise, treated with one antidiabetic drug B) Persons with diabetes on third-line therapy, i.e., diabetes uncontrolled, requiring triple therapy	1) Compared to untreated people, per-patient reductions in CO_2e emissions were observed for scenarios 2 and 3: 2) a 18% reduction (1,546 $kgCO_2e$/patient) in emissions in Group A and a 13% reduction (937 $kgCO_2e$/patient) in emissions in Group B. Emission related to renal complications were reduced by 54% (955 kgCO2e/patient) in Group A and by 34% (504 $kgCO_2e$/patient) in Group B 3) a 12% reduction in emissions (1,049 $kgCO_2e$/patient) in Group A and a 9% reduction (655 $kgCO_2e$/patient) in emissions in Group B. Emission related to renal complications were reduced by 40% (708 kgCO2e/patient) in Group A and by 27% (396 kgCO2e/patient) in Group B Conclusion: Good diabetes management results in the least carbon intensive care by decreasing the risk of renal complications, and ophthalmological and cardiovascular diseases
(Forner et al., 2021)** Canada	Hospital	Proximal care Reduce the carbon footprint associated with patient travel	Proximal care in the form of an oncological head and neck surgical outreach clinic was compared to care at a regional cancer center for 113 patients	- The median distance from patients' homes to the surgery outreach clinic was 29 km compared to 327 km to the regional center: a difference of 317.5 km - The median observed low estimate of emission for travelling to the outreach clinic was 10,411 gCO_2 and the expected estimate of travelling to the regional center instead was 130,082 gCO_2; a difference between 117,495 and 143,571 gCO_2 for a three-month period (107 persons) - On an annual basis, total mean carbon emission savings for providing care at the outreach clinic would reach 46,998,160 gCO_2
(Gadegaard and Penny, 2015)**** The UK	Hospital and primary care	Disease prevention (secondary/tertiary) Reduce all relevant CO_2e emissions associated with management of type 2 diabetes, including emissions associated with complications arising from treatment	Good and poor management of type 2 diabetes in the "typical" diabetes patient (whose care begins in 2015) and 17 possible complications were compared: 1) Good management, considered as maintaining a glycated hemoglobin level, HbA1c, of 6.5% for the lifetime of the patient 2) Poor management, considered as maintaining a glycated hemoglobin level, HbA1c, of 8.4% for the lifetime of the patient	1) Good management resulted in 1,740 $kgCO_2e$ for the lifetime of a patient, or 144 $kgCO_2e$/year per patient 2) Poor management resulted in 1,787 $kgCO_2e$ for the lifetime of a patient, or 155 $kgCO_2e$/year per patient - Good management has a 7% lower annual GHG impact compared to poor management, and a 3% lower GHG impact in total for the lifetime of one patient, despite their longer lifetime - Extrapolated to 5 million diabetes patients in the UK, good management could reduce GHG emissions by 720,000 tCO_2e per year, whereas poor management could increase emissions by 56 tCO_2e per year - The main contributor to the emissions related to diabetes management come from pharmaceutical consumption, patient travel and inpatient admissions - Inpatient admissions are the main contributor to the elevated emissions from poor diabetes management

First author, year, coutry	Health care sector concerned	Intervention type Aim	Description of intervention	Results
(Gatenby, 2011)** England	Hospital (inpatient and outpatient)	Prescription practices (less carbon-intensive treatments) Reduce carbon emissions related to treatment of gastro-esophageal reflux	Two treatment options for gastro-esophageal reflux disease were compared based on observational data: 1) Medical treatment with pharmaceuticals only (n=164) 2) Surgical treatment with laparoscopic surgery (n=154)	- Short-term CO_2 emissions were lower for medication-only treatment compared to surgery, for instance: outpatient appointments (22.6 vs 34.6 kgCO_2/year), day care (41.4 vs 92.6 kgCO_2/year), inpatient care (14.6 vs 21.9 kgCO_2/year), unplanned surgery (68.8 vs 0 kgCO_2/year) and medications (100.2 vs 30.8 kgCO_2/year) - Surgery became more carbon efficient than medicine-only treatment 9 years after surgery - If the failure rate remains low for surgery, and life expectancy remains around 40 years, anti-reflux surgery is a viable less carbon-intensive option for treatment of reflux
(Grimmond and Reiner, 2012)** USA	Hospital	Replacing disposable with reusable material Reduce the CO_2e emissions and solid waste related to the use of sharps-containers	Replacing all disposable sharps-containers in a hospital with reusable sharps containers certified for 500 uses	- With reusable sharps containers, the hospital reduced the sharps management-related global warming potential (GWP) by 83.5%, or 127 tCO_2e, and diverted 31 tonnes of plastic and 5 tonnes of cardboard from being sent to landfills - Although sharps containers only represent a fraction of total hospital GWP, replacing disposable with reusable containers in all hospitals in the USA could reduce emissions from 100,000 tCO_2e to 64,000 tCO_2e annually
(Hardy et al., 2022)**** England	Hospital	Green protocols/ practices/ procedures and behavioral change Reduce the energy consumption caused by dialysis machines	A new strategy for using dialysis machines was compared to BAU where machines are disinfected 3 times per 24 hours and kept on between patients. The strategy included two procedure changes: 1) Reducing the number of disinfections of dialysis machines to one disinfection per 24 hours, and replacing the other two disinfections with a rinsing process, and 2) Placing dialysis machines in standby mode after the initial priming process whilst waiting to connect patients to the machine	In total, the changed practices could result in a reduction of 1,905 kgCO_2e per year in total from: - Electricity savings of 5,741 KWh/year representing 1,672 kgCO_2e/year - Water savings of 114.2 m^3/year representing 42 kgCO_2e/year - Acid savings of 3,509 l/year representing 190 kgCO_2e/year
(Holmner et al., 2014)** Sweden	Hospital and specialist rehabilitation	Telemedicine Reduce CO_2e emissions and km travelled related to patient travel	A telemedicine service providing video consultations and telerehabilitation sessions at patients' homes or at the nearest local health care center instead of face-to-face consultations at two clinics (one hand and plastic surgery clinic and one speech clinic) during 2012 and 2005-2006 respectively	- Teleconsultations helped to avoid 82,310 km of transportation per year and 154,842 km of transportation for two years for the two clinics respectively, compared to face-to-face consultations at the clinics - For the hand and plastic surgery clinic, the annual emissions were 602 kgCO_2e for 238 teleconsultations, which represents 2.8% of the emission from face-to-face consultations at most - Similar results were estimated for the speech clinic, which had 481 teleconsultations - Modelling using two different estimates (Lenzen vs Leduc estimates) suggest that telerehabilitation is effective once the travel distance is at least 3.6 km or 7.2 km by car, respectively, for a one-hour consultation

