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Compiled by the Commission on Sustainability in Anaesthesiology of the German Society of Anaesthesiology and Intensive Care (DGAI) and the Professional Association of German Anaesthesiologists (BDA)

A DGAI and BDA Position Paper with Specific Recommendations*

Ecological Sustainability in Anaesthesiology and Intensive Care Medicine

Update 2024

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The authors declare no competing interests.

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Summary

The position paper entitled "Ecological sustainability in anaesthesiology and intensive care medicine" presents specific recommendations for action to achieve ecological sustainability in the field of anaesthesiology, intensive care and emergency medicine. It outlines the consequences of the environmental crises for our specialty. It is based on the first position paper published in 2020 [1] and was adopted by the executive committees of the BDA and DGAI on July 19th, 2024.

The position paper was created in view of the expected effects of climate change and the threat of further environmental changes and the associated medical state of emergency. The aim was to outline specific measures that anaesthetists can take to minimise the negative ecological impact of their professional activities in intensive care units and anaesthesiology. A sustainable reduction of greenhouse gas emissions within the highly CO_2-intensive healthcare sector is urgently needed in order to prevent the consequential negative effects on health of people worldwide. This should be part of the professional identity of all doctors.

The position paper is subdivided into seven sections. The previous 2020 position paper has now been updated on the basis of the literature published in new and current evidence. It shows how anaesthetists can implement environmental sustainability in their scope of professional practice. Particular attention is paid to the impact of drugs used in anaesthesiology and intensive care medicine on the environment and climate change and the special significance of volatile anaesthetics as direct and potent greenhouse gases is emphasised. The role that filtersystems can play in this area is specified in this update. With regard to medical devices, the increasing use of disposable items is discussed critically and, whenever possible, the establishment of a circular economy in the operating theatre and intensive care unit is suggested. The need to consider the ecological footprint when selecting products is also emphasised. Newly published life cycle assessments of products expand the existing evidence in this area. As waste has considerable direct and indirect negative ecological effects, the 5R concept is used to explain how to actively reduce waste in the OR and ICU without negatively impacting processes. Case reports show that recycling concepts can also be implemented in these areas without major difficulties.

In addition to the direct anaesthesiological field of work, the position paper also addresses other key areas of action that are indirectly associated with the everyday work of anaesthetists. For example, the importance of sustainable mobility with regard to commuting, (patient) transportation and congress travel is highlighted. Improved energy management can begin in the operating theatre and intensive care unit, but must ulti-

mately encompass the entire hospital. Very high CO_2 emissions are generated in these areas, which can efficiently be reduced by energy-saving measures. Many of these actions are easy to implement and should urgently be implemented. Finally, the importance of research and teaching is also emphasised in order to successfully meet the challenge of ecological sustainability in anaesthesiology and intensive care medicine.

At last, this update of the position paper summarises for the first time the effects of climate change and environmental changes on the reality of clinical care in intensive care and emergency medicine and presents options for action for more climate-resilient patient care in the areas of anaesthesiology, intensive care and emergency medicine.

Preface

The first version of the position paper "Ecological Sustainability in Anaesthesiology and Intensive Care Medicine" was adopted by the Executive Committees of the Professional Association of German Anaesthesiologists (BDA) and the German Society of Anaesthesiology and Intensive Care (DGAI) in 2020 [1]. Anaesthesiology was the first specialty in Germany to adopt this position.

This updated version of the position paper incorporates numerous new findings and approaches based on recent publications. The chapters on pharmaceuticals, medical devices, waste management, mobility, energy management, research and teaching have been supplemented to include a chapter on "Impact of global environmental change on patient care."

Our clinical work prioritises patients' well-being at all times. As environmental changes, climate change and their impact on patient care are set to increase in the coming years and decades, we as anaesthetists must actively shape change. On one hand, this entails adapting to actual changes in healthcare provision, in which extreme weather events and yet unknown diseases, for example, will play an increasingly important role. On the other hand we must ensure that the significant greenhouse gas emissions caused by the healthcare sector are effectively and rapidly reduced. Only if all sectors of society, including the healthcare system, do their part it will be possible to halve emissions in Europe by 2030 and achieve net-zero emissions by 2050.

So-called "Green Teams" need to be established in all anaesthesiology departments to achieve the greatest possible effect. They should develop strategies and measures to induce change processes, reduce medication, material consumption and emissions, initiate reduction in energy and water consumption and promote advanced recycling activities. A detailed analysis of packaging, transport and disposal should be conducted to that end.

These sustainability concepts should be developed both on the initiative of the departments themselves (bottom-up) and encouraged and promoted by the administration and management of the clinics (top-down). The "Green Teams" should be open to cooperation across departments, professional groups and hospital areas, and include hospital hygiene departments to develop specific protocols that are favorable to the environment and climate [2].

In this position paper, BDA and DGAI remain firmly committed to the goal of a climate-neutral, sustainable healthcare system and, therefore, in conjunction with the other healthcare sector stakeholders exert their influence on politics and industry to actively drive the necessary transformation process forward.

Introduction

In addition to climate change, other environmental crises threaten the health of the world's population. Currently, six of nine planetary boundaries are considered to have been exceeded to a dangerous extent: climate change, species extinction, land use, environmental pollution, freshwater availability, and global nitrogen and phosphorus cycles [3]. Exceeding planetary boundaries increases the burden of disease on humans and consequently leads to increasing pressure on healthcare systems worldwide [4,5]. Activated, self-reinforcing tipping points in Earth's systems are leading to a non-linear acceleration of this development. These man-made environmental crises can be traced back to our resource-intensive way of life, which, in addition to its environmental consequences, also leads to lifestyle-related diseases [6–8].

The measures adopted by the international community to mitigate and adapt to climate change are insufficient to protect societies from the future impacts of the climate crisis [9]. The main driver is the continued burning of fossil fuels. Therefore, the DGAI and BDA have joined numerous health organisations in calling for a non-proliferation agreement for fossil fuels [10]. We find ourselves in an emergency situation in which healthcare systems are of vital importance [11,12]. This results in a series of specific measures for the field of anaesthesiology with a view to mitigating further developments and increasing the resilience of healthcare facilities in this crisis-ridden environment.

As physicians we are under a special obligation. Over the next decades, climate change will lead to a change for the worse in health care for a great number of people across the planet and pose grave challenges to health care systems in almost every country [4,13]. At the same time, the health care system is itself responsible for significant emissions of greenhouse gases, owning 4.4 % of global greenhouse gas emissions in 2014 [4]. In response, numerous professional medical bodies have issued their own statements indicating the urgent need to reduce CO_2 emissions across the health care sector [14–18]. The German healthcare sector can drastically reduce its CO_2 footprint without compromising quality of patient care [19]. Doctors are also called on to give high priority to climate protection in their personal consumption and, in line with the divestment campaign, in their investment decisions [20].

As high-tech, resource hungry fields, anaesthesiology and intensive care medicine are involved in a significant portion of CO_2 emissions across the health care sector [10–12]. In the past few years, numerous professional anaesthesiologic bodies have published recommendations for anaesthetists on how they can contribute to reducing CO_2 emissions [15–18].

The following recommendations focus on those measures which can be imimplemented immediately at a local level by anaesthesiologists.

Glossar

CO_2e: CO_2 equivalents

Emissions of greenhouse gases other than CO_2 can be converted to **CO_2 equivalents.** This entails calculating the quantity of CO_2 which would exhibit the same effect in the atmosphere as the emission in question by using the mass of that emission and its Global Warming Potential [24].

