Green Technology Book Solutions for confronting climate disasters

WIPO

In cooperation with our partners

Green Technology Book Solutions for confronting climate disasters

WIPO
WORLD
INTELLECTUAL PROPERTY
ORGANIZATION

Suggested citation: World Intellectual Property Organization (WIPO) (2025). *Green Technology Book*: *Solutions for confronting climate disasters*. Geneva: WIPO. 10.34667/tind.58951

Cover: Getty Images/Iboter, Bilanol, mack2happy
WIPO Publication No. 1080.4EN/25

First published 2025

World Intellectual Property Organization
34, chemin des Colombettes
P.O. Box 18 CH-1211
Geneva 20
Switzerland

ISBN:978-92-805-3860-1 (print)

ISBN: 978-92-805-3861-8 (online)

ISSN: 3005-9402 (print)

ISSN: 3005-9410 (online)

Contents

Foreword by WIPO

Thanks to the efforts of researchers, inventors and innovators around the world, we are seeing a surge in technologies and solutions to address climate change. The number of patents relating to climate action rose from under 400,000 in 2013 to more than 1.1 million in 2023. However, the problem is that many of the related innovations do not reach the people on the ground and are therefore not deployed where they are needed most.

WIPO is determined to address this gap and connect the solutions with the people who need them. The *Green Technology Book* showcases some of the thousands of technological solutions that are already available, or that will be soon, drawing on WIPO GREEN, which now has over 145,000 technologies in its database and has become the largest Greentech platform in the United Nations.

In this fourth edition, the focus is on technology related to climate-related disasters such as heatwaves, floods and storms. There were a record 151 such extreme events in 2024, including heatwaves in Australia, Mali and Japan, and severe floods and landslides in Italy, Senegal, Pakistan and Brazil. The Philippines was battered by six typhoons in the space of a month. The year was the hottest on record, and extreme events linked to climate change forced more than 800,000 people from their homes.

The ***Green Technology Book*** showcases some of the thousands of technological solutions that are already available, or that will be soon

The technologies showcased in this *Green Technology Book* help countries and people to prepare for these disasters and to be more resilient when they do happen. They include tools to enhance emergency response capabilities, bolster financial resilience and facilitate risk transfer. From AI-powered forecasting and digital twins to IoT sensors and satellite systems, they allow responders to anticipate, coordinate and deploy more effectively.

I extend my sincere thanks to our partners Climate Technology Centre and Network (CTCN) and the Academy of Scientific Research & Technology (ASRT) in Egypt. Their collaboration and

Daren Tang

WIPO Director General

Foreword by partners

Climate Technology Centre and Network

As the world prepares for COP30 in Brazil, technology will be at the heart of climate negotiations. Technology is a recognized enabler of climate action – critical for building resilience, safeguarding food and water systems, and protecting vulnerable communities. Yet, its potential remains underutilized, and adaptation continues to be underfunded. In this decisive decade, the role of innovation, knowledge sharing and equitable access to technology will determine how effectively we can reduce risks, protect ecosystems and ensure that no community is left behind.

The Climate Technology Centre and Network (CTCN) is honored to continue its close partnership with WIPO's *Green Technology Book*, this year dedicated to the critical theme of disaster risk reduction. In a world where climate-driven disasters are no longer exceptional but increasingly frequent and severe, advancing innovative, inclusive and scalable technological solutions is more urgent than ever.

Through our technical assistance, the CTCN has supported countries in deploying climate technologies that reduce disaster risks while strengthening their long-term resilience. In Malaysia, the development of a Multi-Hazard Platform integrates forecasting models for floods, landslides, heat, and air pollution, enabling local authorities to act decisively in protecting communities. In Georgia, CTCN assistance is helping establish an integrated forest fire early warning system in Borjomi-Kharagauli National Park, preserving ecosystems and reducing greenhouse gas emissions. In Nigeria, a community-based hydroponics project offers a climate-resilient pathway to food security, lessening dependence on erratic rainfall while supporting livelihoods in conflict-affected areas.

These examples highlight the power of technology when paired with local knowledge, institutional capacity, and inclusive planning. As the frequency and intensity of disasters continue to rise, global collaboration is indispensable.

Ariesta Ningrum, Director of the CTCN

Academy of Scientific Research & Technology (ASRT)

We are no longer anticipating climate change; we are enduring it. The escalating fury of climate-induced disasters — from catastrophic floods and relentless heatwaves to prolonged droughts — is a clear call that urgent, coordinated action is no longer optional, but a global imperative. In this critical context, the *Green Technology Book* stands as a vital nexus, connecting pivotal knowledge, innovation and tangible solutions to help nations not only weather these storms but build a resilient future.

This year's special edition could not be more timely, focusing squarely on technologies that combat the immediate and long-term impacts of climate-related disasters. It moves beyond theory to provide a decisive guide for action — showcasing everything from AI-powered early warning systems and nature-based solutions to resilient infrastructure and advanced response platforms. It is an essential toolkit for every decision-maker, practitioner and community on the front lines of our changing planet.

For nations like Egypt, on the frontlines of climate vulnerability, deploying science-based, technology-driven solutions is a fundamental necessity for safeguarding our people, our economies, and our hard-won development progress. The *Green Technology Book* is instrumental in this mission, effectively bridging the critical gap between research and real-world implementation and fostering the essential exchange of technologies and best practices across borders.

I extend my profound gratitude to WIPO, our dedicated partners, and all the contributors who have brought this powerful edition to life. Their work underscores a vital truth: international collaboration, open knowledge-sharing and equitable technology transfer are the bedrock of our collective resilience. Together, we can transform vulnerability into strength and ensure communities worldwide are equipped to face the challenges ahead.

Professor Gina El-Feky, ASRT President

Acknowledgments

We are pleased to present the fourth edition of the WIPO *Green Technology Book*, showcasing climate-induced disaster response technologies. This edition has been made possible through the collective efforts and contributions of numerous individuals and organizations. We extend our heartfelt gratitude to all those who have supported this project.

The book, an initiative under WIPO GREEN, was prepared under the general auspices of WIPO Director General Daren Tang, and the Global Challenges and Partnerships Sector led by Assistant Director General Edward Kwakwa. It was conceived and led by Peter Oksen, Green Technology and Research Manager, who also acted as editor. The book was researched and written by Heather Jacobs, Climate Technology Expert. Maya Spencer supported the identification and management of technologies in the WIPO GREEN Database. Natasha Mahezabin, Climate Technology Expert, served as reviewer, and WIPO GREEN staff members Rishab Raturi, Clarice Aboagye Mporamazina, Eugenia Vazquez Pol, Wenzao Zhen, Yoshinari Oyama, Alicia Pascual Perez, Christy Nomura and Tatiana Hartop provided important communications and operational support in close cooperation.

First and foremost, we wish to thank our partners at the Climate Technology Centre and Network (CTCN), represented by Director Ariesta Ningrum, and the Egyptian Academy of Scientific Research and & Technology (ASRT), represented by Gina El-Feky (President), for their vision, collaboration and continued dedication. Anastasiia Tiurmenko (Communications Specialist, CTCN), provided invaluable support in communication and outreach.

We extend our sincere appreciation to Charlotte Beauchamp, Head, Edwin Hassink, Graphic Designer and Noah Miller, Publications and Design Officer from the WIPO's Publications and Design Section, for their meticulous work on the layout and design of this publication. Vanessa Harwood in collaboration with Book Now Ltd. ensured language revision.

We are also grateful to the WIPO team who contributed to the digital iteration of this book including the dedicated collection in the WIPO GREEN Database: Dan Savu, Head, Javier Aguilar López, Daniel Ribeiro Pando and Mikhail Bezroukov from WIPO's Solutions Design and Delivery Section, and Virginie Roux and Spencer Cabildo, from the Web Communications Section, as well as Daniel Pradilla, from the WIPO IP Portal team. Additionally, we acknowledge Edward Harris, Senior Media Officer of the News and Media Division, for supporting us in our communication and outreach efforts. The Language Division, under the leadership of Mr. Lijun Fan, provided translation services, helping us cater to a much broader audience.

Our sincere appreciation also goes to the WIPO GREEN reference group. This cohort of experts and dedicated colleagues included: Carsten Fink (Chief Economist, Department for Economics and Data Analytics), Kevin Fitzgerald (Director, Information and Digital Outreach Division), Amr Abdelaziz (Counsellor, Division for Arab Countries), Edward Harris (Senior Media Officer, News and Media Division), Charlotte Beauchamp (Head, Publications and Design Section), Dalila Hamou, Director, and Ryszard Frelek, Counsellor (both External Relations Division), Dan Savu (Head, Solutions Design and Delivery Section) and Christopher Harrison (Patent Analytics Manager, Technology and Innovation Support Division).

Finally, we acknowledge the invaluable input provided by the many industry experts, policymakers, practitioners and colleagues who participated in interviews, provided case studies and reviewed the book:

- Maija Bertule, Senior Technical Advisor, UNEP-DHI
- Jana Birner, Office of the Special Advisor on Climate Action, UNHCR
- Amir Delju, Senior Scientific Officer, Climate Services Division/Services Department , WMO
- Susanna Desousa, Programme Policy Officer, Disaster Risk Financing, Climate and Resilience Service, WFP
- Marc Gordon, Senior Coordinator, Midterm Review of the Sendai Framework (MTR SF), UNDRR
- Ben Jacobs, Senior Environmental Scientist/Prescribed Fire Specialist, California State Parks
- Jiaman Lian, Consultant, Climate and Emergency Telecommunications Division, ITU
- Rosie McDonald, Climate Change Officer, Climate and Emergency Telecommunications Division, ITU
- Daniel O'Connor, Deputy Fire Chief- Detailed, Cleveland National Forest, United States Forest Service
- Esmé O'Keeffe, Office of the Special Advisor on Climate Action, UNHCR
- Dr. Daniel Tsegai, Programme Officer, Global Policy, Advocacy, and Regional Cooperation Unit, UNCCD
- Nathanial Wigington, Environmental Scientist, California State Parks

Acronyms

AAP	accountability to affected populations
AC	air conditioning
AEM	airborne electromagnetic
AI	artificial intelligence
AOP	advanced oxidation processes
API	application programming interface
ARC	African Risk Capacity
ARR	automatic rainfall recorder
ASTM	American Society for Testing and Materials
ATM	automatic teller machine
AWLR	automatic water level recorder
AWS	automatic weather station
BED	benthic event detector
BIMS	biometric identity management system
BRO	Border Roads Organization
CAD	computer-aided design
CAGR	compound annual growth rate
CAP	common alerting protocol
CB	cell broadcast
CBS	container-based sanitation
CCC	Crisis Connectivity Charter
CFM	common feedback mechanism
CO_2	carbon dioxide
CPR	cardiopulmonary resuscitation
CRISPR	clustered regularly interspaced short palindromic repeats
CSA	climate-smart agriculture
CT	computerized tomography
CTCN	Climate Technology Centre and Network
CVA	cash and voucher assistance
CWR	crop wild relative
DEM	digital elevation model
DFID	Department for International Development
DOAS	dedicated outdoor air system
DPR	dual-frequency precipitation radar
DRR	disaster risk reduction
ECMWF	European Centre for Medium-range Weather Forecasts
EM-DAT	Emergency Events Database
EPO	European Patent Office
ERP	enterprise resource planning
ERV	energy recovery ventilator
ESA	European Space Agency
ESS	energy storage system
ETC	emergency telecommunications cluster
EU	European Union
EW4ALL	Early Warnings for All initiative
EWS	early warning system

EWSS	emergency warning satellite service
FAO	Food and Agriculture Organization
FEWS NET	Famine Early Warning Systems Network
fintech	financial technology
FIRMS	Fire Information for Resource Management System
FRP	fiber reinforcement polymers
GDP	gross domestic product
GEO	Group on Earth Observations
GFRP	glass fiber-reinforced polymer
GHG	greenhouse gas
GHHIN	Global Heat Health Information Network
GLOF	glacial lake outburst flood
GM	genetically modified
GNSS	global navigation satellite system
GOES	geostationary operational environmental satellite
GPM	global precipitation measurement
GPR	ground-penetrating radar
GPS	global positioning system
GSM	global system for mobile communications
HHEWS	heat health early warning systems
HVAC	heating, ventilation and air conditioning
IBLI	index-based livestock insurance
IBRD	International Bank for Reconstruction and Development
ICF	insulated concrete form
IDMC	Internal Displacement Monitoring Centre
IDP	internally displaced person
IEA	International Energy Agency
IFRC	International Federation of Red Cross and Red Crescent Societies
ILO	International Labour Organization
InSAR	interferometric synthetic aperture radar
Insurtech	insurance technology
IoT	internet of things
IP	internet protocol
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standardization Organization
ITU	International Telecommunication Union
JAXA	Japan Aerospace Exploration Agency
KfW	Kreditanstalt für Wiederaufbau
LB-SMS	location-based SMS
LDC	least developed country
LEO	low earth orbit
LHASA	landslide hazard assessment for situational awareness
LiDAR	light detection and ranging
LLDC	landlocked developing country
mAh	milliampere-hours
MAR	managed aquifer recharge
MHEWS	multi-hazard early warning system
MODIS	moderate resolution imaging spectroradiometer
MOF	metal–organic framework
MT	metric tonne
NASA	National Aeronautics and Space Administration
NDVI	normalized difference vegetation index
NEXRAD	next-generation radar
NGN	next-generation network
NGO	non-governmental organization
NOAA	US National Oceanic and Atmospheric Administration
NOx	nitrogen oxide
NSW	New South Wales
NWS	National Weather Service
ODA	official development assistance
OECD	Organisation for Economic Co-operation and Development

OLSS	ozone laundry support system
PA	precision agriculture
PAR	phased array radar
PBO	poly-p-phenylene benzobisoxazole
PFAS	per- and polyfluoroalkyl substances
PG&E	Pacific Gas & Electric
POE	power over ethernet
PPE	personal protective equipment
QR	quick response code
RFID	radio frequency identification
RO	reverse osmosis
RTK	real-time kinematic
SAR	synthetic aperture radar
SEPI	standardized evapotranspiration precipitation index
SIDS	small island developing states
SMS	short message service
SOIL	sustainable organic integrated livelihoods
SPI	standardized precipitation index
SPV	special purpose vehicle
TLS	terrestrial laser scanner
TRMM	Tropical Rainfall Measuring Mission
UAS	unmanned aircraft system
UAV	unmanned aerial vehicle
UAVSAR	unmanned aerial vehicle synthetic aperture radar
UHI	urban heat island
ULTDH	ultra-low temperature district heating
UN	United Nations
UN OCHA	United Nations Office for the Coordination of Humanitarian Affairs
UNCCD	United Nations Convention to Combat Desertification
UNDRR	United Nations Office for Disaster Risk Reduction
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNHAS	United Nations Humanitarian Air Service
UNHCR	United Nations High Commissioner for Refugees
UNHRD	United Nations Humanitarian Response Depot
UPI-QR	unified payments interface quick response code
UPS	uninterruptible power supply
US FEMA	United States Federal Emergency Management Agency
USD	United States dollar
USV	uncrewed surface vehicle
UV	ultraviolet
VC	venture capital
VOC	volatile organic compound
VR	virtual reality
WASH	water, sanitation and hygiene
WBGT	wet-bulb globe temperature
WFP	World Food Programme
WHO	World Health Organization
WII	weather index insurance
WMO	World Meteorological Organization
WMS	warehouse management systems
WUI	wildland–urban interface
YII	yield index insuranceM
ZLD	zero liquid discharge

Key messages

Climate change intensifies disasters everywhere, affecting everyone

Climate change is driving more frequent and severe disasters: storms, floods, wildfires, droughts and landslides are impacting billions, disrupting infrastructure, economies and livelihoods. Disasters strike regardless of geography or wealth. In 2024 alone, 45 million people were displaced by disasters, with storms and floods accounting for over half of these displacements. Water-related hazards have caused half of all disasters and 45 percent of disaster deaths over the past five decades. Droughts now affect over 1.5 billion people, while wildfires burn increasingly large areas, threatening ecosystems and urban communities alike. The scale and frequency of these events are straining infrastructure, health systems and economies, highlighting that climate-driven disasters spare no one and disproportionately burden the most vulnerable.

Technologies are already available for both disaster preparedness and response

Technologies that help affected populations to both prepare for and respond to disasters are already available and in use – and are rapidly advancing. Disasters are global and so is the availability of both vital low-tech solutions and cutting edge advanced tools. But not all areas are equally well served. Emergency organizations are well experienced in reaching isolated and marginal communities and increasingly benefiting from the use of innovative solutions across diverse geographical areas and disaster types. AI is a major enabler that is rapidly increasing a range of capabilities across the technology landscape. International patenting also indicates strong innovation activity, especially in universal tools such as drones, AI, machine learning, and early warning systems, and also increasingly in specific technologies designed for wildfire prevention, prediction and response. Emerging technologies that range from AI-driven forecasting, satellite monitoring, drones and IoT sensors to resilient infrastructure, early warning systems and digital logistics platforms are transforming how societies anticipate, respond to and recover from these crises. Equitable deployment and inclusive design are essential in ensuring vulnerable communities benefit and global resilience is strengthened.

