Foundation

Global Safety Evidence Centre

The impact of climate change on safety at work

Safe Work

Evidence Review

Technical Report

Preface

This research has been funded by Lloyds Register Foundation, with the aim of supporting the Foundation's Global Safety Evidence Centre. For more information on the Centre, please visit: *lrfoundation.org.uk/news/research-support-for-the-establishment-of-a-global-safety-evidence-centre*

About Lloyd's Register Foundation Global Safety Evidence centre

The Lloyd's Register Foundation Global Safety Evidence Centre is a hub for anyone who needs to know 'what works' to make people safer. The Centre collates, creates and communicates the best available safety evidence from the Foundation, our partners and other sources on both the nature and scale of global safety challenges, and what works to address them. It works with partners to identify and fill gaps in the evidence, and to use the evidence for action.

To find out more about the Global Safety Evidence Centre, visit *gsec.lrfoundation.org.uk*

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Lloyd's Register Foundation is an independent global safety charity that supports research, innovation, and education to make the world a safer place. Its mission is to use the best evidence and insight to help the global community focus on tackling the world's most pressing safety and risk challenges.

To find out more about Lloyd's Register Foundation, visit *lrfoundation.org.uk*

Lloyd's Register Foundation, 71 Fenchurch Street, London, EC3M 4BS, United Kingdom

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This report is authored by: **Giulia Maistrello, Bhavya Singh, Ioli Howard, Avery Adams, Priyanka Cardoz, Nick Fahy, and Joanna Hofman**.

Executive summary

Context, aims and methods

RAND Europe has been supporting Lloyd's Register Foundation in its the establishment of the Global Safety Evidence Centre, to better understand the complex factors that affect safety across the world. To help the Foundation explore possible areas of focus for the Centre, RAND Europe has conducted two scoping reviews. This report presents the findings of one these reviews, examining the impacts of climate change on occupational safety and health (OSH). The other review focuses on the interaction of emerging technologies and OSH will be published later this year.

This report explores how climate change heightens risks for workers in selected economic sectors, assesses the nature and quality of the available evidence, and identifies research areas where the Centre can add value in this area. Our approach combines a scoping review of the available evidence, targeted sector-specific reviews, expert interviews, and a stakeholder workshop. In order to effectively navigate through this vast evidence landscape, the research team utilised innovative AI tools, both developed in house and available online, to identify and summarise relevant literature.

A multifaceted and holistic approach is essential for understanding the interconnected climate-driven risks that span multiple sectors worldwide. Our findings are structured to first highlight the key OSH risks associated with climate change and the geographies impacted. We then provide targeted reviews of seven economic sectors: agriculture, construction, disaster response, energy, manufacturing, mining and transport. These sectors were chosen due to their high-risk nature, as indicated by fatality rates, or else their particular relevance to climate change. While recent reviews have examined OSH risks, few have compared these effects across different economic sectors. Our study aims to address this research gap.

Findings

Risks associated with climate change

The key health and safety risks associated with climate change include excessive heat, UV radiation, air pollution, extreme weather events, vector-borne diseases, and agrochemicals, the use of which is increasing due to declining efficacy and rising pest pressures. These risks are exacerbated by climate change and have widespread effects on the safety and physical and mental health of workers. While certain risks, such as heat stress and UV exposure, are well-documented, others, such as biological hazards and the risks to mental health, are less studied.

Geographies affected

All regions worldwide are affected and will continue to be affected by climate change even if the effects on different regions will vary (e.g. some getting drier, others getting more humid). However, the distribution of evidence and research available is uneven across the globe. While low- and middle-income countries (LMIC) will be disproportionately and more severely impacted, most research and data are focused on and produced by Europe and North America.

Impact on selected economic sectors

All economic sectors are impacted by climate change. However, not all sectors, occupations (or groups of workers) have been researched equally. For example, more evidence is available on the risks for outdoor workers (especially in agriculture and construction) than those working indoors. Furthermore, most research on the health effects caused by climate change have focused on the general population rather than on workers in specific industries or occupations. While similar risks occur across sectors, each sector and group of workers require targeted evidence-based guidelines, policies and regulations to support organisations toas they adapt and mitigate the negative effects of climate change on their workforce. Below, we summarise key findings for each of the selected sectors and their main occupations. The summaries contain references only to the key statistics; all other references can be found in the main body of the report.

Conclusion and recommendations

Nature of the evidence

Addressing the impact of climate change on OSH requires a 'think globally, act locally' strategy. While the challenge is a global one, research, interventions and policy must be tailored to specific contexts in order to be effective. There is increasing attention on understanding this space, and research in the area is growing. However, this review highlights that despite the substantial volume of evidence on the wider topic of climate change and OSH, many specific contexts remain under-researched, leaving gaps in knowledge.

Recommendations for the Global Safety Evidence Centre

Considering the amount of parallel research occurring in this area, the Centre can reduce duplication and streamline activities by coordinating research efforts and identifying understudied priorities. It can also support context-specific capacity for data collection and analysis, particularly in regions with unreliable sources. By facilitating cross-contextual learning, the Centre can ensure that effective strategies are adopted globally, promoting shared learning and application in diverse settings. Finally, the Centre can maximise its impact by focusing on translating and sharing existing knowledge, establishing robust processes for disseminating up-to-date information.

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Abbreviations

AI	Artificial Intelligence
ALNAP	Active Learning Network for Accountability and Performance
ASM	Artisanal and Small-Scale Mining
CCS	Carbon capture and storage
EMF	Electromagnetic Fields
EU	European Union
EU-OSHA	European Agency for Safety and Health at Work
GDP	Gross Domestic Product
HSE	Health and Safety Executive
ILO	International Labour Organization
INT	Interview
ISIC	International Standard Industrial Classification of All Economic Activities
ISCO	International Standard Classification of Occupations
LLM	Large Language Model
LMIC	Low- and Middle-Income Country
LSM	Large-Scale Mining
LRF	Lloyd's Register Foundation
OSH	Occupational Safety and Health
PPE	Personal Protective Equipment
RAG	Retrieval Augmented Generation
RCT	Randomised Control Trial
REA	Rapid Evidence Assessment
UK	United Kingdom
US	United States
UNSD	United Nations Statistics Division
USFA	United States Fire Administration
UV	Ultraviolet
WB	World Bank
WS	Workshop

1. Introduction, research aims and methodology

RAND Europe has been supporting Lloyd's Register Foundation (hereafter the Foundation) in its plans to establish a Global Safety Evidence Centre (hereafter the Centre). This initiative draws inspiration from the UK's What Works Network, a government initiative designed to improve public services by promoting evidence-based decision-making. What Works focuses on evaluating and disseminating research to inform policy and practice across various sectors, such as education, health or policing. RAND Europe's feasibility study for the Centre highlighted that, in order to be successful and have impact, evidence centres need to focus on well-defined topics and priorities (Maistrello et al. 2023).

To aid the Foundation in selecting priorities for the Centre, RAND Europe conducted scoping evidence reviews on potential areas of interest, which emerged from stakeholder consultations during the feasibility study and were refined through further discussions with the Foundation. The present review examines the effects and impact of climate change on occupational safety and health (OSH), with a focus on a selection of economic sectors. While recent reviews have explored the specific risks that climate change poses to workers[1], few have compared how climate change might impact different economic sectors. Our review covers seven sectors, chosen for their high fatality rates and susceptibility to climate change: agriculture, construction, disaster response, energy, manufacturing, mining and transportation.

Simultaneous to this study, RAND Europe conducted a separate review to explore another potential area of interest for the Centre: the interaction of emerging technologies and OSH. This review employed similar research methods and will be published later this year.

1.1. Research aims

This report examines the effects of climate change on OSH in selected sectors. Its primary aim is to map the existing knowledge and evaluate the volume and nature of available evidence. Additionally, it aims to identify potential research gaps to be addressed as well as areas where the Centre could make an impact in this space.

The research questions used to guide the research were:

- What is known about the impact of climate change on OSH in selected sectors?
- What is the nature of the available evidence? What are the gaps?
- How can a Global Safety Evidence Centre add value to this space?

1.2. Methodology

This review was carried out in four stages:

1. A broad mapping of the academic literature on the topic, using innovative artificial intelligence (AI) tools.
2. Targeted reviews on specific economic sectors, using purposive searching and including grey literature to provide an overview of issues and evidence.
3. Expert input through individual interviews.
4. A workshop to review and refine our findings.

Each of these stages is detailed in the following paragraphs.

1.2.1. Broad mapping of the topic using innovative AI tools

The first phase of this review aimed to garner a broad understanding of the evidence landscape around climate change and OSH. Given the vast amount of literature on this topic, we utilised two AI tools developed by RAND Europe to provide a broad mapping of the academic literature and identify key articles. These tools offered a high-level characterisation of the literature, in order to provide a basis for selecting areas of focus. While the tools helped to give a sense of the literature as a whole, researchers remained essential to the process, thoroughly reviewing AI-generated outputs, analysing the information, organising the findings and drafting the report.

We began by conducting a literature search using the **OpenAlex database**, an open-source data catalogue that indexes over 240 million journal articles and updates daily. OpenAlex was selected for its breadth and compatibility with our AI tools, allowing us to efficiently integrate search results into our analysis workflow. The literature search on OpenAlex compiled a dataset containing metadata for each identified paper, including the full abstract, author information and the publishing journal. The search string initially yielded about 1.8 million academic titles published in English between 2021 and 2024. We restricted the publications time frame to three years due to the extensive volume of literature on this topic. These papers were ranked by relevance to the search terms, with the top 2,000 being selected for further analysis. The analysis of the metadata was conducted using two AI tools.

The first AI tool used was an **interactive topic clustering map**, which allowed us to visualise the thematic structure of the literature using the abstracts of all 2,000 selected papers. Onceclusters of related themes were identified, a large language model (LLM)[2] was employed to summarise each of them, providing an overview of key topics across incrementally broader categories.

This facilitated a deeper understanding of the thematic landscape and guided the next stages of our analysis. The map was designed for use at multiple levels: at level one, individual research papers were represented as distinct points, each linked to semantically related

1. For example, ILO, 2024 and P. A. Schulte et al., 2023.

2. This was a RAND Europe private implementation based on Microsoft's Azure OpenAI service using the ChatGPT4 model.

articles and displaying their title, authors and abstract. At higher levels, each point corresponded to a thematic cluster, with a detailed description available by clicking on it.

The second tool, employing a **Retrieval Augmented Generation** (RAG) approach, functioned as a chatbot. Researchers used this tool to ask questions about the identified body of literature. The tool could retrieve information from the abstracts of the selected articles and cluster summaries, providing concise answers along with reliable references to specific articles.

Using these tools, we **refined the search terms** iteratively throughout this first phase of the research. We conducted three rounds of refinement, improving the specificity of the search by excluding topics that were not directly relevant to the research aims. The final research string can be found in Table 1.

Table 1. Final search string

("risk" OR "harm" OR "danger" OR "consequence" OR "outcome" OR "transition" OR "implication" OR "effect" OR "challenge" OR "adapt" OR "resilien" OR "modif") AND ("safety" OR "health" OR "injur" OR "illness" OR "disease" OR "accident" OR "incident") AND ("climate" OR "global warming" OR "environment" OR "sea level" OR "carbon emissions" OR "greenhouse gas" OR "energy" OR "decarbon" OR "heat" OR "extreme weather" OR "change" OR "variability")

1.2.2. Sector-specific reviews

In the following phase, we conducted targeted reviews on selected formal economic sectors to identify key themes and areas that require further research. We chose this approach because there are recent existing reviews and reports focusing on the general risks posed to workers by climate change, while there is a scarcity of reviews considering specific sectors.

We used the International Standard Industrial Classification of All Economic Activities (ISIC)[1] to define the sectors, which were selected using two criteria:

1. High-risk sectors, defined as sectors with the highest number of fatal occupational injuries per 100,000 workers by economic activity in 2022, identified using International Labour Organisation (ILO) statistical data[2].
2. Sectors particularly susceptible to climate change impacts, such as disaster response and energy.

1. The ISIC is the international reference classification of productive activities, and provides a set of activity categories primarily used for statistical reporting.

2. ILO statistics on occupational injuries come from a variety of sources, including various types of administrative records, establishment surveys and household surveys. This hinders the comparability of the data across countries, since each type of source provides information on different specific concepts (ILO, n.d.).

The selected sectors and fatalities per 100,000 workers are presented in Table 2.

Table 2. Selected sectors and their fatalities per 100,000 workers

ISIC sector	Fatal occupational injuries per 100,000 workers in 2022
Agriculture, forestry, and fishing	13.4
Construction	12
Electricity, gas and air conditioning supply, with a focus on energy*	10.2
Transportation and storage	10
Mining and quarrying	4.3
Manufacturing	4.3
Public administration and defence, with a focus on disaster response*	1.6
Average across all sectors	1.7

*Note: *Sectors included as particularly susceptible to climate change impacts.*
Source: ILO (2022).

The research team conducted separate searches for each of the sectors to identify key academic articles and grey literature, complementing the academic sources identified in OpenAlex using the AI tools (Section 1.2.1). Searches were conducted on the Web of Science, Google, Google Scholar, and using online bibliometric tools such as *Litmaps*, *Inciteful*, *Consensus*, *Co-Pilot*, and *Scispace*. We included, as our sources, the most recent publications available in English.

The team then reviewed and analysed the content of the identified academic and grey literature, organising the findings according to the following structure:

- Key statistics on the sector, including figures on employment and estimates on OSH outcomes such as injuries and fatalities.
- The existing risks associated with the sector, regardless of climate change.
- The increased risk that climate change poses to the sector workers.
- The occupations most at risk[3].
- Affected geographies.
- The research team's considerations on the nature of the available evidence.

The findings by sector are presented in Section 2.4.

3. The main groups of occupations are classified following the International Standard Classification of Occupations (ISCO) system: Associate professionals; Clerks; Elementary workers; Farm and related workers; Managers; Operators and assemblers; Professionals; Service and sales workers; and Trades workers (CEDEFOP, n.d.).

1.2.3. Expert interviews

We conducted six stakeholder interviews (INT) to solicit expert inputs, validate interim findings, and gain further insights. We identified stakeholders in the following ways:

1. Two interviewees belonged to LRF and RAND Europe's networks and were experts in the OSH and climate change space.
2. Two were representatives from other organisations working on the topic of climate change and OSH, aiming to explore synergies.
3. Two were lead authors of relevant academic papers identified in the reviews.