First author, year, coutry	Health care sector concerned	Intervention type / Aim	Description of intervention	Results
(Hu et al., 2021)*** England	Hospital (surgery)	Green protocols/ practices/ procedures Reduce GHG emissions from anesthetic gases	Different practices related to the use of anesthetic gases: 1) Different choices of anesthetic gases (Sevoflurane, Isoflurane, Desflurane) 2) Use of vapor-capturing technology that is capable of recycling and reusing anesthetic gases The scenarios were combined with older (A) versus newer (B) manufacturing processes	1) Sevoflurane and isoflurane have a smaller life-cycle carbon footprint than desflurane regardless of practice used 2) Vapor-capturing technology can recycle 70% of the anesthetic gas once in its life cycle - Newer and more efficient manufacturing processes (B) had a smaller carbon footprint compared to the older manufacturing method (A) for all three anesthetic gases - If Propofol was manufactured using renewable energy (halving its carbon footprint) it would be the least carbon intensive anesthetic even if vapor-capturing technology was used nationally
(Masino et al., 2010)** Canada	Hospital	Telemedicine Reduce GHG emissions related to patient travel to specialist consultations at hospitals	840 teleconsultations held at 88 different telemedicine sites instead of at three different hospitals during a 6-month period	Compared to the emissions that would have occurred if the patients visited the specialist at the hospital site: - An estimated 757,234 km of travel and 185,159 $kgCO_2e$ were avoided from vehicle emissions - Approximately 360,444 g of other air pollutants were avoided - The emissions produced by energy consumption for the videoconference units were estimated to 42 $kgCO_2e$
(Maughan et al., 2016)** England	Primary and secondary care (mental health)	Prescription practices (treatment for mitigating resource-intensive care) Reduce CO_2e from secondary care provision to mental health patients	A social prescribing program, "Connect", for mental health patients, consisting of community projects that provide psychosocial and other kinds of support, such as self-help and self-management resources, educational and recreational facilities, as well as leisure, fitness, and health activities. 30 patients used the service for 18 months and were compared to 29 controls.	- Compared to patients receiving routine care from general practitioners (GP), patients in the Connect program had less health care use, although the results were not statistically significant. - Both groups reduced their carbon footprint. The Connect group had a larger reduction related to secondary care compared to the control group: the six-month average carbon reduction per patient achieved by month 12-18 was 53 $kgCO_2e$, compared to a reduction of 7 $kgCO_2e$ in the control group (a difference of 46 $kgCO_2e$/patient/6 months). - However, the difference between groups in psychotropic medication costs and number of GP appointments was small - The Connect service resulted in an average saving related to secondary care of 39 $kgCO_2e$ per patient per six months. However, when the carbon footprint of the Connect service itself was taken into account (87 $kgCO_2e$ per patient per six months), the Connect service was associated with an increase in the carbon footprint of 48 $kgCO_2e$ per patient per six months. - The Connect service has lower carbon emissions compared to cognitive behavioral therapy and antidepressants