GWP: Global Warming Potential

The **Global Warming Potential** describes the substance-specific greenhouse effect compared to CO_2 over a specified length of time. In general, the interval chosen is 100 years (GWP100) [25].

LCA: Life Cycle Assessment

Life Cycle Assessment can be used to determine the actual carbon footprint of consumables, drugs and medical procedures. This involves analysing the ecological footprint from "the cradle to the grave", including the following positions: 1) extraction of raw materials, 2) processing and manufacturing, 3) transport and packaging, 4) use, reutilisation and maintenance, 5) recycling and 6) disposal. Water use and release of toxins are additional important factors besides CO_2 release [26].

A. Medicines

E1: Anaesthesia with volatile anaesthetics should be administered minimise release of volatile anaesthetic into the environment. This requires consistent use of minimal-flow anaesthesia.

E2: Use of desflurane and nitrous oxide is discouraged. Of the commonly used volatile anaesthetics, sevoflurane has the lowest global warming potential.

E3: Use of anaesthetic gas filters should be considered. The industry is called on to integrate anaesthetic gas filters into anaesthesia machines to prevent the release of volatile anaesthetics into the environment.

E4: Unlike volatile anaesthetics, total intravenous anaesthesia and regional anaesthesia do not result in direct greenhouse gas emissions that are inherent to the procedure. To avoid greenhouse gas emissions, use of total intravenous anaesthesia and regional anaesthesia is advisable, provided they are medically appropriate.

E5: Discarding medication should be avoided for economic and ecological reasons. Residual drugs may not be disposed of in the sewage system, rather they must be disposed of with the residual waste to be incinerated.

Volatile anaesthetics (VA) and nitrous oxide exhibit potent greenhouse effects. Both sevoflurane and desflurane are hydrofluorocarbons (HFCs), whilst isoflurane, enflurane and halothane are chlorofluorocarbons (CFCs) and exhibit additional ozone-depleting effects. The same is true for nitrous oxide (N_2O) [22,27–30].

VAs show a significantly larger negative impact on the climate than CO_2. That impact is recorded as the comparative greenhouse effect in relation to CO_2 (**Global Warming Potential,** GWP). To that end, relevant institutions such as the Intergovernmental Panel on Climate Change (IPCC), the United Nations Framework Convention on Climate Change (UNFCCC), the United States Environmental Protection Agency (US EPA) and the European Environmental Agency (EAA) have chosen a consideration period of 100 years (GWP100) [28,30–34] (Tab. 1).

Use of GWP to assess the climate impact of VA has recently been criticised. Since the residence time of VA in the tropopause is relatively short compared to CO_2, distribution in the relevant atmospheric layers is unclear and degradation processes have not been sufficiently taken into account. Therefore, the greenhouse effect of VA is probably lower than assumed [37]. This position is, in turn, contradicted by other climate researchers, who argue that although the processes by which individual greenhouse gases act in the atmosphere are not fully understood and climate research is always based on complex models, the GWP concept is an acknowledged and useful approximation and continues to be used by all relevant institutions for hundreds of substances [33–35].

In addition to the greenhouse effect per quantity of substance used, the actual quantity of the VA required to reach an adequate minimal alveolar concentration (MAC) needs to be factored into the equation. During **steady state** and

Table 1

Global warming potentials and atmospheric lifetimes of inhaled anaesthetics [35,36].

	GWP100	Atmospheric lifetime (in years)
CO_2	1	*
N_2O	273	109.0
Sevoflurane	144	1.4
Desflurane	2,590	14.1
Isoflurane	539	3.5

* For CO_2, no atmospheric lifetime is specified, as the majority of the CO_2 emitted remains in the atmosphere for hundreds or thousands of years.

assuming identical flow rates, use of desflurane for general anaesthesia emits approx. 50 times as much CO_2 equivalent compared to sevoflurane.

During the maintenance of general anaesthesia, doubling the flow rate will double the emissions from VA [30,32, 38-40]. As such, utilising **minimal flow** for maintenance of anaesthesia is to be recommended in any case. Higher fresh gas rates flow should be reserved for situations in which the depth of anaesthesia needs to be changed rapidly. Also at the end of anaesthesia, high flows should only be used once the vapor has been turned off [39]. Stickers on vaporisers can support the use of a consistently low fresh gas flow in everyday clinical practice [41,42]. Such stickers are available from the Forum Nachhaltigkeit website [43].

Currently, most VAs used for general anaesthesia are completely discarded into the environment, causing a significant greenhouse effect. In England, it was estimated that 3 % of National Health Service (NHS) greenhouse gas emissions emanated from use of VAs [44]. Worldwide emissions from VA amount to 3 m tons CO_2 equivalent in 2014, not including the effect of nitrous oxide. 80 % of these CO_2-equivalent emissions could be attributed to desflurane alone [22]. In an average anaesthesia department, use of VAs will be responsible for between 3.5 and 118.3 kg CO_2 equivalent per anaesthesia case [45,46]. For 10,000 anaesthesia cases per year, this corresponds to the annual CO_2 footprint of up to 200 average German citizens, i.e. anaesthetists increase their personal CO_2 footprint fivefold through their professional activity alone.

This leads a to specific management option for anaesthesia teams: Avoiding desflurane could reduce 67 % of emissions attributable to an anaesthesia department [46]. In a US study, combination of reducing fresh gas flow and avoiding desflurane and nitrous oxide reduced VA-induced CO_2 equivalents by up to 90 % [47].

In Scotland, use of desflurane was discontinued in 2023, and the NHS in England will end its use in 2024. Use of desflurane is also declining significantly in other countries for environmental reasons [48,49].

In its Glasgow Declaration, the European Society of Anaesthesiology and Intensive Care (ESAIC) advises against the use of desflurane and nitrous oxide, as more environmentally friendly and clinically equivalent alternatives are available [50]. On 7 February 2024, the European Parliament and the European Council adopted the updated Regulation (EU) 2024/573 on fluorinated greenhouse gases, which prohibits the use of desflurane as a VA from 01.01.2026 due to its significant global warming potential. The regulation only provides for an exception if the use of desflurane is absolutely necessary and no other VA can be used for medical reasons. Users must provide documentation for each individual case. The other VAs are stated in the updated regulation but are not regulated. Therefore, the EU Parliament and EU Council are pursuing their general policy in the updated F-gas Regulation to remove the most climate-damaging alternatives within the F-gas group [51]. Demonstrating the required proof of superiority of desflurane will be difficult since there is no demonstrable, clinically compelling additional benefit of desflurane over other VAs in terms of measurable, patientrelevant outcome parameters based on the current evidence [52]. However, it should be noted that this restriction on the use of desflurane in the EU is the subject of critical discussions by the ESAIC because of concerns regarding reliable VA drug supplies [53].

Various technical solutions have been developed to recapture VA and nitrous oxide instead of releasing them directly into the environment. Using such technologies, VAs can be destroyed by thermal, catalytic or photochemical means, or processed for reuse [38,39,54–56]. Systems which capture nitrous oxide used in obstetrics, destroying it by means of a thermal catalytic process, are already in practical use [38,55]. It should be noted that a significant proportion of the nitrous oxide already is lost on its way to the patient due to losses in the piping system or for technical reasons. Approximately 30% is then lost during recapture, meaning that CO_2 emissions from nitrous oxide-based anaesthesia procedures in obstetrics are about 100 times higher than those from alternative procedures, such as regional anaesthesia [57].