The interviews were semi-structured, lasted approximately 45 to 60 minutes, and were conducted via Microsoft Teams. The questions used as prompts during the interviews can be found in Annex A.

1.2.4. Validation workshop

The team organised a workshop (WS) with colleagues from LRF and Lloyd's Register (LR), as well as contacts within LRF and RAND Europe's networks. Excluding RAND Europe employees, 15 participants attended the workshop. Of these, eight were colleagues from LRF, three were from LR, and four were experts on the topic. The workshop lasted about three hours and was held virtually on Microsoft Teams on 7 October 2024.

During the workshop, the research team presented interim findings from the reviews and interviews, and facilitated discussions around the following key topics:

1. **Completeness of the reviews** – an evaluation of whether any critical elements were missing from the findings.
2. **Evidence gaps** – an exploration of areas where current research is lacking or insufficient.
3. **Impact opportunities for the Centre** – discussion of potential areas where the Centre could make a significant impact.

1.3. Strengths and limitations

The strengths and limitations of this research reflect its exploratory nature:

Scoping exercise

The aim of this research was to provide an initial overview of key themes and potential evidence gaps. Given the large (and continuously growing) body of literature and stakeholder perspectives on the subject, this overview is not exhaustive.

Novel methodological approach

The AI tools enabled an efficient overview of a large body of literature that would not have been possible within the time frame of this study using traditional methods. However, these tools are novel, they do not critically appraise the methodological robustness of the included studies and they still leave large scope for interpretation of the information they provide. Potential issues such as hallucinations and reference inaccuracies, often associated with AI, were mitigated by exclusively including articles within the OpenAlex database as the input for our AI tools for evidence mapping and clustering. Furthermore, any article suggested by these or any other AI tools, such as Inciteful, Consensus, and Co-Pilot, was thoroughly reviewed by the research team before being included in the study.

Selection of sectors

This analysis is not comprehensive as it examines a limited number of sectors. For example, it does not include the maritime sector, which encompasses activities related to the sea, shipping, and the use of oceans and coastal areas for economic and transport purposes. While the maritime industry is of particular importance to LRF, and it includes various interconnected sub-sectors, it is not captured among the main ISIC categories. However, relevant industries are incorporated throughout the report: fishing is included in Section 2.2.1 (agriculture, forestry and fishing), offshore rigs are mentioned in Section 2.2.4 (energy), and seafaring is covered in Section 2.2.7 (transportation and storage).

To facilitate comparisons, we relied on the most recent data issued by international agencies, where available. Our analysis of each sector was conducted at the highest level of aggregation according to the ISIC, unless otherwise specified. However, the effects of climate change vary by occupation and work task even within each sector. Thus, providing only a broad sector overview can sometimes be misleading. To address this, within each sector and where data are available, we provide more granular insights into the occupations and groups of workers most vulnerable to climate change. This inclusion was, however, limited because the literature rarely examines climate change related to OSH risks through the occupational lens; it is more likely to focus on the environments in which work takes place (e.g. outdoor workers [1]).

We also recognise the potential for emerging risks in professions developing in response to climate change, such as geoengineering (Schulte et al. 2023), which were not included in our topic-specific reviews. Exploring these emerging sectors could be a focus for future research.

Finally, our focus was on formal sectors, excluding informal economies, although these too will undoubtedly be impacted by climate change. Investigating the effects of climate change on informal workers could be a valuable area for future research.

1. See, for instance, Ioannou et al. (2022; Petropoulos et al. (2023; Abokhashabah et al. (2021; Habibi et al. (2021).

Holistic approach

The impacts of climate change on OSH are interconnected, requiring a holistic and systems-thinking approach for effective assessment. Climate-driven changes in one area can create cascading risks in others; for example, the shift towards low-carbon fuels such as ammonia, while beneficial for reducing emissions, introduces new safety challenges for workers in the maritime industry[1]. These risks are not isolated but can spread across different sectors and regions, influencing each other in unexpected ways. A systems-thinking approach is essential to understand these interactions, as it allows for a comprehensive view of how changes in one part of the system can affect others, enabling better anticipation and management of emerging risks[2].

2. Findings

2.1. Overview of the findings

Climate change is a significant global challenge, defined by long-term alterations in temperature, precipitation patterns and weather events. These changes are primarily driven by human activities, such as the burning of fossil fuels and deforestation, leading to increased levels of greenhouse gases in the atmosphere (Lynas et al. 2021; Trenberth 2018; Fawzy et al. 2020; Bandh et al. 2021).

The effects of climate change extend beyond environmental impacts, among other things posing serious threats to workers' health and safety. Rising temperatures, extreme weather events and shifting ecosystems can worsen occupational hazards, affecting both physical and mental wellbeing (ILO 2024; 2022).

In recent years, there has been growing interest in understanding the impacts of climate change on OSH, with a substantial increase in evidence and research efforts[3]. This expanding body of knowledge highlights the urgent need for effective strategies to mitigate risks and protect workers across diverse sectors and regions.

This chapter synthesises findings from a review of the literature, interviews and a workshop (as described in Section 1.2), aiming to provide insights and recommendations for future research addressing the challenges posed by climate change in relation to OSH in selected sectors.

2.1.1. Framing the issue: risks, geographies and sectors

Climate change has widespread impacts, affecting different aspects of work across all regions. Its influence is not limited to any single sector of the economy, group of workers or geography, making it a complex issue that requires a multifaceted approach. To effectively map the challenges posed by climate change in relation to OSH and to identify research gaps, one can frame the topic through distinct perspectives, including: examining the risks climate change exposes workers to, understanding how it affects different geographies, and analysing its impact on workers in various economic sectors.

The chapter beings with an overview of the most common occupational risks associated with climate change, highlighting insights from the literature and offering suggestions for future research. These suggestions are drawn from both the literature and feedback from stakeholders during interviews and the workshop. The suggestions for future research are not the result of a systematic gap analysis and are therefore not exhaustive.

The chapter goes on to provide a brief outline of how different geographies are affected by climate change. It also includes a mini case study on the island state of Mauritius, illustrating the specific impacts of climate change on this country.

The final section illustrates the impact of climate change on selected economic sectors, which is the key focus of this review. For each sector, we summarise the existing risks associated with the sector regardless of climate change, the increased risk that climate change poses, the occupations most at risk, the most affected geographies, and the research team's considerations on the nature of the available evidence.

2.2. Risks

An increasing number of reviews have focused on the risks that climate change poses to workers, notably the report 'Ensuring Safety and Health at Work in a Changing Climate' (ILO 2024a) and Paul A. Schulte's framework for assessing hazards posed by climate change, which has been updated twice since its first publication in 2009 (Schulte et al. 2016, 2023; (P. A. Schulte and Chun 2009)).

While some risks, such as heat stress and exposure to ultraviolet (UV) radiation, are well understood[4], others, such as some vector-borne diseases[5], air pollution[6] and mental health[7], have been less studied, and new risks continue to emerge as climate conditions evolve. In terms of protective measures and 'what works' to reduce harm, much is already known and international labour standards have been in place for decades in most countries[8]. However, climate is ever changing, exposing geographies and workers to shifting risks; this requires policy makers and regulators to keep monitoring and adapting their guidance as the situation evolves[9].

This section examines various risks below, offering a concise overview of their implications for OSH.

1. Workshop
2. Workshop
3. See, for example, ILO (2024); Schulte et al. (2023); Parent-Thirion et al. (2024); National Institute for Occupational Safety and Health (2023); Minett (2024).
4. INT1, INT2, INT5
5. INT2
6. INT2
7. INT1
8. Workshop
9. Workshop

Excessive heat

What we know

Heat exposure has been linked to physiological impacts, such as increased metabolic rates and internal heat generation, resulting in a number of adverse health impacts including heat stroke, heat cramps and heat exhaustion (from salt depletion), as well as cardiovascular and kidney diseases, and dehydration (all, in turn, impacting productivity) (Ferrada et al. 2023; Ebi et al. 2021; Cramer et al. 2022). Heat increase can also lead to physical and exertion-related injuries. Extreme heat exposure increases the risk of occupational injuries by 1 per cent for every 1°C increase in temperature and 17.4 per cent during heatwaves, with the highest risk in humid subtropical climates and oceanic climates (Fatima et al. 2021).

Impact on outdoor workers, often working in agriculture and construction, seems most evident, but indoor workers can also be affected when operating in poorly ventilated environments where temperature regulation is inadequate (ILO 2019; J. Lee et al. 2022).

Recent estimates highlight the gravity of heat stress, revealing that each year excessive workplace heat contributes to approximately 22.85 million occupational injuries, 18,970 fatalities, and 2.09 million disability-adjusted life years (ILO 2024).

To address these challenges, the ILO provides guidance on managing heat stress, and many countries have implemented regulations and guidelines. These measures include ceasing work when temperatures exceed certain thresholds, scheduling work during cooler night hours, wearing appropriate clothing to mitigate the effects of heat, and keeping hydrated (ILO 2024; Schulte et al. 2023).

Future research

The effects of heat stress have been extensively studied, making it one of the most well-understood risks associated with climate change (Flouris et al. 2018; ILO 2019; Ioannou et al. 2022; J. Lee et al. 2022; Morris et al. 2020). However, attendees at our workshop suggested that further research is needed to explore the long-term effects of prolonged exposure to high temperatures[1]. Several organisations, including the ILO (2024), EU-OSHA (2023), the HSE (n.d.) and the WHO (2008), have provided guidance on mitigating occupational heat stress. Numerous studies and reviews have evaluated the effectiveness of various control strategies, such as cooling vests, work-rest schedules, hydration interventions and heat education programmes, in reducing heat-related risks for workers (Rowlinson et al. 2014; Nunfam et al. 2019; Esfahani et al. 2024).

UV radiation

What we know

Increased UV radiation occurs as a result of the interaction of greenhouse gases, climate change and stratospheric ozone depletion. Greenhouse gases trap heat in the atmosphere, leading to global warming; this warming influences atmospheric circulation patterns which, in turn, adversely affect the distribution and concentration of ozone in the stratosphere, and the depletion of the ozone layer allows more UV radiation to reach the Earth's surface (Schulte et al. 2023). Excessive exposure to UV radiation poses significant risks to outdoor workers, many of whom work in construction and agriculture. However, its impact extends to a variety of other sectors that employ outdoor workers, as well as occupations such as airline pilots, especially those flying at high altitudes during daylight (Schulte et al. 2016). Prolonged exposure to UV radiation can lead to a range of health issues, from immediate effects like sunburn and skin blistering to more severe conditions such as acute eye damage and weakened immune systems. Over time, workers may also develop pterygium[2], cataracts and various forms of skin cancer (ILO 2024). These risks underscore the importance of implementing protective measures, such as providing appropriate clothing, eyewear and sunscreen, to safeguard workers who are regularly exposed to the sun (Schulte et al. 2023).

Future research

An interview with a representative of an international OSH agency[3] highlighted emerging risks associated with UV radiation. While it is well known that exposure to UV light can increase the risk of ocular diseases, a recent survey conducted by the agency found that those working on snow or near bodies of water are especially at risk during the winter months. This novel insight could prompt regulatory changes, requiring employers to provide protective eyewear to workers in these conditions. Further research is essential to validate these findings and to identify other occupations that may also be at risk of UV-induced ocular diseases.

Air pollution

What we know

Climate change influences air quality, with varying consequences on health, in several ways. Higher temperatures enhance the formation of ground-level ozone, particularly during heat waves (Pu et al. 2017; Galina et al. 2017), which poses serious health risks to humans (Zong et al. 2022). The rise in wildfires contributes to higher emissions of particulate matter and ozone precursors, while drought and elevated temperatures increase windblown dust in certain regions (Fann et al. 2016; ILO 2024; Schulte et al. 2023). One study noted the increased release of radon from permafrost melt in the Arctic and Antarctic, increasing radon exposure levels (Baraniuk 2022). Additionally, increasing carbon dioxide levels in the atmosphere promote the growth of allergen-releasing plants, such as common ragweed (Fann et al. 2016). Indoor air pollution can also be impacted by climate change in some areas, with increased indoor dampness due to more frequent heavy precipitation and rising outdoor humidity (Fann et al. 2016), and increased pollutants like mould and pollen (Fann et al. 2016), as well as ground ozone (Zhong et al. 2017), entering buildings through ventilation systems.

1. Workshop

2. Also known as 'surfer's eye', pterygium is a benign growth of the conjunctiva, the clear membrane that covers the white part of the eye as a result of prolonged UV exposure (Berry 2020).

3. INT5

Air pollution leads to acute and chronic health issues, including cardiovascular diseases such as stroke and ischaemic heart disease[1], respiratory diseases like lung cancer and asthma, increased risk of brain and breast cancer (ILO 2024), allergic illnesses due to elevated airborne allergens (Fann et al. 2016), and increased risk of developing neurodegenerative diseases, such as Alzheimer's and Parkinson's (Cristaldi et al. 2022). Combined exposure to air pollution and excessive heat presents a greater health risk than each individually[2], with a mortality risk of 21 per cent for combined exposure (ILO 2024).

Approximately 860,000 workers die annually from occupational air pollution exposure, a figure that is likely an underestimation (ILO 2024). Outdoor workers are particularly affected, with an estimated 1.6 billion people globally working outdoors and facing continuous exposure (Schulte et al. 2023). This occurs especially in LMICs, where higher exposure levels contribute to 89 per cent of air pollution-related deaths (Landrigan et al. 2022).

Future research

While numerous studies have documented the negative health effects of ambient air pollutants, particularly ozone and small particles (particulate matter with a diameter of 2.5 micrometres or less, or PM2.5), on the general population, fewer have examined the long-term impact of climate change-induced air pollution on workers' health specifically (Schulte et al. 2023).

Extreme weather events

What we know

Global warming is linked to more frequent and severe extreme weather events, including heatwaves, floods, landslides, droughts, storms, lightning and wildfires (Stott 2016). Attribution science is an emerging field of research exploring how these events are linked to climate change by employing advanced climate models and statistical techniques, which allow scientists to assess the probability of such events occurring in a warming world compared to a pre-industrial climate (Otto et al. 2016). Extreme weather events can impact workers' health and safety in a variety of ways, increasing the risk of injuries, fatigue and stress. These affect especially agriculture, forestry and fishing and disaster response workers, such as firefighters and workers in the maritime sector, including shipping (ILO 2024; Schulte et al. 2023). These events can also damage the built environment, leading to potentially hazardous chemical releases and industrial accidents (ILO 2024). Poorer communities are disproportionately affected, with LMICs experiencing 82 per cent of deaths from weather-related hazards (ILO 2024).