First author, year, coutry	Health care sector concerned	Intervention type Aim	Description of intervention	Results
(McGain and Naylor, 2014)* International	Hospital	Multiple areas/any intervention in the hospital sector Reduce the environmental impact in the hospital sector	Sustainable architecture, telemedicine, water saving interventions, replacing reusable with disposable equipment, recycling, and avoid creating waste	- Water saving interventions can achieve 10–25% reductions through, for instance, auditing water use through datalogging meters, checking for leaks, applying flow restrictors on hand basins and showers, installing dual-flush toilets, reclaiming water from dialysis units and sterilizers and replacing water use with other disinfectants for hand scrub - Improved telemedicine can reduce travel demand. Some clinical innovations, however, may increase patient travel due to high centralization. Large reductions in car transport to hospitals are possible with improved public transport services, car-pooling and encouraging active transport - Reusable medical devices have shown to have lower environmental effects (CO_2 emissions, water use, land and water pollution) compared to single-use variants - Environmental benefits of improving waste management processes are generally greater when moving progressively through discarding, recycling, reuse, reduction and avoiding creating waste in the first place - Avoidance of unnecessary hospital procedures is likely to have a greater effect than all current hospital recycling initiatives
(McGain et al., 2016)*** Australia	Hospital	Green protocols/ practices/ procedures and behavioral change Reduce energy consumption related to steam sterilization machines	An electricity saving policy implementing new routines in one hospital, increasing the time that their four steam sterilizer machines are switched off (at certain hours when they would normally be idle): 1) Switching off sterilizers when not in use 2) Switching off one sterilizer at 10 am and a second sterilizer at midnight	1) To switch off sterilizers when not in use would reduce emissions by approximately 78.7 tCO_2 per year; electricity by 26% and water use by 13% compared to BAU 2) To switch off one sterilizer at 10 am and a second sterilizer at midnight would reduce emissions by ~35.8 tCO_2 compared to BAU
(McGain et al., 2017)*** Australia	Hospital (surgery)	Replacing disposable with reusable material Reduce the CO_2e emissions, water use, impact on aquatic environments and human toxicity related to the use of anesthetic equipment	Four scenarios were modelled and compared to the observed use of anesthetic equipment in one Australian hospital: 1) Current (observed) practice using reusable anesthetic circuits, face masks, laryngeal mask airways, and direct and video laryngoscope blades and handles 2) Using single-use anesthetic circuits, masks, laryngeal mask airways, and direct laryngoscope blades, and keeping reusable direct laryngoscope handles and video laryngoscopes 3) Replacing all reusable with single-use anesthetic equipment 4) Replacing only reusable face masks with single-use masks 5) Replacing only reusable direct laryngoscope blades with single-use blades - The observed scenario was also compared to two simulated scenarios where the energy-mix of other geographic locations were applied (USA and Europe)	1) The observed practice (5,575 $kgCO_2e$ per year) had a 9% higher carbon impact compared to Scenario 2. 86% of emissions came from washer electricity, 7% from H_2O_2 sterilizer electricity, and 7% from other processes 2) Scenario 2 would have generated 5,095 $kgCO_2e$ per year, coming from purchasing 9,900 single-use face masks (52%) and 4,500 single-use laryngoscope blades (27%), and other items (21%) 3) Scenario 3 would have generated 5,775 $kgCO_2e$ per year 4) Emissions for shifting to single-use face masks only would have been higher (6,556 $kgCO_2e$) compared to scenarios 1-3, due to the remaining need for 365 washer loads 5) Emissions for shifting to single-use laryngoscope blades only would have been higher (6,763 $kgCO_2e$) compared to scenarios 1-4, due to the remaining need for 550 washer loads - Had the hospital been provided with the energy-mix of Europe or the USA, CO_2e emissions would have been 84% and 48% lower respectively for the observed scenario, mainly due to the less polluting energy source-mixes in Europe and the USA - The impact on aquatic environments and human toxicity was low due to the thorough water and waste treatment in Victoria, Australia

First author, year, coutry	Health care sector concerned	Intervention type Aim	Description of intervention	Results
(McGain et al., 2021)** Australia	Hospital (surgery)	Green protocols/ practices/ procedures Reduce the CO_2e emissions related to anesthetic procedures	Three different observed anesthetic protocols with related use of materials, gases, drugs, electricity for patient warming and anesthetic machines, during total knee replacement surgery were compared: 1) General anesthesia (Sevoflurane or Propofol) (9 patients) 2) Spinal anesthesia (10 patients) 3) General and spinal combined (10 patients)	The carbon footprint of the three protocols for total knee replacement were similar: 1) 14.9 $kgCO_2e$, 2) 16.9 $kgCO_2e$, and 3) 18.5 $kgCO_2e$ - Single-use equipment, electricity for the patient warmer, and pharmaceuticals were major sources of carbon dioxide equivalent emissions across all procedures - Sevoflurane was a significant source of emissions of both general anesthesia (35% of emissions) and combined anesthesia (19% of emissions) - Washing and sterilizing reusable items contributed to the emissions of both spinal (29% of emissions) and combined anesthesia (24% of emissions) - Oxygen use was an important contributor to the carbon footprint of spinal anesthesia (18% of emissions)
(Meier et al., 2021)** Germany	All sectors/ health care system (food service)	Food waste management scheme Reduce food-related waste in hospitals delivered by catering companies	A food waste management scheme was implemented in two catering companies providing food in the health care sector, consisting of four steps: 1) Waste assessment and monitoring for 4-6 weeks 2) Hotspot identification 3) Measures to reduce food waste (such as menu plans) 4) Reassessment of waste	- Compared to before the intervention, the management plan resulted in a reduction in food waste in the health care sectors catered by ~17% overall: 2% reduction for breakfast, 15% reduction for supper and 18% for lunch - When adjusting for menu-plans: - Food waste was reduced by 3.2 t (company 1) and 0.3 t (company 2) - GHG emissions were reduced by 9.5 tCO_2e (company 1) and 0.8 tCO_2e (company 2) - Water use was reduced by 127.3 m^3 (company 1) and 13.3 m^3 (company 2) - Land use was reduced by 6,387 m^2 (company 1) and 577 m^2 (company 2)