Activated carbon-based filter systems are available in many countries to capture VA at the outlet of the anaesthesia machine or the exhalation limb of the intensive care ventilator. After distillation from the filter, purification and sterilisation the VA could be reused. VAs are therefore the first group of drugs in which genuine recycling within the meaning of a circular economy is possible. Activated carbon filters are already in use in numerous hospitals, although technical and regulatory requirements still need to be considered [58]. In an initial observational study, only about 25 % of VA could be recovered [59]. In other observational studies, some of which used a different type of filter, recovery rates of 43 – 51 % and 48 % were reported [60,61]. It is assumed that a significant proportion of the anaesthetic gas used intraoperatively is only exhaled after extubation and that some of it cannot be recycled for technical reasons. Furthermore, methodological limitations of the observation are discussed [52,59, 60,62]. Even if a filter system is used, the above recommendations regarding the choice of VA and use of minimum flow etc. still apply. Further research data on pharmacokinetics and the reprocessing of VA is needed to determine the recycling potential of filter systems. At least no relevant quantities of greenhouse gases are released when the residual VA in the filters are incinerated at 1400 °C, they are destroyed [62].

To date, there is no officially accessible life cycle assessment using a cradle-to-grave approach for these anaesthetic gas filters. This means that a final assessment of the cost-effectiveness of this approach in terms of avoiding CO_2 emissions is not yet available [63]. In this context, eliminating the need for scavenging systems when using filters could be a significant factor [64,65], see section E “Energy management” below. Furthermore, the extent to which greenhouse gas emissions from VA or nitrous oxide will be subject to CO_2 emissions trading regulations is crucial. To date, these emissions have not been recorded. This means that users can cause emissions without having to bear the costs [66].

With regard to CO_2 emissions during production, distribution and disposal, there is a lack of precise data for almost all other drugs that are frequently used for anaesthesia. This means that no detailed statements can currently be made about individual drugs.

Since procedures such as total intravenous anaesthesia (TIVA) or regional anaesthesia do not result in direct greenhouse gas emissions, the procedure-specific emissions are significantly lower than those of inhalational anaesthesia [38,39,67–69]. However, it is important to consider the entire process and take local characteristics into account. A much-discussed Australian study even showed that use of spinal anaesthesia was disadvantageous compared to general anaesthesia in knee replacement surgery in terms of greenhouse gas emissions. This was due to a combination of consistent use of minimal flow and a very low proportion of disposable items in general anaesthesia and to high emissions caused by sterile gowns, which are standard practice in Australia and other countries when administering spinal anaesthesia. It was also found that all patients undergoing spinal anaesthesia were routinely given high amounts of oxygen via a mask. This also led to significant emissions since in Australia the energy required to produce oxygen is mainly generated by coal-fired power plants [70]. Given the different conditions and treatment strategies in Germany, a comparable study design would probably yield different results.

Considering smaller ampoule sizes is advisable if a significant amount of medication is wasted on a regular bases [39]. Switching from 50 ml or 100 ml ampoules of propofol to 20 ml ampoules could reduce wasteage by more than 90 % [71], which also saves costs [72]. In this context, an overall assessment is required, including taking waste into account (see below). Emergency drugs drawn up just in case and actually not being used later also create avoidable costs and waste [73]. Having those drugs manufactured under appropriate hygienic conditions in pharmacies as longer-life ready-to-use syringes or purchasing them as ready-to-use syringes should be considered. This also reduces the risk of incorrect preparation during dilution steps and the risk of bacterial contamination [26].

The **Swedish Stockholm County Council Drug Therapeutic Committee** has developed an environmental classification for pharmaceuticals. The **Hazard Score** (based on the prior **Persistence, Bioaccumulation and Toxicity (PBT) Index**) was designed to grade the risk pharmaceuticals pose to the environment. The score should be consulted whenever possible to select drugs which ensure the smallest possible impact on the environment. Unfortunately, a significant portion of drugs used in anaesthesiology have yet to be graded [74]. Drug waste age could reach to environment via the sewage system when discarded improperly – propofol remnants can be detected in hospital wastewater [75].

The potential environmental hazards posed by propofol are subject of intense debate, including as an argument against the increased use of TIVAs. However, assessing the ecotoxicity of a single substance is extremely complex [76]. Propofol is potentially persistent in the environment. It is not biodegradable neither in water nor under aerobic or anaerobic conditions. Nevertheless, the bioaccumulation potential is low. Propofol has high acute toxicity [77]. Based on the expected environmental concentration and the estimated concentration below which there is no risk to the environment, propofol is currently considered a substance with low environmental risk [76,78], while some antibiotics (such as erythromycin or clarithromycin) and painkillers (such as ibuprofen or diclofenac) have significantly higher overall ecotoxicity [76].

All departments must establish a system for proper disposal of pharmaceutical residues. Educating staff is necessary to implement these measures.

Disposing of unused medication residues in the drain is ecologically unacceptable. Only electrolyte solutions that do not contain any medication can be safely poured down the drain. All medication residues must be incinerated. The temperatures required in that respect vary [39]. In the first version of this position paper from 2020, the temperature required for the destruction of propofol residues was specified as 1,000 °C for at least 2 seconds, based on a US publication [71]. This would pose a problem in that most incineration plants in Germany only use 850 °C as their combustion temperature. A review of existing pharmaceutical safety data sheets for propofol, an enquiry with the German manufacturer and consultation with the Department of Pharmaceutical and Medical Chemistry at the Institute of Pharmaceutical Sciences at Christian-Albrechts-Universität in Kiel revealed that the ignition and decomposition temperature of propofol is below 600 °C (Professor Peifer, personal communication 22.12.2023). Therefore, Propofol – similar to most drugs used in anaesthesiology – can be disposed of as non-hazardous waste in standard incineration plants without any relevant residues being expected to remain in the environment (in accordance with waste disposal regulations of the Federal / State Working Group on Waste Management (LAGA) for the disposal of waste from healthcare facilities under code AVV AS 18 01 09) [39,79]. Since the disposal of medicines is to be organised pragmatically to reduce errors, leftover medicines are to be emptied into cellulose tissues and discarded with residual waste for incineration.

B. Consumables

E1: The increasing replacement of reusable products with disposable ones should be critically reviewed. Efforts should be made to increase use of reusable products to facilitate a circular economy in the healthcare sector.

E2: Use of reusable textiles (such as sterile and non-sterile gowns, surgical caps and drapes) should be implemented.

E3: Disposable metal items, in particular, have a poor CO_2 footprint, and replacing them with reusable products is strongly recommended.

E4: Manufacturers are to be required to present a complete Life Cycle Assessment based on uniform criteria for all medical products and medicines. Sustainable selection criteria should be established for procurement.

E5: Uniform and evidence-based guidelines for proper hygienic preparation of medical devices are required.

Single-use items are ubiquitous in anaesthesia and intensive care and are increasingly displacing reusable products. Main influencing factors in the decision process between single-use and reusable products are quoted as hygienical concerns, convenience, and cost. Environmental factors have traditionally played a lesser role [26].

Life-cycle assessments are available for an increasing number of medical products.

Reusable products often demonstrate clear ecological benefits over disposable materials. This also results in cost savings of 17 %–94 %. An increased risk of infection due to reusable items could not be verified [80,81].