Future research

A conversation with a maritime historian[3] highlighted the consequences that extreme weather events can have on the environment and human health. According to our source, there are hundreds of thousands of shipwrecks (with at least 10,000 in the sea surrounding the UK) currently on the seabed. Many of these vessels contain fuel, the breakdown of which could lead to significant pollution, causing large-scale environmental and financial damage and posing risks to maritime workers (e.g. those involved in fishing, offshore energy production, shipping or maritime safety operations) in the form of diving hazards, explosive risks and chemical exposure. This issue was recently picked up by the BBC (BBC News 2024), with experts highlighting the urgency of identifying and surveying shipwrecks to mitigate risks.

According to the ILO review (2024), workplaces may adapt to extreme weather through infrastructure modifications, preventive training, safety drills and technological advancements, although more research might be needed to understand what types of interventions are effective in different contexts and against different types of events.

Vector-borne diseases and other biological hazards

What we know

Vector-borne diseases are illnesses transmitted to humans through vectors such as mosquitoes, ticks and fleas (WHO 2024b; ILO 2024). Higher temperatures and shifting precipitation patterns impact vector population size, survival and reproduction rates, altering the distribution and prevalence of vector-borne diseases (George et al. 2024; ILO 2024). These diseases, including Lyme disease, West Nile virus, chikungunya, dengue and Zika fevers, are increasing, predominantly affecting outdoor workers in sectors such as construction, agriculture, forestry and fishing. Workers exposed to soil and dust also face risks from fungal diseases such as coccidioidomycosis and histoplasmosis (ILO 2024; Schulte et al. 2023). According to a recent estimate, vector-borne diseases accounted for 550,000 fatalities in 2021 (ILO 2024b). However, due to inadequate data and the fact that occupational exposures are often unrecognised or unreported, this is likely to be an underestimation. It is also difficult to determine whether infections occur at work or at home.

Future research

To mitigate the risks posed by vector-borne diseases, recommendations include disease surveillance, vector control, worker training, and the use of personal protective equipment or PPE (Schulte et al. 2023). However, more research is needed to better understand protective measures for workers (ILO 2024). In general, more evidence and regulations are available on how vector-borne diseases affect the general population rather than workers specifically.

Compared to vector-borne diseases, there is also less evidence regarding the risks posed to workers by other biological hazards such as venomous insects and reptiles, water-borne diseases, non-vector-borne pathogens, and poisonous plants (Schulte et al. 2023). Consequently, information on mitigating these risks is more limited.

1. Heart damage caused by narrowed heart arteries (American Heart Association, n.d.).
2. INT5.
3. INT3.

Agrochemicals

What we know

Agrochemicals, which include pesticides, fertilisers, plant growth regulators, soil conditioners and chemicals used in animal husbandry, play a crucial role in food production and pest control (Koli et al. 2019). However, climate change is driving increased use of pesticides and fertilisers due to declining efficacy and rising pest pressures. These substances, in turn, contribute to climate change due to the significant amount of energy required for their manufacturing, packaging, transportation and disposal, creating a vicious cycle (ILO 2024; Pesticide Action Network 2022).

Workplace exposures to pesticides occur during handling, mixing, application and disposal, leading to both acute and chronic health effects, such as respiratory, cardiovascular, gastrointestinal, neurological and skin-related disorders, as well as an increased risk of certain cancers over time (Mamane et al. 2015; Said 2023). Additional risks include accidental spills, splashes and mistaken consumption, resulting in acute poisonings (Damalas & Koutroubas 2016). Agricultural workers are particularly vulnerable to this risk, as agriculture accounts for about 85 per cent of pesticide use (Cassou 2018). However, workers in forestry, chemical industries and vector control also face exposure risks. Additionally, pesticide runoff and contamination into waterways can affect not only these workers but also the wider population, posing broader environmental and health challenges.

Future Research

Agrochemicals present a substantial threat to human health and the environment. However, in certain regions, they remain essential for ensuring food productivity. The primary issue is not the absence of evidence regarding the risks posed by agrochemicals, but rather a lack of knowledge among workers about proper handling, storage and disposal practices. This is exacerbated by the frequent lack of PPE and the workers' inability to effectively read safety labels, which are often the main source of safety instructions. Consequently, health risks related to pesticide use are more prevalent in developing nations, where farmers seldom have access to in-person training (Said 2023). Additionally, lax adherence and enforcement of regulations can result in some substances being banned in one region while being used in another (Said 2023).

To protect vulnerable workers, future research could focus on raising awareness of these risks among those with limited access to training. Collaborating with local communities to identify agrochemicals that are safer for both workers and the environment, such as biofertilizers and biopesticides (Said 2023), is also crucial.

Impact on mental health

What we know

Climate change has a profound impact on mental health through multiple pathways, leading to a wide range of psychological and psychosocial issues. It contributes to sleep disorders, behavioural changes and increased suicide rates, with extreme weather events such as hurricanes, floods and wildfires exacerbating stress, anxiety and post-traumatic stress disorder. Disruptions in industries reliant on natural resources, such as agriculture, forestry and fishing, can lead to job insecurity and financial stress. These economic stressors are compounded by forced migration and displacement, which lead to the breakdown of social support systems, loss of autonomy and increased social isolation. Additionally, conflicts over dwindling resources, such as water and arable land, are anticipated to rise, further intensifying mental health challenges (Corvalan et al. 2022). Longer hours for emergency responders and healthcare workers can also lead to burnout and stress (ILO 2024; Schulte et al. 2023).

Furthermore, long-term environmental changes caused by climate change – such as rising temperatures, droughts and sea-level rise – create chronic stressors that can lead to anxiety, depression, helplessness and grief. Emerging concepts such as eco-anxiety, solastalgia (distress caused by environmental change) and ecological grief highlight the emotional toll of witnessing the gradual destruction of ecosystems and cultural landscapes (Cianconi et al. 2020). Many people experience feelings of loss, helplessness and frustration as they perceive their inability to stop or mitigate climate change impacts. These psychological responses are particularly pronounced among young people, who often report distress, a sense of betrayal and mistrust of governments due to inadequate climate action (Corvalan et al. 2022).

Future research

Despite the importance of these issues, only a few of the research papers that we identified address the link between climate change and mental health in workers. While there are a number of studies dedicated to understanding the effects of climate change on mental health in the general population (Crandon et al. 2022; Lawrance et al. 2022; Cianconi et al. 2020), not many have focused on the effectiveness of potential interventions in a workplace context. Additionally, there is limited guidance for employers on protecting workers from climate-related mental health conditions (ILO 2024; Schulte et al. 2023).

Other risks

Climate change can also impact OSH in less direct ways. For example, changes in weather patterns can affect supply chains, impacting job stability in various sectors. Climate-induced migration can also disrupt communities and workplaces, leading to social and economic challenges, as well as exposing workers to novel work environments with hazards they are not familiar with. Carbon capture and storage (CCS) emerged in the workshop[1] as a significant area of interest due to its potential role in mitigating climate change. However, this and other mitigation strategies, such as using alternative fuels in shipping, pose unknown risks to the health and safety of workers involved, requiring further investigation and consideration.

Another example of indirect risk to workers posed by climate change is forced migration. Climate change will likely render some areas of the Earth uninhabitable, forcing large numbers of people to move.

1. Workshop.

Such migrations will have indirect effects on OSH because migrants may have difficulties gaining regular employment, resorting to informal positions that are less protected by regulations. Additionally, they might face issues understanding safety instructions due to language barriers. While these factors have not been the primary focus of this study, they could be the focus of future research.

2.3. Geographies

Climate change is a global phenomenon impacting all geographical regions, although in diverse ways. Each location faces unique challenges, necessitating a nuanced understanding of local contexts and evidence needs. While the overarching threat of climate change is universal, its effects on OSH are deeply influenced by regional factors such as climate, socio-economic conditions and existing infrastructure.

Coastal regions, for instance, are particularly vulnerable to rising sea levels and increased storm intensity, which threaten infrastructure and livelihoods (Troccoli 2020). In contrast, arid and semi-arid areas may experience intensified droughts, affecting water availability and agricultural productivity (Zarch et al. 2017). Urban areas face challenges related to air quality, as well as heatwaves and increased temperature compared to surrounding rural areas, a phenomenon called 'heat island effect', impacting public health and urban planning (Leal Filho et al. 2022).

Addressing these varied impacts requires a dual approach: thinking globally while collecting data and providing evidence locally. This means leveraging global insights and frameworks to guide action, while also tailoring strategies to fit local realities and priorities. Localised data collection and context-specific research are therefore crucial for developing effective adaptation and mitigation strategies that resonate with the unique needs of each region. Mauritius, as highlighted in our mini-case study in Box 1, based on information from an interviewee, serves as an example of these global challenges.

This island nation is particularly vulnerable to climate change due to its location, economic reliance on climate-sensitive sectors, and limited resources for adaptation. These factors are reflective of many small island developing states around the world, making Mauritius a pertinent case study for understanding the broader implications of climate change on OSH. The insights provided underscore the context-specific nature of climate change impacts and the local knowledge required to tailor the strategies required to mitigate the negative effects of climate change. Understanding which areas are most vulnerable to climate change is crucial for effective planning and intervention. Figure 1 illustrates regions where multiple severe impacts may occur simultaneously if global temperatures rise by 4°C above pre-industrial levels. These impacts include extreme heat stress, flooding, drought and wildfire risk, combined with indicators of present-day food insecurity. Highlighted regions of concern are those where these severe impacts coincide, underscoring the urgent need for targeted adaptation strategies.

LMICs are particularly susceptible to climate-related risks and fatalities. These regions often lack the resources and infrastructure needed to effectively respond to and recover from climate impacts, making them disproportionately vulnerable. However, it is also important to consider areas where the climate is changing most rapidly. Current data suggest that Europe and North America are among the regions experiencing the fastest climate changes (European Environmental Agency 2024), but information is limited. Each region faces unique risks based on its level of acclimatisation and existing vulnerabilities.

Figure 1. Geographical distribution of multiple severe impacts of climate change

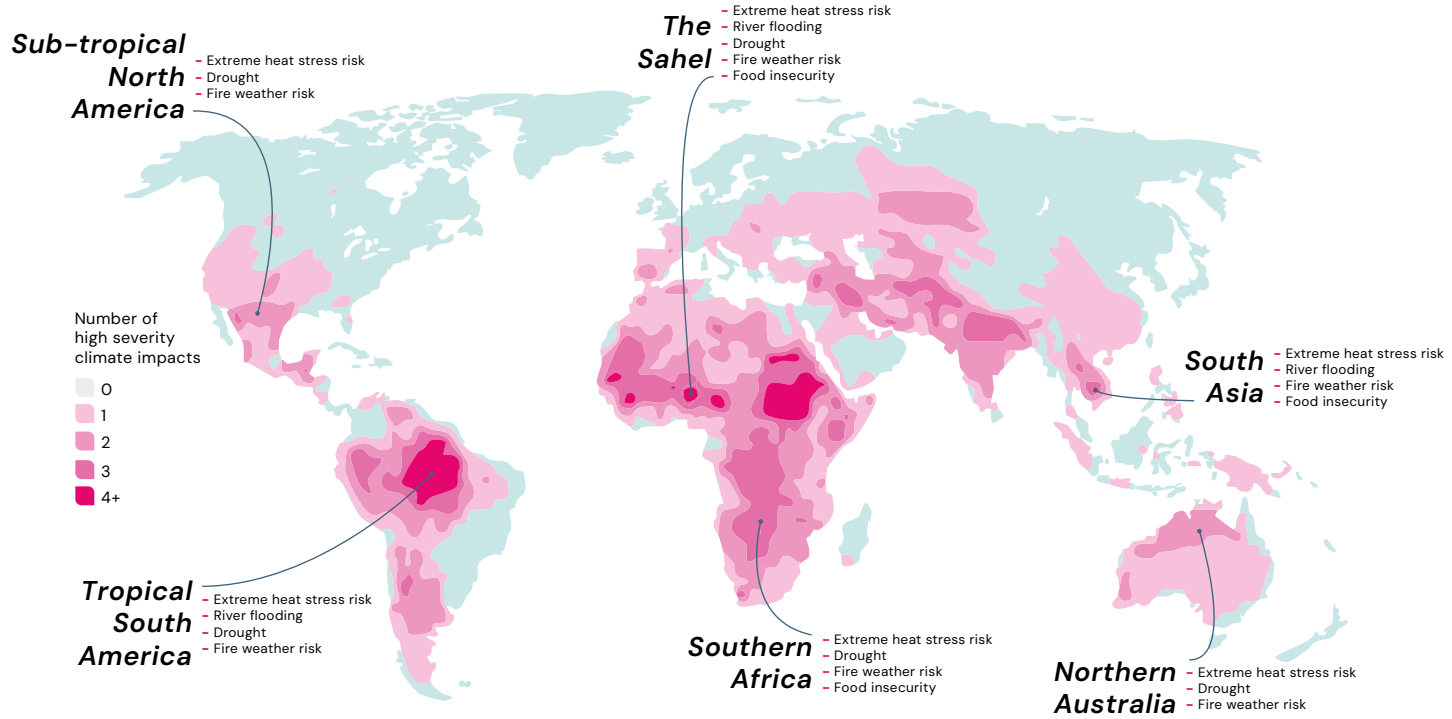

Image adapted from: Met Office, Global impacts of climate change - projections. metoffice.gov.uk/research/climate/climate-impacts/global-impacts-of-climate-change---projections

Box 1. How climate change is affecting OSH in a specific context – a closer look at Mauritius

Mauritius is an island nation particularly vulnerable to climate change due to its location, economic reliance on climate-sensitive sectors, and limited resources for adaptation.

The main ways in which climate change affects Mauritius are:

- **Flash flooding** – A major issue since 2013, flash flooding has become a significant concern, affecting the economy and the Mauritian way of life. This phenomenon was previously unheard of in the region, highlighting a drastic change in weather patterns.
- **Cyclones** – While cyclones have historically been a concern, their impact is now exacerbated by climate change, leading to increased coastal flooding and economic challenges, particularly for the tourism industry.
- **Rising sea levels** – The increase in sea levels poses a threat to coastal areas, affecting the hotel industry and potentially displacing populations.
- **Vector-borne diseases** – There has been a notable rise in diseases like dengue fever, linked to changes in seasonal weather patterns.
- **Heat** – Heat poses less of a challenge in Mauritius compared to other climate impacts, as the region has long adapted to high temperatures. For instance, sugar cane workers traditionally begin their shifts in the early hours, often before dawn, to avoid intense daytime sun exposure. This practice pre-dates current climate change concerns, reflecting established systems and strategies that have been effectively managing heat-related issues for decades.