First author, year, coutry	Health care sector concerned	Intervention type Aim	Description of intervention	Results
(NHS England, 2020)**** England	All sectors/ health care system	Health system-level approach Reach net-zero emissions in the NHS from supply-chain emissions, transportation, hospital and primary care facilities and anesthetic gases and inhalers	Estimations (mathematical modelling) of future long-term impact of multiple NHS climate interventions targeting several areas: - Real estate (e.g. on-site generation of renewable energy) - Travel and transport (e.g. electrification of patient and NHS vehicles and disease prevention) - Supply-chain of goods and services (e.g. reducing use of disposable products) Medications (e.g. switch to low-carbon inhalers)	Annual supply-chain emissions, which need to be reduced by 16,531 $ktCO_2e$ for meeting the net-zero goal, can be reduced by: - Making pharmaceutical (-4,203 $ktCO_2e$) and non-pharmaceutical (-4,458 $ktCO_2e$) suppliers meet the NHS environmental requirements - Process and product innovation (-1,488 $ktCO_2e$) - Other interventions, such as reducing single-use materials, more plant-based diets and reusing devices have small individual impacts, but are important for meeting the targets - Transportation-related emissions require an annual reduction of 3,402 $ktCO_2e$, which could be achieved through: - Electrification of patient and visitor vehicles (-1,636 $ktCO_2e$) - National vehicle efficiency improvements (-1,463 $ktCO_2e$) - Active travel by staff, patients and visitors (-461 $ktCO_2e$) - Electrifying the NHS vehicles (-1,022 $ktCO_2e$) - Digital care pathway redesign (-159 $ktCO_2e$) - Prevention and reduced health inequalities (-62 $ktCO_2e$) - Emissions related to hospital facilities need to be reduced annually by 2,351 $ktCO_2e$, which can be done by: - Interventions targeting on-site generation of renewable energy and heat (-580 $ktCO_2e$, e.g. installing solar power) - Building use optimization (-572 $ktCO_2e$, e.g. energy monitoring) - Upgrading buildings (-473 $ktCO_2e$, e.g. new heating systems) - National electricity decarbonization (-342 $ktCO_2e$) - Other hospital improvements (-205 $ktCO_2e$) - Emissions from inhalers and anesthetic gases (1,286 $ktCO_2e$) can be mitigated through: - Reducing their use (-403 $ktCO_2e$ for metered-dose inhalers (MDIs) and -195 $ktCO_2e$ for anesthetic gases) - Shifting towards low-carbon inhalers (-374 $ktCO_2e$) - Capturing and reusing anesthetic gases (-187 $ktCO_2e$) - Optimizing flow rates (-39 $ktCO_2e$) - Primary care facilities require an annual reduction of 167 $ktCO_2e$, through: - Upgrading buildings (-59 $ktCO_2e$), - National electricity decarbonization (-47 $ktCO_2e$) - Optimizing building use (-34 $ktCO_2e$) - New buildings (-11 $ktCO_2e$) - On-site generation of renewable energy and heat (-7 $ktCO_2e$)

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(Nicolet et al., 2022)*** Swizerland	Primary care	Health system-level approach Reduce CO_2e caused by primary care consultations and practices	The emissions from 10 different primary care sites were collected to identify their most and least polluting activities. The intervention was illustrated in a theoretical primary care practice adopting all the least polluting activities, which required adaptations in the following domains: - Medical practice (medical and non-medical equipment and consumables, solid waste, staff transportation, laboratory analyses, electricity use) - Patient transport - External activities (courier transportation and laboratory analyses)	- A practice that would implement all the most carbon efficient characteristics of the ten practices studied, would produce ten times less CO_2e than a practice with the least efficient characteristics - The largest contributors to the carbon footprint of primary care were not directly linked to medical activities: staff, patient and courier transport (more than half of emissions) - Major reductions are possible without affecting quality of care, for instance through a dense local network of primary care providers, an effective public transport network, and on-site laboratory testing - Optimizing heating and the occupancy of facilities, e.g. providing many consultations at the same time, can significantly reduce a practice's environmental footprint
(Oliveira et al., 2013)** Portugal	Hospital (outpatient)	Telemedicine Reduce emissions related to patient travel	Face-to-face consultations were compared with a telemedicine service: outpatient appointments using video-conferencing equipment to connect patients visiting their GP to remotely located specialists at hospital between 2004 and 2011.	- Patients travelled on average 47 km (one way) to face-to-face consultations at the hospital and 5.9 km (one way) to teleconsultations - 39% of teleconsultation patients walked to the consultation - The total distance covered by teleconsultation patients was <20% of the distance travelled by face-to-face patients - Without teleconsultations, patients would have travelled 2,313,819 km and generated 455 tCO_2e (22 $kgCO_2e$/patient) more in total - Teleconsultations reduced travel-related emissions by 95%
(Pollard et al., 2013)*** England	Secondary health care	Health system-level approach Reduce CO_2e emissions from secondary health care provision	Different health system reconfigurations were compared for the financial year 2009/2010: 1a) Expanding inpatient coverage where currently not available 1b) Rationalizing outpatient and diagnostic services (closure of small sites) 2) Reducing the temperature of hot water in wards 3) Optimizing the scheduling of OR use (improved efficiency) These interventions were simulated using a tool to help health care managers balance economic viability, patient outcomes and climate change mitigation.	The estimated emissions from secondary health care were 5,787 tCO_2e (with patient travel adding 2,215 tCO_2e) for the time period. 1a) Expanding inpatient coverage where currently not available had the highest operational carbon footprint, reflecting the additional catchment area 1b) Closing selected sites would have reduced the carbon footprint by 4% (261 tCO_2e), but with a larger increase (35%) in patient transport emissions 2) Reducing hot water temperatures by 5 °C would lower the footprint by 0.7% (44 tCO_2e), but with an increased risk of bacterial proliferation 3) Improving theater usage would lower the footprint by 0.08% (5 tCO_2e)
(Pradere et al., 2022)* International	Hospital	Multiple areas/ any intervention in the hospital sector Reduce material and non-material resource waste from hospital activities	Any intervention reported in the literature, such as waste reduction by segregation, recycling, reuse, reprocessing, sterilization, anesthetic gas management and energy use	Quantitative analysis was not possible due to the lack of homogeneous data. However, the review identified five climate-smart actions: 1) waste reduction by segregation 2) waste reduction by recycling, reuse, and reprocessing 3) sterilization 4) anesthetic gas management 5) improvement of energy use/reduce energy consumption (especially in the OR) Staff education and awareness was found to have an important impact on waste reduction