- Disposable textiles account for a significant proportion of the CO_2 footprint of the products required for an operation [82]. Washable, reusable surgical textiles (surgical gowns, drapes) have a CO_2 footprint that is approximately 30 % – 50 % lower than disposable textiles. Disposable items consume 200 % – 300 % more energy, 250 % – 330 % more water and produce 750 % more waste [83–86].
- Non-sterile reusable textiles (such as isolation gowns in intensive care units) offer substantial ecological benefits compared to disposable alternatives [87,88]. In one study, this reduced greenhouse gas emissions by approximately 2/3 and water consumption by approximately 80 % compared to disposable gowns [83].
- When comparing disposable and reusable drug trays, the reusable items performed better from an ecological and economic point of view [89].
- Reusable laryngeal masks showed significantly lower negative environmental impacts in all reviewed dimensions [90]. When disposable laryngoscopes are used, CO_2 emissions are 16–25 times higher than with reusable instruments made of stainless steel, in particular if not only the laryngoscope blades but also the handles are made of disposable materials [91,92].
- New LCAs also confirm the environmental benefits of reusable products for sterile sets for central venous catheters [93], collection containers for sharp objects [94], pulse oximeters [95] and blood pressure cuffs [96]. Reusable bronchoscopes are preferable to disposable bronchoscopes from an environmental perspective [97].

The reprocessing of reusable medical products must be validated and performed in accordance with the German Medical Devices Implementation Act (MPDG) and the German Medical Devices Operator Ordinance (MPBetreibV). Requirements beyond this hygienically appriopriate approach do not provide any additional benefit, but generate increased ecological and economic costs. A proposal for a hygienically appropriate classification and corresponding reprocessing of devices that are particularly relevant to anaesthesiology is presented in Table 2 [98].

Ready packed sterile sets of reusable instruments are also used in anaesthesia and intensive care, e.g. for inserting chest drains. For sets containing 10 or more instruments, it makes sense to pack and process them together in a set, even if not every item is used. Single processing and packaging of individual instruments proved to be ecologically inferior [99].

Ecological factors should be taken into account when choosing packaging for reprocessed reusable products. Reusable aluminium hard containers generate the lowest CO_2 emissions when used for their entire. Replacing these with disposable sheet (soft) packaging (also known as fleece or "blue sterile wrap") results in approximately 6 times higher CO_2 emissions, based on 5,000 applications. If the disposable fleece is recycled, the factor is reduced to 3 times [100,101]. The CO_2 footprint of the energy source used, the size, utilisation and efficiency of the processing machines, and the precise size of the hard containers are crucial factors for the hard container results [99].

Extracting metals from ore is extremely energy intensive and leads to a very large carbon footprint [45,102]. The German Society of Hospital Hygiene (DGKH) notes that use of single-use metal instruments (laryngoscopes, scissors, needle holders, forceps etc.) is of particular concern because, if they are being mistakenly introduced into the sterilisation process, there is also a risk of corrosion of the other instruments [103]. In addition, numerous disposable products are manufactured under problematic ethical conditions in countries in the Global South [104]. Disposable metal instruments should be replaced by reusable instruments wherever possible. When this appears impossible, at least effective recycling should be required. One ton of recycled steel reduces CO_2 emissions by approx. 80 % compared to steel manufactured from raw materials [105,106]. If reusable metal products are damaged, they should be repaired rather than replaced if possible [107].

Table 2
Classification and preparation of medical devices relevant to anaesthesiology [98].

Article	Material	Risk classification	Possible treatment processes	Packaging
Laryngoscope blade	Stainless steel	sk A	Manual cleaning and disinfection – better RDG	Prevents recontamination
Video laryngoscope blade	Various metals: steel, aluminium, titanium, copper; glass	sk A (B)		
Laryngoscope handle Handle for video laryngoscope	Stainless steel Polycarbonate or other thermoplastics	uk A	Wipe disinfection	Not necessary
Stylets for endotracheal tubes	PVC (aluminium with plastic coating)/ stainless steel	sk A	Manual cleaning and disinfection – better RDG	Prevents recontamination Sterile barrier
Laryngeal mask, reusable Guedel tube Nasopharyngeal tube	Silicone, polyester, polypropylene polyurethane/polyethylene Wiruprene/PVC/soft rubber/silicone latex	sk B	Manual pre-cleaning (ultrasonic) – RDG	Prevents recontamination
Face mask	Silicone	UK A (B)	Manual pre-cleaning (ultrasonic) – RDG	Prevents recontamination
Breathing circuits Resuscitation bag	PVC, polypropylene, polyethylene Silicone	uk B	RDG	Prevents recontamination

uk: uncritical; **sk:** semi-critical; k: critical; **PVC:** polyvinyl chloride; **RDG:** cleaning and disinfection devices.

Using LCAs, the purchasing process can incorporate sound ecological factors. LCAs are specific to their respective geographic region. As energy sources and transport show significant heterogenicity, extrapolations should be regarded with circumspection and manufacturers called upon to provide national LCAs [26,108]. For example, reusable items perform particularly well in countries with a high share of renewable energies (e.g. in Europe). In contrast, the balance shifts towards disposable products in countries with very high CO_2 emissions per kilowatt hour (e.g. Australia) [109]. In the National Health Service in Great Britain, from 2028 only products with a stated CO_2 footprint shall be accepted [110], which could serve as a model for Germany. Standard survey patterns for LCAs and CO_2 footprints are urgently needed.

PVC (polyvinyl chloride) is a polymer used in approximately one quarter of all plastic medical devices. Examples include catheters and bags for urine, dialysis fluids, blood and some other infusions. PVC is also found in gloves, oxygen masks and tubes, and in suction systems [111,112]. PVC polymers can cause environmental and health problems throughout their entire lifetime, from production via use to disposal [113, 114]. Phthalate plasticisers used in PVC and found, for example, in infusion and transfusion sets, feeding tubes or ECMO consumables [115] are harmful to health. They can disrupt endocrine pathways and, therefore, cause fertility problems. They are also toxic to development and reproduction and promote respiratory diseases, childhood obesity and neuropsychological disorders. In addition, there is a positive correlation between exposure and high blood pressure and possibly atherosclerosis [113,116–120]. Excessive concentrations of plasticisers have already been detected in patients, particularly in neonates in intensive care units [121–123]. PVC can already be substituted in numerous medical devices. Procurement should request appropriate specifications from manufacturers and demand PVC-free products [124].

C. Waste Management

E1: The 5R concept of waste management **(Reduce, Reuse, Recycle, Rethink und Research)** should be implemented.

E2: An efficient recycling concept should be established in all operating theatre suites and intensive care units.

E3: It is necessary to demand that packaging material be reduced and that packaging be made from paper or, where possible, from single-type plastic that can be recycled to a high standard.

E4: As hazardous wastes generate very high CO_2 emissions due to their special disposal method, ordinary waste should not be classified as hazardous and should be disposed of accordingly.

E5: Good cooperation with other professional groups (in particular surgical departments, healthcare professions, hygiene, transport services, waste management, logistics and cleaning staff) is essential to implement a comprehensive waste management concept within a hospital.

Approximately 20–30 % of waste accrued in hospitals is generated in the operating theatre; 25 % of which is generated by anaesthesia, much of it is packaging [125,126]. Each theatre case generates between 7.62 and 16.39 kg of waste [45]. Intensive care units also generate large amounts of avoidable waste, in particular from infectious patients [127].

An Australian study quantified the amount of waste generated during the treatment of ten intensive care patients during the course of a week at 540 kg, 60 % of which could have been recycled if appropriate instructions and processes had been implemented [126].

In a comprehensive analysis of a 56-bed intensive care unit in Amsterdam, all consumables, energy and water consumption, and the total amount of waste were systematically recorded during a period of one year [88]. This study is insightful because it is the first longitudinal cross-sectional study that looked at about 2,900 patients and approximately 13,000 treatment days. Per patient and per day, 108 disposable gloves, 34 infusion bags, 24 syringes and 23 tubes, connectors or other connecting pieces were used. During the entire observation period of one year, the amount of waste generated was 247,000 kg, which corresponds to 17 kg of waste per patient per day and a CO_2 equivalent of 12 kg. In addition, 300 litres of water were consumed per patient per day.