Climate-related OSH management in Mauritius

The meteorological agency has a critical role in guiding OSH decisions during increasingly frequent extreme weather events. The process involves the agency providing evidence to a national crisis committee which then determines whether it is safe for workers to proceed with their duties. Following a decision, an official communication is issued to both the public and private sectors.

The primary challenge in this process is not the availability of evidence – since the meteorological agency effectively supplies the necessary data – but rather the making of a decision and its wider communication. For example, on one occasion, a controversial decision allowed workers to go to work despite impending flooding, only for a midday reversal to advise against it. This led to many workers trying to return home but finding their vehicles submerged in floodwaters. Effective communication during climate events is also essential, as past instances of misinformation and delayed responses have posed unnecessary risks to both the population and the workforce.

Both the private and public sectors have written protocols that serve as guidelines for providing practical advice to organisations in times of heavy rainfall.

Evidence needs

There is a pressing need for research focused on the vulnerabilities of populations living in areas prone to flooding in Mauritius. Many of these communities have constructed homes without adhering to proper building guidelines, making them particularly susceptible to climate-induced flooding. Understanding the socio-economic factors that contribute to these vulnerabilities is crucial for developing effective interventions. Research should aim to identify the specific needs of these populations, assess the resilience of existing infrastructure, and explore sustainable construction practices that can mitigate the risks posed by extreme weather events. Enhanced evidence in these areas will support targeted policy-making and resource allocation to protect the most at-risk communities.

Source: INT4. The interviewee was a highly experienced professional in OSH management, holding leadership roles in Mauritius and international organisations.

2.4. Sectors

Below, we present the findings from our targeted reviews of selected sectors. For each sector, we summarise the existing risks associated with the sector regardless of climate change, the increased risk that climate change poses, the occupations most at risks, affected geographies, and the research team's considerations on the nature of the available evidence.

2.4.1. Agriculture, forestry and fishing

Overview

This sector comprises three main divisions, each including multiple activities: agriculture, including the growing of crops, animal production, and hunting or trapping; forestry and logging, including the management and cultivation of forests, and the cutting and processing of trees and logs; and fishing and aquaculture, including the capture and farming of fish and other aquatic organisms (Standard Industrial Classification Codes, n.d.).

Agriculture

Inherent risks

According to the latest ILO Global Estimates, at least 210,000 agricultural workers are killed by accidents each year. Workers in agriculture are over three times more likely to die on the job compared to workers in other sectors. Agricultural mortality rates have also increased in the last decade compared with other sectors (in which fatal accident rates have generally decreased). Millions more agricultural workers are seriously injured in workplace accidents involving agricultural machinery or poisoned by pesticides and other agrochemicals (ILO 2015a).

Molina-Guzmán & Ríos-Osorio (2020) found that agricultural workers face systemic diseases, respiratory issues and skin problems, often linked to agrochemical exposure. Cancer rates, including lip cancer and multiple myeloma, are notably higher among farm workers. Additionally, musculoskeletal disorders from repetitive movements and heavy lifting, respiratory disorders from allergen dust, and infections such as tuberculosis are prevalent. Despite legislative efforts, challenges persist in monitoring and reporting work-related injuries, especially in developing countries. El Khayat et al. (2022) found that vulnerable populations, including migrant and child farmworkers, face challenges such as poor working conditions, piece-rate payment systems, and inadequate access to water, shade and medical care.

Increased risks due to climate change

Extreme heat is among the primary factors affecting the safety of agricultural workers. Several authors, such as El Khayat et al. (2022), Morris et al. (2020), and Molina-Guzmán & Ríos-Osorio (2020), cite heat stress due to climate change as a major concern for agricultural workers. Physically demanding agricultural tasks increase the workers' metabolic rates, leading to higher internal heat production and overall heat stress. Outdoor work exposes workers to high ambient temperatures and humidity, contributing to heat accumulation. Additionally, agricultural workers often face limited water availability, leading to dehydration throughout the day (El Khayat et al. 2022).

Chemical exposure is another critical risk. Higher temperatures can increase the volatilisation of pesticides and fertilisers, increasing the risk of respiratory and skin diseases. Furthermore, farmers often work in areas with trees, bushes or high grass, where pathogen-carrying ticks and insects thrive. This will further increase the risk of contracting vector-borne diseases like Lyme disease and tick-borne encephalitis[1] (EU-OSHA 2024).

The mental health of agricultural workers is also an area of concern. Unpredictable weather patterns and increased disaster frequency contribute to psychological stress and mental health issues among farmers due to the uncertainty and instability they introduce into agricultural planning and livelihoods. Issues include anxiety, depression and increased suicide rates, exacerbated by the physical demands and stress associated with adapting to climate change (Jones et al. 2024).

Occupations most at risk

Smallholders are especially vulnerable to climate-induce occupational health and safety risks. Many are located in areas at high risk of extreme weather events, such as the tropical and subtropical regions of Asia and Africa, and to some extent Latin America (Talukder et al., n.d.). Smallholders are exposed to the same types of risk mentioned above, including diseases such as malaria, dengue[2], cholera and respiratory infections; higher incidence of heat-related illnesses, cardiovascular diseases and chronic kidney disease due to rising temperatures and heatwaves; increased stress, anxiety, depression and even suicide due to the uncertainty and challenges posed by climate change; and increased risk of accidents and injuries from natural disasters like floods and cyclone (Talukder et al., n.d.). Additionally, smallholders often lack the resources needed to face the health and safety risks posed by climate change, as they are subject to a cycle of poverty due to limited financial resources, environmental stresses and poor social support. This lack of resources makes it difficult for smallholders to plan for and counteract extreme weather events, and they frequently suffer from food and nutritional insecurity and have limited access to healthcare and other essential services (Talukder et al., n.d.).

Affected geographies

Geographical regions that are most affected by climate change span various economies, with developing countries facing more significant challenges. In tropical and subtropical areas, agriculture revenue is severely impacted by rising temperatures, notably in Asia and Africa, where high-emission scenarios could reduce crop yield by 2050 (Jack & Wilkinson 2022). Semi-arid regions like the Sahel and Horn of Africa experience extreme weather variables causing both floods and droughts, which directly impact crop viability and lead to food insecurity. Agriculture, a major sector in LMICs, employs two-thirds of the workforce and contributes significantly to GDP, making these regions particularly vulnerable to climate-induced disruptions. Jack

1. A viral infectious disease that affects the central nervous system (WHO, n.d.).
2. A viral infection transmitted to humans through the bite of infected mosquitoes (WHO 2024a).

& Wilkinson (2022) estimate this vulnerability could trigger internal climate migration for millions by 2050.

Forestry

Inherent risks

Forestry workers face numerous safety risks that are exacerbated by demographic, technological and work arrangement factors. Demographically, young workers often lack the experience and training to handle hazardous tools, while older workers may struggle with declining physical capacities, both leading to higher accident rates. This is corroborated by a study from Slovakia where the authors found that '*though older workers aged between 51 and 60 years were the most prone to suffer an occupational accident (OA) (31% of all OAs), a much younger class of 21- to 30-year-olds followed as the second most prone to suffer an accident*' (Jankovský et al. 2019). Women in forestry face unique risks, including ergonomic issues and exposure to chemicals, often without access to properly fitting PPE (FAO et al. 2023).

Technological advancements, such as mechanisation and robotics, improve efficiency but introduce new risks related to the operation and maintenance of machinery within forestry work (Jankovský et al. 2019; FAO et al. 2023). Furthermore, diverse work arrangements, including seasonal, temporary and informal employment (especially high developing countries), often lack labour regulation and inspection, thus intensifying safety challenges. Forest management certification, a voluntary process that verifies a forest is managed responsibly, covers only 11.5 per cent of global forest areas, leaving many workers outside the protective scope of these voluntary standards (FAO et al. 2023).

Increased risks due to climate change

Forestry and logging are increasingly affected by climate change, with extreme weather events becoming one of the most severe risks to workers. Increased frequency of storms, floods and fires has created hazardous working conditions, including risks from falling trees and dangerous salvage logging operations. Clean-up operations after disasters also carry hazards. The increasing intensity and frequency of forest fires are posing significant risks, including lung cancer and cardiovascular diseases from smoke exposure (FAO et al. 2023).

Rising temperatures and humidity levels have made work in forests even more challenging and hazardous. These lead to dehydration, heatstroke and fatigue, affecting both physical and mental health (ILO 2015a). Additionally, climate change may lead to a faster spread of vector-borne diseases (e.g. Lyme disease, malaria, dengue, etc.) and zoonotic diseases[1] (FAO et al. 2023) affecting forestry workers.

Occupations most at risk

The three most dangerous roles in the forestry industry are fellers, foresters, and mechanics/maintenance workers (Fulton 2021). However, we could not identify literature exploring how climate change exacerbates the risks associated with these specific roles.

Affected geographies

Climate change is expected to affect forests across various regions. A recent meta-analysis by Altman et al. (2024) indicates that forests in the Mediterranean, the western and southeastern United States, Africa, Oceania and South America are likely to experience an increased risk of fires, with some of the most vulnerable areas seeing a rise of over 31 per cent per year. Conversely, temperate and boreal forests are anticipated to see a reduction in fire risk. The study also predicts a notable rise in pest outbreaks in boreal and temperate forests, whereas (sub-)tropical forests are expected to see a decline, and Mediterranean forests are projected to experience no significant change. Furthermore, hydro-geomorphic disturbances, such as erosion and flooding, are expected to intensify in boreal forests and, to a lesser extent, in temperate forests. It is also suggested that warmer climates will considerably enhance wind disturbances in (sub-)tropical moist broadleaf forests and mangroves, as well as regionally in other biomes like southeastern North America and East Asia (Altman et al. 2024).

Fishing and aquaculture

Inherent risks

The aquaculture and fisheries industry, crucial for global food security and livelihoods, employs around 200 million people worldwide (FAO 2018). Workers in this sector face significant OSH risks, including chemical exposure, infection risks and physical hazards. Handling aquatic animals exposes workers to pathogens, such as Vibrio bacteria[2], leading to serious illnesses (Williams 2023). The physically demanding nature of the work, involving heavy equipment and machinery, increases the risk of injuries and musculoskeletal disorders (MSD) (FAO 2018; Thorvaldsen et al. 2020). In a survey of Norwegian fish farm employees, Thorvaldsen et al. (2020) found that 40 per cent of respondents suffered from MSDs, with 34 per cent of these attributing their issues to work-related exposures. The authors also found that long working hours during busy periods exacerbated issues, with 71.8 per cent of respondents working between 9 and 16 hours continuously. Another study found that falls, object blows, net entanglement and skin injuries are the most prevalent incidents among workers in the aquaculture sector (Garforth & Brown 2021). Needle-stick injuries and electrocution are also common. Environmental conditions, such as adverse weather and wet, slippery surfaces, heighten the risk of accidents (Williams 2023).

Increased risks due to climate change

The aquaculture sector faces heightened vulnerabilities due to its dependence on environmental conditions (Williams 2023). Rising sea surface temperatures (SSTs) and the increased frequency of extreme weather events pose direct threats to workers' safety. For instance, higher SSTs promote the growth of pathogenic bacteria in marine environments, increasing the risk of infections such as vibriosis among workers handling aquatic animals. Additionally, climate-related disasters now account for over 80 per cent of all disaster events, further threatening the safety and livelihoods of those in the industry (FAO 2018).

1. Infectious diseases that are transmitted from animals to humans.

2. Bacteria usually found in coastal water that can cause potentially serious infections, called vibriosis, in humans (CDC 2024).

Chemical exposures, which cause respiratory issues and skin irritations, may become more prevalent with changing environmental conditions and accompanying increased use of chemicals. Physical hazards, including injuries from heavy machinery, slips, trips, falls and musculoskeletal injuries from manual handling, are exacerbated by adverse weather conditions and the physical demands of longer working hours (Ngajilo & Jeebhay 2019; FAO 2018).

Occupations most at risk

Artisanal or small-scale fisheries, typically involving individual fishers or fishing households, face increased health and safety risks compared to their larger commercial counterparts. These workers have poorer access to safety equipment and training and have fewer financial resources to invest in safety improvements (FAO 2024; Turner 2024).

Affected geographies

Climate change will have deep consequences on both marine and freshwater ecosystems. Ocean warming, increased thermal stratification and sea level rise are impacting marine environments, while freshwater ecosystems are affected by temperature rise, altered precipitation regimes and melting glaciers (Prakash 2021). A review by Reid et al. (2019) highlighted the risks posed to aquaculture by climate change in different geographical regions. Southeast Asia will be especially impacted due to increased flood frequency, sea-level rise and saltwater intrusion, particularly in countries such as Vietnam and Bangladesh. As the largest producer of aquaculture, China will also face significant risks from temperature fluctuations, altered precipitation patterns and water stress, impacting major aquaculture areas like the Yangtze and Yellow River basins. Islands in the tropical Pacific are particularly susceptible to extreme weather events and ocean acidification[1], which threaten aquaculture operations and the livelihoods dependent on them. Northern Europe and North America, meanwhile, are expected to experience increased frequency and intensity of heavy precipitation events, leading to flooding and potential damage to aquaculture infrastructure (Reid et al. 2019).

Considerations on the nature and volume of the evidence

The literature combines statistical data, case studies, empirical studies and literature reviews to highlight risks faced by workers in this sector. There is substantial evidence for agriculture and forestry, particularly regarding the impact of heat and extreme weather on workers' health and safety. However, evidence linking climate change to OSH in aquaculture is sparse, with more focus on food security impacts. High-income countries such as the UK, Norway and the US have updated data on occupational injuries and fatalities, whereas LMICs often lack comprehensive data, suggesting underreporting. This challenge is exacerbated by the prevalence of informal employment in these regions, complicating global data comparison and analysis.

1. Ongoing decrease in the pH of the Earth's oceans, primarily caused by the absorption of carbon dioxide from the atmosphere (Rafferty 2025)

2.4.2. Construction

Overview

The construction sector is a pillar of the global economy, driving growth and development across various industries. It encompasses a broad range of activities, including the planning, design, construction and maintenance of buildings, infrastructure and industrial facilities. This sector also provides essential services such as housing, transportation networks and utilities. It is characterised by its diverse workforce, which includes architects, engineers, skilled tradespeople and labourers.