First author, year, coutry	Health care sector concerned	Intervention type Aim	Description of intervention	Results
(Purohit et al., 2021)* International	Hospital and primary care	Telemedicine Reduce emissions related to patient travel	Any telemedicine services reported in the literature	- Studies unanimously report that telemedicine reduces the carbon footprint of health care, primarily by reducing transport-related emissions - The CO_2e savings for different telemedicine services range between 0.70–372 kgCO_2e per consultation - The carbon emissions produced from the use of the telemedicine systems are low compared to the emissions saved from travel - Videoconferencing has a higher energy consumption compared with telephone consultations - More specialized care (serving wider geographic areas) has greater reductions in travel-related emissions from teleservices - Double consulting (a teleconsultation followed by a face-to-face consultation) increases the net carbon emission of telemedicine services
(Rizan et al., 2021c)** England	Hospital	Solid waste management/ recycling Reduce the CO_2e emissions related to how waste is disposed of	Three different waste streams/disposal processes in one NHS organization were compared: 1) Low temperature incineration with prior decontamination via autoclave steam sterilization where necessary 2) High temperature incineration, as recommended for clinical, anatomical and contaminated waste 3) Recycling (for domestic and dry recyclable waste)	1) Low temperature incineration had the second lowest footprint (172-249 kgCO_2e/t waste). When the waste was also decontaminated using an autoclave prior to incineration, the carbon footprint increased to 569 kgCO_2e 2) High temperature incineration had the highest footprint (1,074 kgCO_2e/t waste) 3) Recycling had the lowest footprint (21-65 kgCO_2e per t waste) Careful segregation of waste streams is required to prevent unnecessary carbon burdens; the choice of waste stream can have a 50-fold impact on the waste-related carbon footprint
(Rizan et al., 2021b)*** UK	Hospital	Green protocols/ practices/ procedures Reduce the CO_2e emissions and related to the sterilization of surgical instruments	Different processes for instrument decontamination and packaging at a typical sterilization unit at one hospital, combining: - Single packaging or set packaging - Rigid containers, tray wraps or flexible pouches - Reusable or disposable wraps - Washers or steam sterilizers - Decontamination loads and number of instruments in set - Different energy sources (country models)	The carbon footprints were higher when instruments were wrapped individually compared to when packed in sets: - 77 gCO_2e/instrument in aluminium containers (2,252 g/set) - 66 gCO_2e/instrument in tray wraps (1,918 g/set) - 189 gCO_2e/individually wrapped instrument - If <11 instruments are required for an operation, individually wrapped items are preferable to opening another set - The footprint of single-use packaging is dependent on its disposal: - High-temperature incineration of waste increased the carbon footprint of single-use packaging by 33–55% - Recycling reduced it by 6–10% - The carbon footprint of decontaminating and packaging instruments can be reduced through maximizing the loading of decontamination machines and processing instruments in sets in tray wraps: - By up to 42% compared to packing them in tray wraps and aluminium containers - By up to 76% compared to individually wrapped instruments The absolute carbon footprint depends on the energy source used, but without impact on which process is most optimal