Innovation delivers results and lowers the cost of disaster preparedness and risk reduction

Investing in disaster preparedness and risk reduction is far more cost-effective than responding to crises once they have occurred. Yet global financing for prevention remains critically low. With over 300 million people needing humanitarian assistance annually, and funding meeting less than half of what is required, risk-layered financing and early action are essential. Pre-arranged mechanisms, such as insurance and contingency funds to forecast-based financing, can accelerate response and reduce losses, particularly in vulnerable countries where access remains limited. The Sendai Framework emphasizes the central role of technology in all disaster phases, promoting early warning systems, hazard monitoring, geospatial tools and resilient communications that enable governments to anticipate, mitigate and respond more effectively.

Expanding coverage, especially in least developed countries and small island states, is vital in ensuring timely, coordinated and equitable disaster preparedness and response worldwide. Beyond efficiency, disaster preparedness and response are a moral imperative – no community should be left behind when climate-induced disasters strike.

The innovation ecosystem is a technology enabler

As stressed in the previous three editions of the *Green Technology Book,* innovation and technology hold some – though not all – solutions to climate change and, by extension, to the impacts of climate-induced disasters. Such solutions emerge from strong innovation ecosystems and effective technology transfer processes, moving from laboratories to national and foreign markets, and then across borders, whether from south to south, north to south or south to north. These ecosystems rely on broader societal foundations, including education, finance, law and information systems, with the international intellectual property (IP) framework playing a key role. Ensuring these foundations function fairly and effectively is essential for fostering a lively innovation ecosystem and enabling the transfer of technologies. Respect for efficient IP systems, in particular, underpins the successful diffusion of solutions.

Technology gives responders real-time visibility and predictive foresight

Technologies like AI, digital twins, IoT sensors, and satellite systems empower responders, supporting them in efforts such as anticipating floods before they breach levees, mapping heat risk block-by-block or pre-positioning relief supplies ahead of a cyclone. This results in lives saved, shortened response times and a more efficient use of resources. Real-time situational awareness is improving via IoT sensors that track river levels and temperatures or supply stock in real time, and drones and satellites that provide visibility in places humans cannot safely reach. This supports decision-making, and through predictive supply-chain analytics ensures that food, medicine and shelter arrive at the right place at the right time. Instead of fragmented and delayed reactions, disaster managers can make data-backed, proactive choices that reduce uncertainty, cut losses and save more lives.

Disaster response combines technology with local knowledge and nature-based solutions

Effective disaster response requires blending advanced technologies with practical, locally grounded approaches. In water-related disasters, responses are shifting from reactive sandbags and drainage ditches toward integrated digital–physical resilience. Traditional defenses like levees and seawalls can be layered with smart, adaptive and nature-based systems. Technologies such as AI flood models, satellites and insurance algorithms are most effective when paired with low-tech tools, local knowledge and community-level measures. Innovations increasingly combine elements – drones with ground sensors, crowdsourcing with citizen observations and analytics with traditional practices – to create holistic solutions. Climate resilience grows when sectors dissolve boundaries – like smartphone-linked satellite insurance for farmers, drought-tolerant crops accessible to smallholders, fog harvesters in informal settlements, or flood-resilient housing for vulnerable communities. Disaster logistics are evolving from siloed aid toward interoperable platforms that integrate multi-hazard alerts, inclusive finance and real-time data. Top-down systems, such as the United Nations' Security Communications Cluster (ETC) standardize global responses, while local efforts, such as emergency alerts, are vital on the ground. Balancing centralized coordination with localized action ensures timely, effective and equitable responses.

Proactive is the new reactive

Disaster response communications technologies are enabling a shift from post-disaster reactive, fragmented logistics toward anticipatory systems. AI-enhanced forecasting and digital twins simulate floods, heatwaves and supply chain shocks before they happen. Early warning

systems empower authorities to act days in advance. The cross-cutting trend is not simply digitization, but rather a fusion of physical mobility (drones, vehicles, shelters) with digital intelligence (AI, data, communications). AI and predictive analytics are transforming disaster finance and response by enabling the preparation of aid before disasters strike. For example, GiveDirectly used Google AI to deliver targeted pre-disaster cash assistance for hurricane relief. Flood forecasts in Nigeria and Mozambique trigger early insurance payouts, while parametric insurance can provide funds ahead of droughts. Pre-positioned technologies like Field Ready's Mobile Makerspace support local repairs during floods. AI combined with satellite data enables proactive, flexible aid and shifts disaster management from reactive to anticipatory. Driven in part by the Sendai Framework, there has been a deliberate shift in focus – which has driven technological developments as well – from recovery to preparedness. This has placed an emphasis on early warning systems, digital twins, improved satellites and radar systems, and other advancements.

Information is aid

Technology is essential for disaster communication and coordination. Digital tools are not just support – they are core infrastructure for modern disaster response. No single technology suffices; multi-layered, flexible systems must function, even under stress. Reliable communication saves lives. It requires decentralized and redundant networks: mobile broadband, next-generation networks (NGNs), legacy GSM (2G), satellites, radios and mesh networks all have a vital role to play. Mobile apps, chatbots and alert systems keep communities informed. Early warning systems depend on robust channels combining modern and traditional media. AI and ICT improve forecasting, but messaging must be clear, community-specific and two-way. Seamless coordination across agencies, supported by interoperable, IP-based networks and shared standards, ensures a unified disaster response.

Technology is transforming disaster finance

Disaster finance is no longer just about post-event relief. It is about building systemic resilience before disaster hits. Insurance, cash transfers and anticipatory aid are now seen as core strategies for disaster risk reduction. Parametric and index-based insurance, AI-powered risk models and catastrophe bonds automate payouts, reduce fraud and expand coverage. Digital cash and voucher assistance, enabled by mobile money platforms like M-Pesa and bKash, deliver aid quickly and transparently, even in low-infrastructure areas. Predictive analytics allow pre-disaster disbursements, improving preparedness. These technologies shift risk and impact burdens and help better serve the uninsured.

Effective deployment of disaster response technologies requires public–private collaboration

Effective disaster and humanitarian technology requires strong collaboration between public and private sectors. For example, flood resilience depends on coordination among scientists, engineers, local governments, communities, tech providers and insurers. Flood forecasts combine satellite data (NASA), ground sensors (utilities) and evacuation alerts (telecoms). Rapid data sharing between satellites, drones, and citizen observers is essential, with IoT sensors and crowdsourced observations providing vital ground truth. Disasters evolve rapidly, requiring the instantaneous sharing of data between satellites, drones and community observers. The WFP, IFRC, and startups are co-developing scalable communications technologies, showing that multi-actor ecosystems are essential. Some technologies repurpose military-grade tools and combine AI with physical systems to enable a faster, smarter response.

Disaster technologies are powerful but come with challenges

Technologies hold transformative potential for disaster preparedness and response. But they must be deployed with close attention to data protection, bias, inclusivity and accountability. In disaster response, AI and digital tools offer real-time insights and predictive coordination. Yet they come with major challenges: data quality, algorithmic bias, lack of transparency and privacy risks. Biometric identification systems can reduce fraud and improve efficiency. However, they also risk excluding undocumented individuals or enabling surveillance that can be used in other non-disaster related contexts. AI-driven systems also require careful auditing. For instance, satellite-based damage assessments may unintentionally overlook informal settlements if not properly validated. Without such accountability, technology can reinforce existing inequalities and even overlook already marginalized groups and individuals. Wildfire technologies, especially, reveal deeper societal divides. While wealthier communities can afford fireproof homes, advanced modeling tools and even private fire response services, low-income and marginalized groups may rely on outdated or inaccessible systems. This creates a "protection gap" rooted not in technical capacity, but in social and economic priorities and imbalances. Additionally, technologies must balance fire suppression with ecological wisdom, integrate relevant indigenous knowledge, and ensure equitable access to retrofits and low-cost solutions.

Disaster risk and response technologies are best when inclusive

While technology has revolutionized preparedness for climate-related disasters, its benefits are still unevenly distributed. To avoid deepening a "climate resilience divide," the focus must shift to democratizing access to these innovations. Vulnerable regions, including least developed countries and small island developing states, face the most risks, yet have the fewest resources. For example, only 50 percent of countries have a multi-hazard early warning system. In this context, technology can become a double-edged sword. While mobile alerts powered by IoT sensors and AI can improve reach and speed, barriers such as cost, digital literacy and algorithmic bias can further marginalize at-risk communities. Open access tools, such as freely available weather apps, open-source climate models and shared risk-mapping platforms, can empower local actors to anticipate, prepare for and respond to risks. Public access to disaster modeling, weather data and risk maps is foundational for innovation – but only if that access includes the most vulnerable communities. It is critical that the data underpinning these multiple warning systems are reliable and of a high quality. This often requires authoritative coordination and quality assurance, especially for data that originates from unverified and multipoint sources such as crowdsourcing and a multitude of sensors of varying quality. Ultimately, the question is not simply what technology can do, but who it protects, who it excludes, and who has the power to shape it. Equity, transparency and inclusive design must guide the development and deployment of disaster technologies.

Executive summary

Climate-driven disasters are no longer rare events – they are the new normal. Over the past two decades, more than 80 percent of recorded disasters have been linked to climate and weather extremes, with water-related hazards causing nearly half of all disaster-related deaths. Events are also increasing in frequency. Fewer than 50 disasters were recorded in 1950, whereas today the world faces between 300 and 500 climate-related disasters annually. Sea-level rise, urbanization and heat-island effects compound risks, while vulnerable populations in informal settlements, low-income rural areas and displaced communities bear the harshest impacts.

Disasters are increasingly straining traditional response systems, with global economic losses exceeding USD 2.3 trillion annually when accounting for indirect social and environmental costs. Yet financing for disaster risk reduction remains limited. Less than 0.5 percent of development spending, and only a small fraction of humanitarian aid, go toward prevention and preparedness. Global and regional mechanisms, including catastrophe bonds, pooled funds and forecast-based finance, are emerging to enable rapid, anticipatory response. Nonetheless, coverage remains uneven, particularly in least developed countries, small island states and marginalized communities.

Technology plays a central role in bridging these gaps. Satellites, AI, IoT, drones and cloud-based analytics improve hazard monitoring, early warning and impact assessment, while mobile networks and applications enhance real-time communication with affected populations. Patent activity in disaster response is growing rapidly, particularly in UAVs (drones), AI-enabled monitoring, and multi-functional platforms, reflecting a shift toward faster, more integrated and data-driven solutions. The Sendai Framework underscores the importance of such technologies across prevention, preparedness and response, emphasizing equitable access, capacity building and inclusive design to ensure that technological advances translate into actual resilience.

Stronger storms and rising floods met by next-generation solutions

Tropical cyclones, known as hurricanes or typhoons, are intensifying because of climate change, driven by warmer ocean temperatures and increased atmospheric moisture. While the frequency of storms may be decreasing, their severity is rising, with major hurricanes becoming more destructive. For instance, Hurricane Helene (2024) caused 246 deaths in the United States, while Cyclone Freddy (2023) devastated Mozambique and Malawi. Climate change is also slowing storm movement, prolonging rainfall and flooding. Over the past 50 years, tropical cyclones have accounted for 38 percent of disaster-related deaths and economic losses globally, with long-term recovery often spanning decades.

Flooding, a major consequence of storms, is exacerbated by glacier melt, urbanization and poor infrastructure. Over 1.8 billion people face significant flood risk, 90 percent of whom live in low- and middle-income countries. Glacial lake outburst floods (GLOFs) threaten 10 million people, a risk projected to triple in High Mountain Asia by 2100. Floods damage infrastructure, contaminate water supplies and disrupt economies, with urban slums particularly vulnerable.

Improved weather forecasting, powered by satellites (e.g., NASA's CYGNSS, ESA's Sentinel), AI and drones, has reduced hurricane tracking errors from 400 nautical miles in the 1970s to under 80 miles today. But, while early warning systems (EWS) save lives, half of countries lack adequate coverage. The United Nations' Early Warnings for All initiative aims to bridge this gap by 2027. AI enhances EWS by predicting cascading risks (e.g., floods post-storm), but faces challenges such as data bias and false alarms.

As storms and floods become more severe, integrating advanced forecasting, resilient infrastructure and inclusive early warning is critical. Innovations like AI, IoT and nature-based solutions offer scalable protection, but equitable access remains a challenge, particularly in vulnerable regions. Collaborative efforts are essential in building global resilience against escalating climate threats.

Landslides countered by innovation

Landslides are triggered by heavy rainfall, earthquakes or human activities such as deforestation. They pose severe risks and cause fatalities, infrastructure damage and long-term economic disruption. Climate change is exacerbating the frequency of landslides, particularly in mountainous and tropical regions. While they are unpredictable, advanced monitoring technologies are improving early detection and response. Ground and subsurface sensors (tiltmeters, piezometers and seismic sensors) track slope stability in real time. Satellite and remote sensing technologies SAR/InSAR (millimeter-precision deformation tracking), LiDAR, and NASA's LHASA model provide large-scale hazard mapping. AI and big data integrate multisource data (drones, IoT, historical records) for dynamic risk assessment. Drones can be deployed for high-resolution post-disaster surveying (e.g., Swiss tunnel collapse assessment) and fissure mapping (e.g., Tbilisi innovation). Debris management technologies range from barriers to slurry pumps and hydraulic excavators used for efficient cleanup. Stabilizing innovations involve bioengineering using biogrout and engineering solutions including soil nailing, rock bolting and geotextiles.

Technology enables resilience to intensifying droughts

Droughts, intensified by climate change, are escalating into systemic crises, threatening food security, water access and energy production. Rising temperatures and erratic rainfall deplete groundwater, with 40 percent of humanity already facing water scarcity. Agriculture – consuming 70 percent of global freshwater – suffers yield losses, while droughts disrupt hydropower and amplify health risks like cholera (FAO, 2025; WHO, 2024a). Innovative technologies offer solutions: satellites (GRACE, InSAR) and AI monitor groundwater in real time; CRISPR-edited crops (e.g., drought-resistant HB4 wheat) and precision agriculture (IoT sensors, drones) optimize water use. Atmospheric water harvesting, from fog nets to metal-organic frameworks (MOFs), extracts moisture from the air, while sand dams and managed aquifer recharge restore groundwater. Energy systems are adapting, with floating solar panels to offset hydropower losses and smart grids to reduce water-dependent generation. Wastewater recycling (e.g., zero-liquid-discharge) can recover over 95 percent of industrial water.

Yet barriers persist, especially for small-scale farmers and vulnerable regions. Initiatives like the United Nations' CTCN, delivering drought forecasts via WhatsApp in Saint Kitts, prove that scalable models do exist. Bridging gaps requires policy coordination and investment, so as to deploy these tools equitably. Without action, droughts may cost 5 percent of global GDP by 2050 – but with strategic technology adoption, societies can build resilience against aridification's growing threats.

Wildfires worsen, while advanced technologies prevent, predict and protect

Wildfires have evolved from seasonal events into year-round crises, fueled by rising temperatures, prolonged droughts and shifting wind patterns. They now threaten ecosystems, communities and economies globally, with record-breaking burns – like Canada's 2023 fires,

which accounted for 27 percent of global tree cover loss – becoming the norm. The wildland–urban interface (WUI) is particularly vulnerable, where urban sprawl intersects with flammable vegetation, turning wildfires into urban disasters as embers ignite homes far from the fire front. Compounding the challenge, power lines and grid failures increasingly spark fires, as seen in California, where electrical infrastructure has caused 19 percent of burned acreage in recent years.

Technology is revolutionizing wildfire management, from early detection to suppression and recovery. Satellite networks (e.g., NASA's FIRMS, ESA's Sentinel) paired with AI analyze real-time data to detect fires within minutes, while drones and thermal cameras map hotspots through smoke and darkness. Innovations like mini-satellites and 360-degree cameras enable rapid response, while advanced modeling tools (e.g., FARSITE, digital twins) predict fire behavior with unprecedented precision. Aerial firefighting has also advanced, with drones conducting nighttime operations and retardant-spreading robots reducing risks to human crews. On the ground, fire-resistant materials (e.g., hempcrete, intumescent coatings) protect homes, while prescribed burns and mechanical thinning mitigate future risks.

Yet challenges persist. Traditional fire models struggle with climate-driven extremes, and retardants often harm ecosystems. Emerging solutions like biodegradable fire suppressants and AI-driven peatland fire prediction in Indonesia highlight the need for sustainable innovation. Grassroots tools, such as the Watch Duty app, which outpaced government alerts during California's 2025 fires, underscore the power of community-driven technology. As wildfires grow more unpredictable, integrating global satellite networks, adaptive AI models and equitable policy frameworks will be critical to safeguarding lives, ecosystems and economies in the future.