Inherent risks

The most common physical safety hazards for construction workers include slips, trips and falls; transportation incidents; working at height (including lifting platforms, scaffolding, roofing, using cranes); heavy machinery and hand tools (e.g. bulldozers, drills, pneumatic tools, excavation equipment); ambient heat; and working with explosives and demolition sites (Li et al. 2019; Vitharana et al. 2015; Morrissey et al. 2023; U.S. Bureau of Labour Statistics 2023).

Construction workers are also subjected to long-term exposure to noise and vibration, and face respiratory issues due to dust and hazardous substances (Vitharana et al. 2015). Adverse health effects arise from exposure to various hazardous substances, such as asbestos, silica, radiation, ionization sources, biological agents, and emissions of smoke and chemicals. Additionally, workers face psychosocial risks such as work-related stress (Li et al. 2019; Vitharana et al. 2015). The spread of vector-borne diseases has also been documented on construction sites (Liu et al. 2021).

Increased risks due to climate change

Climate change has been documented to increase risk to outdoor workers in the construction sector (ILO 2024; Ndugga et al. 2023).

Risks related to extreme heat and UV radiation exposure particularly affect construction workers due to the long hours of intense physical labour in direct sunlight and heat (EU-OSHA 2024a; 2024c). Between 1992 and 2016, construction workers in the US accounted for 36 per cent of heat-related deaths, despite making up only 6 per cent of the total workforce (Dong et al. 2019). An analysis of Italian construction injuries identified that heat exposure resulted in a higher risk of injuries from specific physical activities, such as working with hand-held tools, operating machinery, or handling sharp, pointed or coarse materials (Gariazzo et al. 2023).

The construction sector is particularly vulnerable to extreme weather events (Parent-Thirion et al. 2024). Flooding, wildfires, hurricanes and storms can impact workers by blocking access to construction sites (Kendle 2023), or can endanger them due to the risk of industrial accidents including chemical spills, damage to infrastructure, and fires (Minett 2024). As such, these events could also lead to injuries, fatalities, exposure to harmful chemicals, and mental health impacts.

Outdoor workers are also increasingly exposed to vector-borne diseases such as Lyme disease, tick-borne encephalitis, yellow fever,

malaria, dengue and Zika virus (PAHO and WHO 2021). EU-OSHA does not disaggregate these data between types of outdoor workers, and specifies that this issue is not unique to the construction sector (EU-OSHA 2024a). Outdoor workers in general are also subject to workplace air pollution, although EU-OSHA and the ILO do not mention construction workers specifically (Minett 2024).

Occupations most at risk

The construction industry is made up of a diverse set of roles, ranging from workers and labourers to engineers, managers and designers (ILO, n.d.). Some of these roles are evidently more at risk from the impacts of climate change – mainly the outdoor workers carrying out manual labour on construction and industrial sites, and those handling tools and machinery (Gariazzo et al. 2023).

In many areas, the construction industry is reliant on migrant workers. Several studies show that there is a further difference in the risks to migrant over native workers (Pradhan et al. 2019; Amnesty International 2016; Moyce & Schenker 2018; Messeri et al. 2019). One study noted that 'migrant workers were more likely to be informed of risks via informal written or oral communications, whereas native workers received training on heat illness issues through formal courses' (Gibb et al. 2024).

Affected geographies

In Australia and the Pacific Islands, the construction industry is notably large, and there is an increased risk of wildfires impacting workers in this region. In Europe, particularly in southern European countries such as Cyprus, Italy and Spain, workers in construction have been severely affected by past heat waves and continue to face significant risks (Gibb et al. 2024)[1].

Another study highlighted that heat loss through sweat is reduced in areas of high humidity (Acharya et al. 2018). Heat stress can be exacerbated by the urban heat island effect, where urban areas emit more heat from the surrounding infrastructure (ILO 2019), which is increasing the vulnerability of workers to heat-related illnesses (Gibb et al. 2024).

Other studies on the climate impacts on construction OSH in specific countries have covered Italy (Gariazzo et al. 2023), the US (Dong et al. 2019; Morrissey et al. 2023) and Central America[2] (Petropoulos et al. 2023). One review summarised epidemiological studies from several regions across the globe (Acharya et al. 2018).

Considerations on the nature and volume of the evidence

There is convincing evidence that climate change significantly heightens health and safety risks for construction workers, particularly through heat-related impacts (Acharya et al. 2018). While most studies concentrate on heat stress and heat-related mortality, there is increasingly more evidence of other risks, such as vector-borne diseases. However, research on the burden of these diseases on construction workers, including annual exposure levels and consequences, is limited. Studies on vector-borne diseases tend to have a broader scope, without specifically linking these diseases to climate influences and their impact on construction workers (Liu et al. 2021; H.S. Lee et al. 2017).

An EU-funded study highlighted the scarcity of evidence regarding the health effects of climate change on construction workers, particularly those with chronic cardiovascular or respiratory diseases who are at greater risk (Levi et al. 2018). There is also a lack of detailed evidence on the geographic distribution of impacts, with assessments based on regions with large construction sectors rather than specific studies on climate-related occupational incidents in construction.

Moreover, there is insufficient research on which specific occupations within the construction sector are most at risk. Studies often group all construction occupations together, although some research has identified roofing as particularly susceptible to risks such as falls from heights. An Italian study categorised work environment, noting that construction, quarry and industrial sites are most at risk from heat exposure (Gariazzo et al. 2023).

2.4.3. Disaster response (public administration and defence)

Overview

Disaster response is part of the public administration and defence sector according to the ISIC nomenclature. Although this sector includes a diverse array of activities, such as traffic regulation, court administration, legal representation and prison management, our focus is on workers most susceptible to the impacts of climate change, such as first responders (including police officers, firefighters, emergency service workers, ambulance officers and paramedics), as well as humanitarian aid workers.

Inherent risks

First responders are workers who are typically the first to arrive at the scene of emergencies such as natural disasters (Gray & Collie 2017). They face a number of occupational challenges and deal with death or life situations on a regular basis. High-stakes job demands combined with long working hours and shift work that contribute to poor sleep make these workers at high risk of occupation-induced fatigue. Fatigue in first responders can lead to reduced cognitive function, increased injury and accident risk (1.6-fold), and elevated levels of depression, anxiety and post-traumatic stress disorder (Marvin et al. 2023).

Firefighters in particular face a variety of physical risks, including thermal stress and dehydration, which can raise heart rate and body temperature, along with exposure to environmental agents such as carbon monoxide and hydrogen cyanide. Chemical risks are prevalent as well, with harmful chemicals such as aerosols and particulate matter posing threats, and there is an increased risk of skin cancer stemming from the dermal absorption of carcinogenic compounds. Mechanical risks include a high incidence of slips, trips and falls, often exacerbated by the weight of protective boots and fatigue, as well

1. Note, this study applies to workers across a number of industries, not only in construction.
2. Nicaragua, El Salvador.

as injuries resulting from the use of equipment, tools and machinery (Cuenca-Lozano & Ramírez-García 2023). Psychosocial risks are also significant, with high stress levels leading to burnout, cognitive and physical fatigue, and an increased likelihood of depression, post-traumatic stress disorder and problematic drinking (Cuenca-Lozano & Ramírez-García 2023).

Traffic police suffer serious OSH hazards as a result of prolonged exposure to vehicle pollution, noise and harsh weather conditions. These dangers put them at risk of respiratory illnesses, noise-induced hearing loss, musculoskeletal issues, UV-related skin diseases and psychological stress. Furthermore, traffic officers are vulnerable to vehicle accidents and assaults while on duty. Long-term exposure to air pollution increases the likelihood of developing chronic illnesses, including cancer (Jahan et al. 2023)

Humanitarian aid workers, another essential group within this sector, face significant occupational risks, especially as global armed conflicts and natural disasters become more frequent. These workers are increasingly targeted in conflict zones, with violations of international humanitarian law posing a significant threat to their safety and disrupting aid delivery. Physical dangers include exposure to violence, health risks from infectious diseases, and the physical strain of working in disaster zones. Mental health risks are also prevalent due to exposure to trauma and violence, high levels of stress, and a lack of psychological support (Guisolan et al. 2022).

Increased risks due to climate change

Climate change significantly increases occupational risks in the emergency, public order and safety sector by intensifying the frequency, severity and duration of extreme weather events.

Following extreme weather events, first responders may encounter damaged chemical storage facilities, increasing their risk of exposure to toxic substances such as lead, asbestos and solvents. These risks extend into the clean-up and recovery phases, where responders continue to face hazardous conditions as they work to restore affected areas (ILO 2023).

Firefighters face heightened exposure to wildfires, which are becoming more common due to climate change. These wildfires expose them to prolonged wood smoke, leading to serious long-term health effects. Additionally, firefighters are at greater risk of heat stress, as they often work in extreme temperatures while wearing heavy PPE. Heat stress impairs physical function, reduces work capacity, and can cause severe conditions such as heat stroke, heat exhaustion and even death. It also affects how the body processes chemicals, increasing the toxic effects of hazardous substances encountered during firefighting operations (Forte 2021).

Flood responders are exposed to hazardous chemicals and raw sewage, which increase the immediate dangers as well as the risk of long-term diseases (Wrack 2021).

As humanitarian needs rise – from 235 million people in 2021 in need of humanitarian assistance to an estimated 274 million in 2022 – workers will face greater demands in environments increasingly affected by extreme weather, food insecurity and sociopolitical instability. These challenges, coupled with underfunding and heightened violence against humanitarian aid workers, will amplify the physical and mental strain on staff. Climate change-driven crises will force humanitarian workers into more dangerous and unpredictable situations, intensifying their exposure to health risks (Baxter et al. 2022; Humanitarian Action 2023b).

Occupations at risk

A cohort study of Australian first responders found that while all face an elevated risk of traumatic injuries, firefighters are at the highest risk of lower-body musculoskeletal injuries and ambulance workers have the highest risk of upper-body musculoskeletal injuries (Gray & Collie 2017). Police officers, on the other hand, have the highest risk of developing a mental health condition. Burden of injury, measured as working weeks lost per 1,000 workers, was also highest among police officers (Gray & Collie 2017).

According to 2016 data from the US Bureau of Labor Statistics, firefighters had an annual recordable incident rate of 9.5, and police responders 10.2, compared with the national average of 3.2 for all industries (Stahl 2020). Workers such as police officers and firefighters wearing heavy protective gear are especially vulnerable to heat stress, dehydration and heat-related illnesses, including heat exhaustion and heat stroke (Oostlander et al. 2020).

The heat-violence link, in particular, has been well-documented, with research showing that hot weather can increase psychological stress, aggressive behaviour and violent crime rates, leading to more intense and dangerous policing scenarios (Matczak & Bergh 2023). Outdoor traffic officers will be particularly affected. As climate change causes higher levels of pollutants such as PM2.5, ozone, nitrogen dioxide (NO2) and sulphur dioxide (SO2), traffic officers who spend extended periods of time outside will also face increased health risks. These pollutants, particularly during warm months, are associated with work-related injuries and diseases such as hyperuricemia in traffic police. Furthermore, the physical demands of their jobs may compound the consequences of pollution, making them more susceptible to respiratory and cardiovascular problems (Schulte et al. 2023).

Geographies affected

The increasing frequency and intensity of climate-related disasters, which account for 83 per cent of all disasters in the past decade, have led to over 410,000 deaths, predominantly in LMICs, where workers often lack sufficient protections (Alreshidi et al. 2022; International Federation of Red Cross and Red Crescent Societies 2015). Emergency responders face heightened physical and mental risks as they contend with more severe and frequent incidents, particularly in Africa and Asia, where floods accounted for 47 per cent of weather-related disasters between 2005 and 2015, causing 40 per cent of all disaster-related deaths, with 89 per cent of these fatalities occurring in low-income countries (ILO 2018).

Workers in developing countries are especially vulnerable to climate change impacts on disaster response due to inadequate

infrastructure, limited safety regulations and lack of resources. First responders in these regions face greater risks from harsh conditions, insufficient protective gear and inadequate medical support. Many of these workers also have physically demanding roles with little job security, making them more susceptible to both economic and health challenges (Ansah et al. 2021).

Australia is expected to face significant impacts from climate change, particularly in its coastal zones, where over 80 per cent of the population lives. The increased frequency and intensity of climatic events and natural disasters will require communities and emergency managers to integrate climate change adaptation and mitigation into disaster preparedness efforts. Additionally, rising temperatures are predicted to lead to a higher incidence of heat-related illnesses across the country, further stressing public health systems and necessitating enhanced strategies to manage these growing risks (Alreshidi et al. 2022; Jago 2017).

East and Southern Africa have the most people in need. In 2023, it was estimated that 74.1 million individuals there would require humanitarian aid in the following year. The turmoil in Sudan accounts for about 40 per cent of this figure. Sudan's and the region's in-country requirements have escalated since the conflict began in August 2023, with a major exodus of people to neighbouring nations (Humanitarian Action 2023a). In South Sudan, for the third consecutive year, unprecedented flooding has destroyed roads, contaminated water, decimated food supplies and compromised access to humanitarian assistance for hundreds of thousands of people (Baxter et al. 2022). In Sudan alone, the number of individuals in need has climbed from 16 million in 2023 to 28 million in 2024 (Humanitarian Action 2023a).

Considerations on the nature and volume of the evidence

There is substantial credible evidence on the general occupational risks faced by firefighters as first responders in an emergency. Multiple systematic reviews discuss the threats and countermeasures for protecting firefighters. However, there is lack of substantial evidence on the safety of firefighters in relation to an increase in extreme weather events more specifically in developing countries. The majority of the publications studied as part of this systematic review (5 out of 8) are from the United States, with the remaining three coming from Europe, two from Portugal and one from Denmark (Forte 2021). Similarly, evidence on rising temperatures and their broad impact on emergency operations is available for Australia and New Zealand (Rickards & Keating 2021). This demonstrates the global scarcity of information on this topic, particularly in Asian and African nations, where no studies were located in this research. There is potential to build evidence on the safety of firefighters specific to different types of exposure and geographies.

There is a recent systematic review on occupation-induced fatigue among emergency responders but it does not discuss the impact of climate change (Marvin et al. 2023). According to this review, the safety of firefighters and paramedics is less explored compared to the police and military. Moreover, it also points to the need for more research to study how gear affects fatigue and its contribution to safety risks.

A systematic review conducted on occupational hazards has identified climate change to be a major concern among police officers in Sub-Saharan Africa. However, there is limited contextual evidence to guide the police officers (Mona et al. 2019).