First author, year, coutry	Health care sector concerned	Intervention type Aim	Description of intervention	Results
(Rizan et al., 2021a)*** England	All sectors (social and health care)	Replacing disposable with reusable material Reduce the carbon footprint related to the use of disposable PPE during the Covid-19 pandemic	Five different strategies for procurement, reduction, reuse and recycling of personal protective equipment (PPE) within all NHS health and social care services were modelled: 1) reducing supply-chain emissions by domestic manufacturing of PPE 2) eliminating glove use (by hand washing) 3) reusing gowns and face shields 4) maximal recycling of all equipment and their components 5) implementing all these interventions Scenario modelling was used to determine the effect that each strategy could have had during the first six months of the COVID-19 pandemic	Compared to the observed scenario during the six first months of Covid-19, the carbon footprint could have been reduced by: 1) 12% with domestic manufacturing of PPE 2) 45% by eliminating gloves by hand washing 3) 10% by reusing gowns and face shields 4) 35% with maximal recycling 5) 75% with a combination of all strategies, additionally saving 183 DALYS
(Rizan et al., 2022)*** England	Hospital (surgery)	Replacing disposable with reusable material Reduce the CO_2e emissions related to the use of disposable surgical scissors	Three different scenarios where surgical scissors are replaced or repaired: 1) Reusable surgical scissors are used 40 times and then replaced with new reusable scissors 2) Reusable surgical scissors are used 40 times and then repaired off-site 3) Reusable surgical scissors are used 40 times and then repaired on-site	1) The carbon footprint of reusable scissors was 70.3 gCO_2e per use, when replaced after 40 uses 2) If these scissors were repaired off-site instead every 40 uses, the footprint would have been 57.0 gCO_2e/use (19% reduction) 3) If these scissors were repaired on-site instead every 40 uses, the footprint would have been 56.3 gCO_2e/use (20% reduction) - The reparation of scissors could reduce the footprint stemming from raw material extraction, manufacture, packaging, and transportation of new scissors by 90% - Increasing the number of uses from 40 to 400 before disposal reduced the carbon footprint by one fifth, in addition - Reductions were estimated to impact 18 environmental categories, inc. global warming, ozone layer depletion, fine particulate matter (PM), freshwater and soil damage, human carcinogenicity, resource scarcity and water consumption.
(Roschnik et al., 2017)**** England	All sectors/ health care system	Health system-level approach Reduce the overall environmental footprint, energy and water use and non-recycled waste within the NHS	Implementation of the NHS sustainable Development Unit, created by the NHS in 2008, which has largely focused on five main areas: 1) Governance (setting up national advisory boards, local networks, developing sustainable development management plans etc.) 2) Stakeholder engagement (involvement of health workforce, management, local leaders, general public and industry) 3) Carbon measurement and reduction (including goal development) 4) Building resilience and adaptation to climate change (including risk assessments) 5) System support (developing metrics, reviewing progress, carbon footprint changes and uptake of processes, research, development of sector and industry guidelines, and workforce support through factsheets, guidelines, climate awards and communication campaigns)	- Between 2007 and 2015, the NHS reduced its overall footprint by 11% (from 25.7 to 22.8 $MtCO_2e$), while activity levels rose by 18% - There was a 4.3% decrease in buildings' energy carbon footprint between 2007/2008 (3.3 $MtCO_2e$) and 2014/2015 (3.2 $MtCO_2e$) - 38% of the NHS organizations have reduced their building energy carbon footprint by more than 10% since 2007/2008 - There was a 4.2% reduction in water consumption between 2007/2008 (36 m^3) and 2014/2015 (35 m^3) within the NHS - Non-recycled waste decreased by one third between 2007/2008 (0.3 million t) and 2014/2015 (0.2 million t)

First author, year, coutry	Health care sector concerned	Intervention type Aim	Description of intervention	Results
(Roschnik et al., 2019)*** England	All sectors/ health care system	Health system-level approach Reduce GHG and water use in the NHS overall	The Sustainable Development Unit, created by the NHS in 2008, and the environmental development plan for meeting the government's commitments under the UK Climate Change Act. Since its implementation, the overall progress in reducing the carbon footprint o the NHS has regularly been assessed.	- Between 2007 (before implementation) and 2017, the GHG emissions were reduced by 18,5% - Between 2007 and 2017, the carbon intensity (emissions per health care act) decreased by 35% - Between 2010 and 2017, the water consumption in the NHS decreased by 21% - Reductions (around 19%) were also achieved for energy consumption, business travel and use of medical gases between 2007 and 2017
(Sand Lindskog and Bjuhr Männer, 2019)*** Sweden	Hospital (surgery)	Green protocols/ practices/ procedures Reduce solid waste generation from procurement for surgeries	"Best procurement practice" involving a waste audit and intervention protocol identifying most and least waste generating practices observed, such as: - Procurement standards - Environmental product requirements in place - Packaging practices The waste from actual observed practices were compared to a theoretical combination of the best practices observed.	- Waste produced from hip surgery varied between 5,0 to 6,6 kg per surgical operation - If all hospitals used the lowest level of materials observed, the amount of waste generated would be reduced to 4,5 kg per operation - With further changes in procedures, procurement and product requirements, waste could be reduced to 3,9 kg - For instance, not packing more than the single-use material necessary for one surgery could have reduced sterile packaging waste by 96% per year (or -0,7 kg per surgery)
(Shift et al., 2021)**** France	All sectors/ health care system	Health system-level approach Decarbonize the health care system	The impact of interventions, such as procurement strategies, active transportation, disease prevention, policy etc., necessary to reach France's climate goals are estimated through modelling.	- 99% (-7.1 $MtCO_2e$) of the emissions caused by health-care related transportation in France could be reduced through replacing fossil fueled vehicles with electric vehicles, promoting and facilitating active transportation, carpooling and the use of collective transportation, encouraging personnel to telework, prioritizing e-learning and local conferences for professional training, and expanding telemedicine - 75% (-4.3 $MtCO_2e$) of emissions stemming from the heath care-building sector in France could be reduced through interventions such as better insulation, shift from fossil-fueled heating to low-carbon energy sources, using biomaterials for new constructions, refer to an "energy referent/expert" in health care facilities and train health care staff in the matter of sustainable consumption habits - 50% (-0.08 $MtCO_2e$) of emissions stemming from anesthetic gases in France could be reduced by prohibiting the use of anesthetics with high environmental impact - 40% (-1.1 $MtCO_2e$) of food-related emissions in France could be reduced through better food quality, favorizing local food production as well as replacing a part of animal proteins with vegetal proteins - 1% emissions related to material waste in France could be reduced by improving recycling of single-use materials, promoting the wider use of reusable medical equipment and other domestically produced materials, reducing the generation of hazardous waste, and implementing monitoring to make sure that biowaste is systematically composted - Prevention of care needs and reducing unnecessary care acts and adverse medical effects are also necessary to attain climate goals

