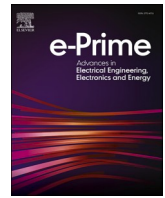


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## Potential for climate protection in hospitals

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### ABSTRACT

Achieving national and international climate protection targets is a major challenge for many stakeholders. An often overlooked sector in this context is the healthcare sector. This is particularly significant because hospitals play a crucial role in sustainability. On the one hand, climate change poses the greatest global health threat of the 21<sup>st</sup> century. Hospitals will inevitably face increasing challenges due to climate change, such as the emergence of new pathogens or if extreme heat exacerbates preexisting cardiovascular conditions, leading to more health complications. On the other hand, hospitals are energy-intensive and significantly contribute to climate change. In Germany, the healthcare sector accounts for 5.2 percent of CO<sub>2</sub> emissions, with hospitals being a major source. The need for energy-efficient modernization in hospitals is urgent, especially since they are part of our critical infrastructure. Ensuring their energy supply, even in crises, is vital for a resilient and independent energy system. Given the importance of climate protection in the healthcare sector, this article analyses which strategies hospitals should pursue to achieve climate protection targets and which measures should be prioritized. In addition, the analysis includes an estimation of the associated costs, providing a basis for understanding the financial implications of climate mitigation efforts in hospital settings. Through stakeholder workshops and a narrative literature review, we have identified 10 suitable climate protection measures for the hospital sector. Our initial cost analysis indicates that implementing these measures would require an investment of approximately 7.1 billion euros for the 315 hospitals in North Rhine-Westphalia.

### Introduction

From a global perspective, the greatest health threat of the 21st century is climate change [1–3]. Hospitals will inevitably have to increasingly deal with the consequences of climate change [4] when new pathogens from distant countries emerge, antimicrobial resistances further increase [5] or when elderly people, the chronically ill, children or other particularly affected people become dehydrated on hot days with unprecedented heat records, resulting in cardiovascular problems. This is because there are considerable risks to human health associated with extreme and prolonged periods of heat. A recent study by the Robert Koch Institute summarizes the results of numerous studies and makes it clear that high temperatures lead to an increased burden on the health system and that there is "a systematic link between heat events and increased mortality" [6].

In 2021 and 2022, extreme weather events have wreaked havoc on every continent, further increasing the pressure on health services already struggling with the impact of the COVID-19 pandemic. Flooding occurred not only in Australia, Brazil, China, Malaysia, Pakistan, South

Africa and South Sudan, but also in Europe. The floods in Germany in July 2021 devastated a number of communities. In the federal state of Rhineland-Palatinate, a total of 135 people lost their lives and 766 others were injured, some of them seriously. In many countries, including Italy and the UK, record temperatures were again measured in 2022, which had far-reaching consequences for agriculture and, of course, for the healthcare system. The current Lancet Countdown 2022 report concludes that the worsening effects of climate change are increasingly affecting the foundations of human health and well-being. According to the report, the global population will become even more vulnerable to health threats [7].

However, the healthcare sector also contributes significantly to the climate crisis as it is itself responsible for a considerable proportion of climate-damaging emissions [8]. With a high energy demand, many technical devices and numerous buildings as well as a large number of employees [9] the healthcare sector accounts for around 11% of Germany's gross domestic product. According to a study by Health Care Without Harm / ARUP, is responsible for 5.2% of Germany's total national CO<sub>2</sub> emissions [10], of which the management of hospitals

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accounts for a very large proportion. In this regard, scope 1 and 2 emissions contribute 15–50% of total emissions, while Scope 3 accounted for 50–75%, primarily from disposables, equipment, and pharmaceuticals. Staff travel and infrastructure contributed 10–15%, while water, waste, and patient travel had minimal impact [11]. 1 % of the global greenhouse gases caused by the healthcare sector come from anesthetic gases and metered dose inhalers [12] and could be significantly reduced with reasonable effort and without endangering the well-being of patients. The climate-friendly management of hospitals therefore offers considerable potential for achieving climate protection targets.

A unique challenge in Germany, the dual financing model of its healthcare system, impedes the full utilization of this potential. This model separates operating costs, covered by health insurance companies, from investment costs, which are the responsibility of the federal states. This creates a user-investor dilemma, as there is insufficient incentive to invest in cost-effective energy-saving measures. The resulting energy cost savings benefit health insurance companies, not the federal states. Because dual financing in the healthcare system separates investment costs from ongoing operating costs [13,14], hospitals have limited capacity to make substantial investments without external funding under the current regulatory framework. However, investments in energy efficiency and renewable energy are essential for long-term profitability [15]. Therefore, it is crucial that federal states provide hospitals with the necessary financial resources for energy-efficiency renovation projects, while adhering to de minimis regulations.

This paper aims to show how hospitals can change in line with their responsibilities and become part of the solution to what is currently the biggest transformation challenge. Hospitals can certainly be seen as a microcosm of society. Hospitals literally reflect everything that makes up the life of a society with regard to the challenge of climate protection: electricity and heat supply, mobility, nutrition, resource consumption and waste. This opens up the possibility of seeing hospitals as real-life laboratories of the imminent transformation process towards a climate-friendly and resource-light society. This paper is intended to provide an impetus to jointly develop solutions for climate protection and climate adaptation using the example of hospitals and to make it clear that a collaborative approach based on the whole institution approach is important for success.