2.4.4. Energy (electricity, gas, steam and air conditioning supply)

Overview

The energy sector encompasses a broad variety of industries involved in the production, distribution and consumption of energy. It encompasses various activities and subsectors, but a distinction can be made between high-carbon sources of energy, such as oil, gas and coal, and low-carbon sources such as biomass, geothermal, solar, wind, hydropower, hydrogen and nuclear (Sovacool et al. 2016).

The energy sector is not part of the official ISIC classification. However, given the significant impact from climate change, this report focuses on energy rather than the broader 'Electricity, gas, steam and air conditioning supply' ISIC sector, which is the closest classification.

Nuclear energy presents unique occupational health and safety challenges, primarily due to radiation exposure and the handling of hazardous materials, and will not be covered in this report.

Inherent risks

Certain occupational health and safety risks are prevalent across all energy subsectors, while others are unique to specific areas. Amongst the risks common to most subsectors:

Physical, musculoskeletal and ergonomic risks are particularly widespread. These arise from repetitive movements, awkward postures and physical exertion, affecting workers throughout the energy sector. (Benson et al. 2021; Bogopolsky et al. 2024; Karanikas et al. 2021; Behrani et al. 2023; Gejdoš & Lieskovský 2024; Febrian 2023).

Physical hazards include exposure to noise, vibration, high temperatures, falling from heights, and slips and trips. Health effects can range from hearing loss and skin burns to hand-arm vibration syndrome and heat stroke (Benson et al. 2021; Bogopolsky et al. 2024; Karanikas et al. 2021; Behrani et al. 2023; Gul et al. 2018; Medeni et al. 2024; Gejdoš & Lieskovský 2024; Febrian 2023).

Chemical hazards include exposure to toxic substances such as drilling fluids, oil spills and welding fumes for oil and gas workers (Benson et al. 2021; D'Antoine et al. 2023; Bogopolsky et al. 2024); epoxy resins and styrene for wind farm workers (Karanikas et al. 2021); glyphosate for biomass workers (Gejdoš & Lieskovský 2024); and cadmium, lead, arsenic and nickel for those working with photovoltaic solar cells (Behrani et al. 2023). Health effects include respiratory diseases, leukaemia, skin irritation and headaches (Benson et al. 2021; Bogopolsky et al. 2024; Karanikas et al. 2021).

Biological hazards include exposure to bacteria, ticks, fungi, organic

dust and bioaerosols, especially in rural and offshore environments. These can lead to infections, respiratory illnesses and digestive system disorders (Benson et al. 2021; Bogopolsky et al. 2024; Karanikas et al. 2021; Gejdoš & Lieskovský 2024).

Electrocution and other electrical hazards are common to wind and solar workers (Behrani et al. 2023; Karanikas et al. 2021; Gul et al. 2018).

Psychosocial hazards, particularly among offshore workers, stem from work pressure, long hours, fatigue and isolation. They can lead to anxiety, depression, hypertension and cardiovascular diseases (Benson et al. 2021; D'Antoine et al. 2023; Bogopolsky et al. 2024; Gejdoš & Lieskovský 2024).

Oil and gas

Explosions and fires pose a serious risk to oil and gas workers due to the volatile nature of hydrocarbons and the aggressive environments in which production processes occur (Bogopolsky et al. 2024).

Wind

Exposure to electromagnetic fields (EMFs) is among the most cited hazard for wind energy workers (Karanikas et al. 2021). EMFs originating from electrical components of wind farms can lead to long-term health effects, including increased risk of cancer (Karanikas et al. 2021).

Shadow flicker is a unique hazard in wind farms, occurring when light passes through moving turbine blades. While shadow flicker frequencies (0.5–1.0 Hz) are generally below the threshold for triggering epileptic seizures (above 3.0 Hz), there are anecdotal reports of temporary symptoms such as headaches, fatigue, dizziness and nausea. Large turbines usually rotate at less than 1 Hz, minimizing the risk, but smaller turbines that rotate faster may pose a greater risk (Karanikas et al. 2021).

Adverse weather conditions, including lighting and high wind, can increase the risk of accidents, especially during maintenance (Karanikas et al. 2021; Gul et al. 2018).

Biomass

Exposure to wood dust can cause respiratory problems, allergies and even cancer (Gejdoš & Lieskovský 2024).

Self-heating of biomass can lead to spontaneous combustion, posing a fire hazard, while accumulation of wood dust can create explosive mixtures (Gejdoš & Lieskovský 2024; Rohr et al. 2015).

Emissions from stored biomass, including aldehydes, monoterpenes and carbon monoxide, can cause irritation and respiratory problems (Rohr et al. 2015).

Geothermal

Geothermal plants are usually located in mountainous areas, exposing workers to high humidity and low temperatures (Febrian 2023).

Solar

The most common hazards to solar energy workers are working at height, heat stress, electrocution and ergonomic injuries (Duroha & Macht 2023; 2021; Behrani et al. 2023).

Hydroelectric

Few reviewed articles address the health and safety risks of hydroelectric energy workers in general. Some studies focused on health and safety measures adopted in specific power plants.

Increased risks due to climate change

Climate change affects workers in the energy sector both directly and indirectly. Direct impacts are similar to those experienced in other sectors. For instance, increased heat can pose health risks for outdoor workers in the solar industry (Samaniego-Rascón et al. 2019), while the growing unpredictability of wind patterns can significantly affect those working at heights or on offshore infrastructure (Parent-Thirion et al. 2024). Accidents related to electrical equipment, for instance involving electrical fires and electric shocks, have also been on the rise due to an increase in natural disasters (Jeong & Kim 2019). In general, although there is a broad understanding of OSH hazards in the energy sector, there is considerably less research on how climate change will intensify these risks.

Indirectly, climate change influences worker health and safety by driving shifts in energy use, processes and materials. These changes introduce new risks and necessitate adaptations in workplaces and organisational practices (Laurent et al. 2024), which require further research to be fully understood. As one study notes '[a] better understanding of the OSH issues that result from the human response to climate change – renewable energy, carbon capture and sequestration, material substitution, and changes to indoor air quality from new building and infrastructure designs – would also be helpful' (Kiefer et al. 2016).

One example of indirect effect is the transition from high-carbon to low-carbon fuels, a shift that has significant implications for worker safety and health. In the maritime sector, for instance, low-carbon alternative fuels such as ammonia, methanol and hydrogen are being explored. Some research has been conducted on the safety hazards posed by these fuels, including the risk of fires, explosions and toxicity (Baalisampang et al. 2018; Zanobetti et al. 2023). One study found that methanol, despite having different vapor points and other properties compared to traditional fuels, does not pose additional risks to ship occupants (Baalisampang et al. 2018). Additionally, Lloyd's Register has reported on the OSH risks associated with ammonia exposure, noting potential chronic and acute toxicity effects, explosion risks from ammonia stored in high-pressure vessels, exposure to extreme temperatures, and injuries from mechanical equipment (Eriksen et al. 2023). While there is little research identifying the long-term impact of systematic exposure to ammonia, the Energy Institute is focusing on 'understanding the Health, Safety, Security and Environment (HSSE) issues associated with large scale use of ammonia and methanol in maritime transport fuel as well as transported commodities' and 'addressing broader

industry issues around "incident data" availability for hydrogen and ammonia to assist in safety case development' (Energy Institute 2024). There are limited standards and practices in place to consider OSH in the transition to alternative fuels. In 2021, the European Transport Workers' Federation called for more clarity and guidance on this issue (Boynukalin 2021).

With the growth of the renewable energy sector, there are significant safety challenges that need to be addressed, since there are risks associated with the installation, maintenance and operation of renewable energy systems (Ferns 2022). Improved training and the development of safety standards specific to the renewable energy sector are needed to ensure worker safety, translating learnings and best practice from the oil and gas industry (Ferns 2022). Specifically, the wind energy sector has been singled out for its 'lack of consistent procedures and standards' (EU-OSHA 2013). However, another source noted that 'worker safety standards and activities are often based on experience from other industries assumed to have similar hazards', but which may not be adequately tailored to renewable technologies (Schulte et al. 2016).

Occupations most at risk

OSH challenges in the energy sector may be related to a number of contributing factors: the lack of safety data and understanding of safety issues in emerging renewable energy technologies; the lack of processes and regulations in place for new players in the energy industry; and the diversification of energy sources. Small businesses and the public are become key stakeholders but may be unfamiliar with safety requirements and procedures (Metherall 2011). Small businesses may also be at a higher risk while transitioning to low-carbon energy systems.

The majority of reported incidents in 2020 were at operational wind farms and fewer than 15 per cent of incidents were at construction or development sites (SafetyOn 2020). In general, the onshore and offshore wind industry has recently seen a greater increase in OSH incidents compared with offshore oil and gas (O&G Job Search 2022).

Affected geographies

There is a distinct lack of incidents data globally, as well as a lack of standards and low prioritisation of OSH in the renewable energy sector.

Considerations on the nature and volume of the evidence

Most of the information on OSH in the energy sector comes from guidance on OSH best practices, which is mostly published by trade associations, rather than academic articles and research. This guidance gives an indication of the types of risks involved – particularly with well-established energy technologies – but there is limited evidence and research on OSH risks in emerging technologies.

In terms of academic literature, there are limited examples of comprehensive reviews in this space. There is also a lack of literature on risks in solar and wind energy production (Schulte et al. 2016; Schulte et al. 2023).

There is a significant gap in understanding OSH risks associated with the energy sector, since much of the research on OSH in energy predates 2020 and has seldom been updated. This is particularly concerning given the growth of the renewable energy technology industry, which necessitates an updated understanding of OSH, especially regarding adverse health effects (Mulloy et al. 2013). For instance, one study highlighted the lack of quantitative or qualitative risk assessment research on occupational health issues arising during the mining of component materials, as well as during solar and wind energy manufacturing and recycling processes (Schulte et al. 2023a).

There are also notable data gaps. While physical injuries and incidents are more frequently tracked, there is less understanding of the health impacts arising from increased exposure to hazardous chemicals in photovoltaic, hydrogen and nuclear energy, as well as from air pollution relating to biomass and biofuels.

Lastly, there is a gap in standards and regulations. There is a need for the sector to consult workers on OSH, publish data on workforce health, and establish standards. This is crucial to address the lack of data and research on the impact of wind energy developments – and the exacerbating effect of climate change – on workers (EU-OSHA 2013; Ferns 2022).

2.4.5. Manufacturing

Overview

Manufacturing involves the transformation of materials into new products (United Nations 2008)[1]. According to the United Nations Statistics Division (UNSD), manufacturing comprises 23 industries[2], and within these industries there are further sub-industries. The boundaries between manufacturing and other sectors in the classification system are not always clear. Overall, manufacturing involves the transformation of materials into new products (even if the definition of what those are can be subjective).

The manufacturing industry is one of the largest contributors to greenhouse gas emissions worldwide (United Nations, n.d.). Machines used in manufacturing often run on coal, oil or gas; materials produced in the process are often made from or with chemicals sourced from fossil fuels; and the production of goods results in emissions. In the US, manufacturing accounts for almost a quarter (23 per cent) of direct carbon emissions according to the Environmental Protection Agency (United States Environmental Protection Agency 2022). Similarly, in Europe the manufacturing industry emits 880 million tonnes of carbon dioxide equivalents per year, making it one of the largest emitters of greenhouse gases (Lundstedt 2021).

1. The definition of a 'new product' is subjective.

2. Manufacture of food products; manufacture of beverages; manufacture of tobacco products; manufacture of textiles; manufacture of wearing apparel; manufacture of leather and related products; manufacture of wood and of products of wood, cork, straw and plaiting materials; manufacture of paper and paper products; printing and reproduction of recorded media; manufacture of coke and refined petroleum products; manufacture of chemicals and chemical products; manufacture of basic pharmaceutical products and pharmaceutical preparations; manufacture of rubber and plastics products; manufacture of other non-metallic mineral products; manufacture of basic metals; manufacture of fabricated metal products, except machinery and equipment; manufacture of computer, electronic and optical products; manufacture of electrical equipment; manufacture of machinery and equipment; manufacture of motor vehicles, trailers and semi; manufacture of other transport equipment; manufacture of furniture; other manufacturing (UNSD, n.d.).

Inherent risks

Fire and explosions pose a serious threat to the health and safety of workers in manufacturing. Sparks from welding, leaking fluids, flammable materials/gases, etc., can cause severe injuries or even the death of workers (Sentinel Safety Solutions 2023).

Chemical hazards include exposure to toxic substances such as cleaning solutions, solvents, metalworking fluids, carbon monoxide and fuel. These can cause long-term health concerns and serious injuries, especially if they are ingested, inhaled or spilt on skin. Prolonged exposure to these chemicals causes many issues including cancer, asthma and breathing problems (Sentinel Safety Solutions 2023).

Physical hazards are caused using heavy and specialist equipment such as rollers, belts and pulleys, which can cause eye injuries from dust, sparks and flying particles, crushed limbs, cuts to the skin from sharp edges, etc. Lifting/handling is a major cause of non-fatal injuries, along with contact with machinery (Sentinel Safety Solutions 2023; HSE 2017).

Musculoskeletal disorders are prevalent in this sector because of how repetitive the work is. Due to the labour-intensive nature of manufacturing jobs, its common to strain muscles and suffer repetitive strain injuries and 'pinched' nerves (DiVincenzo 2023).

Slips, falls and trips caused by poor lighting, wet floors, uneven surfaces, elevated platforms, etc., are among the leading causes of injury and death in the manufacturing sector (Sentinel Safety Solutions 2023; HSE 2017).

Heat stress is common in areas of manufacturing where work is done in enclosed spaces. Body heat and core body temperature might increase due to work rate; this causes heart rate to increase, leads to dehydration and puts strain on the body (HSE 2024).

Increased risks due to climate change

High temperatures directly impact worker productivity, safety and absenteeism in manufacturing settings, especially in developing countries such as China and India. Somanathan et al. (2021) found that in India, manufacturing output declines by approximately 2 per cent per degree Celsius increase in temperature. This decline is due to reduced labour productivity rather than capital factors. Worker output and attendance declined on hot days across various manufacturing settings, such as cloth weaving, garment sewing and steel production. Research on around 70,000 manufacturing plants in India indicated a 3 per cent decline in output value for each degree above the average temperature. As temperatures rise globally, workers in temperate areas are also at greater risks of accidents and work-related fatalities (Carlin et al. 2023). According to the Directorate General Factory Advice Service and Labour Institutes, an office within the Indian Ministry of Labour & Employment, in 2020 a total of '32,413 accidents were reported across various industries, resulting in 1,050 fatalities and 3,882 injuries' (Dhar & Potdar 2023).