The paradox of extreme cold in a warming world

While global temperatures rise, extreme cold events remain deadly threats, exacerbated by climate-driven disruptions to atmospheric systems like the polar vortex. When weakened, this vortex allows Arctic air to spill into mid-latitudes, triggering severe cold snaps in regions like North America. Though less frequent, these events are becoming more erratic and dangerous, compounded by aging infrastructure and inadequate preparedness. Cold-related deaths linked to cardiovascular stress, hypothermia and respiratory illnesses far outpace heat-related fatalities, accounting for between four and nine times the number of annual deaths globally. Vulnerable populations, including the homeless, elderly and energy-insecure households, face heightened risks, especially during an energy affordability crisis like Europe's 2022 inflationary price surge.

Key cold resilience technologies target energy grid hardening via winterized power plants, insulated pipelines and smart grids with predictive analytics to prevent outages like Texas's 2021 crisis. Building innovation focuses on high R-value insulation (e.g., double-stud walls, quadruple-glazed windows), heated roofs and 3D-printed shelters like Icon's USD 4,000 homes. Community solutions include GPS-guided snowplows, ultra-low-temperature district heating, and portable fuel heaters for emergencies (–45°Celsius capability). Avalanche management involves remotely triggered systems and AI-powered snowpack monitoring mitigates risks in mountainous regions.

The escalating extreme heat crisis

Heatwaves are "silent killers," responsible for over 35,000 deaths in Europe (2003) and record-breaking events in 2024–2025. Urban heat islands amplify dangers, with cities like Phoenix, Arizona, hitting temperatures 10°C above surrounding areas. Between late May and June 2024, a severe heatwave in southern Pakistan caused over 568 deaths as temperatures soared between 45 and 49°C in many areas. Heat stress also endangers workers, with the 4,200 global heat-related workplace deaths in 2020 disproportionately affecting low-income countries. For urban cooling, there are reflective "cool roofs," misting systems (affording up to 10°C reduction) and sponge cities like Vienna's Praterstern, which combines green space with smart fog cooling. Worker protection technologies have been evolving quicky, with wearables such as hydration sensors and military-grade core temperature algorithms adapted for construction

and agriculture. In terms of early warning, AI-driven platforms (e.g., HEAT-SHIELD in Europe) combine weather forecasts with health data to trigger alerts and cooling center activation. Lower tech solutions can be surprisingly effective, for example, Ahmedabad's Cool Roofs" Program and Seville's Cartuja Qanat reviving ancient water tunnel cooling techniques.

Disaster response logistics are being reshaped by a diverse set of technologies

Disasters displace millions annually and strain traditional response systems. In 2024 alone, 45 million people were displaced by disasters, with storms and floods accounting for over half of these displacements. The scale of such crises demands innovative solutions to deliver aid faster, coordinate effectively and empower affected communities. From AI-driven forecasting to blockchain-enabled supply chains, emerging technologies are transforming disaster logistics, making responses more efficient, transparent and resilient.

When a disaster strikes, the immediate priority is to establish operational capacity within the crisis zone. 3D-printed shelters provide durable, scalable housing solutions. Mobile medical units – often repurposed shipping containers – provide emergency health care, while inflatable shelters deploy within minutes for triage or command centers. Energy independence is critical: nanogrids deliver renewable power within 15 minutes, supporting pop-up hospitals and communication hubs. For last-mile aid delivery in inaccessible terrain, amphibious vehicles like WFP's SHERP navigate flooded roads, reducing transport costs by 75 percent compared to airlifts.

Effective disaster response hinges on communication. While 5.5 billion people are online, gaps persist – 2.6 billion lack internet access, often in disaster-prone regions. Solutions such as mesh networks (used after Typhoon Haiyan) and satellite systems restore connectivity when traditional infrastructure fails. AI-powered platforms like SKAI (developed by the WFP and Google) analyze satellite imagery to map damage in real time, while chatbots and common feedback mechanisms (CFMs) enable two-way communication between responders and survivors. In Cox's Bazar, Bangladesh, INSTANT, a forecast portal, delivers early warnings to Rohingya refugees via SMS, triggering preemptive evacuations.

Economic losses from disasters disproportionately impact low-income countries, with drought costing some nations 2 percent of GDP annually. Innovations in finance are bridging gaps:

- Digital cash transfers: mobile money platforms such as bKash in Bangladesh enable instant aid disbursement. Ahead of Cyclone Remal, the WFP sent USD 43 via mobile wallets to 30,000 families, allowing them to prepare in advance.
- Parametric insurance: programs like the African Risk Capacity (ARC) use satellite data to trigger automatic payouts. In 2024, Zimbabwe received USD 16.8 million within days of a drought declaration.
- Blockchain and biometrics: Igloo's blockchain-based weather insurance pays coffee farmers in Viet Nam automatically when rainfall thresholds are breached. Biometric vending machines (e.g., GrainATM in India) prevent fraud in aid distribution.

Technologies like blockchain and IoT sensors improve transparency within the humanitarian supply chain, while drones (e.g., Zipline in Rwanda) deliver medical supplies to remote areas within minutes. AI optimizes inventory management, predicting demand spikes and pre-positioning supplies. During Hurricane Harvey, big data analytics helped reroute shipments around flooded highways.

Despite progress, barriers remain with regard to equity, scalability and interoperability. Biometric ID systems, while reducing fraud, raise privacy concerns and can exclude those without documentation. 3D printing and drone delivery are limited by cost and infrastructure gaps in low-resource settings. Siloed data systems hinder coordination; open-source platforms are critical for standardization. Technology is revolutionizing disaster logistics by accelerating responses, cutting costs and saving lives. Yet, its full potential depends on inclusive design, local capacity building and global collaboration.

Methodology

The *Green Technology Book* for 2025 presents an overview of the global state of innovation in disaster preparedness and response. By showcasing concrete, practical technologies, it highlights how communities can better anticipate, withstand and recover from intensifying climate-driven disasters. The book addresses the needs of diverse end-users from local governments and humanitarian organizations to community groups and households, thereby making the role of technology accessible and actionable.

This year's *Green Technology Book* does not comprehensively cover all disasters, but instead focuses on those that have been affected and exacerbated by climate change, and for which appropriate technologies are available. The disasters addressed are related to water (storms, flooding and landslides); dry weather (wildfires and drought); and extreme temperatures (heat and cold). Disaster response logistics across these three thematic areas are surveyed in Part 4, which showcases technologies for emergency operations and infrastructure, communications and digital coordination, and financial risk and insurance.

The UNDRR disaster cycle encompasses the following four key elements: mitigation (or prevention/reduction) → preparedness → response → recovery. This concept is widely used by the UNDRR and disaster management agencies worldwide. The 2025 edition includes technologies and solutions targeted at disaster response, but also toward disaster preparedness. This reflects the shifting focus of disaster management agencies and the larger humanitarian and development community, which has increasingly been placing greater emphasis on disaster risk reduction and preparedness since the adoption of the Sendai Framework for Disaster Risk Reduction in 2015. It is widely acknowledged that greater efforts must be channeled into risk reduction and preparation for disasters, as threats continue to increase owing to factors like climate change. And because the costs of overlooking these challenges are significant and increasing every year.

The *Green Technology Book* welcomes the opportunity to highlight a diverse and inclusive set of technologies ranging from simple low-tech solutions to advanced digital technologies. Often the best technology is the one available locally, but not widely known. It may be nature-based or built on traditional knowledge and insights. These are vital solutions, especially when considering the local context in which disasters strike, and the specific vulnerabilities of the affected populations. The *Green Technology Book* is more than a catalogue meant for inspiration – it is a living project to which everyone can contribute. This publication links to the free public WIPO GREEN Database of needs and green technologies, where users can create a profile and share climate solutions and needs.

How we wrote the book

For the purposes of this publication, we considered a broad set of scientific articles and gray literature, together with technology databases developed by private, public and civil society entities and organizations. Search strings used included broad terms related to disaster response paired with key terms for the four thematic areas, and key terms related to specific technologies ("drone" "IoT" "satellite" and so on). Translation engines enabled us to search articles in several languages to ensure a broad geographical spread.

Owners of the technologies identified were contacted, and all technologies uploaded to the WIPO GREEN Database of needs and green technologies, either by the technology owner themselves or by us at WIPO.

How we found the technologies

Throughout the publication, we operate with three concepts: innovation, solution, and technology. Although sometimes used almost interchangeably, they do have different meanings. We here use the term innovation to cover all intellectual creativity that could result in a solution. Solution is broadly taken to mean the deployment of an innovation output to solve a specific challenge. The third concept, technology, is a broad term, but we apply it more narrowly to mean any physical entity or technique, with or without additional equipment, that is deployed to resolve a specific challenge. We cover technologies that range from the very simple to the highly complex. Often the scope of disaster response technologies is expanded to include enabling mechanisms such as ownership and the institutional arrangements that pertain to that technology (e.g., insurance mechanisms and community platforms). However, while recognizing the importance of such mechanisms, the primary focus is on tangible technologies or actual techniques.

It is important to emphasize that the technologies presented here have not been tested or in any way vetted by WIPO, and that we rely on publicly available material. Inclusion within the *Green Technology Book* is therefore not a recommendation of a particular technology. Technologies presented should instead be seen simply as examples of a technology area, and there may be many other similar offerings that to our knowledge are in no way inferior. Photos illustrating the various technologies are reproduced with permission from the technology owners. When such permission could not be obtained, relevant stock-photos or AI generated images have been used instead. Therefore photos of technologies may not always represent the actual technology example described. Technology owners can freely upload their technology to the WIPO GREEN Database and in doing so become part of the project.

The appropriateness of a technology is often highly context-specific and relates to factors other than geographical location. Therefore no recommendations on where, when or how the technologies might be suitable have been provided. Such an assessment should always be made with the involvement of local experts and stakeholders.

The following criteria were used when selecting technologies for the *Green Technology Book*:

- relevance for disaster preparedness and response;
- relevance for the disaster themes and logistics: 1) water-related, 2) dry weather related, 3) extreme temperatures; and 4) disaster response logistics.
- pertinence to:
  - a product or service available for purchase or licensing;
  - a product or service available for free/open source;
  - a guidebook on application of a method or technique;
  - a research project or similar (for horizon technologies).

The following additional factors were also taken into consideration:

- anticipated impact from implementation;
- availability of sufficient quality information or third-party endorsements;
- market availability (for proven and frontier technologies);
- cost in relation to impact;
- geographical balance;
- business balance (large- and small-scale businesses, humanitarian organizations, start-ups, research teams, non-governmental organizations and so on);
- no harm principle.

Technologies have been divided into three broad groups in order to indicate their maturity and availability. Proven technologies are those that have been on the market for some time and therefore rely on a tried and tested concept. Frontier technologies are those that are available,

but still relatively new, and as such possibly less validated within a real-world setting. Horizon technologies are those new concepts currently at the research or development stage expected to become available within a few years' time.

Technologies have been classified in order to provide an easy guide to relevance for a reader. We have aimed for a broad representation of technologies at various levels of complexity and stages of readiness. Technologies are classified as having either a low, medium or high level of complexity. This is an indication only and does not adhere to a strict definition of complexity; rather, it reflects the level of human, material and monetary resources required to implement the solution in question. Meanwhile, technology maturity is broadly assessed according to the quasi-standard Technology Readiness Level (TRL) definition. According to this measure, horizon technologies have the lowest readiness level, but are nonetheless close to full development (TRL 2–6), whereas proven and frontier technologies have been validated and are ready to be scaled-up, if this has not already been done (TLR 7–9).

We hope you will be inspired by the creativity, ingenuity and diversity of the technologies presented here. We welcome any feedback and suggestions, which can be sent to us through the WIPO GREEN website.

Disclaimer

This publication, WIPO, and WIPO GREEN are in no way affiliated with any of the featured companies. Nor does this publication imply that other non-featured companies or technology solutions do not exist. All content in this publication is provided in good faith and based on information provided directly from the providers and/or using publicly available materials. Photos of technologies may not necessarily depict the actual technology. Therefore WIPO and WIPO GREEN disclaim any warranties, express or implied, as to the accuracy, adequacy, validity, reliability, availability, or completeness of any information provided. WIPO and WIPO GREEN are not responsible for any negative outcomes as a result of actions taken based on information in this publication.

URL Links

This publication contains weblinks to external websites not provided nor maintained by WIPO or WIPO GREEN. Responsibility for the content of listed external sites lies with their respective publishers. Weblinks are provided solely for contact and informational purposes; WIPO and WIPO GREEN do not sponsor or endorse any of the content therein. While every effort has been made to establish the legitimacy of each linked website, WIPO and WIPO GREEN disclaim any warranties, express or implied, as to the accuracy of the information within the linked content, and also disclaim any responsibility regarding the potential for data breaches as a result of accessing the weblinks.

Introduction: The new reality of climate-driven disasters

Climate change is no longer a distant threat – it is intensifying disasters today. Storms are stronger, floods more damaging, heatwaves longer and deadlier, and droughts and wildfires are reshaping landscapes and livelihoods. Sea-level rise is amplifying coastal erosion and flooding, while for urban populations risks are exacerbated by the heat-island effect and air pollution. This year's *Green Technology Book* is concerned with climate-induced disasters. Although these cannot be precisely defined, we adhere to the United Nations Office for Disaster Risk Reduction (UNDDR) definition of a disaster as being a major disruption to economic, material and human conditions, including societal functions.[1]

> More than four in five disasters recorded worldwide have been driven by climate and weather extremes

To put this into numbers, over the past two decades, more than four in five disasters recorded worldwide have been driven by climate and weather extremes (UNDRR, 2025a). Between 1970 and 2019, water-related hazards caused half of all disasters and 45 percent of disaster deaths. Droughts have affected at least 1.5 billion people, with the number of recorded events increasing 29 percent over 20 years, and extreme heat now standing out as a leading weather-related hazard (UNDRR, 2025a). Wildfires, fueled by climate change, burn twice as much tree cover as they did two decades ago, accounting for roughly 33 percent of global tree cover loss, up from 20 percent in 2001 (WRI, 2024b).

Disasters have also become more frequent. Fewer than 50 disasters were recorded in 1950, but since 2000, the world has faced 300 to 500 climate-related disasters every year (World Bank, 2023). Human activity and climate change are increasing the likelihood of catastrophic disasters. Sea levels are rising 3.3 mm per year, threatening infrastructure worth at least USD 1.8 trillion in low-lying nations and coastal megacities. Such risks are often underestimated (UNDRR, 2025a).

Climate change spares no one, striking wealthy and poor communities alike. Climate-related disasters have affected billions of people and caused trillions of dollars in economic losses. Yet its harshest impacts fall on the most vulnerable. Those living in informal settlements, low-income rural areas or undergoing protracted displacement, bear the greatest burden, having fewer safety nets and less resilient infrastructure. These events not only destroy lives and assets; they exacerbate food insecurity, strain health systems and destabilize fragile economies.

1 The full UNDRR definition of a 'disaster' is a follows: "a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts" UNDRR. Definition: Disaster. United National Office for Disaster Risk Reduction (UNDRR). Available at: https://www.undrr.org/terminology/disaster [accessed September 15 2025].

This rapidly changing situation is outstripping the capacity of traditional disaster management. Historical baselines no longer predict future risks reliably, and formerly "once-in-a-century" events now occur much more frequently. This volatility creates an urgent need for new technologies, tools and approaches. Technologies that can improve forecasting, accelerate response, rapidly protect infrastructure, and ensure aid reaches those who need it most are more essential than ever.

> Historical baselines no longer predict future risks reliably, and formerly "once-in-a-century" events now occur much more frequently.

The good news is that these technologies are available across all disaster contexts globally, and are reshaping how societies anticipate, endure and recover from disasters in a changing climate. From satellites that forecast cyclones and heatwaves, to artificial intelligence (AI) systems that direct relief supplies, to modular shelters, innovation is moving disaster management from reactive crisis response toward anticipatory resilience. Yet, technology alone is not a silver bullet. Its potential can only be realized when well adapted to the local context and combined with inclusive design, ethical safeguards and accountability to the most vulnerable.