The implementation of climate protection measures not only leads to reduced greenhouse gas emissions but is also associated with further co-benefits, like a higher quality of care and reduced occupational hazards from air pollution [3,16]. Furthermore, the current fossil fuel crisis, which has arisen against the backdrop of the war in Ukraine, highlights another aspect that underlines the urgency of action: vulnerability and security of supply [17]. The more independent the energy supply of our critical infrastructures (which undoubtedly include hospitals) is, the more securely they can be operated and the less vulnerable they are to external factors with high price increases. Countering this trend requires a plan that leads to an increase in energy efficiency in hospitals and to the shooting of locally available renewable energies. This crisis shows that every kilowatt hour of energy saved is not only a contribution to climate protection, but also a contribution to safety. Energy-saving measures also lead to savings in energy costs. This often requires investment, but even changes in behavior that are promoted through special campaigns can lead to savings. The energy saving potential (electricity and heat) of such behavior change strategies is estimated at 2 to 10 % based on implemented examples [18–20]. Although there is an effect of these measures and promoting a sustainable culture can support long-term behavioral shifts among staff and patients, it should be noted that many factors play a role in calculating the savings (continuity, attributability of the measure, calculation method). Overall, such campaigns must be repeated regularly, as old routines "grind in" again after a certain period of time. Experience shows that a maximum duration of effect of around two years can be assumed for behavioral and

organizational measures [21]. Although the climate protection effect of a campaign is difficult to estimate, it definitely has additional co-benefits [3]. Communicating environmental knowledge and creating environmental awareness are key elements in anchoring climate protection in people's minds, so that effects for climate protection are also achieved in the private sector. Studies show that the motivation to actively protect the climate is increased when a common goal is pursued. The close connection between health protection and climate protection in particular shows that the topics cannot be treated separately and that a common understanding is necessary. In addition, studies show that employee motivation and the identification with the employer increases. Another effect is that the "sense of unity" in the workforce is enhanced by joint projects in climate protection [22].

## Methods

In order to estimate the investment requirements, a multi-stage process was used to determine which areas of action can be assigned to which scopes by defining the system boundaries and sectoral targets. Based on this, a narrative review was conducted and a workshop was held to determine which climate protection measures are particularly effective for hospitals. Subsequently, by defining a typical model hospital, it was possible to determine which financial resources are required to manage hospitals in a significantly more climate-friendly way. While these methods can provide practice-oriented insights, we acknowledge that it does not offer causal certainty of randomized controlled trials (RCTs).

### *Defining the system boundaries and sectoral targets*

In order to implement climate protection at hospitals, it is first necessary to identify the relevant areas and determine the potential for reducing greenhouse gas emissions. In this regard, hospitals can be seen as real laboratories of the upcoming transformation process because of two reasons: firstly, other sectors are in similar situations to hospitals and face the same challenges, and secondly, a large part of the potential for reducing greenhouse gases lies outside the spatial boundaries of a hospital and can only be influenced to a limited extent by the measures taken by a hospital. It is therefore important to make clear which adjustments hospitals can make in order to make an appropriate contribution to climate protection.

We want to show in which scopes a hospital can actively pursue climate protection itself and where it can exert an indirect influence through its actions. For that reason, the system boundaries and sectoral targets are defined first. A proven method (which is also used e.g. in [8, 23]) is the distinction between the following three areas when determining a greenhouse gas balance of hospitals:

**Scope 1:** This area includes emissions that emanate directly from the facilities and their vehicles. These are, for example, gas-fired heating systems and fuel-powered company vehicles.

**Scope 2:** These include indirect emissions from purchased energy sources such as electricity or district heating.

**Scope 3:** This area includes all those emissions that arise in the supply chain from the production, transportation and disposal of goods and services. It therefore also refers to the origin of medicines and other chemicals, food, medical equipment and instruments, as well as the journeys made by employees and patients and visitors to a hospital.

This subdivision corresponds to the GHG protocol (see <https://ghgprotocol.org/>) and is often used as a standard for subdivision [24]. The system has been adapted accordingly for the specific application to hospitals (Fig. 1).

A major problem in this context is that it has so far hardly been possible for healthcare facilities to determine the greenhouse gas