The concept of the 5 Rs **(Reduce, Reuse, Recycle, Rethink, Research)** was introduced to reduce the ever-growing amount of waste [108]. A clear hierarchy applies here: the most important and effective measure is to avoid using unnecessary materials (Reduce). Essential products should be reused wherever possible (Reuse). Any waste that remains after this should be recycled to the highest possible standard and used for new products (Recycle). New solution strategies must be found and innovations implemented for all of these and for materials for which none of the strategies outlined above can be used (Rethink, Research).

Reduce:

Consuming fewer resources and reducing waste is a concept that is both ecologically and economically sustainable [128]. There are numerous ways to save material without compromising patient safety or quality.

The following measures are examples of this:

- Breathing circuits can be used for 7 days (except in cases of contamination or infectious patients) when using individual HME filters. Several studies showed no increase in bacterial growth in the tubes after 24 hours vs. 7 days [129–132]. Therfore the DGAI and the German Society for Hospital Hygiene (DGKH) recommend this approach [133]. In addition, use of reusable circuits should be considered [130].
- Ready-packed sets, for example for inserting central venous catheters or regional anaesthesia, as well as surgical trays, often contain unnecessary disposable materials, plastics or dressings. The contents of such kits should be reviewed regularly to ensure they are still relevant, as many items are often discarded unused [134]. These can usually be eliminated cost-effectively by the manufacturers on request [135].
- The decision to order diagnostic tests should not be taken lightly – for example, routine blood tests in healthy patients prior to minor elective surgery [136]. Effective patient blood management is at the same time a sound ecological approach [137,138].
- Adequate staff training can reduce the inappropriate use of non-sterile gloves. Wearing such gloves, unless indicated for hygienic reasons, can lead to a false sense of security and promote the transmission of germs through unclean, gloved hands [127]. During the SARS-CoV-2 pandemic, disposable gloves contributed most to the carbon footprint of personal protective equipment [139]. Performing such analyses should be required because they can identify the items with the greatest potential for savings.
- The consumption of disposable masks has risen sharply worldwide during the SARS-CoV2 pandemic. An evaluation should be performed to determine how the associated ecological footprint can be reduced [140–144]. A polypropylene layer in the mask, aluminium strips in the nose piece and long transport chains have a particularly poor ecological footprint [143,145], which should be taken into account when purchasing. Therefore, unnecessary use or changing face masks too frequently should be avoided.
- The size of infusion bags should correspond to the desired amount of intravenous fluid administration. Since the main emission is caused by the bag rather than the infusion solution, emissions per millilitre are lower for large bags, while small bags result in lower total emissions [146].

Realisation of material flow analyses (e.g. [88]) should be required because this allows identification of items with the greatest savings potential.

Reuse:

Please refer to the section "B Consumables" for information about reusing.

Recycle:

Recycling strategies offer opportunities to reduce the footprint of unavoidable waste. However, the first step should at all times be to reduce the overall amount of waste produced [147], for example by switching from disposable to reusable materials (see section "consumables").

Approximately 60 % of waste in the operating theatre is potentially recyclable. Insufficient containers and infrastructure, ignorance, convenience and a lack of support are cited as obstacles to effective recycling in operating theatres [148].

Materials such as paper/cardboard, plastic, glass, batteries, printer cartridges, electronic waste and metal can be recycled in the operating theatre and intensive care unit. Approximately 30 %

of surgical waste consists of plastic. This includes items made of polypropylene and PET (disposable textiles, blue sterilisation packaging for medical and surgical instruments), polyethylene (plastic tubes, cups and trays), polyurethane, PVC (suction tubes, oxygen tubes), copolymers and other mixtures. The composition is often insufficient or not declared at all. Some types of plastic needs to be processed separately, for example PVC [125]. Recycled plastic requires only 25 % of the energy needed for primarily produced plastic [149]. However, recycling co-mingled plastics will reduce the quality of the recyclate. Therefore, manufacturers should be held accountable to create packaging (which is easiest to recycle) out of single-type plastic and to lable it accordingly.

Most waste is generated when unpacking materials, even i.e. before the patient has entered the operating theatre. Contamination can be prevented by closing the recycling bags or finishing the collection of recycling waste before the patient is taken to the operating theatre [26].

Clearly structured programmes facilitate the introduction of a recycling programme and increase efficiency. Waste bins and recycling containers should be clearly colour-coded, easily accessible and labelled with clear instructions on what can be disposed of in them. The often limited German language skills of cleaning staff needs to be taken into account. In addition, the size of the containers should be appropriate (e.g. small containers for infectious waste next to larger residual waste containers). The involvement of local recycling companies and recurrent education of staff are essential [26,150].

A multidisciplinary "Green Team" of volunteers who oversee implementation is important. Most employees are highly motivated to promote environmental protection. Recycling programmes are therefore well received [150]. Approximately 50 % of potentially recyclable material, representing 14 % of total waste, was recycled in an intensive care unit [151]. Effective waste management brings not only ecological but also economic benefits [152].

Waste disposal

Different types of waste generate emissions at various levels. Therefore, waste types need to be clearly separated [153,154]. Hospitals generate approximately 60 % of household-type waste, which can be incinerated at low cost in a nearby waste incineration plant, ideally with energy recovery, at 850 °C. Approximately 30 % of waste is hospital-specific waste from nursing and treatment areas (e.g. sharp objects, pharmaceutical waste and infectious waste). Only about 10 % of the total waste is hazardous (3 % infectious and 7 % waste containing harmful substances such as chemicals and cytostatic drugs) [155].

Infectious waste needs be disposed of in special hazardous waste incineration plants [79,156]. The incineration of infectious and hazardous waste at temperatures of 1,100 °C or higher produces 949 kg of CO_2e/tonne, accounting for the majority of emissions related to waste disposal (data for the UK) [157]. Added to this are long transport routes to the 33 hospital and hazardous waste incineration plants in Germany [156,158].

To reduce waste-related emissions, different types of waste need to be separated and the proportion of infectious and hazardous waste kept as low as possible [21]. The LAGA definitions for infectious waste are to be taken into account. Accordingly, only waste contaminated with notifiable pathogens (e.g. blood containing HI or hepatitis viruses, stool contaminated with cholera, dysentery or typhoid, or sputum, urine or stool colonised by tuberculosis bacteria) is to be treated as infectious [79]. The indiscriminate disposal of materials in special waste bins should be avoided at all costs [159].

By implementing a waste separation concept in the intensive care unit, a case report showed a 50 % reduction in the amount of waste categorised as infectious. This has been accompanied by a reduction in CO_2 emissions of almost 40 % and disposal costs of approximately 30 % [160].

D. Mobility

E1: Hospitals should develop and promote alternative mobility strategies to minimise fossil fuel-based individual transport by staff and patients. Hospital internal logistics should be converted to low-emission concepts.

E2: Electric mobility and telemedicine should be used in pre-hospital emergency medicine as well as in intensive care and other patient transport. The necessity of airborne patient transport should be critically assessed for each individual case.

E3: Video consultations should be established to avoid unnecessary travel and ensure local care.

E4: Public transport should be used as the preferred means of transport for attending conferences and association work. Domestic flights should be avoided and only reimbursed as travel expenses in exceptional cases.

E5: Congress streaming, video conferences and webinars should be offered to reduce travel-related CO_2 emissions.