Carlin et al. (2023) highlight similar findings in China, where temperatures above 32°C led to substantial output losses. Without intervention, heat stress could reduce China's manufacturing output by 12 per cent, equating to nearly US$40 billion annually, which could directly impact the safety of workers in the industry. In 2021, there were over 30,000 production safety accidents in China, resulting in more than 26,000 deaths (China Labour Bulletin 2024). Pogačar et al. (2018) and Krishnamurthy et al. (2017) further corroborate these findings, reporting significant health and productivity impacts due to increased heat stress in Slovenia and Southern India, respectively.

In Bangladesh, Alam et al. (2022) identify OSH concerns especially within the garments and textiles industry, with workers facing musculoskeletal disorders due to poor working conditions and breathing problems due to enclosed and small working spaces. Climate change can worsen these conditions through increased temperature and humidity. Ali et al. (2021) highlight challenges in maintaining safe work environments, with poor OSH disclosure scores indicating inadequate accountability in Pakistan. As climate change intensifies, the lack of adequate reporting and accountability could hinder efforts to address the increased risks associated with extreme weather and temperature fluctuations.

Water-intensive manufacturing processes are vulnerable to climate-induced water scarcity. Carlin et al. (2023) note that droughts can significantly impact production capacity, as seen during the 2018 Rhine River Drought. Similarly, petrochemical industries in the Middle East face significant risks due to chronic water scarcity, forecast to impact GDP by 6–14 per cent by 2050. The security of water in the manufacturing process can have several implications for workers. For example, reduced water availability for cooling systems in manufacturing plans can lead to overheating and heat stress (Jun Liu et al. 2023). It can also affect dust suppression, increasing respiratory hazards (Tarmac Limited 2022). Additionally, insufficient water for sanitation can exacerbate hygiene-related risks for workers.

Flooding and wildfires pose additional risks to workers in the manufacturing sector. Approximately 59–64 per cent of companies manufacturing computers and electronic products are at high risk of flooding in over 30 per cent of their facilities. This risk is particularly significant for facilities in Asia, where many manufacturing companies are based. In 2021, Floods in central China inundated the manufacturing hub of Zhengzhou resulting in at least 69 fatalities (Carlin et al. 2023).

Globally, Carlin et al. (2023) also note that 18–23 per cent of chemical manufacturing company assets are vulnerable to flooding. Stronger storms have heightened the risk of chemical spills and safety incidents, especially due to damage to power sources. From 2011 to 2015, US municipal fire departments responded to an average of 37,910 fires annually at industrial or manufacturing sites. Of these, 71 per cent were wildfires or unclassified, resulting in an average of three civilian deaths, 38 injuries, and US$265 million in property damage each year.

Climate change can exacerbate risks in the textile and fashion sector by increasing the frequency and severity of extreme weather events, which disrupt supply chains and production processes. Higher temperatures and humidity levels may worsen indoor working

conditions, leading to heat stress and respiratory issues. Additionally, climate change can affect the availability and quality of raw materials, pushing factories to adopt more intensive production methods that may increase chemical exposure and related health risks for workers (Seidu et al. 2024).

Occupations most at risk

Workers in transportation equipment manufacturing such as machinists, engineers, assemblers and welders face significant risks. Similarly, those in machinery manufacturing, including technicians, mechanics, machine operators, and packaging operators, operate complex and powerful machinery that increases the likelihood of injury. Chemical manufacturing especially poses dangers to chemical plant operators, chemical loading operators, laboratory technicians, chemical packers and chemical engineers due to hazardous substances and equipment (Wagner 2023; Xiang et al. 2022). Occupations most at risk in the textile and fashion industry include sewing machine operators, garment workers and those involved in fabric cutting and dyeing processes. These roles often require prolonged sitting in poor postures, exposure to hazardous chemicals and dust, and high physical and mental demands. The lack of adequate PPE and ergonomic support further increases the vulnerability of these workers to health-related issues (Seidu et al. 2024).

Affected geographies

In Sub-Saharan Africa, the effects on labour productivity and supply are profound, with potential declines of up to 50 percentage points in effective labour under a scenario where temperatures rise by 3.0°C (Somanathan et al. 2021).

In South Asia, rising temperatures are leading to reduced worker productivity and increased absenteeism. In India, for instance, a vast majority of workers have reported experiencing heat-related health issues such as excessive sweating and fatigue (Krishnamurthy et al. 2017). Additionally, firms in LMICs such as Pakistan struggle to provide safe working conditions and adequately report OSH performance (Ali et al. 2021). In Bangladesh, the workforce endures heavy workloads in crowded, hot and humid environments, resulting in both physical and mental stress (Alam et al. 2022).

Without further interventions, heat stress could potentially reduce China's annual manufacturing output by approximately 12% (Carlin et al. 2023). The manufacturing hub of Zhengzhou in central China experienced severe floods in 2021 (Carlin et al. 2023). Key textile and garment manufacturing regions, including India, Bangladesh, and parts of Southeast Asia, are notably affected. These areas have large labour forces working in factories that often lack adequate safety measures, and any adverse health impacts can affect a substantial number of workers (Seidu et al. 2024).

In Southeast Asia, manufacturing hubs are grappling with rising temperatures and high humidity, leaving workers in poorly ventilated sweatshops facing extreme heat conditions (Tan & Wanichwethin 2023).

The Middle East, particularly along the Persian Gulf, hosts a significant portion of chemical production in water-stressed countries like Kuwait, Saudi Arabia and the UAE. Facilities in this region are especially vulnerable due to chronic water scarcity (Carlin et al. 2023).

Even temperate regions are not immune, as rising global temperatures pose risks to workers. For instance, a study of a Slovenian manufacturing plant revealed suboptimal summer conditions, with many workers reporting headaches and fatigue due to heat, and the majority finding the temperature unsuitable (Pogačar et al. 2018).

In Mexico, heat-related effects such as dehydration, heat exhaustion, heat stroke and even death are becoming more prevalent. These impairments not only impact workers' health but also diminish their productivity. As climate change progresses, these health effects are expected to become more frequent and widespread (Samaniego-Rascón et al. 2019).

Considerations on the nature and volume of the evidence

The evidence regarding risks to manufacturing workers, particularly heat stress, is extensive and covers various geographical regions. However, direct studies on the impact of climate change on these workers, or in fact on the manufacturing sector in general, are limited. Many studies use surveys to gather responses from employees and employers in the manufacturing sector. Secondary data predominantly involves qualitative analysis, with few studies employing regression analysis to establish causality related to climate change's effects on worker health and safety. Most studies are focused on LMICs, considering the large share of manufacturing in their economies.

Government websites generally emphasise the economic role of manufacturing, lacking any focus on climate change impacts or worker health and safety risks. Websites such as the World Economic Forum, UNEP, company blogs and various think tanks provide useful statistics and insights on worker safety and future trends related to climate change.

It's important to note differences in how the manufacturing sector is classified between the Global North and Global South. In the Global South, there is significant underreporting of workplace accidents. The prevalence of informal employment within manufacturing makes it challenging to distinguish between different industries and their workers, and to recognize which industries would be at most risk within this sector.

2.4.6. Mining and quarrying

Overview

Mining is generally categorised into two main types: formal mining and informal mining. Formal mining, also known as large-scale mining (LSM), involves extensive operations typically managed by major companies. These operations are well-funded, highly mechanised and well regulated. LSM is mining conducted predominantly by

multi-national companies with tens of thousands of employees. The number of people working in the formal mining economy has been estimated at around 9 million (Elgstrand et al. 2017).

Informal mining, on the other hand, often referred to as artisanal and small-scale mining (ASM), includes smaller operations that are usually unregulated. Carried out by individuals, families or small groups using minimal technology, ASM provides livelihoods for an estimated 40 million people while a further 150 million are dependent on ASM, typically in LMICs (Schwartz et al. 2021). As an industry, ASM contributes about 20 per cent to the yearly worldwide supply of mined gold, representing a market worth over 50 billion USD annually, based on 2024 gold prices (Planet Gold 2024).

Quarrying, distinct from mining, refers to the extraction of building materials such as stone, sand and gravel, used in construction and infrastructure. Quarrying typically involves the removal of surface materials at open pits rather than the exploitation of underground resources. Quarrying operations can be both large scale and small scale, with examples including limestone quarries and sand and gravel pits (Armstrongs Group 2024).

Inherent risks

Large-scale mining

LSM employs extensive automation and mechanisation in various stages of the mining process, which generally reduces risks to workers when compared to ASM. However, LSM is not without significant health and safety challenges.

One major concern is the inhalation of dust, which can lead to serious respiratory diseases such as silicosis, tuberculosis and lung cancer (Stewart 2020).

The mechanised nature of LSM, while reducing some physical risks, still poses dangers of injury and death from accidents, which remain a critical issue (Elgstrand et al. 2017).

Additionally, the mental health of workers in LSM is an area of concern. Workers may experience anxiety, depression and fatigue, which are exacerbated by the stressful working environment and pressures from management (Pizarro & Fuenzalida 2021).

Artisanal and small-scale mining

Miners engaged in ASM often operate under harsh conditions, with minimal regulatory oversight and a lack of OSH protections. The broader psychosocial environment of ASM can involve serious issues such as child labour, conflicts between miners and local residents, sexual violence, and economic exploitation (Landrigan et al. 2022; Schwartz et al. 2021). These conditions contribute to a range of documented health risks.

Injury and death can occur from various hazards, including drowning, crushing, and falls. Miners are also exposed to toxic chemicals such as cyanide and mercury, which pose significant chemical hazards. Inhalation of dust is another critical concern, leading to diseases such as silicosis, tuberculosis and lung cancer, with coal miners facing a 10–21 per cent risk of developing coal miners' pneumoconiosis (Landrigan et al. 2022; Schwartz et al. 2021).

Ergonomic hazards are prevalent, stemming from the physical demands of carrying and using heavy tools.

Infectious diseases are also a major risk, as silica exposure can increase vulnerability to infections like COVID-19, and sexually transmitted diseases are common among ASM miners.

Water and sanitation issues further exacerbate health risks, leading to diseases such as cholera.

The migration of workers to mining areas often results in inadequate infrastructure and overcrowded living conditions.

Additionally, miners are at risk of hearing damage due to the noise from machinery and the use of dynamite (Landrigan et al. 2022; Schwartz et al. 2021).

The communities supported by ASM are also exposed to increased risk as a result of the mining. These include exposure to toxic pollutants such as mercury, lead, arsenic, cadmium and cobalt, both in breast milk and the wider environment. Some processing of gold and mercury may also take place in household kitchens, increasing the risk of exposure for families (Landrigan et al. 2022; Schwartz et al. 2021).

Quarrying

Exposure to dust is a major hazard to quarry workers, as dust in the lungs can lead to respiratory problems such as bronchitis, silicosis and asthma (Ilo et al. 2018; Asiegbu et al. 2019). A significant number of quarry workers in Nigeria experience mild cough (38.8 per cent), severe persistent cough (6.6 per cent), and hemoptysis (coughing up blood) (4.1 per cent). Additionally, 48.2 per cent of the workers had reduced lung function compared to the control population (Henry et al. 2017).

Workers are also prone to eye and skin irritation from dust exposure. This can lead to conditions such as cataracts, blurry vision, itching and eye irritation (Asiegbu et al. 2019).

Exposure to noise from quarry activities is another significant hazard, contributing to hearing loss and other auditory issues (Asiegbu et al. 2019).

Increased risks due to climate change

Climate change mitigation will increase the demand for materials used in low-carbon technologies such as tantalum, cobalt and lithium. This is likely to increase the number of people working in the industry as a whole and particularly poses a concern in relation to mining in conflict zones and ASM settings. For example, 20–30 per cent of the global cobalt supply is from ASM conducted in the DR Congo (Landrigan et al. 2022). Climate change will also contribute to broader economic uncertainty and exacerbate challenges in industries such as farming, forcing greater numbers in LMICs to work in ASM. More broadly, climate change will impact the economics of mining and quarrying because climate-related hazards will reduce the viability of operations and increase related costs in operating and transportation (Landrigan et al. 2022). This may have a secondary impact on working pressures, working conditions and work-related stress (Qarahasanlou et al. 2024).

The literature highlights additional OSH risks for mine and quarry workers associated with climate change (Odell et al. 2018; Qarahasanlou et al. 2024). One significant danger is the increased risk of landslides and the failure of tailings dams, exacerbated by water scarcity. The collapse of these dams can also lead to the hazardous flow of polluted water. Another concern is the thawing of permafrost in mining locations, which can destabilise the ground and infrastructure. Extreme rainfall events pose further risks, potentially leading to flooding and erosion. Moreover, higher temperatures elevate the risk of physical exertion and heat exhaustion among workers.

Occupations at risk

Most available research examines safety risks in general (without reference to specific roles) or the risk of safety in mining and quarrying in relation to other sectors. However, Kasap et al. (2017) contains an interesting assessment of the various roles and associated risks in the context of open-cast pit mining. The 'worker' category was understood to have the greatest overall level of risk, with the most likely cause of accident being transportation/hand tool/fall, followed by landslides. The group with the second highest risk level was operators (of machinery and vehicles), who were most exposed to hazards in the 'other' category such as crashing, tipping, burning or collision of machinery (Kasap & Subaşı 2017).

While many risks, such as musculoskeletal disorders, are prevalent across the sector, working in mining has variable associated health impacts depending on the type of mining being conducted and the kinds of mineral that workers are exposed to. For example, coal-mining is specifically associated with coal miner's silicosis, while working in diamond mines is associated with silicosis and cancer due to the presence of asbestos-like deposits (Stewart 2020).

Underground mining is generally understood to be more dangerous than open-cast mining or quarrying. Risks include exposure to minerals which can cause cancer, silicosis, coal miners' pneumoconiosis and other health problems; exposure to fumes from diesel machines used in the mines; noise exposure from the use of machinery and explosives; and exposure to heat and vibration from hand-tools or mining machines (Elgstrand et al. 2017).

Open-cast mining and quarrying are associated with heat stress in warm climates; exposure to dust and fumes; serious accidents due to transport and manual handling; noise and vibration (Elgstrand et al. 2017). One study found that the most likely overall hazard in open-pit mines was due to the slopes on which the mining is conducted, which can move if disrupted by workers, vehicles or machinery (Kasap & Subaşı 2017).