Technology and the Sendai Framework for disaster risk reduction and response

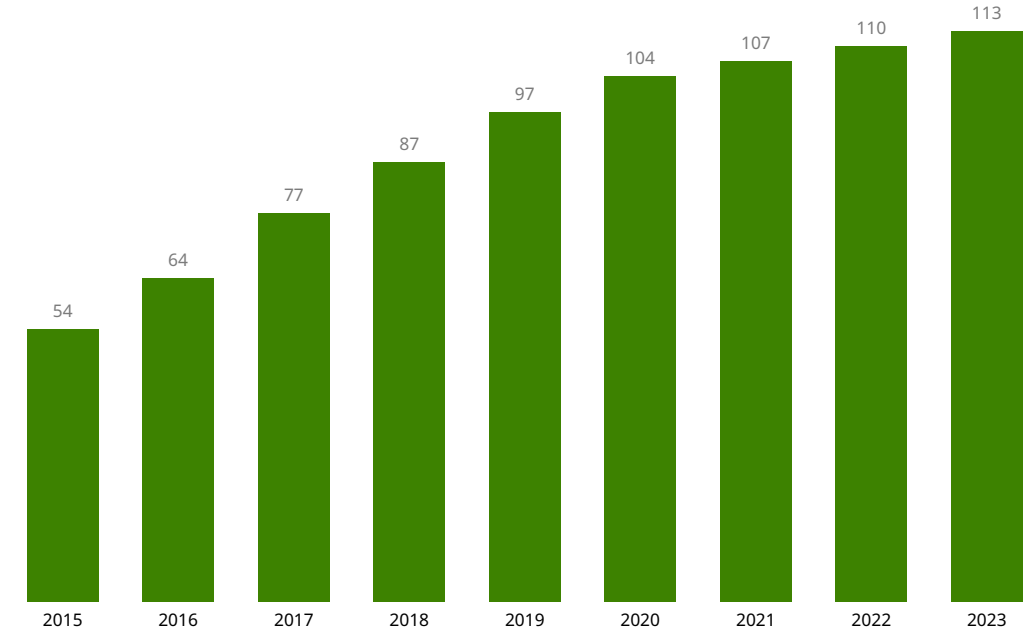
The Sendai Framework for Disaster Risk Reduction 2015–2030 highlights the central role of technology across all phases of disaster management. Its emphasis is strongest on risk reduction, promoting hazard monitoring and forecasting systems, early warning technologies, robust data platforms, and geospatial tools that enable governments to anticipate and mitigate risks before they escalate (UNDRR, 2015). These technologies are critical for prevention and preparedness.

However, several of the Sendai Framework's priorities also directly inform disaster response technologies. The Framework stresses the need for resilient communications infrastructure to ensure continuity during a disaster, real-time monitoring and data systems to guide emergency operations, and earth observation and modelling tools for making rapid impact assessments. It underscores the importance of technology transfer and capacity building, so that even in disaster contexts personnel can operate such systems. Although the Framework is not response-oriented by design, it does establish a foundation for understanding how technologies can enable faster and better coordinated and informed disaster response.

The Framework's Target G aims to increase the availability and accessibility of early warning systems and disaster risk information. Since 2015, many countries have expanded their multi-hazard early warning system (MHEWS) coverage, with 113 countries reporting having such a system in 2023, up from 54 in 2015. Figure 1.1 shows the number of countries reporting the existence of an MHEWS from 2015 to 2023. Progress has also been made in risk information, with 103 countries producing assessments, but only 69 make this information accessible. And gaps remain in the least developed countries (LDCs) and Small Island Developing States (SIDS), where many systems still do not reach or are not trusted by vulnerable communities. Figure 1.2 shows the number of LDCs, landlocked developing countries (LLDCs) and SIDS reporting the existence of a MHEWS. Access to MHEWSs remains limited, with only 49 percent of LDCs, 63 percent of LLDCs, and 38 percent of SIDS having coverage, underscoring the urgent need to close resilience gaps (UNDRR, 2025a).

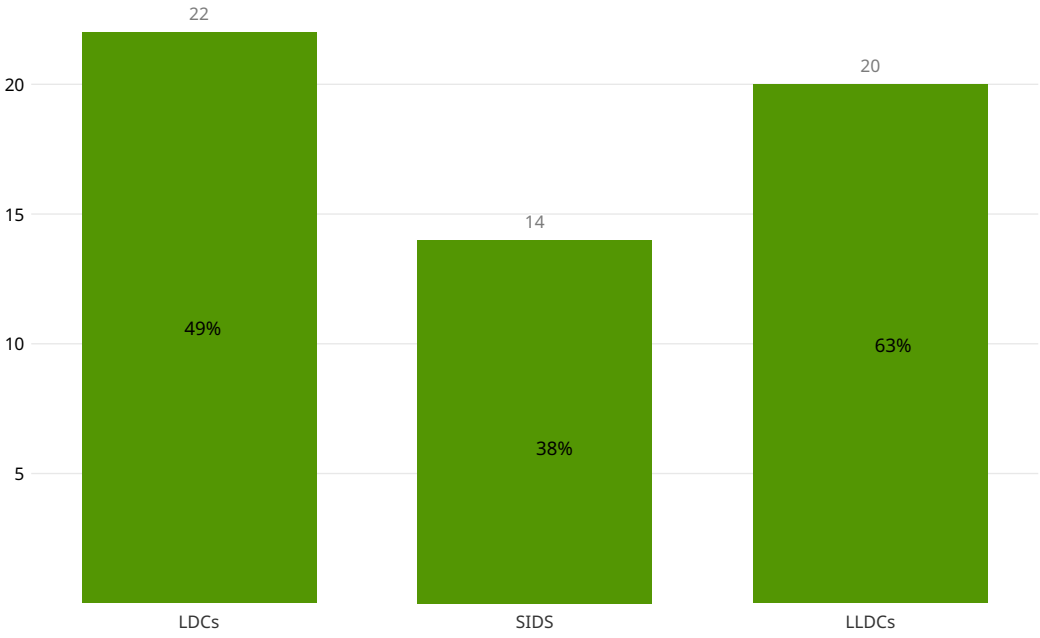
Box 1.1 highlights the heightened disaster risks faced by LDCs, LLDCs, and SIDS, and the key technological and financial challenges they encounter in effective disaster risk reduction.

Figure 1.1 Total number of countries reporting the existence of MHEWS, 2015–2023



Source: UNDRR, 2025a

Figure 1.2 Number of LDCs, LLDCs and SIDS reporting the existence of MHEWS in 2023



Source: UNDRR, 2025a

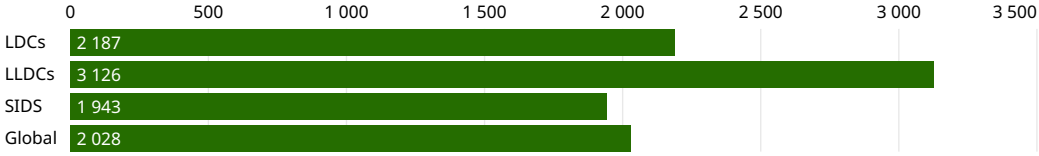
Box 1.1 Disaster risk reduction technology challenges facing LDCs, LLDCs and SIDS

LDCs, LLDCs and SIDS face disproportionate disaster risks. Between 2014 and 2023, annual disaster mortality rates averaged 1.97 per 100,000 in LDCs and 2.43 in LLDCs, compared with 0.79 globally. Moreover, LLDCs reported 3,126 disaster-affected people per 100,000 of the population – 54 percent above the global average. Economically, LDCs accounted for 10.4 percent of global disaster losses, despite accounting for only 1.06 percent of global GDP, and LLDCs 5.6 percent of losses, with 1 percent of GDP.

Figure 1.3 Disaster-related mortality per 100,000 population, 2014–2023

Source: UNDRR, 2025a

Figure 1.4 Disaster-affected people per 100,000 population, 2014–2023



Source: UNDRR, 2025a

SIDS face acute technology challenges in disaster risk reduction, needing stronger monitoring and forecasting systems, expanded observation networks, resilient telecommunications, and better data tools. Progress is hindered by limited financing, high costs and rapid equipment obsolescence. Gaps persist in digitization, down-scaled climate data, risk mapping, and applying forecasts to sectors like agriculture, water and urban planning. Reliable early warning systems are vital as climate change continues to drive more severe weather. Additional barriers include donor dependence, procurement delays, poor asset maintenance, reliance on regional hubs, connectivity issues, equipment upkeep in remote areas, and staff shortages. To align with the Sendai Framework, SIDS must secure sustainable financing, build local data and technology capacity, and strengthen resilient, interoperable systems for communication and early warning. Source: (UN DESA and UNDRR, 2022)

Financing disaster response and resilience

Recent reports by the UNDRR and the Organisation for Economic Co-operation and Development (OECD) make clear that the financial impacts of disasters are growing (both direct and indirect damage). Whereas annual direct losses averaged USD 70–80 billion between 1970 and 2000, this figure surged to USD 180–200 billion per year from 2001 to 2020. Current disaster reporting significantly underestimates the full economic, social and environmental costs; and when indirect impacts like human displacement, ecosystem loss, and climate-related risks are included, total disaster losses exceed the reported figures (UNDRR, 2025a). Thus, the total economic burden of disasters now exceeds USD 2.3 trillion annually when these indirect impacts are taken into account (UNDRR, 2025a).

Much of disaster management and recovery expenditure is dispersed across multiple national ministries and agencies, making it difficult to capture a complete, aggregated picture. Funding for response and proactive response technologies (e.g., early warning, impact assessment), is often ad hoc, reactive and not well-prepared (UNDRR, 2025a; OECD and ADB, 2020). Global disaster response is financed through a combination of international funds, insurance mechanisms and national-level instruments.

> While annual direct losses averaged USD 70–80 billion between 1970 and 2000, this figure surged to USD 180–200 billion per year from 2001 to 2020

International and multilateral mechanisms, such as the World Bank's Immediate Response Mechanism, allows countries to access up to 5 percent of their undisbursed investment project balances following a crisis, facilitating rapid funding for emergency response. The United Nations Central Emergency Response Fund (CERF) was established by the UN General Assembly to deliver fast funding for crises worldwide, providing relief for emergencies not to have received sufficient funding through other channels. And the International Federation of Red Cross and Red Crescent Societies (IFRC) Disaster Response Emergency Fund (DREF) is a central fund that releases funds rapidly for immediate disaster response, with requests approved within 24 hours and disbursed in under 72 hours.

Philanthropic and private-sector contributions, such as the Bill and Melinda Gates Foundation, provide essential funding for immediate relief (shelter, food, water, medical care and cash-for-work), with the Center for Disaster Philanthropy reporting USD 1.7 billion in total given for disaster relief in 2022 (Center for Disaster Philanthropy, 2025).

Catastrophe Bonds (Cat Bonds) are issued to countries in order to transfer disaster risk to international capital markets. When a disaster occurs, the funds are used for response and recovery. Catastrophe bonds and other mechanisms are increasingly capable of integrating advanced risk modelling using Earth observation data and big data analytics.

At a national level, a major disaster can significantly strain public finances. Technology can play a critical role in supporting public financial management by improving risk assessment and forecasting, and allowing governments to evaluate fiscal exposure, select cost-effective risk reduction measures and leverage insurance, reinsurance and capital markets (OECD and ADB, 2020). National-level instruments are also available, such as Australia's Disaster Ready Fund (DRF), a government-managed fund that allocates resources for disaster prevention and resilience.

Investing in future resilience: financing disaster risk reduction

Research shows disaster losses far exceed the costs of disaster risk reduction (DRR), with resilience investments yielding large returns that can be up to 300 percent for droughts, 1,200 percent for storms in sub-Saharan Africa, and 100–900 percent for certain climate adaptation measures. Yet financing remains very low. Between 2019–2023, only 1 percent of total official development assistance (ODA) was classified as DRR, and disaster prevention/preparedness made up just 3.3 percent of humanitarian aid (down from 3.6 percent in 2015–2018) (UNDRR, 2025a).

Between 2018 and 2022, global climate adaptation finance increasingly supported disaster risk reduction, with cross-sectoral projects that included policy support, capacity building and disaster management accounting for 36 percent of flows (CPI, 2024). Water and wastewater projects, which help reduce flood risk and water stress, received between 44 percent and 51 percent of adaptation finance and grew at a compound annual growth rate (CAGR) of 39 percent (CPI, 2024). Despite this progress, critical sectors, such as climate-related disaster response, remain underfunded, even as extreme weather events intensify.

Households and venture capital (VC) also contribute to disaster-related adaptation. Households invest USD 48–61 billion annually in products such as flood infrastructure, resilient building materials and cooling systems, while at least USD 6.3 billion is spent in VC investments (mainly in agriculture, forestry, and other land use) (CPI, 2024). But while adaptation finance has grown,

it still remains far below what is required to address increasing disaster risks, leaving vulnerable populations, including those in SIDS and LDCs, exposed.

In 2024, over 300 million people required humanitarian assistance, a figure expected to climb to 340 million in 2025. Yet global response funding was insufficient and just USD 22.6 billion of the USD 49 billion required was met (OCHA, 2023). Adaptation financing needs in the Global South are 10–18 times higher than current flows, yet DRR remains underprioritized, accounting for less than 0.5 percent of development spending. From 2005 to 2017, 96 percent of USD 137 billion in disaster-related aid went to response and recovery, whereas only 4 percent (USD 5.2 billion) went toward supporting prevention and preparedness (UNDRR, 2025a).

Humanitarian disaster risk finance is evolving rapidly, with increasing numbers and types of mechanisms available. Global mechanisms have historically dominated, with pooled funds providing predictable grants and loans when disasters struck, including global pooled funds (approximately USD 1 billion), the World Bank's International Development Association Catastrophe Risk Window (approximately USD 2.5 billion), USAID's Bill Emerson Humanitarian Trust (USD 280 million) and the World Food Programme's Global Commodity Management Facility (USD 950 million) (Choularton and Montier, 2023). Regional risk pools, such as the African Risk Capacity (ARC), provide rapid payouts to states and increasingly to humanitarian organizations and social protection programs. Countries pay an annual premium to access pre-agreed triggers, with some humanitarian partners taking "replica" policies to extend coverage.

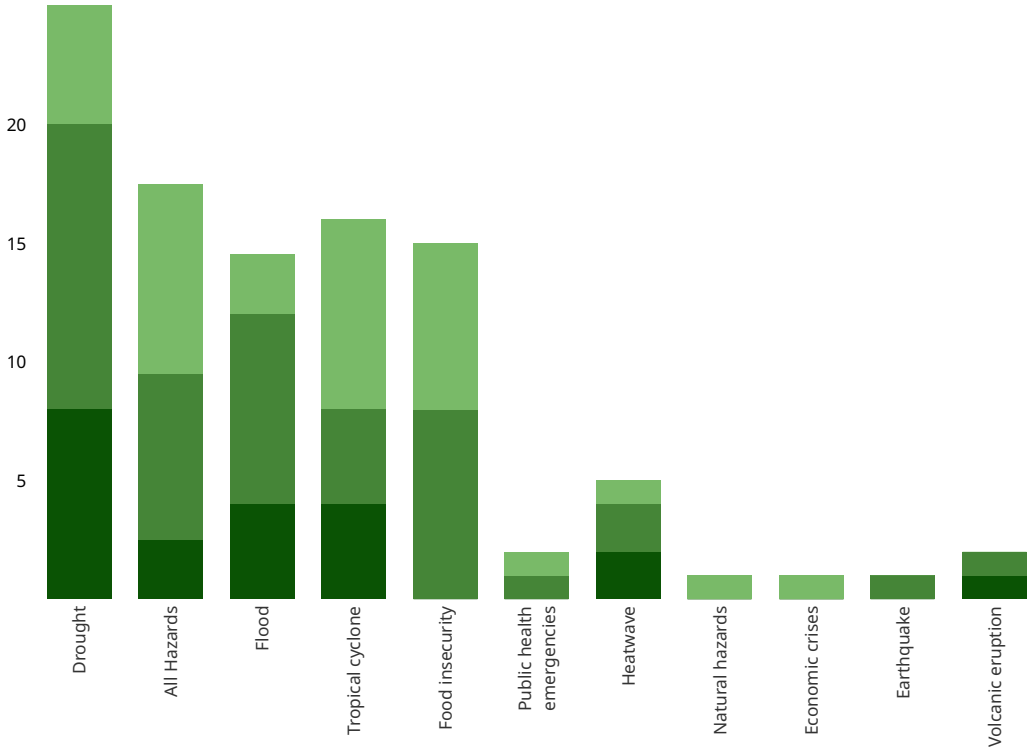
In 2024, over 300 million people required humanitarian assistance, a figure expected to climb to 340 million in 2025

At the national level, sovereign disaster risk finance is evolving beyond traditional contingency funds. Governments are implementing insurance through regional pools or private partnerships, and credit lines like the World Bank Catastrophe Deferred Drawdown Option. United Nations country-based pooled funds provide rapid financing in a protracted crisis, while networks such as the Start Network enable non-governmental organizations to coordinate risk analysis, undertake contingency planning, and disburse locally led funds. Local and community-level mechanisms are expanding, though more slowly than global mechanisms, and remain underrepresented both in terms of scale as well as visibility.

Many mechanisms now have either hard, that is, objective triggers based on hazard forecasts or indices and soft ones based on declarations or requests. These enable earlier action. Forecast-based procurement and supply chain finance are also being used, such as ordering or pre-positioning food ahead of an anticipated crisis. Most mechanisms trigger relatively modest payouts (tens or hundreds of thousands of US dollars) most frequently, whereas larger sums are reserved for crises that are more severe and less frequent. Pre-arranged finance typically covers only a small proportion (2–3 percent) of total needs in a major disaster.

Humanitarian disaster risk finance falls into two broad categories. Some mechanisms are hazard-specific, covering floods, droughts or storms, or else linked to food security early warning systems such as FEWS NET or Integrated Food Security Phase Classification (IPC). Others are more open, covering either multiple or all hazards (Choularton and Montier, 2023). Figure 1.5 shows humanitarian risk finance mechanisms aggregated by hazard. Drought has the highest number of mechanisms that involve pre-arranged finance, and across all types of disaster, the most common response window in which these mechanisms are enacted is early response.