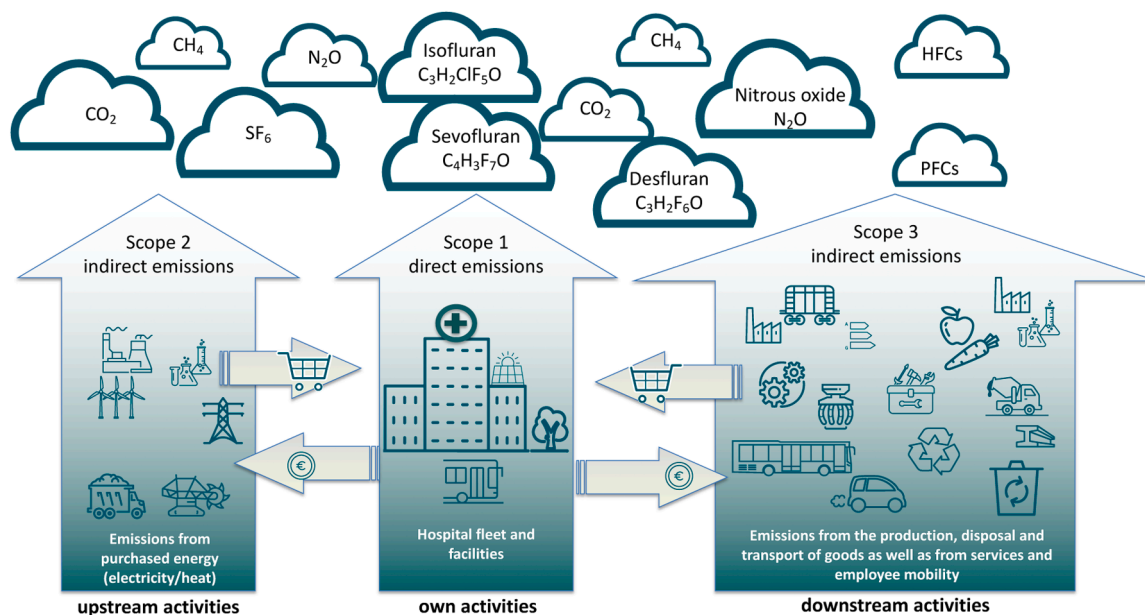


Fig. 1. Scopes of greenhouse gases in hospital management, own presentation.

emissions for their own facilities comprehensively and according to uniform standards. The direct emissions caused in the clinics themselves, for example for inpatient technical facilities and the vehicle fleet or volatile gases (Scope 1), have so far only been accounted for by very few clinics [15]. Particularly in view of the high proportion of indirect greenhouse gas emissions at hospitals, which result from Scope 3 and account for around two thirds of greenhouse gases in the healthcare sector [10], a standardized measurement method would be useful. This is because the upstream and downstream value chains, business trips, commuting by employees, transportation and manufacturing costs in the global supply chains for the procurement of goods and medical products and medicines, as well as the disposal of waste generated, require a great deal of effort to determine and a uniform data collection procedure to evaluate. For controlling it is useful to set sectoral targets. If, for example, a fictitious hospital with around 600 beds has an annual heat requirement of 9 million kWh and an electricity requirement of 6 million kWh, the CO<sub>2</sub> emissions of the building energy can be calculated from this. Depending on the energy mix, this amounts to around 5,400 tons of CO<sub>2</sub> per year in this example [25, p. 25].

#### Stakeholder workshop

A stakeholder workshop was held in order to develop an integrated and practical approach to the development of implementation proposals. The Association of Hospitals invited all members of the more than 300 hospitals in North Rhine-Westphalia. In addition to energy experts, this workshop was also attended by actors from hospital practice who would be responsible for the concrete implementation of the corresponding measures. During the workshop, the planned measures were presented by the energy experts, discussed together with the managers and employees of the hospitals, and supplemented with evaluation criteria for the preparation of the measures.

The method of a stakeholder workshop is a suitable method to ensure an integrated approach [26]. The aim was to identify those measures that would enable hospitals throughout Germany to independently identify, implement and permanently realize suitable climate protection measures against the background of the specific local conditions. A large number of possible options for action were presented to the participants at the workshop. The aim of this workshop was also to ensure a high degree of practicality, applicability and transferability of the measures. Therefore, in addition to the energy and climate protection experts,

numerous stakeholders from hospital practice also took part in this workshop. During the workshop, the planned measures were presented by the team of experts, discussed and, if necessary, specified and supplemented with further evaluation criteria for the preparation of the measures. It became clear that it is important to the experts from nursing, hospital management, the medical profession and the hospital association that the measures

- Should address all three scopes and
- All hospital stakeholders should be involved in the climate protection measures.

Because it was a physical meeting and the coronavirus pandemic was not yet over, eight external experts attended. An additional 12 participants participated in an expanded stakeholder event organized by the Hospital Society Association, meaning that 20 stakeholders could be involved in this first phase.

Given the broad invitation, the low number of participants was disappointing. In order to realize the initial goal of surveying a large group of stakeholders, it became necessary to intensively validate the results of the stakeholder dialogue. There was considerable interest, and several invitees apologized, citing the particularly high risk of infection for hospital employees at that time. To better engage stakeholders, the project design was adapted to offer the project team opportunities to participate in stakeholder events. Consequently, the proposed measures were discussed both digitally and at established stakeholder gatherings. In total, several hundred stakeholders were reached and involved in the evaluation of the measures. The topic gained significant traction due to the outbreak of the war against Ukraine, which led to a sharp increase in energy prices, prompting hospital managers to seek ways to reduce energy costs. Furthermore, discussions with managers revealed that reducing hospitals' vulnerability to energy price fluctuations has become increasingly important. Hospitals, as part of the critical infrastructure, should be as resilient to external influences as possible.

In this way, the stakeholder dialogues could take place within the framework of the following ten events (the German name of the event is in brackets):

1. Energy Management Symposium of the Association of Hospital Directors in Germany, North Rhine-Westphalia Chapter, in Iserlohn (Energie-Management-Symposium des Verbands der