In ASM communities, processing of minerals is sometimes carried out in communal spaces without appropriate protections, using dangerous chemicals. For example, cyanide and mercury can both be used in the extraction of gold. While exposure to these chemicals is a risk for everyone living in proximity to mines where ASM is being conducted, the workers and family members in immediate proximity to the processing are likely to be at greatest risk (Schwartz et al. 2021).

Geographies affected

As noted below, there are significant knowledge gaps in the literature relating to the impact of climate change on safety and health in mining and quarrying. However, the impacts of climate change on ASM are likely to be felt most acutely by LMICs in the Global South. People in regions where the impacts of climate (e.g. on crop yields) are felt most severely are more likely to turn to ASM as a form of income diversification (Landrigan et al. 2022).

Considerations on the nature and volume of the evidence

There are major challenges with regards to the volume and quality of evidence available on safety specifically in relation to ASM, with the only available data being estimates of production volume and the number of people working in/supported by the sector. There are gaps in relation to the demographics and communities involved in ASM, the global supply chain, the structure of the industry and the role of economic factors (Landrigan et al. 2022; Schwartz et al. 2021). As Schwartz et al. (2021) argue, this is not simply an issue of 'inattention or a lack of resources', but the inability of countries to 'provide a framework for action or the capacity to manage ASM activities'. While some countries (e.g. South Africa) have experienced success in creating a framework for managing ASM, oversight remains poor,whether due to a lack of resources or the capacity to enforce laws/regulations (Schwartz et al. 2021).

There is more evidence relating to large-scale mining, which typically falls within an OSH framework. For example, a recent review identified four primary themes in the literature: technology to reduce the occurrence of mining accidents; development of models and software; challenges relating to mining accidents; and the broader impact of mining accidents (Ismail et al. 2021).

There is some literature on quarrying, but most articles are focused on specific regions, such as Ebony State in Nigeria (Henry et al. 2017; Asiegbu et al. 2019).

2.4.7. Transportation and storage

Overview

The transportation and storage sectors are a vital part of the global economy, encompassing various activities related to the movement and storage of goods and people. These sectors include land transport, such as rail and road; water transport, both inland and maritime; air transport, covering both passenger and freight services; and essential support activities such as storage, warehousing and logistics (Eurostat 2024).

Inherent risks

In road transport, workers are particularly vulnerable to accidents, physical injuries, exposure to harmful substances and violence, with long, irregular hours contributing to fatigue and stress (EU-OSHA 2011; ILO 2015b). Road transportation workers have also a high risk of developing cancer, particularly liver, intrahepatic bile duct and digestive organ cancer, due to prolonged exposure to motor vehicle

emissions (W. Lee et al. 2020; Gromadzińska & Wąsowicz 2019). A study focused on bus drivers highlighted several health and safety risks faced by this occupation which are also common to other land transport workers (Golinko et al. 2020). Prolonged sitting and the stress associated with driving can lead to cardiovascular diseases. Additionally, the constant vibration and poor posture experienced while driving can result in physical discomfort and long-term musculoskeletal disorders. Drivers are also exposed to harmful substances within the bus cabin, which can cause respiratory issues. Mental health problems, such as stress and emotional fatigue, are common due to the demanding nature of the job. Safety risks include exposure to high levels of noise, which can lead to hearing loss and increased stress. High temperatures within buses can result in heat stress and related health problems. Furthermore, exposure to harmful impurities such as dust and gases can lead to respiratory issues (Golinko et al. 2020).

Rail transport workers, especially those in trackside maintenance, are exposed to significant physical dangers from moving trains, heavy machinery and hazardous chemicals, along with ergonomic challenges and the psychosocial toll of isolation and fatigue (EU-OSHA, 2011).

Air transport workers, particularly those in aircraft maintenance and ground handling, deal with high-risk environments involving heavy lifting and repetitive tasks which can lead to musculoskeletal disorders (W. Lee et al. 2019; EU-OSHA 2011). Airport workers are also exposed to jet exhaust and ultrafine particles, which may contribute to cancer, heart disease, mental illness and respiratory symptoms (Merzenich et al. 2021). A study showed that air transportation industry workers in Korea have an increased risk of leukaemia compared to government employees and the general working population (W. Lee et al. 2019). There are also psychosocial and mental health risks associated with the stress of the job (W. Lee et al. 2019; EU-OSHA 2011).

A review by Aikaterini et al. (2019) highlighted that seafarers often face issues related to poor diet and lack of physical activity, leading to metabolic syndrome, obesity and cardiovascular diseases. The nature of maritime work also exposes seafarers to a high risk of accidents and injuries, including falls, machinery-related incidents, and drownings (Aikaterini et al. 2019). Long working hours, irregular schedules and isolation contribute to significant levels of fatigue, stress and mental health issues, sometimes leading to suicide (Aikaterini et al. 2019; Maistrello et al. 2023).

Similarly, workers involved in warehousing and storage handle heavy goods, leading to musculoskeletal disorders. Strains and sprains often occur when workers lift loads improperly or attempt to carry loads that are too large or heavy. Additionally, there is a significant risk of fractures, cuts and bruises, which can result from being struck by materials or getting caught in pinch points. Mechanical handling of materials also presents its own set of hazards, since overloading equipment can lead to accidents (EU-OSHA 2002).

Climate-related risks

Climate change increases risks in the transport sector by disrupting infrastructure, exposing workers to extreme weather, and creating new safety hazards. Outdoor transport workers, including those in logistics and ground handling, face rising health risks from heat stress, respiratory issues and exposure to vector-borne diseases (Habibi et al. 2021).

A recent review by Hernández-Duarte et al. (2024) highlights that climate change exacerbates health and safety risks for land transport workers by increasing the prevalence of cardiovascular, respiratory and mental health issues. Physical health risks include diseases related to heat exposure and pollution, while mental health issues involve stress, anxiety, depression and eco-anxiety due to long working hours and insufficient infrastructure (Hernández-Duarte et al. 2024).

In road and rail transport, increased precipitation can lead to infrastructure damage, such as road erosion and weakened drainage systems, making travel hazardous for workers (United States Environmental Protection Agency 2025).

In air transport, increased frequency of severe weather events (storms, heavy rains and high winds) can make ground operations more challenging. Similarly, climate change has been linked to an increase in turbulence, which can directly affect the ability of flight crews to deal with stressful turbulence-related events at a higher frequency (Gratton et al. 2022).

In sea transport, rising temperatures and humidity levels due to global warming exacerbate heat stress, dehydration and heat-related illnesses among seafarers. This is particularly problematic as their work often requires high physical exertion and the use of personal protective equipment, which can worsen heat impacts (Ferrari et al. 2023; Tang 2021).

Workers involved in physically demanding roles such as warehousing and storage can be impacted by heat stress due to rising temperatures (NBC News 2023).

Occupations at risk

Informal land transport workers in lower-income regions face additional risks from poorly maintained vehicles and inadequate training (ILO 2015b).

Air pilots are at increased risk of eye diseases due to exposure to UV radiation (Schulte et al. 2016).

Affected geographies

Much of the available literature on the impact of climate-related hazards in the transportation and storage sector is at the national or regional level. There are significant risks observed across multiple regions; nevertheless, there is insufficient information to make claims specific to the transportation industry. Based on existing research, coastal communities and ports are considered more vulnerable to rising sea levels and storm surges, which might have a direct impact on water transport workers. Similarly, Southern Asia and Western

Africa are likely to suffer major hazards, which would exacerbate working conditions, particularly for those involved in railways and roads. In comparison, Europe and North America may see smaller productivity consequences but still face significant health and economic concerns during extremes. Tropical and subtropical regions are at particularly high risk due to excessive heat and the frequency of precarious, informal jobs (ILO 2024).

Considerations on the nature and volume of the evidence

The available evidence on the OSH risks related to climate change in the transport and storage sector remains uneven. A notable EU-OSHA publication focuses on general transport safety concerns, but much of the work is limited to European contexts and there has not been an updated version since 2011 (EU-OSHA 2011).

The review from Hernández-Duarte et al. (2024) confirmed that the quality of the available evidence on the impact of climate change on land transport workers is somewhat limited, suggesting that the field may suffer from a lack of recent and focused studies.

Rail transport lacks comprehensive reviews addressing the OSH impacts of climate change, with much of the existing literature also being relatively dated.

A systematic review of the organisational risks factors for aircraft workers highlighted that most of the evidence comes from the in the United States and the European Union and had moderate or low-quality methodology and evidence (Marqueze et al. 2023).

However, maritime transport shows stronger evidence, particularly in the context of transitioning to green shipping. The decarbonisation of shipping through the use of alternative fuels and technologies introduces several health and safety risks, including fire and explosion hazards from hydrogen and batteries, and toxicity risks from ammonia (H. Wang et al. 2022; Q. Wang et al. 2023).

2.5. Workshop findings: how the Global Safety Evidence Centre can make an impact

This review provides an overview of the issues and evidence related to the complex challenges posed by climate change in relation to OSH. While numerous areas within this field require further investigation, there is already a substantial body of existing research, with many researchers continuously generating new insights.

In discussions with LRF colleagues and broader stakeholders during the workshop, it became evident that the Centre's greatest impact might lie not in conducting primary research, but in synthesising and disseminating existing evidence. By focusing on these activities, the Centre can serve as a hub for collating and interpreting data, ensuring that critical findings are accessible and actionable for policy makers, practitioners and the public.

Additionally, the Centre can play a crucial role in coordinating research efforts across different regions and disciplines. By fostering collaboration and communication among researchers, the Centre can help to align priorities, avoid duplication of efforts, and identify gaps in knowledge that require attention. This strategic approach would ensure that resources are used efficiently and that the evidence generated is robust and relevant to diverse geographical and sectoral contexts.

The recommendations for the Centre's activities that emerged from the workshop were integrated with the findings from the reviews and interviews, and are summarised in Box 2.

Box 2. Recommendations for the Centre's activities

Focus on translating and sharing information

- Up-to-date information dissemination:

The Centre could prioritise establishing robust processes for providing and sharing the most current information. Rather than generating new evidence, the Centre might achieve more impact by focusing on making existing knowledge accessible and actionable for stakeholders.

- Living evidence synthesis:

Developing 'living evidence synthesis' documents could provide a useful reference point. These dynamic resources would continuously integrate new findings, ensuring that stakeholders and policy makers have access to the latest and most relevant information.

Coordinating research efforts

- Centralised coordination and research priorities:

There is a lot of parallel research happening simultaneously in this space, so the Centre could add value by coordinating these efforts. By signposting existing research, and highlighting evidence gaps and research priorities, the Centre could help to streamline efforts and reduce duplication.

- Context-specific capacity building:

Given the context-specific nature of both climate change and OSH, understanding local contexts means improving local capacities for data collection and analysis. Often short-term solutions cause long-term negative consequences, making local capacity for monitoring and evaluation essential. The Centre could help establish and disseminate methods to improve data reliability, particularly in regions with historically unreliable sources, such as parts of the Global South.

- Facilitating cross-contextual learning:

Sharing knowledge across different contexts is vital. The Centre could foster shared learning at a global level. This approach could ensure that effective strategies are adapted and applied in diverse settings.

3. Conclusions

This scoping review was conducted to support LRF in its goal to establish a Global Safety Evidence Centre. The review's aims were to explore the multifaceted impacts of climate change on OSH by mapping existing knowledge, considering the nature and quantity of the evidence, and identifying research gaps where the Centre could add value. The methods used included a scoping review of the available evidence, targeted sector-specific reviews, expert interviews and a stakeholder workshop. The research team utilised innovative AI tools, both developed in house and available online, to identify and summarise relevant literature.

This research underscores the profound and varied impacts of climate change on OSH across different sectors and regions. Climate change exacerbates several occupational risks, including heat, UV radiation, air pollution, extreme weather events, vector-borne diseases and agrochemicals. Some of these, especially heat and UV radiation, have been well-studied, while others, such as other biological hazards and risks to mental health, would benefit from additional evidence.

Targeted evidence-based interventions, guidelines and policies tailored to specific sectors and occupations are necessary to effectively mitigate the adverse effects of climate change on workers in diverse settings.

Climate change impacts all regions worldwide, yet research and data collection are unevenly concentrated in Europe and North America, leaving significant gaps in LMICs. Addressing this imbalance necessitates a 'think globally, act locally' strategy, developing mechanisms for cross-regional learning while designing and implementing targeted interventions and policies tailored to specific contexts.

Despite the growing body of research, many areas remain underexplored, highlighting the need not only for targeted studies in specific contexts, but also for better coordination between researchers.

Similarly, our reviews of a selection of seven economic sectors revealed that while all economic sectors are impacted by climate change, not all sectors and groups of workers are researched equally. Outdoor workers, notably in agriculture and construction, have been more extensively studied compared to those in indoor settings. Some sectors, especially transport, lacked recent and up-to-date evidence that focuses specifically on the effects of climate change.

The Global Safety Evidence Centre can potentially add significant value by synthesising and disseminating evidence, facilitating cross-sectoral and cross-regional knowledge exchange, and developing adaptive methods in order to maintain an up-to-date body of evidence that evolves alongside the risk landscape (i.e. living evidence reviews). By facilitating improved local data collection and cultural adaptation, and fostering global collaboration, the Centre can make an impact in terms of improving the evidence base.

The challenges posed by climate change are complex and multifaceted. Continued collaboration and research are essential in order to adapt OSH policy and guidance to evolving climate conditions. By addressing knowledge gaps and leveraging innovative research methods, substantial progress can be achieved in advancing the knowledge base aimed at safeguarding workers from climate-related risks.

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Annex A. Interview guide

The questions used as prompts during the interviews conducted as part of this study are provided below. The questions were tailored depending on the interviewee's background to ensure relevance and maximise the depth of information obtained.

1. Can you please tell me about your professional background and role at [organisation]? How does your role address OSH and/or climate change?
2. What are the most high-risk industries when it comes to the impact of climate change on occupational safety and health?
3. Which sectors have received a lot of attention from an occupational safety and health perspective? Which sectors have received less attention? Why do you think this is?
4. How is the available evidence on climate change and OSH distributed by geographical regions?
5. Do you think there is additional need for evidence focusing on low- to middle-income countries?
6. Where are the evidence gaps? Are there any risks, or sectors, which might benefit from additional evidence?
7. If you were going to conduct (or commission) an evidence/literature review on a topic related to climate change and occupational safety and health, which topic would you choose and why?
8. What do you think is most needed to have a positive impact? More evidence (e.g. primary studies and RCTs to determine what works), more literature reviews, implementation strategies, or something else?
9. Is there anything else you'd like to add on this topic, including anything you wish you'd added to your earlier responses or anything you thought I might ask but didn't?