Figure 1.5 Humanitarian risk finance mechanisms aggregated by hazard



Source: Choularton and Montier, 2023

Best practice involves risk-layering. This entails combining cheaper sources, like budget reserves or contingency funds, for frequent, small-scale risks with more expensive tools, like insurance and parametric risk transfers for rare, large-scale shocks (UNDRR, 2025a). Global contingency funds are driving innovation by creating anticipatory windows, integrating reinsurance and supporting forecast-based supply chain finance. Embedded mechanisms within projects, programs and social protection schemes are also improving responsiveness. However, innovations at the national, sub-national and community levels remain under-represented, highlighting a need for further mapping in order to strategically deploy layered financing across different risk holders ahead of disasters.

> Drought has the highest number of mechanisms that involve pre-arranged finance

With regard to financial and insurance mechanisms, uptake in vulnerable countries is low due to barriers such as cost, risk, lack of data and limited regulatory and institutional capacities (OECD, 2015; OECD and ADB, 2020). Nonetheless, there is growing investment into insurance, contingency funds, rapid response windows, and anticipatory action, reflecting an increasing recognition of the importance of pre-arranged financing in reducing disaster impacts and accelerating recovery.

The role of emerging technologies

In previous editions of the *Green Technology Book*, we increasingly emphasized how climate technologies often bridge the divide between adaptation and mitigation. In this 2025 edition, technologies for disaster response are almost exclusively directly related to adaptation. This is hardly surprising since disasters are the direct consequence of climate change, which we

have not been able to mitigate and hence avoid. They encapsulate the extreme effects of climate change, and therefore require very different responses to prevent human suffering, infrastructure loss, and economic and ecosystem damage. Here the focus is mainly on those technologies that address the immediate impact of disasters on human populations, though also included are some technologies that target preparedness and resilience building. All, however, are related to climate change adaptation rather than mitigation.

Technologies for disaster response are almost exclusively directly related to adaptation

The digital transformation – driven by explosive growth in big data, advanced analytics and AI, and widespread internet and smartphone use – offers major opportunities for disaster and climate risk management (OECD and ADB, 2020). Greater data access and cloud-based analytical tools enable more accurate risk assessments to be made, while expanded connectivity allows the faster, broader and more effective transmission of risk information to vulnerable populations.

Earth observation has become cheaper and more precise, with high-resolution satellites, LiDAR and radar providing detailed, near-real-time imaging, while drones (i.e., unmanned arial vehicles (UAVs)) are significantly expanding coverage. Street-level imagery, affordable cameras and crowdsourced data fill gaps in mapping infrastructure, while connected devices and 5 G networks generate large amounts of sensor data. Social media provides real-time updates during disasters. These data sources are increasingly analyzed through cloud computing, big data analytics, AI, and machine learning, which enable descriptive and predictive insights. The spread of broadband, smartphones and mobile apps is transforming disaster communication, making information more accessible, timely and interactive. Together, these innovations are reshaping disaster preparedness, response, and financial risk management (OECD and ADB, 2020).

Emerging technologies are enhancing how hazards, exposure and vulnerabilities are measured and understood. Traditional historical data, field surveys and engineering studies have often struggled to capture evolving threats, changing land use and structural resilience, especially in areas with data gaps (OECD and ADB, 2020). Advances in Earth observation, social media, and crowdsourced geographical information provide richer, more frequent and more accurate hazard data. At the same time, big data analytics and AI enable the modeling of complex, multi-hazard scenarios and changing risks with greater precision. Improved imagery, drones and street-level mapping allow more detailed assessments of exposure, even identifying unrecorded infrastructure, while machine learning supports evaluations of vulnerability, from structural conditions to socioeconomic resilience (OECD and ADB, 2020).

Emerging technologies are enhancing how hazards, exposure and vulnerabilities are measured and understood

These technologies also accelerate the generation of disaster impact assessments and improve emergency response. Cloud-based mobile applications allow rapid, field-level damage reporting. High-resolution satellite imagery, supplemented by drones, street-level imagery, connected sensors and crowdsourced data, provides near-real-time assessments of affected areas, infrastructure and power disruption. Advanced analytics and AI detect changes in imagery, map impacts quickly, and process social media posts, so as to identify those in need of rescue. Integrated platforms now combine multiple data sources to deliver comprehensive assessments that improve preparedness, response and recovery (OECD and ADB, 2020).

Patent trends in disaster response technologies

The global incident and emergency management market is projected to grow in size from USD 137.45 billion in 2024 to USD 196.20 billion by 2030, at a CAGR of 6.1 percent during the forecast period (MarketsandMarkets, 2024). Globally, patenting for disaster response technologies is growing rapidly, driven by innovations in digital technologies, particularly AI, drones (UAVs) and the internet of things (IoT). Key areas include forecasting and early warning systems, sensor-based monitoring, communication platforms, and advanced data analysis.

Specific technologies undergoing patent activity include AI-powered disaster prediction, drone-mounted cameras for monitoring and thermal imaging, personal transponders for tracking individuals during an emergency and robotics for search and rescue operations in hazardous environments where human presence is limited. These technologies enhance the efficiency and safety of disaster response teams. Innovations in communication technologies, such as satellite communications, portable cell towers and mobile applications for direct alerts to emergency services, are also improving connectivity in disaster-affected areas. Recent patents reveal a strong trend toward integrating automation, connectivity and data-driven intelligence, with a growing emphasis on multi-functional platforms that combine hazard monitoring, situational analysis and operational coordination. Together, these developments reflect a shift toward faster and more integrated disaster response solutions that prioritize resource allocation, reduce response times and improve the safety of affected populations.

> Globally, patenting for disaster response technologies is growing rapidly, driven by innovations in digital technologies

Patent activity around drones for disaster response has grown rapidly over the past decade, led by those countries with a strong UAV industry such as the United States, China, Japan, the Republic of Korea and Israel. In the United States, Google Patents lists filings such as US20200031438A1 for autonomous search-and-rescue drones and US11727817B2 for UAV medical and emergency delivery systems. Chinese companies, particularly DJI, hold broad patent portfolios, including rescue UAVs such as drowning-response drones (US11840363B1, Google Patents). Japan and the Republic of Korea have emphasized UAV communications relay systems for disaster zones (KIPO, 2025; JPO, 2025), whereas Israeli assignees focus on autonomous UAV navigation and tactical emergency uses (WIPO, 2025; Google, 2025).

Across these filings, common themes include UAVs serving as temporary base stations when ground networks fail, drones with multi-sensor payloads (thermal, multispectral, ultra-wide band (UWB)) for locating survivors, and automated dispatch systems integrated with vehicles or control centers. Examples include US11250262B2 for wildfire surveillance UAVs with multispectral sensors and US2024/0241520A1 from General Motors, which patents a vehicle-launched emergency drone (Google, 2025; WIPO, 2025). Together, these data from Google Patents, WIPO's PATENTSCOPE and national offices (KIPO, 2025; JPO, 2025) highlight a global surge in UAV patenting for disaster response, highlighting how drones are becoming smarter, more connected and quicker to deploy in emergencies.

Modern early warning systems for disasters, floods and hurricanes, and other environmental hazards leverage a combination of real-time sensors, predictive analytics and automated communication channels to detect and respond to emerging threats. These systems typically gather data from IoT devices, satellites or ground-based sensors, process it using algorithms, and issue alerts to authorities, organizations and affected communities. Over time, patents in this space increasingly reflect integration with cloud computing, AI and mobile communication, highlighting a broader trend toward multi-hazard platforms that monitor conditions and forecast potential disasters to guide decision-making in increasingly complex situations.

As discussed in the wildland fire chapter, patent activity in forest fire technologies has also surged over the past decade, showing strong growth within the last five years. Countries like

the Russian Federation, Australia, Spain and Portugal stand out for innovation, particularly in AI- and drone-based fire detection and management. Most patents in this field focus on extinguishing technologies, while prevention, protective equipment, and especially post-fire restoration, remain underdeveloped (OEPM and INPI, 2022).

Part 1: Water-related disasters

Photo: Getty Images

Water is essential for life. But when it arrives in excess, the consequences can be devastating. Tropical cyclones, hurricanes and typhoons – powerful storms that form over warm ocean waters – bring with them a deadly combination of strong winds, torrential rain and storm surges. Climate change is exacerbating these events. Warmer oceans and a warmer more moisture-saturated atmosphere are triggering stronger and slower-moving storms that linger over land for longer, causing greater damage, and often leading to more catastrophic flooding.

The growing threat of water-related disasters can be particularly devastating in vulnerable regions where infrastructure and early warning systems may be inadequate. Yet, also in wealthier nations, the increasing frequency and intensity of storms is straining infrastructure and stretching emergency services.

Coastal erosion and landslides are additional critical consequences of extreme weather events. As storm surges and intense rainfall erode coastlines and destabilize slopes, they threaten infrastructure, ecosystems and communities. This not only exacerbates flood risks, but also creates long-term environmental challenges demanding urgent attention and innovative solutions.

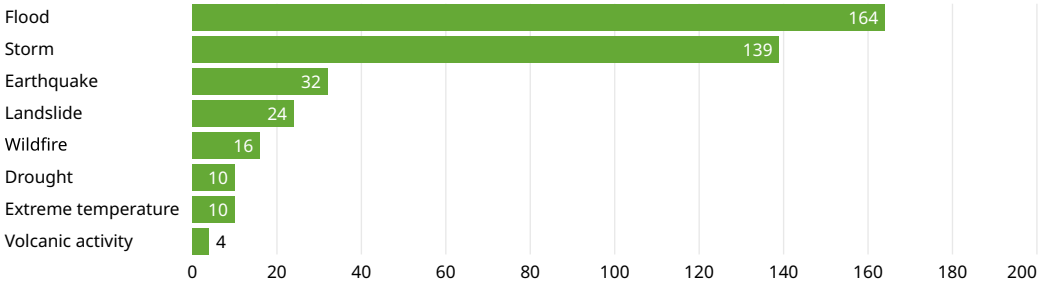
Storms and flooding

As floods and storms grow fiercer, technology is building dynamic defenses. Advanced satellite networks now provide real-time tracking with unprecedented precision, while drone-deployed minisondes gather hyperlocal storm data. Cities are fortifying defenses with self-healing concrete and impact-resistant smart roofs, and automated flood barriers activate at the first sign of danger. From AI-powered early warnings to digital twins that simulate floodwater, these innovations form a shield against intensifying disasters.

Technological developments and trends

The aftermath of a storm can often be just as destructive as the storm itself. The most common consequence of a storm – flooding – can destroy homes, disrupt livelihoods and contaminate water supplies, leading to long-term health and economic challenges. Floods were the most common disaster on Earth in 2023 (Statista, 2024). As depicted in figure 2.1, storms and floods in 2023 comprised 76 percent of disasters worldwide.

Figure 2.1 Number of natural disasters worldwide in 2023, by type



Source: Statista, 2024

Riverine and inland flooding have long been a major concern, exacerbated by heavy rainfall and poor infrastructure, leading to widespread devastation in many parts of the world. In 2022, Pakistan experienced record monsoon rains that caused severe riverine flooding, affecting one-third of the country, 33 million people, and causing over 1,700 deaths. In 2023, catastrophic inland flooding in Libya resulting from Storm Daniel resulted in more than 4,000 deaths and widespread destruction. And in 2024, severe flooding affected parts of Spain, leading to widespread infrastructure damage, evacuations, and at least 232 fatalities.

This chapter explores the wide range of simple to advanced technologies that help predict and respond to such events, and the innovative solutions being developed to bolster resilience to their impact. From advanced satellite and remote sensing technologies and early warning systems to flood-resistant architecture and infrastructure, this chapter delves into how humanity can more efficiently and effectively respond to a world where too much water is becoming an ever-greater threat.

Riverine and inland flooding have long been a major concern, exacerbated by heavy rainfall and poor infrastructure, leading to widespread devastation in many parts of the world

What are tropical cyclones?

Tropical cyclones are rapidly rotating storms that form over warm tropical oceans, also known as hurricanes or typhoons, depending on location (WMO, 2024). They develop from clusters of individual thunderstorms, intensifying over warm waters due to Earth's rotation, then weakening over cooler oceans or land (National Centre for Atmospheric Science, 2024). Large-scale climate phenomena like El Niño (periodic warming of sea surface temperature) and La Niña (periodic cooling of sea surface temperature) can influence tropical cyclone behavior.

Climate change is increasing storm frequency and severity, and altering trajectories

Storms are intensifying. Over the period between 1979 and 2017, the number of major hurricanes increased, whereas smaller hurricanes decreased (Kossin *et al.*, 2020). Although there may be fewer storms in the future, they are likely to be stronger (NASA, 2022). The 2024 Atlantic hurricane season was extremely destructive, producing 18 named storms,[1] 11 hurricanes and five major hurricanes[2] (NOAA National Weather Service (NWS) National Hurricane Center, 2024). Hurricane Helene caused devastating rainfall-triggered flooding and 246 deaths, rendering it the second-deadliest hurricane to strike the continental United States in 50 years. Cyclone Freddy, which struck Mozambique and Malawi in February 2023, was one of the strongest and longest-lasting cyclones in recorded history. It caused widespread damage and displaced thousands of people, disrupting agriculture and leaving many without food or livelihood.

Warmer temperatures due to climate change intensify storms by increasing atmospheric moisture, leading to heavier precipitation. Climate change increases the intensity of storms, while at the same time decreasing the speed at which they travel. The reason for this is still debated. A prominent theory is that Arctic warming is contributing to the slowdown (C2ES, 2020). Additionally, warming at mid-latitudes may be altering tropical storm patterns, resulting in more storms at higher latitudes.

Impacts of tropical storms are often severe and long-lasting

Over the last 50 years, 1,945 disasters have been attributable to tropical cyclones, resulting in nearly 800,000 deaths and USD 1.4 trillion in economic losses. During this period, tropical cyclones have accounted for 17 percent of all weather, climate and water-related disasters, and were responsible for 38 percent of total deaths and 38 percent of total economic losses from such events (WMO, 2024).

Longer-term impacts can persist for up to several years as communities struggle to recover from damage and often displacement. For example, some neighborhoods in New Orleans in the United States are still rebuilding almost 20 years after Hurricane Katrina struck, with a similar

1 Every year, weather agencies assign storms a name from pre-approved lists that are often specific to the region in question, in order to aid communication and tracking. The names chosen usually alternate between male and female names (though this convention is being adjusted in some regions in favor of gender-neutral names). When a storm is particularly severe, its name may be retired out of respect for the disaster it caused.

2 Tropical storms and hurricanes/cyclones/typhoons are categorized based according to the sustained wind speed and storm surge. The scale typically used is the Saffir-Simpson Hurricane Wind Scale (for hurricanes and typhoons). This scale has five categories, with Category 3 and above being classified as "major" storms able to cause widespread and severe damage.

situation in communities affected by Hurricane Maria in Puerto Rico and the Caribbean, and Typhoon Haiyan in the Philippines.

Flooding: the disaster after the storm

Flooding typically occurs when heavy or persistent rainfall exceeds the soil's ability to absorb water and the capacity of rivers, streams and coastal regions to cope with the flow. Flooding is triggered by events such as heavy rainfall, thunderstorms, tornadoes, tropical cyclones, monsoons, melting snow and dam failures. Among the most common types of flooding are flash floods, snowmelt floods, coastal and river floods (UNDRR, 2025c).

Glacier melt and thawing permafrost are exacerbating flooding. The loss of global glacier mass has accelerated, leading to the formation of more and larger glacial lakes. These lakes are potential sources of glacial lake outburst floods (known as GLOFs) and represent a significant risk to both people and infrastructure. In fact, more than 10 million people worldwide are at risk from GLOFs. In High Mountain Asia, the threat of such floods is expected to triple by 2100 (Zhang *et al.*, 2024).

Flood risk is rising while record floods wreak havoc

Between 2000 and 2015, the number of people living in flood-prone areas increased from 58 million to 86 million. This growth reflects both increased flooding hazards and expanded settlement in vulnerable zones. Today, 1.8 billion people (nearly one-quarter of the global population) face significant flood risk, 90 percent of whom live in low- and middle-income countries (World Bank, 2024). Climate models project that by 2100, without adequate protection, the global land area at risk of flooding will grow by nearly half, with the exposed population and value of vulnerable assets increasing by more than 50 percent and 46 percent, respectively (Hernández-Delgado, 2024).

> Today, 1.8 billion people (nearly one-quarter of the global population) face significant flood risk, 90 percent of whom live in low- and middle-income countries

Flooding causes structural damage – weakening or collapsing buildings, and damaging roofs, floors and walls. Furthermore, it erodes soil and causes landslides (discussed in the landslides chapter), damages electrical systems, contaminates drinking water and causes waterborne illnesses, damages businesses and disrupts local economies.