- Krankenhausdirektoren Deutschlands e.V., Landesgruppe NRW in Iserlohn)
2. Marburger Bund Medical Association of Schleswig-Holstein (Marburger Bund Schleswig-Holstein)
  3. Health Committee of the Rhineland Regional Association (Gesundheitsausschuss des Landschaftsverbands Rheinland)
  4. Event of the German Hospital Association "Climate Protection in Hospitals - Do We Need a Climate Protection Movement as a Facet of the Sustainability Debate for the Healthcare System?" (DKG „Klimaschutz im Krankenhaus - Brauchen wir eine Klimaschutzbewegung als eine Facette der Nachhaltigkeitsdebatte für das Gesundheitswesen?“)
  5. Healthcare Industry Forum: Psychosocial Care Responses to the Climate Crisis (Forum Gesundheitswirtschaft: Impulsvortrag für Workshop 2: Antworten der psychosozialen Versorgung auf die Klimakrise)
  6. Kick-off event for the North Rhine-Westphalia Hospital Association's "Climate-Neutral Hospital" initiative (Aufaktveranstaltung der KGNW-Initiative „Klimaneutrales Krankenhaus“)
  7. 38th Spring Colloquium of the Vocational Training Center of German Hospitals: Moving forward with caution - keeping a cool head in hot times (38. Frühjahrskolloquium: Mit Bedacht nach vorne gehen - kühler Kopf in heißen Zeiten vom Berufsbildungswerk Deutscher Krankenhäuser e.V.)
  8. Western Health Congress 2023: Quick wins: Concrete implementation examples for sustainability and resource conservation in hospitals (Gesundheitskongress des Westens 2023: Quick wins: Konkrete Umsetzungsbeispiele für Nachhaltigkeit und Ressourcenschonung im Krankenhaus)
  9. Retreat of the South Westphalia Hospital Association in Nachrodt-Wiblingwerde (Klausurtagung des Zweckverbandes der Krankenhäuser Südwestfalen e.V in Nachrodt-Wiblingwerde)
  10. 5th Hospital Technology Trade Fair with Technology in Healthcare Conference in Gelsenkirchen (5. Fachmesse Krankenhaus Technologie mit Fachtagung Technik im Gesundheitswesen in Gelsenkirchen)

The redesign of the stakeholder workshops proved to be highly successful. It allowed for the involvement of significantly more stakeholders than originally intended, and the needs of the diverse professional groups within hospitals could be addressed much more effectively. For example, aspects of employee mobility, such as incentives to commute by bicycle or public transport, were far more important to nurses and trainees than to managers. Similarly, the use of climate-friendly anesthetics was discussed particularly intensively with physicians. In contrast, improvements to buildings and heating systems, and the installation of solar panels, were a key focus of stakeholder dialogues with managers, but of far less interest to nurses.

During the initial meetings, the number of measures to be proposed was discussed. All participants expressed a desire to limit the proposal to a manageable number of strategically important measures. The hospital association, in particular, voiced concern that a lengthy list of measures could be overwhelming and that a multitude of possible measures would reduce clarity. Furthermore, it was necessary to limit the calculation of required investments. Given the poor financial resources of hospitals and their limited investment opportunities, it was important to develop a consistent and concise mix of measures for political discussion. Hospitals are poorly positioned to access existing funding opportunities because they are subject to de minimis aid regulations [27]. The participants therefore agreed on a target of 10 measures, which was also considered the maximum that could be effectively communicated.

Another aspect of the compilation arose from the need to equally consider the various stakeholders in the measures. The allocation of measures to specific stakeholder groups—management, nursing staff, physicians—was particularly praised during the validation events. In keeping with the Whole Institution Approach, it is beneficial for the

success of a transformation process when different stakeholder groups and functional units within a company are involved in pursuing a common goal. The following figure shows the components of this approach and has been adapted for hospitals. It clearly shows that a holistic approach addresses both internal processes and the physical components relevant to climate protection. Furthermore, this approach requires that the entire value chain, including contractual relationships with suppliers (e.g., of pharmaceutical products), be examined with regard to sustainability and adapted if necessary (Fig. 2).

Furthermore, care was taken to ensure that the proposed measures would make a substantial contribution to climate protection. Cost-effective measures were prioritized over inefficient ones. However, since the cost-effectiveness of measures always depends on local specifics, the values of a defined average hospital were used for the calculations.

Against this background, ten following central measures were identified and confirmed by stakeholders in order to determine the investment requirements necessary to achieve the required level of climate protection in hospitals. They are to be understood as a set of measures, each of which represents an offensive in relation to the following aspects:

1. climate protection management in hospitals,
2. photovoltaics on roofs and façades,
3. climate-friendly energy sources for heating and cooling,
4. building envelope renovation / thermal insulation,
5. LED lighting,
6. renovation of heating pumps,
7. ventilation systems with heat recovery in patient rooms,
8. without a car to the hospital,
9. improvement of cycling conditions for e-mobility and
10. replacement of anesthetic gas

The measures identified are described in more detail in the "Results" chapter (Table 1).

#### Determination of investment requirements

Determining investment requirements is fundamentally faced with the problem that the (technical) starting position of hospitals with regard to climate neutrality is unknown in many cases. For example, an exact calculation of investment requirements would require knowing how many hospital buildings already have efficient building or façade insulation, what proportion of interior lighting is already provided by energy-saving LEDs or how many outdated circulation and recirculation pumps are still in use. Furthermore, not all climate measures can be implemented in every hospital because, for example, technologies such

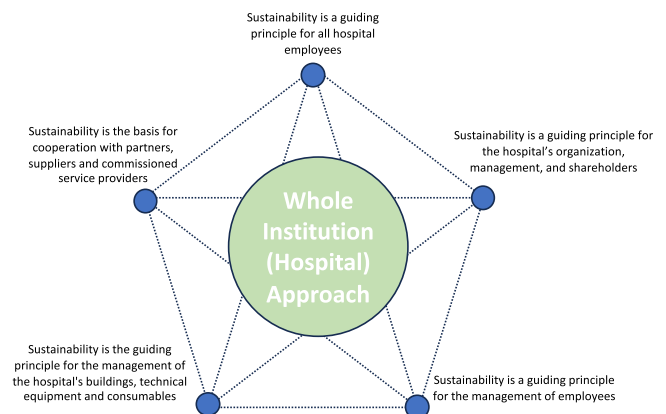


Fig. 2. The whole hospital approach, own illustration based on Eulenberger and Bahn-Walkowiak et al. [28,29].