First author, year, coutry	Health care sector concerned	Intervention type Aim	Description of intervention	Results
(Siu et al., 2017)* International	Hospital	Replacing disposable with reusable material Reduce the environmental impact and solid waste of the use of disposable instruments	Any intervention aiming to reduce the environmental impact of solid waste from disposable instruments by replacing them with reusable material	- Reusable instruments are more environmentally favorable than disposable instruments - For instance, disposable steel has an 80% higher negative environmental impact than disposable plastic and 99% higher negative impact compared to reusable steel - Few studies exist on the advantages of single-use instruments - The evidence suggests that it is necessary to limit use of disposal instruments, both from an economic and environmental perspective. - There is great variability between studies, demonstrating the complexity of comparing single-use and reusable instruments
(Tennison et al., 2021)*** England	All sectors/ health care system	Health system-level approach Reduce the carbon footprint of the NHS	The Sustainable Development Unit, created by the NHS in 2008, and the environmental development plan for meeting the government's commitments under the UK Climate Change Act, as well as other national-level governmental actions. Two of the major actions have been the decarbonization of the UK energy system (less reliance on coal and oil) and the phase-out of chlorofluorocarbon propellants in inhalers, and improved technology reducing supply chain emissions from pharmaceuticals, chemicals, and gases.	- Between 1990 and 2019, the carbon footprint of the NHS decreased approximately 26% (to 25 $MtCO_2e$), while the population of England increased by 17%, care provision doubled and health spending more than tripled in real terms - The carbon intensity of the NHS decreased by 37% for CO_2e per capita and 64% per finished inpatient admission episode - Engineering and sociotechnical interventions such as widespread insulation and upgrading of building envelopes, could reduce energy use by 40%, and electrification of buildings, grid decarbonization and on-site solar photovoltaics or wind generation can potentially reduce the carbon intensity of UK grid electricity to net-zero by 2050
(Thiel et al., 2018)*** USA	Hospital (surgery)	Green protocols/ practices/ procedures Reduce waste, GHG emissions from anesthetic gases and energy use laparoscopic hysterectomy	A Climate audit and intervention protocol for laparoscopic hysterectomies consisting of: - Recycling, reusing and sterilizing medical equipment and material - Replacing inhaled anesthetics with propofol - Reducing energy use during non-operatory time - Switching to low-carbon energy sources	- Compared to BAU, if the hospital performed all laparoscopic hysterectomies via the ideal combination of green interventions, they would reduce the carbon footprint of an average hysterectomy by 80% - Replacing desflurane with a less polluting option, such as sevoflurane, can reduce emissions by >25% per laparoscopy - Switching to propofol when clinically appropriate can reduce GHG emissions by 28% - Reuse of surgical instruments through reprocessing results in about 10% GHG reduction per case - Isolated material interventions, such as maximizing recycling, or using reusable gowns and drapes, resulted in GHG reductions of <5% per case - Minimizing material use and using reusable surgical instruments reduced GHG emissions by nearly 50% - Occupancy sensors in ORs reduced air turnover (when unused), reducing electricity consumption by one third annually per OR - Switching to renewable energy sources could reduce GHGs about 10% per hysterectomy - A combination of approaches is needed to yield significant reductions in GHG emissions per surgery

First author, year, coutry	Health care sector concerned	Intervention type Aim	Description of intervention	Results
(Thiel et al., 2021)*** USA	Hospital (food service)	Food and solid waste management/ recycling Reduce amount of waste sent to landfills and CO_2e emissions related to food and service ware	Two waste disposal scenarios were modelled for one hospital kitchen: 1) Ideal disposal where everything that can be recycled or composted are diverted from landfill 2) Most feasible disposal where recycling is increased, regular sorting is achieved, and composting is implemented according to the kitchen's setup	Compared to BAU (where 15% of total daily waste in the kitchen is recycled and where 294,466 $kgCO_2e$ per year is generated): 1) In an ideal scenario, the total waste to landfill could be reduced by 76% (of the weight) and GHG emissions by 90% 2) In a more feasible scenario, a 55% reduction in landfill waste (-205,245 kg waste/year) could be achieved, and GHG emissions could be reduced by 64% (-189,025 $kgCO_2e$/year)
(Wanegård and Fagerberg, 2019)** Sweden	Hospital (surgery)	Green protocols/ practices/ procedures Reduce CO_2e emissions in the hospital sector from all activities related to surgical units	Two surgical departments implemented the Climate friendly health and care (CLIRE) protocol consisting of 3 steps: 1) Climate audit: identification of emission sources and their magnitude related to the service (such as materials, energy use, transport, food products, water use and laundry) 2) Assessment of the domains to be prioritized in reduction efforts 3) Guided steps for reducing the emissions (for instance through replacing single-use with reusable materials, changing working protocols and patient flows, and reducing heating, lighting, and electricity use)	Compared to the before-scenario, implementing the protocol resulted in: - CO_2e reductions of up to 40% per patient - Emissions in the hand surgery department reduced from 1.1 to 0.7 $kgCO_2e$ per examination/rehabilitation visit, from 12.2 to 8.2 $kgCO_2e$ per surgical operation and from 25.7 to 15.2 $kgCO_2e$ per inpatient care episode - Emissions in the urology surgery department increased from 1.5 to 1.8 $kgCO_2e$ per examination visit, and decreased from 51.7 to 45.9 $kgCO_2e$ per surgical operation and from 41.7 to 37.8 $kgCO_2e$ per inpatient care episode - The number of patient trips to the urology department were reduced by 700 trips (equivalent of 7.5 tCO_2e) annually, by changing inpatient registration procedures and by using home visit nurses to a larger extent