Mobility accounts for a significant proportion of the CO_2 footprint of the healthcare sector. The following four areas of transport are to be taken into consideration: commuting to work, emergency services, outpatient and individual transport of patients, and travel to conferences and other educational trips. Different approaches are relevant for reducing the CO_2 footprint in the individual areas.

In daily commuting, the average car occupancy rate is 1.4 people [161]. In one study, commuting to work accounted for approximately 12 %–39 % of the CO_2 footprint of an anaesthesia department [46]. Alternative mobility concepts tailored to local conditions are necessary to limit these work-related CO_2 emissions.

Possible targets for interventions within the hospital include [162]:

- Enhancement of the of cycling infrastructure together with a sufficient number of bicycle parking spaces on hospital grounds; calls for hospitals to be connected to cycle path.
- Charging infrastructure for e-mobility.
- Discounted tickets for switching to public transport. Good connections between hospitals and public transport must be ensured.
- Hospital-based commuter portals/ carpooling services for employees
- Expansion of home office options, video conferencing and video consultatios
- The implementation of a mobility concept targeting commuter traffic is expected to also facilitate patient use of enhanced cycling and pedestrian infrastructure, as well as improved public transportation services.

A switch to alternative, non-fossil fuel-based, engines will be unavoidable in the emergency services sector. Another possibility is to critically question transport options with particularly high fossil fuel consumption (such as air rescue) if they are not clinically necessary. Given the high proportion of emergency calls that do not require medical intervention, use of telemedicine is already established in some cities to reduce the requirement for a second vehicle with emergency medical personnel. Following the introduction of the telemedical system in the city of Aachen between 2013 and 2021, the number of emergency ambulance call-outs was reduced by more than 40 % [163]. In general, the implementation of telemedical consultations can significantly reduce the CO_2 footprint. A telemedical doctor's visit is already the more climate-friendly alternative compared to travelling by car for distances of more than 3.5 km [164]. This also applies to anaesthesiology [165].

The number of large, international conferences with ever more participants travelling long distances is increasing. Conference participation causes significant CO_2 emissions associated with travelling, especially over long distances as is required in some cases. The journeys of all participants to a single international conference were associated with a 22,000 t carbon footprint, equivalent to the average annual carbon footprint of 2000 citizens in Germany [166]. Air travel is especially problematic because of the associated emission of 238 g CO_2 per passenger kilometre, by far the largest carbon footprint associated with travel. CO_2 emissions per passenger kilometre are significantly lower for car (166 g/km) or rail journeys (31 g/km) [161]. Air travel should be critically questioned and at all times offset by meaningful programmes. Furthermore, the possibility of online options for congresses should be expanded. Online streams of lectures and interactive sessions should be offered as an attractive option to enable participation in conference events without having to travel, in particular because this can reduce the carbon footprint by up to two orders of magnitude [166,167].

E. Energy management

E1: Anaesthesia equipment and intensive care ventilators, as well as monitors, syringe pumps and other medical technology, consume a considerable amount of energy in standby mode. These devices should be switched off completely at the end of the regular programme, with the exception of the emergency operating theatre.

E2: To reduce the high energy consumption required to operate the scavenging systems, these should be disconnected at the end of normal operating hours. If using anaesthetic gas filters, the use of scavenging systems can be discontinued altogether.

E3: Concepts aimed at reducing the considerable power consumption associated with heating, ventilation and air conditioning in operating theatre suites and intensive care units should be implemented, for example, including setback options outside regular operating time, optimisation of temperature and ventilation settings, and restriction of user-side temperature adjustment in operating theatres.

E4: All departments should contribute to ensuring that their hospitals systematically evaluate options for energy-saving measures, energy-efficient refurbishment, and the utilization of renewable energy sources, and implement these options in a timely and effective manner.

E5: A switch to renewable energy is essential to reduce the carbon footprint of hospitals in Germany.

Operating theatres, as well as intensive care units, are generally very resource-intensive areas with very high energy consumption [21,168]. In England, for example, electricity consumption per intensive care patient per day was equivalent to the consumption of a four-person household [169].

Until now, medical devices used in anaesthesia or intensive care have often been put into standby mode when not in use. However, devices in standby mode consume 88 %–93 % of energy needed during full operation and, therefore, significantly more than is required to start up the devices from a switched-off state [170–172]. Simply switching off anaesthesia equipment routinely could save approximately 25,000 kWh or 10 tonnes of CO_2 p.a. at a German university hospital even if taking emergency operating theatres into account [170]. A comparable study conducted at another university hospital showed that avoiding standby mode could result in potential energy savings of 20,000–46,000 kWh and emission reductions of 8.5–19.2 tonnes of CO_2 p.a.[172]

To prevent contamination of the ambient air in the operating theatre with VA, scavenging systems are to be provided at all anaesthesia workstations where VA is used. Operating these scavenging systems requires medical compressed air, generated via air compressors run through a cleaning process, which is energy and cost intensive. As soon as the scavenging system is plugged in, medical compressed air and the Venturi effect create suction that draws the exhaust air from the anaesthesia machine into the ambient air of the hospital. This process requires 14–80 litres of compressed air per minute and extraction point, causing 0.5 to 6.7 t CO_2 per scavenging system p. a. and up to 4,000 € of electricity costs p.a. if they are not switched off outside normal working hours [64,173]. The scavenging system connectors can be easily disconnected at the end of the regular working hours. The hose can be hung over the anaesthetic machine to ensure that reconnection, which only takes a few seconds, is not forgotten. This simple measure can save over 70 % of associated electricity costs and 0.4–4 tonnes of CO_2 emissions per year and per extraction point [173]. Demand-driven scavenging systems could be an alternative. These systems reduce compressed air consumption by more than 90 % and were developed more than 10 years ago, but have yet to be implemented in any commercially available anaesthesia machines [54]. Here, industry is called upon to develop energy-efficient and cost-effective solutions. Professional maintenance of compressed air systems to detect pipe leaks, which are a common problem, and upgrading scavenging connections to the latest technology can also result in significant savings in electricity and CO_2 emissions.

Under certain regulatory conditions, use of anaesthetic gas filter systems could render scavenging systems redundant, even when VA is used, thereby completely avoiding the costs and emissions associated with scavenging [58,63].

In many hospitals, in addition to medical compressed air at 5 bar, a separate 10-bar line is also provided for air motor devices, which are only used very rarely, e.g. in trauma or heart surgery. If these air motor devices are replaced by battery-powered devices, the entire system can be throttled to 5 bar, resulting in significant energy savings.

The energy consumption for paediatrics and burns cases of operating theatres is 3 to 6 times higher than that of the rest of the hospital. The majority of energy in the operating theatre is used for heating, air conditioning and ventilation alone [45].