**Table 1**  
Investment and operating cost effects.

Package of measures	investment costs	operating cost effects p.a.
Climate protection management	no	0.0067 full-time equivalents / bed EUR 68,000 p.a. Gross personnel costs for photovoltaics
Photovoltaics	600,000 EUR / hospital	-450,000 kWh energy requirement (electric)
Heat and cold production thermal insulation	3,300 EUR / bed 500 EUR / m <sup>2</sup> floor area, of which 35% as additional costs for climate protection = 175 EUR / m <sup>2</sup> floor area	- -50% energy requirement (thermal)
LED lighting	10 EUR / bed	-88 kWh energy requirement (electric) / bed
Heating pumps	100 EUR / bed	-220 kWh energy requirement (electric) / bed
Ventilation systems	1,000 EUR / bed	+10 EUR / bed
To the hospital without a car	220 EUR / employee	+780 EUR / employee minus 180 EUR of employee contribution = +600 EUR / employee
Expansion of e-mobility no anesthetic gases	240,000 EUR / hospital -	- -

Source: various sources, compiled in the Wuppertal report [37].

as geothermal energy or biogas cannot be used due to the geographical location and structural conditions. The protection of historical monuments can also play an important role. For this reason, the measures identified were considered for an "average" hospital. The parameters (beds, employees, floor space, energy demand (thermal), energy demand (electric), heating costs per kWh, electricity costs per kWh, see Table 2) were defined on the basis of literature, databases (such as data from the Federal Statistical Office), assumptions based on scientific publications and expert interviews [30]. In the case of the literature screening, a narrative literature review was carried out, i.e. a non-systematic analysis of selected references. The selection of literature does not follow a systematic approach and was not defined on the basis of criteria or search specifications. According to Green et al. [31] a narrative literature review is helpful to put many pieces of relevant information together and to present a broad perspective of a problem. It is flexible and practical and offers a synthesis of diverse literature [32]. However, this approach has several limitations like the reproducibility and the limited generalizability. The interpretations may vary depending on the authors [32].

A cost framework was created to determine the investment requirements for such an "average" hospital. This includes the investment costs for new or replacement purchases of longer-term, climate-protecting assets (e.g. buildings, plant and equipment). We also estimate possible effects on the ongoing operating costs of a hospital, as some measures may reduce thermal and electrical energy requirements, for example, or be accompanied by additional personnel requirements and

**Table 2**  
Parameters of the model hospital for North Rhine-Westphalia.

Parameter	Value
beds, [number]	339
Employees, [number]	737
Floor area [m <sup>2</sup> ]	40,000
Energy requirement (thermal) per year and bed [kWh]	25,000
Energy requirement (electrical) per year and bed [kWh]	7,800
Electricity costs per kWh [EUR]	0.2664

Source: various sources, compiled in the hcb report [30].

higher procurement costs for materials. The data for the cost structure was determined through literature review (e.g. [9,33] and analysis of case studies (like the KLIK Green database [34,35] or the Health Care Climate Council Playbook for Hospitals [36]). The operating cost effects are estimates.

In this way, the investment costs could be estimated as a function of specific hospital parameters (e.g. floor space, number of beds) and then extrapolated to the total population of all North Rhine-Westphalian hospitals. The following table shows the relevant parameters of a typical North Rhine-Westphalian hospital, which were obtained from the narrative literature review and expert surveys for a model (average) planned hospital in NRW [30]. On average across all 315 planned hospitals in NRW (in 2019), it is assumed that the different initial conditions balance each other out so that a solid estimate can be made of the total investment requirements for the whole of NRW.

In order to be able to compare the investment costs with the operating costs, the annual tax depreciation of the investments was used for the calculation. As the initial situation of the hospitals is not known and data on the actual useful life of climate protection measures is lacking, the respective period was determined using the tax depreciation option published by the Federal Ministry of Finance, assuming straight-line depreciation. For example, this results in 33 years for thermal insulation and 5 years for an LED light. Nevertheless, the actual useful life is likely to be significantly longer in most cases [30].

## Results

To confirm the results of the stakeholder workshop, we reviewed relevant literature. Studies show that hospitals play an important role in climate protection [8,23]. The relevance of this topic was confirmed by the World Health Organization [38], which found that the number of articles published in the field of climate change and health has increased more than six-fold in the last decade, with a focus on studies assessing health vulnerabilities to climate change. The term green hospitals has also become well known for climate-friendly hospitals and is defined and used in a variety of ways. The United States Environmental Protection Agency defines green hospitals as "the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction. This practice expands and complements the classical building design concerns of economy, utility, durability, and comfort. Green building is also known as a sustainable or high performance building" [39].

In this chapter we present some overall results of the stakeholder workshop that were confirmed by literature. It is important to note that this is not an exhaustive list and that there are other relevant areas for reducing greenhouse gas emissions in hospitals (such as waste, water consumption, food (see e.g. [8,16,40])).