Growing urban communities are most vulnerable to flooding. In the 2023 edition of the United Nations Environment Programme (UNEP) Adaptation Gap Report 2024, 69 percent of the most common hazards reported by 536 cities across the globe were flood-related hazards (2,411 actions) and coastal hazards (978) (UNEP, 2024a). Studies have also revealed a correlation between faulty infrastructure that is more susceptible to riverine flooding and the prevalence of urban slums (IPCC, 2022; WMO, 2021b; Alfieri *et al.*, 2017). Strikingly, the population living in slums and unplanned urban settlements is projected to double by 2050, representing an increase from 760 million in 2022 to 1,570 million in 2050 (Arnell and Gosling, 2016). This group will be exposed to higher flood risk.

While climate change and extreme weather events are key drivers of increasing flood risks, human activities, particularly land and infrastructure development, are crucial contributors. Urban sprawl into floodplains and coastal areas, combined with poor ecosystem management, has intensified flood vulnerability in many regions. Without consideration of natural flood defenses and more sustainable land-use policies, the risk of devastating floods will only grow. Integrating nature-based solutions and stronger regulations on land development could play a critical role in mitigating flood impacts.

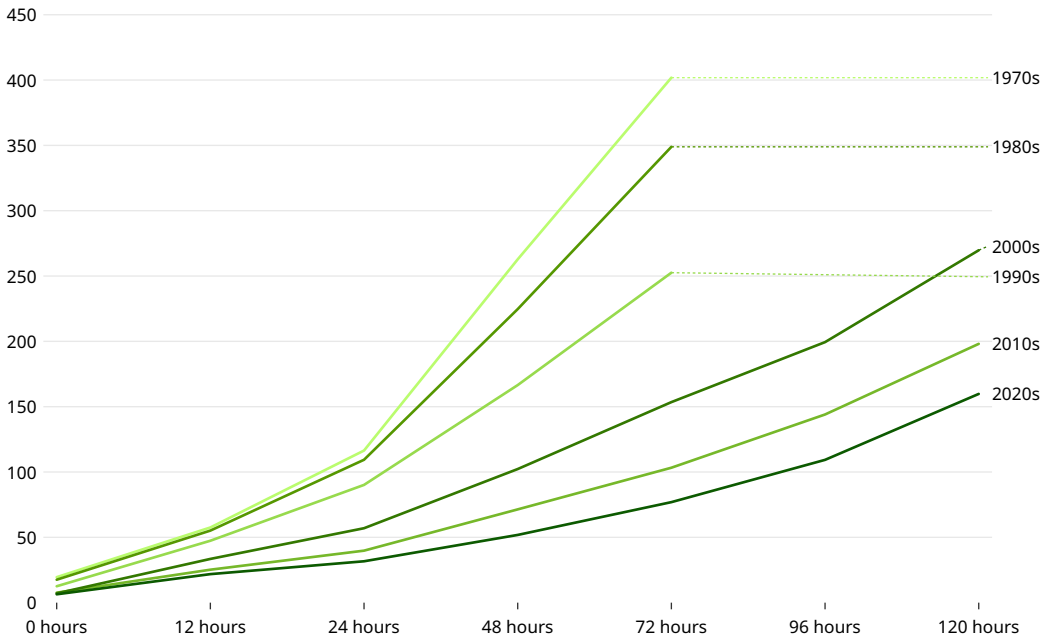
In addressing flooding, the focus is primarily on solutions that respond to its impacts, rather than preventing inland or riverine flooding from occurring. Although we may not control the exact conditions that lead to these floods, the strategies for managing the aftermath — such as improving infrastructure, enhancing flood resilience, and providing early warning systems — are broadly similar across various flood types, whether coastal or inland. Both types of flooding can cause significant damage to homes, infrastructure, and the environment. Therefore, the technologies and approaches designed to respond to flooding, such as storm tracking, flood-resistant infrastructure, and real-time data gathering, are often adaptable to multiple contexts, helping communities prepare for and recover from water-related disasters more effectively.

Weather forecasting has improved significantly

Weather forecasting is challenging because of the many variables involved. However, it has come a long way in recent decades, primarily thanks to better data and technology. Scientists have developed sophisticated technologies, including advanced global climate models, an ever evolving and profound understanding of how storms develop, and an expanding record of past cyclone activity (NASA, 2022). Higher-resolution observations from satellites and an enlarged network of land-based stations provide more accurate inputs for models. Faster computers are capable of processing increasingly complex and higher-resolution climate and forecasting models (Ritchie, 2024b).

Additionally, the way in which forecasts are communicated has evolved, with minute-by-minute updates now available online. The United Kingdom (UK) meteorological office claims that its four-day forecasts are now as accurate as its one-day forecasts were 30 years ago (United Kingdom Met Office, 2023). The National Hurricane Center in the United States provides data on the "track error" of hurricanes and cyclones, which refers to the margin of error in predicting where a storm is likely to make landfall. Figure 2.2 illustrates this track error from the 1960s to the present. Each line represents the average error for each decade, with the forecast period shown on the horizontal axis, ranging from 0 to 120 hours. During the 1960s and 1970s, the error for a 72-hour forecast was over 400 nautical miles (740 kms). Today, that error has decreased to under 80 miles (148 kms) (Ritchie, 2024b). This allows cities and communities to prepare accordingly, while avoiding the unnecessary evacuations that were once much more common.

Figure 2.2 Hurricane forecasting errors in the Atlantic basin per decade, 1960s-2020s (in nautical miles)



Source: National Hurricane Center – processed by Our World in Data, 2023

Technology dives deeper into storms

Advanced storm tracking technologies, developed by organizations like the National Aeronautics and Space Administration (NASA), European Space Agency (ESA), Japan Aerospace Exploration Agency (JAXA), and other space agencies, use satellite-based systems to monitor and track storms in real time. These technologies employ a combination of radar, infrared, and visible light imaging to capture detailed data on storm development, movement and intensity.

For example, NASA's Cyclone Global Navigation Satellite System (CYGNSS) uses a network of small satellites to measure wind speed in tropical cyclones. The ESA uses Sentinel satellites equipped with a synthetic aperture radar (SAR) to monitor storm surges, track rainfall and assess flood risk. SAR is a remote sensing technology that uses radar waves from satellites to generate images of the Earth's surface even under cloud cover. It is particularly good at mapping surface water bodies and, under certain conditions, can help detect shallow subsurface moisture.

> Advanced storm tracking technologies use satellite-based systems to monitor and track storms in real time

Box 2.1 provides a glimpse into a joint satellite mission to measure precipitation using a more comprehensive coverage and to enhance those global precipitation datasets that support improved storm and flood forecasting.

Box 2.1 Global precipitation measurement (GPM)

This is a joint satellite mission initiated by NASA and JAXA to advance the work begun under the earlier Tropical Rainfall Measuring Mission (TRMM), which measured heavy-to-moderate rainfall over tropical and subtropical oceans. The GPM system Core Observatory satellite uses the GPM Microwave Imager (GMI) and Dual-frequency Precipitation Radar (DPR) to measure precipitation from space, combining active and passive remote sensing techniques to enhance global precipitation datasets. NASA is responsible for managing the mission and overseeing operation of the GPM Core Obervatory, while JAXA provides the DPR, a core instrument on the satellite.

GPM covers both land and the ocean across 65°N–65°S, improving upon its predecessor, TRMM, by offering better coverage (including in medium-to-high latitudes), improved estimates of light rain and snowfall, and more frequent observations taken every 3 hours. GPM data benefits operational forecasters, climate prediction, water resource management, crop monitoring and disaster management, while also advancing the scientific understanding of Earth's water and energy cycle. Global reinsurance companies also use GPM rainfall data to set rainfall thresholds for insurance payouts.

Dropsondes and minisondes: parachuting into storms

Dropsondes and minisondes are weather probes released from aircraft into storm systems to collect real-time data on the temperature, humidity, pressure and wind speed at different altitudes within a storm. Dropsondes are most commonly used to measure the vertifcal profiles of these parameters. They are dropped from P-3 aircraft operated by the National Oceanic and Atmospheric Administration (NOAA) from an altitude of 10,000 feet (roughly 3,000 meters) and descend to the surface using a small parachute. Data obtained are used by forecast models to predict storm track and intensity. Dropsondes have been used for decades, but NOAA is continuing to make them lighter and cheaper with the development of minisondes. Minisondes are a smaller version, and their lighter weight renders them better for high-altitude

deployment. They can also be deployed in larger numbers for high-density measurement across storm systems, enabling a more complete data set over a larger area (NOAA Office of Marine and Aviation Operations, 2024). StreamSondes are the latest frontier. Developed by Skyfora, StreamSondes are an even smaller, parachute-less variation of traditional dropsones. Rather than descending quickly by parachute, they are engineered to descend slowly without assistance thanks to a lightweight design and aerodynamic structure that allows them to remain in the air longer. Unlike what is considered akin to a *snapshot* in time provided by dropsondes, the data provided by StreamSondes amount to something more like a *movie* (FedScoop, 2024), meaning that StreamSondes offer a more dynamic picture of what is occurring.

> Drones gather data in areas otherwise difficult or dangerous to reach and are relatively cost-effective

State-of-the-art drones gather data from inside a storm

Drones are also at the cutting edge in storm research by providing real-time, high-resolution data from within storms. Equipped with sensors and cameras, advanced drones can fly into storm systems, capturing atmospheric conditions such as wind speed, temperature, humidity and pressure. They gather data in areas otherwise difficult or dangerous to reach, such as the storm's eye, and are relatively cost-effective. The localized information they provide complements satellite and radar data, helping to improve the accuracy of storm prediction.

New drones, such as NOAA's Altius-600 can fly very low, enabling better surface-level information-gathering where storms are actually impacting people (FedScoop, 2024). The first drone flight into a hurricane was during Hurricane Ophelia in 2005 (the drone remained there for 18-and-a-half hours). The Altius-600 was flown for the first time in 2022's Hurricane Ian.

Early warning systems crucial, yet still lagging in many vulnerable countries

As human-induced climate change drives more extreme weather events, the need for early warning systems has never been more critical. A multi-hazard early warning system (MHEWS) is an integrated system that enables predictions of hazardous weather or climate events, and informs how governments, communities and individuals on how act to minimize impacts. MHEWSs are built on partnerships within and across relevant sectors (WMO, 2025a). They are life-saving tools that reduce economic losses. The public and decision-makers rely on forecasting and warning information provided by advanced technologies to help predict the trajectory and intensity of storms, rainfall quantities and potential impacts, so as to prepare and prevent as much damage as possible.

The information shared globally is first analyzed by advanced supercomputing modeling centers where models simulate the interaction between weather, hydrology, oceans and the cryosphere. Global data exchange and coordination is then facilitated by the World Meteorological Organization (WMO), with support from the UN Development Programme (UNDP), UN Educational, Scientific and Cultural Organization (UNESCO) and UN Environment Programme (UNEP).

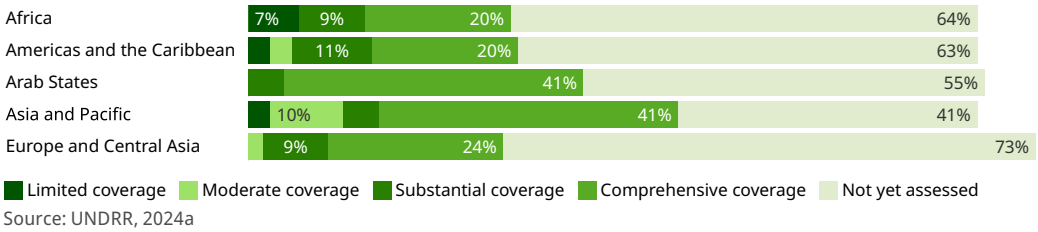
Over the last few decades, early warning for storms and flooding has significantly improved, allowing for better preparedness and response. Yet, only half of countries worldwide have sufficient multi-hazard early warning systems in place (WMO, 2025a). Despite global advances in mobile and internet technology, reaching vulnerable communities using multi-hazard early warning systems, especially in least-developed countries (LDCs), remains challenging due to poor network coverage and high mobile internet costs. Sixty-two million people directly affected by disasters over the last decades reside in countries that lack a fully operational early warning system. Many countries already have such a system, but gaps prevent full functionality.

Over the last few decades, early warning for storms and flooding has significantly improved, allowing for better preparedness and response

In 2022, the Early Warning for All (EW4All) initiative was launched by the United Nations Office for Disaster Risk Reduction (UNDRR) in partnership with the WMO and other key organizations. This initiative aims to ensure that everyone, everywhere – especially vulnerable populations – has access to early warning systems for disasters like floods, storms and other extreme weather events by the end of 2027. The initiative receives support from the International Telecommunication Union (ITU) and the International Federation of Red Cross and Red Crescent Societies (IFRC).

The 2024 Global Status of Multi-Hazard Early Warning Systems report analyzes the latest data on the initiative's progress (UNDRR and WMO, 2023). As depicted in figure 2.3, while some regions like Asia-Pacific show strong adoption of multi-hazard early warning systems, vast assessment gaps in Africa and the Americas highlight an urgent need for expanded monitoring.

Figure 2.3 Countries reporting having multi-hazard monitoring and forecasting systems, 2024



Source: UNDRR, 2024a

Box 2.2. History of Doppler radar and its innovations

Doppler radar uses the Doppler effect to collect velocity data from particles being measured. In this way, Doppler radar sends out a signal that bounces off the raindrops within a storm, the radar's receiver then detects the reflected signal and measures the frequency shift, which is directly related to the movement of the raindrops (NSF NCAR Earth Observing Laboratory, 2025).

Developed in the 1980s, *NEXRAD* (Next-Generation Radar) is the weather radar used by the US National Weather Service. It measures precipitation, predicts flooding and hail, provides wind speed and direction, indicates the presence of wind shear and gust fronts, and predicts and tracks storms. NEXRAD represented an evolution from earlier radar systems when it became operational in the 1990s, as it incorporated Doppler radar capabilities in order to measure both precipitation intensity and storm particle movement (called radial velocity). NEXRAD also improved weather information by digitally processing radar data, making the data easier for non-meteorologists to interpret.

PAR (Phased Array Radar) technology then emerged as the next significant advancement in Doppler radar systems. PAR offers faster scanning capabilities, allowing the real-time tracking of storms and rapidly changing weather conditions. Unlike traditional NEXRAD systems, which require mechanical movement to scan, PAR uses electronically-controlled beams, thereby enabling continuous, high-resolution monitoring to enhance the precision and timeliness of weather forecasts, improving early warning systems.

Satellite systems. Satellites play a vital role in early warning systems by providing real-time data on weather patterns. Copernicus, operated by the ESA, offers a range of environmental monitoring tools through its Sentinel satellites. Sentinel-1 satellites are equipped with SAR, and monitor ground displacement and flood levels. The Sentinel-2 satellites offer high-resolution optical imagery, providing valuable information about land use, vegetation and disaster impacts. Sentinel satellites operate in sun-synchronous, low Earth polar orbits at an altitude of about 800 km.

Other satellite networks, such as NOAA's Geostationary Operational Environmental Satellite (GOES) and the Japan Meteorological Agency's Himawari 8 (launched in 2014) and Himawari 9 (launched in 2019), also enhance forecasting by providing imagery and atmospheric measurements, real-time mapping of lightning activity, and the monitoring of space weather. GOES and Himawari are both situated at approximately 36,000 km above the Equator in a geostationary orbit. This means they orbit Earth at the same rate as the planet, which allows them to remain fixed over one spot on the Earth's surface for continuous monitoring.

AI can improve early warning, with some limitations

Early warning systems (EWS) have been shown to reduce flood-related fatalities by up to 40% and the integration of artificial intelligence and innovative detection methods has the potential to further enhance their accuracy and effectiveness (Camps-Valls *et al.*, 2025). Artificial intelligence (AI) can support EWS in some important ways, such as by processing vast amounts of real-time data from various sources and using machine learning to analyze historical data in order to identify patterns and predict future events with greater accuracy.

> Early warning systems (EWS) have been shown to reduce flood-related fatalities by up to 40%

AI-enabled multi-hazard monitoring systems can integrate diverse datasets to predict secondary disasters. These cross-domain models capture the interconnectedness of hazards – for example, storms can trigger floods and landslides. By synthesizing this information, AI provides a more comprehensive understanding of cascading disaster scenarios, helping emergency response teams better prepare for, or even mitigate, cascading impacts.

AI can also assist in calibrating non-contact video gauges (camera-based systems that remotely estimate water levels using computer vision) and guide forensic analysis in assessing flood risk and vulnerability. It can improve communication during emergencies by generating AI-based maps and photorealistic visualizations from digital elevation models, predicting inundation areas and damage (Lütjens *et al.*, 2024). Additionally, AI can translate messages into multiple languages and adapt them for different populations, including the visually impaired. Chatbots based on large language models can enhance interactivity, providing real-time responses to inquiries (Camps-Valls *et al.*, 2025). Box 2.3 discusses how big data and machine learning technologies enhance disaster prediction, especially for floods and hurricanes, by integrating diverse data sources and real-time analysis. These developments will be further discussed in the communications and digitial coordination chapter.