These CO_2 emissions can be diminished by reducing energy consumption [45,168,174]. Energy-saving measures in operating theatre suites can reduce carbon footprint of the operating suite by 50%, a measure which also significantly cuts costs [45]. The following practical steps should be taken:

- In operating theatres, heating, ventilation and air conditioning are frequently operational around the clock, despite the fact that those theatres are often unoccupied at least 40 % of the time. Setback operation in systems in unused operating theatres ("night setback" or "unoccupied setback") – with the exception of required emergency theatres – can facilitate energy savings of up to 50 % [45,175].
- First steps with regard to heating and air conditioning concern the temperature settings in central control systems [174]. In operating theatres with high ambient temperature, every reduction of temperature by 1° C can reduce the energy required for heating by 5–8 % [174]. However, frequent adjustments to the temperature in an operating theatre are associated with high energy consumption. Therefore, it makes sense to agree on a fixed temperature in consultation with the surgical departments and building services, which should then not be adjusted – except operating theatres for pediatric and burn patients. A room temperature of 21 °C has proven to be a reasonable compromise between preventing hypothermia in patients, ensuring comfortable conditions for operating personnel and technical implementation, and is also recommended in the S3 guideline "Prevention and Treatment of Perioperative Hypothermia" [176]. This is within the lower range of the temperature corridor of 19 °C–26 °C specified for operating theatres in DIN 1946-4 and is, therefore, also advantageous in terms of energy consumption and ecology. Patient's thermal homeostasis is maintained by warming devices, not by room temperature [176]. It may be necessary to technically disable the temperature adjustment options in operating theatres to prevent thoughtless actions by staff. For staff freezing in theatre, appropriate warm theartre attire must be provided, e.g. in the form of additional washable long-sleeved surgical gowns or jackets.
- Ventilation systems must be checked and the air exchange rates adjusted in line with room air temperatures [174]. In other European countries, it is already common practice to switch off ventilation systems completely during non-operating hours [177].
- In less frequented areas (storage or auxiliary rooms, toilets, etc.) it is expedient to control the lighting using motion detectors [178].
- The halogen lamps traditionally used in operating suites should be exchanged for LEDs. This can reduce energy consumed for lighting by 80 % [174,179]. In addition, LEDs radiate less heat, which reduces the energy required for cooling [21].

Care for intensive care patients caused the emission of 88–178 kg CO_2e per patient day, with energy consumption (dominated by requirements for heating, ventilation and air conditioning), again making up 76–87 % of the carbon footprint [168]. A switch to renewable energy is recommended together with optimisation of the energy efficiency of the building to reduce the carbon footprint [180]. Holistic energy management concepts can enable hospitals to reduce their energy requirements by up to 30 %, reducing the associated CO_2 emissions by up to 50 %. In addition to technical solutions, these concepts also integrate approaches aimed at optimising user behaviour [42]. Energy saving measures such as these can lead to longterm cost reductions [174,181]. Each and every hospital in Germany should identify their options for introducing such measures and implement those.

The combined heat and power systems (CHP) commonly used in German hospitals exhibit a high primary energy yield by using the heat produced during electricity generation for heating or cooling the building. High energy yields can, however, only be achieved during optimum operation of the CHP system. Because they currently typically consume fossil fuels, these systems should be regarded as interim technologies [181, 182]. The switch to a climate-friendly future necessitates the use of renewable energy for electricity and heating in hospitals. Using wind or waterpower, photovoltaics, solar thermal and geothermal energy or biogas allows for generation of energy with a reduced carbon footprint, and can be shaped to be cost efficient [174,181].

F. Research and teaching

E1: The effects of climate change on intensive care and emergency medicine, and on hospital capacity have not yet been adequately researched. Appropriate research projects should be developed and supported, including to promote an environmentally resilient healthcare.

E2: Research projects on ecological sustainability should be promoted in all pillars of anaesthesiology.

E3: All research projects should take into account the ecological, social and economic dimensions of sustainability. Measurable and comparable indicators must be developed for this purpose. This focuses at all times on providing the best possible patient care while taking planetary health aspects into account.

E4: Conferences, meetings and training events in anaesthesiology and intensive care medicine should be planned, organised and carried out in an environmentally responsible and CO_2-neutral manner.

E5: Ecological sustainability in the health sector and the consequences of global environmental change for patients and healthcare should be an integral part of student teaching, medical training and the training of healthcare professionals. This is intended to encourage environmentally friendly behaviour.

Pulmonary, nephrological and infectious diseases will increase to a relevant extent as a result of climate change. This will have a significant impact on required emergency medical and intensive care capacities. Further research is needed to address the health consequences of climate change and other global environmental changes for the population in the best possible way and, consequently, to build an environmentally resilient health system [183–185].

Both the CO_2 footprint and ecological sustainability in the health care sector have not been sufficiently investigated to date. In this regard considerable research efforts will be necessary in the coming years to develop specific options for reducing CO_2 emissions and ecologically sustainable concepts in healthcare [186,187]. Research projects relating to environmental sustainability in anaesthesiology and intensive care medicine should focus on treatment pathways that provide the best possible patient care while taking planetary health aspects into account.

Little is known about the ecological impact of different treatment regimens. A systematic review analysed ecological aspects in health economic evaluation of intensive care measures, but none of the 278 included studies took ecological aspects into account [188]. There is undoubtedly consensus that, in the case of two equally successful and cost-intensive treatment strategies, preference should be given to the one that has a lower impact on the environment [189].

Measurable and comparable indicators should be developed for various dimensions of sustainability in everyday clinical practice (e.g. social, ecological, economic). These should also be included primarily in patient-related research projects. By taking them into account in these early, evidence-gathering steps, sustainability-related facts should also be available for the development of recommendations for action.

Events such as conferences, meetings and training courses should be planned and conducted in as sustainable and CO_2-neutral a manner. To that end, unnecessary emissions from travel, event venue, accommodation and catering for participants, materials used and waste produced should be avoided [190].

As academic teachers, we have a special responsibility to continuously develop knowledge about sustainability aspects of clinical work, incorporating subject-specific planetary health aspects through research, and pass this on to the next generation of doctors. Therefore, longitudinal integration of sustainability and planetary health aspects into the curriculum of student education is essential. It should become an integral part of every event (including internships, electives and other student practice experiences). Future doctors should learn about the impacts of global environmental change on patient health, clinical work and the health sector as a whole. Above all, ecologically sustainable treatment pathways should be learned aiming towards providing the best possible patient care.

One possible tool for assessing the quality of medical education in this regard is the Planetary Health Report Card (https://phreportcard.org/). Planetary health aspects should also be implemented by the educational institutions themselves. In addition to education, it is necessary to promote research into planetary health and sustainability in healthcare and support student initiatives in this area.

To the same extent, corresponding efforts are required to promote knowledge of ecologically, socially and economically sustainable patient care as part of continuing medical education and training. Appropriate anaesthesiology training and continuing education enable anaesthetists to work not only in their everyday clinical practice. They can also convince other departments about the importance of environmental sustainability and environmental change adaption. Thanks to their collaboration with many other departments in everyday clinical practice, anaesthetists could play a key role here and initiate a broad rethink.

Interprofessional training for all employees is essential to raise awareness about the topic. For example, hospital staff and hospital administrators should be educated about the importance of life cycle analyses of medical devices and materials used. Sustainability aspects should be considered in quality concepts and quality improvement projects. Patients and students can be informed about current sustainability concepts and research projects via newsletters, podcasts, patient colloquiums or the website of the respective department, for example, and this information should be published in regular, publicly accessible, sustainability reports [186,187]. Research findings and quality improvement projects on sustainability should have a permanent place in publications, at conferences and in continuing education in our field [187].

G. Consequences of global environmental changes for patient care

E1: Climate change and other global environmental changes have a major impact on health. Both emergency and intensive care medicine have a special obligation to adapt to this and create environmentally resilient structures that facilitate immediate, efficient and professional management in the event of natural disasters, heat waves or unusual transmissible diseases.

E2: In the field of emergency services and disaster control, emergency plans must be developed in close coordination with inpatient and outpatient service providers and local authorities to cope with, potentially prolonged, extreme weather events (heat waves and floods etc.).

E3: All hospitals are being urged to develop emergency plans to protect patients in non-air-conditioned areas from extreme heat. The clinical infrastructure, including personnel and materials, must be taken into account accordingly.