The following list focuses on building energy and mobility, as the potentials are very high in these areas. Consequently, the following ten measures were rated as particularly relevant:

1. *Climate protection management in hospitals:* The successful implementation of a climate protection process requires certain people to take responsibility and act as "drivers and promoters" who work closely with the management, for example as a climate management office. Planning and implementing measures and campaigns, conducting employee surveys, collecting consumption data, developing a refurbishment or decarbonization roadmap and monitoring climate protection progress are further tasks that need to be taken on. A team of employees ("climate protection team") from various departments of the hospital should be involved (e.g. technical management, purchasing, environmental and waste management officers, corporate communications). Practical experience shows that one person with a scientific

background is needed for every 150 beds in order to manage these tasks. This is also confirmed by a survey by Schmidt and Bohnet-Joschko, in which the climate protection measures of German hospitals were compared. The results of the study show that the commitment of a hospital's employees depends on how the hospital's management organizes and communicates the issue of climate protection in their facilities [41]. The importance of strategic leadership for climate protection in hospitals is therefore a crucial success factor, to which a climate protection manager can make a significant contribution.

2. *Photovoltaic on roofs and façades systems*: In contrast to other renewable energies, such as wind power, which are highly location-dependent, photovoltaics can be installed practically anywhere [3]. But despite many advantages, in 2019 only 14% of hospitals use the electricity from their own photovoltaic system on the company premises [9]. Whether a rooftop system, a façade system, a ground-mounted system on a parking lot or a combination of both - the suitability of each variant depends on the local conditions. Rooftop systems are generally the most common form of installation. Roof pitch, orientation and shading are decisive factors for the efficiency of the system. If the roof is not suitable or space is limited, façade systems can be an alternative. For hospitals, e.g. with large parking lots or open spaces, ground-mounted PV systems can be an attractive option. On average, it is expected that a large PV system with a capacity of 500 kW<sub>peak</sub> can be installed at each hospital. The investment costs for such systems vary greatly depending on local conditions, such as the complexity of the installation and the structural integrity of the roof. Such a system could generate around 450,000 kWh of electricity per year, depending on the location and orientation. In this context, the remarkable impact of photovoltaic technology, which has led to a significant reduction in solar energy costs, must be mentioned. Technological innovations in photovoltaic materials and manufacturing processes are the driving factors behind enormous cost reductions per watt of solar power. Numerous analyses (summarized, for example, by Castellano et al. [42] and Ogundipe et al. [43]) demonstrate that further innovations and cost reductions can be expected in the future.
3. *Climate-friendly energy sources for heating and cooling*: A nationwide survey of hospitals in Germany found that every second hospital sees a need to optimize its technical systems when it comes to heat supply. Currently, only around 2-4% of hospitals use renewable energy to generate heat. 56% of hospitals also have great potential for improvement when it comes to cooling supply. This includes replacing energy sources but also optimizing system technology and using alternative cooling methods and coolants [9]. Transitioning hospitals from fossil fuel-based heating to renewable energy sources is therefore vital for climate goals. Existing fossil fuel heating systems in hospitals must be replaced by alternatives based on renewable energies, depending on local possibilities such as geothermal energy, wood, biogas, large heat pumps, solar thermal energy or a combination of these. Due to the high cooling requirements in hospitals, heating systems can also be used for cooling, with the excess heat being used to drive absorption chillers. Due to the high reliability requirements, several thermal systems are often operated simultaneously, possibly incorporating parts of existing heating systems. The cost of converting heating systems varies depending on current conditions and specific requirements.
4. *Building envelope renovation / thermal insulation*: Well-insulated roofs, facades / house walls and triple-glazed windows are important for reducing heat loss and significantly lowering heating energy requirements. These measures also contribute to thermal insulation in summer, help to adapt to the effects of climate change and at the same time reduce energy consumption for cooling. Factors such as listed buildings, previous renovation work, the construction method and the window areas influence the cost of thermal refurbishment. In-depth renovations with more expensive measures could bring even greater energy savings.
5. *LED-Lighting*: Replacing inefficient light sources with LED technology is one of the quickest and easiest ways to save energy in hospitals. Accordingly, over 40% of hospitals already use energy-saving lighting concepts, which include the use of energy-saving LEDs as well as brightness and presence-controlled lighting [9]. Energy consumption varies depending on the model and specific lighting requirements, from night lighting to surgical lighting. Certain areas such as corridors or stairwells need to be continuously lit. Overall, energy savings of up to 30% can be achieved by switching to more efficient lighting [44]. For example, replacing a fluorescent tube (60 watts) with an LED (20 watts) can save around 8,800 kWh of electricity per year (for 100 beds) per bed that is used for an average of 6 h a day. In addition, energy efficiency can be further improved by introducing lighting management systems.
6. *Renovation of heating Pumps*: Replacing old heating pumps with regulated high-efficiency pumps can lead to significant energy savings of 66% on average [44], which usually result in quick financial returns. Such a measure is particularly effective when combined with a hydraulic balancing of the heating system. It may then also turn out that some pumps are superfluous. Around 40% of hospitals have not yet carried out a hydraulic balancing, although this makes a lot of economic sense given the complex supply structure of hospitals [9]. Different systems are needed for various hospitals, which require individual solutions. An old inefficient standard pump consumes around 2,500 kWh per year, costing €500 at an electricity price of €0.20 per kWh. With a large number of pumps in a hospital, these costs quickly add up. A highly efficient pump, on the other hand, consumes only 300 kWh per year.
7. *Ventilation System with heat recovery in patient rooms*: In this measure, decentralized ventilation systems with heat recovery are installed in every room. Each room requires a compact, wall-mounted ventilation unit. In hospitals, compliance with hygiene standards is of the utmost importance. In addition to the energy aspects, ventilation systems help to improve air quality through regular air exchange. The costs vary greatly depending on the local conditions. The additional costs are minimal if ventilation systems are already in place, but higher if all installations have to be carried out from scratch. Fire protection aspects can also play a role, which can lead to higher costs. However, the energy savings in heating can be considerable depending on the building physics. Ventilation systems significantly improve air hygiene, make window ventilation superfluous and increase comfort.
8. *Mobility without a car to the hospital*: When it comes to emission reduction potentials, the mobility of patients and medical staff is a relevant area, as they travel to appointments, pick up recipes or results, or receive visits, among other things [16]. To promote cycling among hospital employees, a weather-protected and secure bicycle parking space with barrier-free access should be provided for every fifth employee in hospitals. In addition, 10% of these parking spaces should be equipped with charging facilities for e-bikes and pedelecs as well as lockers for batteries and tools. As an alternative to the car, all hospital employees should receive a publicly funded, site-specific public transport ticket to encourage the use of public transport for commuting to work. It is assumed that the majority of staff would opt for this cost-effective option. The exact costs depend on the conditions negotiated with the transport companies, the routes and the local and regional subsidy programs.