However, while being a potentially highly efficient tool, AI models can be wrong and misinterpret vulnerability data, potentially leading to inappropriate emergency responses. Non-expert interpretation of AI outputs may therefore be problematic. Erroneous data and false alarms can undermine public trust, especially as AI models struggle with imprecise definitions of what is an "extreme" event (Camps-Valls *et al.*, 2025).

The effectiveness of AI depends on the availability of data, and there may be different outcomes in data-rich versus data-scarce regions. Addressing the digital divide is therefore crucial, as biased data can lead to the underrepresentation of certain communities. This is particularly challenging in the Global South, where "one-size-fits-all" models may not address local needs.

Tailored models with active involvement from affected communities offer a promising solution to reducing bias (Camps-Valls *et al.*, 2025). Ethical issues such as transparency and bias can be addressed through accountability measures, ethical guidelines and frameworks that promote the responsible development and use of AI (UNU-EHS, 2024).

For more information on EWS technologies, see the *Green Technology Book* Adaptation edition.

Box 2.3 The next frontier – multi-source data integration is facilitated by big data

Big data (vast, complex datasets from multiple sources) technology plays a crucial role in disaster prediction through integrating diverse data sources. Unlike traditional methods that rely on a single data source, big data combines inputs like rainfall, runoff and historical records to improve flood forecasts. Rapid processing supports timely evacuation planning for governments and communities.

Machine learning and deep learning models trained on historical data can predict events, such as hurricane paths, by analyzing long-term meteorological and oceanic data. Deep learning also improves precision by continuously analyzing satellite imagery for early signals like cloud patterns and surface temperature shifts. This real-time analysis enhances flood risk maps and resource allocation, as discussed in the emergency infrastructure and rapid response chapter.

Historically, applying machine learning to natural hazard prediction has proved challenging because of the rarity of events and limited data availability. This is especially true for hurricanes, where complex, high-dimensional meteorological data and small datasets hinder mode accuracy (Ayyad *et al.*, 2022; Hou *et al.*, 2019). Machine learning models lack the foundations of traditional numerical models that incorporate physical processes, raising concerns about reliability (Arachchige and Pradhan, 2025b). Predicting hurricane damage is even more complex, involving environmental, social and economic factors, and is further complicated by inconsistent and limited damage data (Arachchige and Pradhan, 2025a). Despite these challenges, machine learning applications in hurricane and hurricane damage modeling are increasing.

IoT and LiDAR drive real-time flood monitoring

Technologies for monitoring rainfall are critical for managing the impacts of storms and flooding. They can be quite simple, as seen in bucket rainfall sensors that tip when the bucket is full, sending a pulse signal. Other sensors use infrared light to detect raindrops as they scatter or reflect light. Sensor networks can provide comprehensive coverage. Internet of things (IoT)-based flood sensors monitor water levels in flood-prone areas and send real-time data that enable early warnings to be issued for communities, while IoT-enhanced river gauges provide continuous data to flood managers planning responses. The technologies feature wireless communication capabilities, allowing remote data transmission (via FTP, cloud platforms, SMS alerts, and so on), which ensures easy access from anywhere. Several solutions have been designed to integrate into other monitoring stations and data systems (data loggers, platforms, cloud environments) to provide a more holistic view of systems and environmental conditions. Finally, many solutions offer automated data collection and alerting features that notify users when a threshold, such as rainfall or water level, is exceeded, triggering prompt responses for disaster mitigation.

Flood risk mapping is essential for informing an emergency response, infrastructure planning and risk assessment, as it helps quantify potential impacts and supports awareness campaigns. There are some relatively simple flood risk mapping tools available based on digital elevation models (DEMs). However, sometimes this mapping relies on complex models and expertise, and requires costly data collection. And to effectively contribute to risk management, such maps must be integrated into broader strategies (Climate Tech Wiki, 2024).

Flood risk mapping is essential for informing an emergency response, infrastructure planning and risk assessment

Technologies such as LiDAR, which stands for Light Detection and Ranging, further enhance flood assessment and response. LiDAR uses laser pulses to create accurate 3D maps that enable the identification of structural damage from water, depicting terrain changes and flood severity, while satellites offer near-real-time imagery that supports decision-making. Importantly, LiDAR can infiltrate hard-to-reach areas like basements and wall cavities to assess water intrusion and damage. Its accuracy helps calculate the volume of materials damaged by water, such as flooring, insulation and drywall, which is vital for planning drying, material removal and reconstruction.

Roofing technologies build top-down resilience

A multitude of roofing technologies and accessories enhance the strength and resilience of homes and buildings in regions prone to storms and extreme wind events.

Accessories to strengthen infrastructure. Simple, proven technologies can help fortify buildings against extreme winds. They include hurricane clips, hurricane straps, roof tie-downs, and storm braces – metal connectors and supports that secure roofs to walls and foundations.

Metal roofs perform well in storms. There are various types, including steel, aluminum and copper. They may, however, be more expensive than asphalt shingles – and noisier.

Clay roofs. Clay tiles provide storm resistance through their weight and interlocking design, which limits wind and water infiltration. Naturally water-resistant and hail-tolerant, they shed water efficiently and last 50–100 years with minimal upkeep.

Impact-resistant shingles are made of advanced polymer composites and can withstand hail and windborne debris, outperforming traditional asphalt or rubber materials in terms of durability.

Sensor-embedded roofs incorporate advanced monitoring systems that track weather conditions (temperature, humidity, wind speed), structural integrity (cracks, material fatigue) and moisture intrusion (early leak detection to prevent water damage). These sensors provide real-time alerts, enabling early leak detection and automated responses such as vent adjustment or closure of skylights.

Seamless roofing systems lack seams and joints, rendering them superior for waterproofing. They are made from liquid-applied membranes, such as silicone or polyurethane, and some offer reflective surfaces that reduce heat absorption as well.

Bituminous roofs are seamless solutions employing bituminous membranes, a type of waterproofing material used for flat or low-slope roofs. Membranes are reinforced with fiberglass or polyester and topped with gravel or foil for added protection, providing long-lasting waterproofing.

Siphonic roof drainage rapidly removes rainwater from flat roofs using negative pressure, often draining at over twice the speed of a gravity system – without requiring pumps.

Construction technologies to stormproof houses

Increasingly common in storm-prone regions like Florida in the United States, *impact-resistant windows* feature laminated glass that has a durable polymer interlayer and dual-pane construction. Even if shattered, such windows maintain integrity and protect against flying debris and glass shards.

Storm shutters. Roller shutters made of interlocking metal slats provide strong storm protection and can be rolled up when not in use. Motorized hurricane screens offer convenient, remote-controlled protection via smartphone or automatic activation.

Green bars. Stainless steel reinforcement bars are known for the high corrosion resistance they offer due to their chromium content. Epoxy-coated steel rebar, known as "green bars," enhances corrosion resistance in reinforced concrete. It is a cost-effective alternative to stainless steel and helps prevent cracking in storm-exposed structures.

Fiber reinforcement polymers (FRPs), including fiberglass and carbon fiber, are emerging as green, low-carbon alternatives, offering improved corrosion resistance and improved tensile strength. Though carbon fiber is costly, using recycled waste materials in FRPs helps reduce carbon footprint.

Floating infrastructure is transitioning from a once far-fetched idea to a viable solution. First highlighted in the 2019 IPCC Special Report on Oceans and the Cryosphere in a Changing Climate (IPCC, 2019), it has been recognized as a potential answer to the challenges faced by coastal areas vulnerable to rising sea levels and extreme weather. Designed to adapt to rising waters, floating infrastructure can also generate renewable energy and support floating agriculture (Global Center on Adaptation, 2022).

Modern building materials are game changers for waterproofing

Traditional airbricks are ventilation openings in a building's foundation that allow airflow. *Smart airbricks* integrate technology enabling them to actively respond to environmental changes, such as flooding. These advanced bricks can automatically seal to prevent water from entering through ventilation gaps. Some models come equipped with sensors that detect rising humidity or water levels and can connect to smart home systems, enabling automatic activation when needed for flood protection.

Self-healing concrete is an innovative material that can automatically repair cracks over time without human intervention. It incorporates healing agents like bacteria (commonly *Bacillus* species) or chemical capsules (with polyurethane or epoxy resins), which activate when cracks form and water or air enters, sealing the damage. *Concrete admixtures*, added during mixing, enhance concrete performance, including its strength and durability. For example, Sika's watertight concrete system includes water-resisting admixtures, along with additional solutions like SikaSwell profiles and sealants that expand on contact with water to seal joints and penetrations.

Flood defenses reinvented

Next-generation flood defenses are transforming protection with lightweight materials and automated systems. Innovations – from self-deploying barriers to smart seals and rapid-drying tools – are delivering faster responses and more efficient protection and recovery for vulnerable properties.

Sandless sandbag solutions. Modern flood barriers have evolved beyond traditional sandbags, employing innovative materials that combine portability with rapid deployment. These water-activated systems use advanced absorption technologies to create instant barriers when needed. Some use superabsorbent polymers that rapidly expand upon contact with water to form a solid, stable barrier, while maintaining a lightweight design. Alternative solutions use hydraulic polymers or gel-based formulations that similarly absorb moisture and solidify, creating effective flood protection with significantly easier handling and placement compared to conventional sandbags. When exposed to water, such barriers activate within minutes – absorbing moisture, expanding in volume, and hardening into position.

Source: Getty Images/BeritK

Flood doors and barriers. Flood doors are sealed entryways that prevent water from entering a building. Hydrostatic barriers use water pressure to create a solid seal, often automatically deployed in doorways or windows. FloodGuard screw-in barriers can be screwed into place, while pivot barriers are hinged, swing-out barriers ideal for flash flooding, featuring quick opening and closing. Slot-in barriers slide into pre-installed frames to block floodwaters.

> Innovations – from self-deploying barriers to smart seals and rapid-drying tools – are delivering faster responses for vulnerable properties.

Water-inflated dams are flexible barriers that use water to inflate and create a dam-like structure for temporary flood control. Water-gate barriers, on the other hand, inflate automatically when exposed to water, are deployed in smaller areas like doorways, gates or entrances, and use the pressure of rising floodwaters to inflate and create a watertight seal.

Air movers and dehumidifiers help dry out and restore water-damaged areas. These are powerful fans designed to circulate large volumes of air across wet surfaces, accelerating the evaporation process. Dehumidifiers work as heat pumps and remove moisture from the air by pulling in humid air, cooling it so as to condense the moisture, and then releasing dry air back into the environment.

See the *Green Technology Book* Adaptation edition for more information on flood control solutions.

From runoff to resilience – transforming cities with stormwater technology

As urban expansion and frequent flooding intensify, cities are investing in advanced stormwater management solutions. Impermeable surfaces like roads and buildings hinder natural water absorption, worsening runoff and flood risks. In response, governments are implementing underground drainage, retention basins and green infrastructure. The push for water conservation is also driving innovation, including underground detention systems and real-time monitoring technologies.

Modern stormwater technologies are smarter and more sustainable than ever before, incorporating IoT, AI and digital innovation to improve runoff management and flood resilience. Cities and industries now use real-time monitoring, automated drainage systems and digital twin simulations to optimize planning and response. Cloud-based solutions are further driving the digital transformation of stormwater management.

Nature-based solutions also play a critical role. They include:

- Rain gardens and green roofs that absorb and filter water, while enhancing urban aesthetics.
- Permeable pavements that reduce runoff and recharge groundwater.
- Sponge cities, an urban design concept originating in China, integrate permeable surfaces, green infrastructure (parks, wetlands), rainwater harvesting and natural drainage systems to absorb, store and purify rainwater either for reuse or controlled release.

San Salvador, El Salvador, for example, is combating both floods and landslides washing away valuable topsoil and fertility through a forest and coffee farm restoration project known as CityAdapt. Led by city officials and local coffee farmers on the city's surrounding hillsides, the project is reforesting 1,150 hectares in order to restore the land's natural absorption capabilities, while protecting 115,000 residents from flooding (UNEP, 2024b).

> Modern stormwater technologies incorporate IoT, AI and digital innovation to improve runoff management and flood resilience

Modular infiltration systems manage stormwater runoff by promoting rainwater absorption. Composed of interlocking modular units, they can be customized to fit site-specific needs, enhancing natural infiltration and replenishing groundwater supplies.

Active attenuation technologies. Unlike passive solutions, these systems dynamically control water flow to prevent flooding using sensors, automation or human intervention. Key features include:

- Real-time adjustments via detention basins, pumps or gated channels that temporarily store and slowly release excess water.
- Smart monitoring such as moisture sensors that detect water damage in buildings.
- Automated systems like StormHarvester (see frontier technologies) that use predictive algorithms to adjust the water level in tanks based on rainfall forecasts. These "smart" tanks optimize storage, reduce costs by 50 percent and require less space than traditional systems.

See the *Green Technology Book* Adaptation edition for more information on these technologies.

Safe sanitation and hygiene

Rapid spreading of diseases is a common risk in relation to flooding when sanitation facilities and wastewater conduits are flooded and waste released. In flood-prone areas, effective sanitation and water purification rely on technologies designed for resilience, mobility and safety. Elevated or raised latrines such as Sky Latrines and urine diversion dry toilets prevent floodwater contamination by keeping waste above ground level. These systems often include sealed vaults or urine separation features that reduce pathogen risk and facilitate safe waste removal, even when the ground has become waterlogged. Container-based sanitation (CBS) is a flood-resilient, off-grid system that captures waste in sealed, removable containers that are serviced regularly and transported off-site for safe treatment, reuse or disposal. CBS is ideal for flood-prone areas, as it requires no digging. It also works in high groundwater zones, dense settlements or rocky terrain, providing a hygienic alternative where pit latrines or sewer systems are impractical. Floating treatment pods are also used in areas where ground-based toilets are infeasible, containing and processing waste in buoyant units (CBSA, 2024).

For drinking water, manual and solar-powered ultrafiltration units use membranes to remove bacteria and viruses without the need for electricity, chemicals or spare parts. Mobile

purification plants mounted on trailers or trucks provide rapid-response treatment at scale. These often include built-in power sources. All of these technologies emphasize portability, low maintenance and adaptability to unstable environments. See the chapters on drought and emergency infrastructure and response for more information on water purification within disaster settings.

Digital twins for flood protection – promising technologies for cities

Digital twins are transforming water management and hazard mitigation worldwide, enabling more efficient governance and decision-making (Yang *et al.*, 2024). A digital twin is a virtual model or digital representation of a physical system. By using integrated physical models and data integration algorithms, a digital twin can address high-dimensional optimization problems that are difficult to solve through traditional modeling methods. When used for flood protection, digital twins enable the simulation and analysis of water levels, soil moisture and river flows to help predict potential flood events. They provide water conditions informed by real-time data integrated from various meters, sensors and IoT devices. Disaster authorities can then use them to conduct scenario planning without having to undertake physical tests. Digital twins are also used extensively in industry to model and optimize energy and material use, and so on. This is described in the Industry 4.0 section of the *Green Technology Book* Mitigation edition.

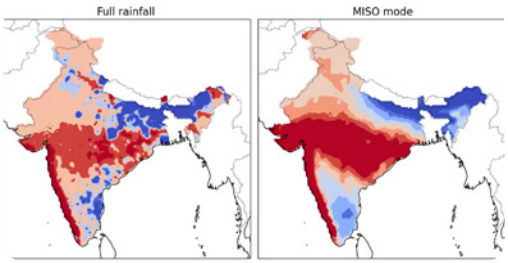
Innovation examples

Autonomous saildrones investigate hurricane rapid intensification forecasting

Source: Saildrone

The Saildrone Explorer is helping scientists improve hurricane prediction, particularly with respect to forecasting rapid intensification, when wind speeds can increase by more than 30 knots in just 24 hours. While NOAA has made progress in tracking hurricanes, understanding ocean processes during intensification remains a challenge. To tackle this, NOAA and Saildrone launched a multi-year mission in 2021 using uncrewed surface vehicles (USVs) in tropical storms and hurricanes. The goal is to collect data on near-surface atmospheric and ocean parameters to study energy and momentum exchange between the ocean and atmosphere. These USVs, equipped with special “hurricane wings” for extreme conditions, are deployed in high-risk areas like the Tropical Atlantic and Gulf of Mexico. They transmit real-time data such as air temperature, wind speed, water salinity and wave height. NOAA coordinates sampling using underwater gliders and aerial assets to measure the surface flux within a hurricane, especially around the eyewall. This helps create a complete picture of the atmospheric and water column. The data obtained from several 2021 and 2022 missions is available to the public (NOAA, 2024).

Machine learning breaks the monsoon rainfall prediction barrier in South Asia



Source: California Institute of Technology

The South Asian monsoon sweeps in annually during cycles known as monsoon intraseasonal oscillations (MISOs), deluging the people of the region with heavy rains between June and September. The rainfall fluctuates widely, with some weeks seeing several inches, while other weeks remain mostly dry. Precise prediction of these wet and dry periods more than one or two days in advance is difficult. Current large-scale forecasts that predict up to 10 days in advance use numerical modeling based on computer simulations of the atmosphere. These simulations are derived from modeling the motion of fluids. By using a new machine-learning based forecast model, South Asian monsoonal rainfall prediction can be extended to 30 days with a 70 percent improvement in accuracy. This will be useful for both agriculture and urban planning, as well as deepening our understanding of how climate change is likely to affect the South Asian monsoon and other weather events. The research is a collaboration between Caltech, George Mason University, Portland State University, University of Maryland, UCLA, Imperial College London, and École Normale Supérieure in Paris, with funding from India's Ministry of Earth Sciences, NASA, and the National Science Foundation (Caltech, 2024).