Notes: *Peer-reviewed systematic review **Peer-reviewed observational study (implemented intervention) ***Peer-reviewed modelling or simulation study (theoretical intervention) ****Grey literature
Abbreviations: BAU: Business as usual, CO2: Carbon dioxide, CO2e: Carbon dioxide equivalents, DALY: Disability-adjusted life-years, GHG: Greenhouse gas, GWP: Global warming potential, NHS: National health system, NOx: Nitrogen Oxides, OR: Operating room, PEC: Predicted Environmental Concentration, PM: Particulate matter.

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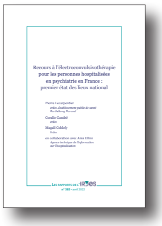

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The Environmental Sustainability of Health Care Systems

A literature review on the environmental footprint of health care systems and interventions aiming to reduce it: towards a framework for action for France

Global warming poses an increasing threat to health and health care systems. At the same time, health care systems have a significant effect on the environment and are major contributors to global warming. Nevertheless, the contribution of health care to global warming is largely overlooked in policy, and there is an urgent need to identify interventions that could reduce the environmental impact of health care systems and to develop strategies to improve their environmental sustainability.

In this report we present the results from two complementary literature reviews: the first provides an overview of the environmental impact of the main health care sectors and sources of pollution, and the second – a scoping review – identifies a representative sample of interventions used in high-income countries to reduce the environmental footprint of health care, and their estimated impact. We pooled the results from these two reviews to propose a holistic framework for action for improving the environmental sustainability of the health care system.

In all care sectors, numerous "green interventions" have been reported to successfully reduce the environmental impact of health care across a range of domains, such as reducing and recycling waste, shifting to less ozone-depleting anesthetic gases and green energy sources, but these remain insufficient unless accompanied by sustainability strategies transforming the way care is provided and consumed, assuring the pertinence of care, and attenuating care need for a more sustainable care consumption. Our framework identifies a set of concrete measures to be implemented simultaneously to reduce both direct and indirect causes of environmental impact in the health care sector in France.

La soutenabilité environnementale des systèmes de santé

Une revue de littérature sur l'empreinte écologique des systèmes de santé et les mesures visant à réduire son impact : vers un cadre d'action en France

Le réchauffement climatique constitue une menace majeure pour la santé des populations et les systèmes de santé. En même temps, les activités de soins ont des effets non négligeables sur l'environnement et contribuent au réchauffement climatique. Le rôle joué par les soins dans ce phénomène reste néanmoins largement sous-estimé dans les politiques publiques. Il est donc urgent d'identifier les mesures susceptibles de réduire l'impact environnemental du système de santé, et de développer des stratégies visant à garantir sa soutenabilité environnementale.

Ce rapport présente les résultats de deux revues de littérature complémentaires : la première propose un panorama des principales sources de pollution et des principaux domaines du système de santé qui contribuent à l'empreinte écologique ; la seconde identifie un échantillon représentatif des mesures mises en œuvre dans les pays industrialisés – et leur impact estimé – pour réduire l'empreinte écologique des activités de soins. A partir des résultats de ces deux revues de littérature, nous proposons un cadre d'action holistique visant à améliorer la soutenabilité environnementale du système de santé en France.

Dans tous les secteurs, il existe de nombreuses interventions « vertes » ayant été démontrées comme efficaces pour réduire l'empreinte écologique des soins, telles que la réduction et le recyclage des déchets, le passage à des anesthésiques moins polluants et à des sources d'énergie propres. Pour autant, celles-ci resteront insuffisantes tant qu'elles ne seront pas accompagnées de stratégies de soutenabilité visant à transformer la façon dont les soins sont dispensés et consommés, à assurer la pertinence des soins et à atténuer les besoins en santé pour soutenir une consommation plus durable. En ce sens, notre cadre d'action identifie, à travers des exemples concrets, divers types de mesures à mettre en œuvre simultanément afin de réduire les sources directes et indirectes de pollution dans le secteur de la santé.

Ce rapport, rédigé en anglais, propose une synthèse en français.

Haut Conseil pour l'avenir de l'assurance maladie

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