9. *Improvement of cycling conditions for E-mobility*: In order to promote the acceptance of electric vehicles among hospital employees, charging stations should be installed in hospital parking lots to provide charging facilities for one in ten hospital employees. This initiative aims to encourage employees who are unable to use alternatives such as public transport, cycling or walking to switch from conventional combustion vehicles to battery electric cars.
10. *Replacement of Anesthetic Gases*: Avoiding or reducing desflurane as an inhalational anesthetic can significantly reduce climate-damaging gases in hospitals. Anesthetic gas collection systems can also help reduce greenhouse gases. However, a survey found that 79% of hospitals do not use these systems [9]. Educating healthcare professionals, especially anesthesiologists, about the climate impact of anesthetic gases is crucial. Initially, restricting the use of desflurane to strict indications through voluntary or legislative measures can be effective. A University of Wisconsin campaign example achieved a 64% reduction in carbon dioxide equivalent emissions per case through education and awareness initiatives [45]. As recommended by the American Society of Anesthesiologists [46], changes in anesthesia routines, such as preparing only the necessary medications and using reusable equipment, can further increase carbon dioxide equivalent savings. These efforts can be effectively managed by the hospital's climate management.

Based on the method described above, costs for implementing measures could also be determined. The investment costs were calculated on the basis of the parameters shown above. The measures mentioned require a total investment amount of EUR 7.1 billion (EUR 6.4 to 7.8 billion) or an average of EUR 23 million per hospital (EUR 21-25 million) for the 315 hospitals in the state of North Rhine-Westphalia (all hospitals, however, excluding 6 university hospitals, which could not be considered due to numerous special features), with the thermal insulation measure in particular requiring a high level of investment with a total investment requirement of EUR 6.3 billion (EUR 5.7 to 6.9 billion). However, it should be noted that only 35% of the investment costs for this measure can be allocated to climate protection (climate protection investment), with the remainder being allocated to regular "basic investment". The other measures together amount to an investment volume of around EUR 0.8 billion (EUR 0.7 to 0.9 billion) [30]. All of these calculations were made on the basis of 2019 prices. As energy prices, construction prices and commodity prices have risen sharply in some cases since then, the economic situation at current prices may be different.

It can be seen that some measures can also lead to savings in the ongoing operating costs of an individual hospital (approx. EUR 260 thousand p.a. for the standardized hospital). The additional operating costs are nevertheless higher than the savings at around EUR 600 thousand. This is also due to the fact that measures such as the hiring of climate managers or the assumption of costs for public transport tickets do not result in any directly measurable cost savings [30]. Nevertheless, even such measures have an economic effect, although this could not be calculated as part of these studies. It is noticeable in higher staff retention, in increased comfort for staff and patients as well as in increased property values and a lower risk of rising prices. Assuming that the hospitals in the rest of Germany are roughly as equipped as those in North Rhine-Westphalia, one can also estimate the nationwide investment needs. This will then amount to a total of EUR 31 to 37 billion. The additional operating costs will then be between EUR 556 and 680 million per year. Since the conditions in hospitals in Europe are very different and the energy requirements are also very different in different climatic regions, an extrapolation beyond this cannot be carried out reliably.

While determining specific investments for each hospital requires detailed technical assessments, certain measures, such as climate

protection management, are universally beneficial. However, other measures must be assessed on a case-by-case basis to determine how the full potential can be leveraged. To ensure effective implementation, individual renovation plans must be developed and followed to ensure effective implementation. Economic considerations and uncertainties in the energy markets as well as labor shortages must also be taken into account.

## Discussion

Various approaches and frameworks exist to identify relevant areas for hospitals. The World Health Organization (WHO) released the Operational Framework for Building Climate Resilient Health Systems [47], which contains ten intervention components including risk monitoring, sustainable technologies and health financing. Corvalan et al. (2020) further analyzed four of these components with a focus on climate resilience [8].

While these frameworks provide valuable guidance, their applicability varies depending on regional and national conditions. The present analysis focuses on Germany and the measures, challenges, potential and benefits can differ greatly in other countries due to variations in healthcare infrastructure, existing regulations, or financial resources (see e.g. [3]).

While, according to [48], sustainability is not a priority in the healthcare sector in Germany and no overarching national strategy has yet been published, examples from other countries show that climate-neutral hospitals have been formulated as a goal and backed up with concrete measures. One example comes from the UK. The National Health System (NHS) net-zero initiative is aiming to achieve net zero in all emission classes (Scop1-3) [49]. Concrete measures include inter alia a Net Zero Travel and Transport Strategy [50], a clinical waste strategy [51], a Net Zero Building Standard [52] and a carbon reduction plan and net zero commitment requirements for the procurement of NHS goods, services and works [53].