Global warming and climate change have become directly noticeable in recent years, even in Europe, as demonstrated by the increase in heat waves and other extreme weather conditions (floods, wild fires, lowering of groundwater level). The consequences of climate change for health are subject of numerous studies and publications [191]. The World Health Organisation (WHO) estimates that there will be 250,000 additional deaths worldwide each year [192]. The emergence of “New” diseases or diseases that are becoming more prevalent, in particular infectious diseases, is highly relevant to intensive care medicine [183,193].

Exact data on the significance of heat waves or climate change-related natural events for intensive care management is not (yet) available. However, it can be assumed that intensive care will also be in greater demand during extreme weather events, in particular since calculations for Germany indicate that each heatwave is likely to result in an increase of approximately 10,000 deaths [194].

Climate change-related illnesses mainly affect respiratory, cardiovascular and renal systems: people with pre-existing chronic lung diseases (COPD, asthma) are more susceptible to inflammatory reactions when exposed to high temperatures, as heat waves are associated with increased concentrations of CO_2, greenhouse gases, ozone, nitrogen dioxide and particulate matter. In addition, extreme dryness causes airway hyper-reactivity [195]. Epidemiological studies show that during heat waves there is an excessive increase in emergency room visits and hospital admissions due to respiratory diseases (e.g. [196]).

Climate change and heat waves are associated with an increased incidence of cardiac events (heart attacks, cardiac decompensation), which is likely to result in an increased need for intensive care treatment [197]. Renal dysfunction appear to play a particularly important role during heat waves. Older people with multiple comorbidities, in particular, are at increased risk of renal dysfunction, including renal failure, due to dehydration and volume loss. In this context, it was also demonstrated that prolonged and uncompensated heat exposure triggers an inflammatory response within the kidneys which, analogous to the cardiovascular system, sets off a damaging cascade (e.g. rhabdomyolysis, increased vasopressin expression). The term “Heat stress nephropathy” was coined to describe this complex of symptoms [198]. In regions with pronounced and prolonged exposure to heat (e.g. California, southern Europe), indications for renal replacement therapy significantly increased compared to regions with “normal” temperatures [199].

The significant increase in respiratory, cardiac and renal diseases associated with climate change, with high morbidity and mortality rates, requires comprehensive pathophysiological knowledge and sufficient human resources for targeted treatment.

Similarly, unusual infectious diseases that have previously been considered “Exotic” in Central Europe and were only observed in people who had spent time abroad, potentially represent a growing need for intensive care treatment. Viral (e.g. hanta, West Nile, Zika and dengue viruses), bacterial (e.g. Vibrio vulnificus, Borrelia burgdorferi) and fungal infections (e.g. Aspergillus) are increasingly identified in Central Europe, particularly during heat waves [200]. The risk of Plasmodium infections (malaria) is also expected to increase by approximately

5 % in the event of further global warming [201].

"Unusual" bacterial, fungal and viral transmissible diseases that are also spreading in Central Europe due to increasing warming require specialist knowledge with regard to rapid differential diagnosis and targeted treatment. This requires adequate isolation facilities and infectious disease expertise. The situation is similar with zoonotic infectious diseases. The risk of such infectious diseases with potentially pandemic proportions is greatly increased as a result of greater contact with wild animals, which is caused by increasing land use by humans [202,203]. An environmentally resilient healthcare system must also be adequately prepared for this [185].

The EuroHEAT study [204] investigated the link between heat waves and mortality per day in nine European cities. There was a significant increase in overall daily mortality of up to 40 % (in particular in Mediterranean cities) during periods of pronounced temperature increases lasting several days. Approximately 50 % of deaths were due to cardiac events.

Acute heat illness encompasses various manifestations and degrees of severity (heat cramps, heat oedema, heat exhaustion, heat stroke) and poses a growing challenge for emergency and intensive care medicine, in particular since it requires immediate, treatment with special expertise [205]. The most severe form of heat exposure, known as heatstroke, is a life-threatening condition. Analyses from France examining the effects of the extremely hot summer of 2003 showed a massive increase in number of patients admitted to intensive care units with heatstroke. The hospital mortality rate for these patients was around 60 % [206], meaning that professional treatment (cooling, special supportive intensive care) is of enormous importance. The authors of the aforementioned study even admit that they were not adequately prepared for such patients because not all intensive care units were equipped with air conditioning or mats or cooling baths.

In the event of flooding or power outages, the supply chains of the healthcare system can be jeopardised. Hurricane Sandy, which swept across New York in 2012, caused a total power failure at Tisch Hospital (one of New York University's clinics), necessitating the evacuation of all patients. At the same time, many people suffering from hypothermia, psychological shock or the worsening of chronic illnesses had to wait for treatment. The St. Antonius Hospital in Eschweiler suffered a similar fate during the massive flooding of the Ahr Valley region in 2021. Not least because of the above examples, healthcare facilities must also prepare for such scenarios and have a realistic crisis plan in place.

Climate change and biodiversity loss reinforce each other. In addition, the effects of climate change are becoming more noticeable due to the loss of biodiversity because the resilience of ecosystems is weakened. Heat is more bearable in dense forests, green and blue areas can cool down cities, and vegetation protects against erosion and flooding during heavy rainfall. Natural processes that purify the air are declining [185,207]. At the same time, diverse nature is the foundation of modern medicine. The majority of medicines prescribed in Germany have natural origins in plants, animals or microbes. This applies, for example, to opiates, aspirin, ACE inhibitors, penicillin, Marcumar, as well as non-depolarising muscle relaxants such as curare. Research in medicine and pharmacy is based in many respects on research of other species, and a large proportion of natural species have not yet been discovered [208]. The loss of biodiversity is also directly noticeable as a result of a shift in infection risks. Deforestation, for example, leads to reduction of mosquito diversity, so that mosquito species that are particularly effective at transmitting malaria dominate [208].

These trends may be further exacerbated by global pollution. Pollution is currently the biggest environmental risk factor for premature death – possibly because it is much easier to quantify than other environmental changes [209]. As anaesthetists and intensive care physicians, we are primarily confronted with the effects of air pollution and the associated respiratory diseases. The consequences of chemical and water pollution are usually less tangible in everyday anaesthesiology, but should be taken into account when disposing of medicines and medical devices.

For all reasons mentioned above, a corresponding curriculum should be implemented as part of intensive care training, and the topics associated with climate change and other global environmental changes and their resulting. Diseases should be regularly integrated in intensive care training courses. In addition, the professional associations involved in intensive care medicine should be required to set up appropriate working groups and forums.

Development of specific structural concepts is required to respond to the continually growing demand for intensive care capacities, both due to the general rise in temperature and in the event of acute and overwhelming demand in the context of natural disasters or pandemics.

An environmentally resilient healthcare system is necessary [185] to ensure that intensive care and emergency medicine are as well equipped as possible to meet the challenges ahead and remain fully functional, including in the event of simultaneous crises. Specifically, the following approaches to solving the intensive care challenges posed by global warming, climate and other global environmental changes should be discussed [183,184,210]:

- Increase the capacity of intensive care beds, in particular in coastal regions and large cities, for patient care in conjunction with heat waves or air pollution.
- Provision of a sufficient number of renal replacement therapies for the treatment of patients with acute kidney injury during heat waves
- Establishment of a "reserve" of intensive care beds and personnel that can be activated in an emergency, in particular in the event of a mass influx of critically ill patients in conjunction with rapid weather changes, floods, forest fires or other natural disasters.

- Provision of isolation facilities and expansion of the knowledge of intensive care personnel in respect of managing “unusual” infections.
- Ensuring adequate precautionary and supply management for hospitals in the event of relevant restrictions in energy supply, logistics and supply chains in the event of natural disasters.

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