Another example comes from the Netherlands. Here the third Green Deal 'Working together for Sustainable Care' was published including measures with regard to CO<sub>2</sub> reduction, awareness, circular use of resources and environmental impact of medication (use). The Green Deal Sustainable Healthcare has already been signed by numerous care facilities, including 52 hospitals to highlight efforts to create a climate-neutral healthcare sector [54,55].

Even if only a small selection of examples from other countries can be shown here, the areas are similar to the measures proposed in this article.

The ten measures that were identified in this report on the basis of a narrative literature review and stakeholder workshops primarily concern internal processes and technical questions of energy supply. Nevertheless, some measures also have a direct impact on patients. This directly affects, for example, measure 10 (replacement of anesthetic gas) and of course also measure 7 (ventilation systems with heat recovery in patient rooms). Mobility measures 8 and 9 also have an indirect impact on patients and their visitors. Better options for getting to the hospital in a climate-friendly way by bike or public transport also create advantages for patients and visitors. A survey by Scholz et al. shows that this is certainly appreciated by patients. 88.2% of the patients surveyed supported such initiatives in hospitals and 86.5% were in favor of sustainable alternatives, provided that quality standards in terms of hygiene and medical care are not worse. Well over half of the patients surveyed are interested in finding out more about the environmental and climate impact of their medical treatment and hospital stay [56].

Sustainability measures in hospitals can contribute to improved patient care and staff well-being, for example, through better ventilation systems and waste reduction. Importantly, these measures can reduce emissions without compromising critical care standards. For instance, an improved ventilation systems not only lower energy consumption but also increases indoor air quality by maintaining optimal temperature

and humidity levels, which benefits both patients and staff. Similarly, replacing aesthetic gases with alternatives reduces greenhouse gas emissions while maintaining the same level of patient safety and procedural effectiveness.

Although implementing these measures may pose temporary challenges—such as disruptions to established safety protocols, the need for staff retraining, and potential inefficiencies during the transition phase—these risks can be mitigated through careful planning, phased implementation, and a close monitoring. In the long term, sustainability initiatives not only support climate protection goals but also strengthen hospital resilience, ensuring that healthcare facilities remain adaptable to future environmental and economic challenges.

## Conclusion

Hospitals are already subject to legal requirements for implementing climate protection measures. These include, for instance, the EU Corporate Sustainability Reporting Directive (CSRD), which mandates the disclosure of detailed information on environmental, social and governance impacts, and the Energy Efficiency Act, which mandates the establishment of an energy or environmental management system for healthcare facilities with an average annual energy consumption exceeding 7.5 GWh [57]. However, the measures implemented so far are insufficient to fully harness the significant potential that exists. Therefore, politicians are called upon to make the necessary investments in hospitals possible, to set up funding programs and also to improve the general conditions. Anyone who has to make an investment should know that it is only economically sustainable if it also meets the requirements of climate protection and independence. What began in the last quarter of 2021 with a drastic increase in energy prices (contract renewals or new contracts for household consumers rose by 83% from 6.47 cents per kilowatt hour to 11.84 cents per kilowatt hour) coincided with Russia's war against Ukraine [37]. A look at the current price trends makes it clear that saving energy and developing our own renewable energies have become much more strategically important. In the meantime, end customer prices for electricity have doubled, those for natural gas have increased sixfold and those for district heating (when prices are linked to the development of natural gas prices) have even increased eightfold in some cases [37]. Even if prices have now fallen again significantly, energy will probably not be as cheap in the foreseeable future as it was just a few years ago. Geopolitical risks have also become considerably more important. A general risk check is therefore required for the central energy transition and climate protection strategies and paths [58].

With this article, we want to provide an insight into the options for action and necessities in order to achieve the goal of a climate-neutral hospital. To achieve the climate targets, major changes to routines and considerable investment in infrastructure and building materials are required. Karl Lauterbach, the former German Health Minister made it clear at a federal press conference on November 3, 2022 that the consequences of climate change are "by far the biggest and most important crisis of these times" for health and climate experts [59].

This article also suggests that a holistic view of the "hospital system" including broad support is required. No hospital is likely to achieve the goal of climate neutrality without also changing its environment. This means, for example, that climate-friendly energy sources must be sufficiently available, to which local heating networks can make an important contribution or national strategies for decarbonizing the gas supply are also required. Cycle paths are another option so that employees can cycle to work safely and, of course, this is linked to good public transport service that is compatible with the special working hours of a 24/7 operation, just to give an example of the joint task of climate protection.

Due to the complexity of the health sector, it may be useful to analyze international examples, e.g. from the UK, in more detail and compare the extent to which North Rhine-Westphalia and Germany can learn from other countries, bearing in mind that each country has different

healthcare system conditions. This article has a strong regional focus, which does not yet adequately cover a comparison with other countries. It should therefore be investigated in future to what extent the proposed measures can also be implemented in other countries, to what extent measures that have been successfully implemented in other countries should also be transferred to Germany and where challenges and limitations exist.

## CRedit authorship contribution statement

**Oliver Wagner:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Lena Tholen:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation.

## Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Oliver Wagner reports was provided by Wuppertal Institut for Climate Environment Energy gGmbH. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Data availability

Data will be made available on request.

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