Tiny bamboo homes bolster resilience against flooding in Bangladesh

Source: Asif Salman / Marina Tabassum Architects

An award-winning architect in Bangladesh, Marina Tabassum, has developed an innovative housing solution to help people cope with the increasing threat of flooding caused by climate change. Her design, the "Khudi Bari" or "tiny house" is a two-floor home built on bamboo stilts, elevated to protect against rising floodwaters. During the annual monsoon floods, farmers no longer have to abandon their homes. Instead, they can simply climb a ladder to the second floor and wait for the floodwaters to recede. Unlike cyclone shelters, which are designed for short-term use during storms, Khudi Bari houses are built to withstand long-term flooding, offering both safety and mobility. Each Khudi Bari house costs around USD 450 to build, using locally-sourced materials like bamboo poles and metal sheeting. The houses are modular, meaning they can be assembled, disassembled and relocated easily. The design was inspired by traditional homes raised on stilts in central Bangladesh, but Tabassum's innovation makes them more adaptable and practical for modern needs, allowing residents to stay safe during extended floods without losing valuable possessions (Phys.org, 2023).

Digital twin technology takes on flood management water scarcity in China

Source: Dr. Xiaopeng Wang

Urbanization and climate change have increased flood risks and water scarcity in China. To address these challenges, China has adopted digital twin technology for water management, enabling real-time monitoring and simulation of water systems to optimize flood control, drought relief and resource allocation. In 2022, the Ministry of Water Resources launched a nationwide digital twin system with 94 pilot programs in 48 locations. This system monitors all 5,186 small and medium-sized rivers at flood risk, collecting data from 53,000 precipitation stations, 25,000 hydrological stations, as well as meteorological satellites. A dynamic national water conservation map integrates data from 16 million water management projects, including reservoirs and river dikes. Key projects, such as the Xiaolangdi Water Conservancy Project on the Yellow River, enhance flood forecasting and early warning systems. In a simulated flood control drill at Xiaolangdi, digital twins applied 2021 flooding data and increased it by 10 percent to predict extreme water levels, helping develop response strategies. In 2025, China plans to digitalize key river basin components for real-time simulations, advancing flood prevention and water management across the country (Wang *et al.*, 2025).

Proven technology solutions

Water and sanitation: modular sanitation unit

Wetlands Work!

Source: Wetlands Work!

The HandyPod by Wetlands Work! is a contained and flood-resistant sanitation system designed for floating, flood-prone or high groundwater communities. Installed directly beneath a home or schools, the HandyPod collects waste into the first of three sealed containment units, preventing contact with floodwaters and groundwater contamination. It uses a multi-stage, passive gravity flow process involving treatment by anaerobic digestion and microbial biofilm, often completed with filtering through a small, constructed wetland to reduce pathogens and organic matter. The treated effluent can be safely discharged into the environment or used for home garden irrigation, while solids are periodically removed. Requiring no electricity, no moving parts, minimal water, and low maintenance, the HandyPod is particularly suited to areas where pit latrines or sewer connections are infeasible, such as on lakes, floodplains, beaches and mangroves.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Cambodia, Myanmar
- Availability: Worldwide
- Contact: WIPO GREEN Database

Water and sanitation: container-based toilet and composting waste treatment

Sustainable Organic Integrated Livelihoods (SOIL)

Source: Sustainable Organic Integrated Livelihoods (SOIL)

SOIL provides full-cycle sanitation services, including container-based toilets and composting waste treatment services, in Haiti. Their EkoLakay toilets seal waste in containers, preventing exposure and reducing the risk of waterborne diseases during floods. Unlike traditional sanitation methods, such as pit latrines, the EkoLakay remains safe and operational even during floods or high water tables. SOIL staff regularly collect waste and transport it for treatment, generating nutrient-rich compost that supports local agriculture and depleted soils.

- Technological maturity: Proven
- Contracting type: For sale/service
- Technology level: Medium
- Place of origin: Haiti
- Availability: Haiti
- Contact: WIPO GREEN Database

Water and sanitation: community water filter

Grifaid

Getty Images/anmbph

The Grifaid Community Filter is a manual, membrane-based water purifier designed for community or institutional use. Users can treat up to 300 liters per hour by simply placing an inlet pipe into a container of untreated water, and then hand-pumping it through the system. It uses ultrafiltration membranes to remove bacteria and viruses to WHO standards, delivering clear water without altering taste. It is an affordable solution requiring no electricity, chemicals, spare parts or consumables to function. Built-in self-cleaning and back-flush mechanisms prevent clogging and ensure long-term, trouble-free use for up to 6 years.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United Kingdom
- Availability: Worldwide
- Contact: WIPO GREEN Database

Water and sanitation: compact mobile water purification system

Metawater

Source: Metawater Co. Ltd.

Metawater Co. Ltd has developed a mobile ceramic membrane filtration system mounted on a 4-ton truck to deliver safe drinking water during emergencies and in underserved areas. The unit uses a durable, high-performance ceramic membrane with a 0.1 µm pore size, effectively removing protozoa (e.g., *Cryptosporidium*), *E. coli*, and other bacteria, even from highly turbid or fluctuating raw water. All essential components including power generators are onboard, enabling it to operate in areas without electricity. The system is designed for quick deployment to disaster zones, like flooded regions, and for use in rural or remote communities where centralized treatment is impractical. Its simple configuration ensures easy operation and maintenance, and the ceramic elements allow long-term storage without chemicals or membrane degradation.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Japan
- Availability: Worldwide
- Contact: WIPO GREEN Database

Flood response: sandless sandbag

FloodSax

Source: FloodSax

FloodSax sandless sandbags are quick and easy to deploy, being transformed within roughly 5 minutes into an effective flood barrier. FloodSax bags are designed with a semi-porous inner lining containing a gelling polymer and absorbent crystals. When activated, these crystals absorb water and expand, creating a taut, sandbag-like barrier that blocks floodwaters. Once activated (when submerged in water) they hold the water inside, preventing it from escaping. Each bag can absorb up to 20 liters of water. Before activation, they are lightweight, weighing just 370 grams. Once expanded, a standard 520 mm × 470 mm × 170 mm bag weighs 20 kg and is strong enough to withstand powerful floods. A row of FloodSax can hold back around 18 cm (7 inches) of water and they have proven to be reliable flood barriers worldwide.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United Kingdom
- Availability: Worldwide
- Contact: WIPO GREEN Database

Storm-resilient infrastructure: hurricane clips

MiTek South Africa

Source: Getty Images/maksime

The eCo Hurricane Clip is a galvanized steel framing anchor for roofing used to connect structural timber members at right angles to each other, commonly in high-wind areas. These clips are often employed for truss-to-beam connections, providing additional strength and stability during extreme weather conditions. Hurricane Clips work by securing the roof or structural elements to the walls of a building, helping prevent roof uplift or structural separation during high winds. The Clip is installed using nails through pre-punched holes and must be used in pairs for optimal effectiveness. When fully nailed with Permfix nails, a pair of eCo Hurricane Clips can handle a design load of 1.6 kilonewtons.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: South Africa
- Availability: South Africa
- Contact: WIPO GREEN Database

Storm-resilient infrastructure: green rebar (epoxy-coated)

Zeta Industry

Source: Getty Images/TW Farlow

Epoxy-coated rebar is essential for reinforcing roads, bridges and industrial plants, providing protection against corrosion caused by rainwater and moisture. When either penetrate steel fittings inside concrete foundations, platforms, columns and beams, corrosion occurs, weakening load-bearing components. Corrosion also lowers the pH value, diminishing the durability of concrete and steel construction, leading to cracks, reduced mechanical strength and the need for costly repairs. The epoxy coating acts as a physical and electrochemical barrier, isolating the steel and preventing corrosion. Within the United States and Europe, using epoxy-coated rebar that meets American Society for Testing and Materials (ASTM) standards is a requirement for airports and highways. Extensive testing has shown epoxy-coated rebar to be more durable than regular rebar, offering long-term cost savings of up to 50 percent.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Low
- Place of origin: Türkiye
- Availability: Worldwide
- Contact: WIPO GREEN Database

Storm-resilient infrastructure: fiber-reinforced polymer (FRP)/ glass-reinforced plastic (GRP) composite rebar

Asia Composite

Source: Getty Images/Dizfoto

Steel rebar has been used in construction for over a century. But in corrosive environments, deterioration can be rapid and catastrophic. Composite rebar, known for its corrosion resistance, is being increasingly used in the retrofitting of tunnels, coastal structures and buildings exposed to a harsh environment. Made from polymers reinforced with glass fiber and resin, composite rebar is more durable. Its tensile strength and elasticity depend on factors such as fiber content, type of epoxy or polyester resin used and the orientation of the glass fibers, as well as quality control during manufacturing. This technology offers an alternative to traditional steel rebar, particularly in areas prone to corrosion, in building longer-lasting and more reliable structures.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Low
- Place of origin: Islamic Republic of Iran
- Availability: Islamic Republic of Iran
- Contact: WIPO GREEN Database

Storm-resilient infrastructure: siphonic roof drainage systems

Pipelife

Source: Getty Images/Дмитрий Коростылев

Effective rainwater drainage is crucial in maintaining the safety and integrity of flat or low-gradient roofs. Siphonic systems require fewer, smaller pipes compared to traditional gravity systems. Pipelife's siphonic roof drainage system is designed to prevent overflows, leaks and structural damage. It contains pre-welded outlets and high-quality pipes made from durable, UV-resistant thermoplastics. Pipelife fittings are compatible with butt-welding and electrofusion connection technologies, providing strong, leak-free joints.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Austria
- Availability: Worldwide
- Contact: WIPO GREEN Database

Storm-resilient infrastructure: hurricane windows and doors

Neuffer

Source: Getty Images/Leschenko

As climate change leads to more unpredictable storms and stricter building regulations, high-quality hurricane windows and doors with impact-resistant glass are essential for protection. Neuffer offers Miami-Dade-certified hurricane windows, such as the Reynaers CS 77 model, designed to withstand hurricane-strength winds and heavy rainfall. These windows feature laminated glass covered with a thick polymer film, which provides protection from flying debris and high wind pressure (up to 5,000 Pa). Unlike regular windows, Reynaers hurricane windows have five invisible layers of strong PVB polymer film and can be tempered for added flexibility upon impact. This technical design ensures that, if broken, the glass remains in place, providing excellent storm protection and injury prevention. Additionally, windows are encased in durable aluminum and uPVC frames that have a built-in drainage system to prevent water damage during storms.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Germany
- Availability: Asia, Europe, North America
- Contact: WIPO GREEN Database

Storm-resilient infrastructure: wind-resistant lightweight roofing systems

Onduline

Source: Getty Images/victorass88

Onduline's wind resistance is attributable to several key features that work together to enhance its durability in extreme conditions: a fixation system with washers of at least 16 mm; a minimum of 10 fixations per m^2 that ensures a strong connection to the structure; corrugated sheets that improve rigidity and stability; a flexibility and resilience that allows the sheets to absorb shocks and vibrations from gusty winds; and accessories designed to prevent wind from passing through the sheets. Onduline CLASSIC sheets can withstand winds up to 225 km/h on metal structures and up to 260 km/h on wooden purlins (horizontal structural components used in roofing systems to support the sheeting). The Onduvilla variant offers even greater resistance, handling winds of up to 315 km/h on metal structures and up to 290 km/h on wooden purlins.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: France
- Availability: Worldwide
- Contact: WIPO GREEN Database

Frontier technology solutions

Water and sanitation: septic tank-like upgrade for pit latrines

International Development Enterprises (iDE), Cambodia, and Engineers Without Borders (EWB) Australia

Source: iDE Cambodia

Pour-flush pit latrines that direct waste into underground pits often face issues of rapid filling and overflowing in flood-prone areas, resulting in many latrine owners resorting to unsafe emptying practices. In response, iDE and EWB Australia developed the All Seasons Upgrade (ASU), a latrine pit upgrade providing year-round pit functionality (i.e., flushing) in high groundwater and low infiltration soils. The ASU attaches a gravel filter pit and leach field to an existing latrine pit. The filter pit is filled with gravel and offers an additional treatment reactor, while preventing the leach field from clogging. And the leach field offers increased surface area for infiltration at a depth above the groundwater table, but deep enough to prevent the upward flow of contamination. The solution minimizes households' exposure to untreated fecal sludge, thereby improving latrine functionality and reducing environmental pollution. It is sold, manufactured, installed and delivered to rural households in Cambodia's flood-prone areas through iDE-connected sanitation entrepreneurs.

- Technological maturity: Proven
- Contracting type: For collaboration
- Technology level: Medium
- Place of origin: United States
- Availability: Cambodia
- Contact: WIPO GREEN Database

Weather monitoring: Automatic Weather System (AWS), Automatic Rainfall Recorder (ARR) and Automatic Water Level Recorder (AWLR)

Mertani

Source: Getty Images/pedphoto36pm

Mertani's IoT systems collect precise monitoring data. The AWS provides real-time data on weather parameters like temperature, humidity, wind speed and solar radiation, aiding in weather forecasting and agricultural planning. The ARR accurately measures rainfall intensity and volume, crucial for flood prediction and water resource management. The AWLR monitors water levels in rivers, lakes and reservoirs, supporting flood warning systems and irrigation management. They are equipped with sensors, data loggers and cloud-based platforms for remote access and analysis useful for the hydrology, disaster management and agriculture industries.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: Indonesia
- Availability: Indonesia
- Contact: WIPO GREEN Database

Precipitation monitoring: hail monitoring system

KISTERS

Source: KISTERS

HailSens IoT is an advanced sensor for real-time hail monitoring, detecting hail impacts through kinetic energy measurement. It records key hailstone characteristics such as kinetic energy, diameter and timestamp of the impact in real-time. The receiver's software allows for immediate assessment of the hail event and can trigger near-instant alerts based on the incoming data. The IoT allows for detailed measurements that are useful for meteorologists and insurance adjusters, as they can help optimize prediction models, manage insurance indices or even help protect solar panels by adjusting their position during hail events.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Germany
- Availability: Worldwide
- Contact: WIPO GREEN Database

Stormwater management: smart tanks for active attenuation

StormHarvester

Source: Getty Images/hamikus

The StormHarvester Smart Tank combines flood prevention and rainwater harvesting within a single solution. It transforms an ordinary attenuation tank into a "smart" tank, allowing water to be stored and reused on-site. The system continuously monitors short- and medium-term rainfall forecasts and automatically adjusts water levels within the tank to create enough volume to manage stormwater runoff from upcoming rainfall. By connecting a valve or attenuation pump to a precise rainfall runoff prediction algorithm, StormHarvester optimizes water levels. It can reduce space requirements and lower the cost of a rainwater harvesting system by 50 percent.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United Kingdom
- Availability: Worldwide
- Contact: WIPO GREEN Database

Flood barrier: easy movable dam

WaveSave

Source: WaveSave

The SLAMDAM® is a patented, flexible modular flood barrier system designed to provide temporary or permanent protection against floodwaters. Its unique construction includes two tubes that must be filled simultaneously, with a specially developed intermediate membrane forming two interlocking compartments. When water pressure is applied, the stressed compartment rises slightly, while the opposing compartment slots in underneath to provide counterpressure. This design ensures that the SLAMDAM® remains firmly in place, even at high water levels. SLAMDAM® can adapt to any surface and withstand variations.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Kingdom of the Netherlands
- Availability: Worldwide
- Contact: WIPO GREEN Database

Water damage response: dehumidifier

Lunor

Source: Getty Images/DonNichols

Lunor dehumidification systems are designed to save space and energy when drying. Featuring options like fresh air intake, sound insulation and climate monitoring, their key feature is the intelligent control system that automatically regulates the dehumidification process. These systems can be instaled on brackets up to 2.4 meters high, ensuring clear spaces and eliminating injury risk. Technicians also perform core drillings in concrete or brick, guide condensation water to drains via Geberit PE pipes or install condensation water pumps. A mobile version is available for garages, production areas, civil defense facilities and other locations. Units come with options like overflow protection or a prepared connection for drainage via a hose into a floor drain.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Switzerland
- Availability: Switzerland
- Contact: WIPO GREEN Database

Storm-resilient infrastructure: anti-flood airbricks

Eco Coverage Technologies

Source: Getty Images/sisen

Traditionally, airbricks are used to allow air to flow under floors. But in flood-prone areas, they can also allow water to enter a building. Smart AirBricks work as a passive flood protection system designed to prevent water ingress into properties. They automatically activate to seal ventilation openings in buildings when floodwaters are detected, thereby preventing water ingress, while maintaining airflow during dry conditions. They operate without the need for an external power supply and are easy to clean after a flood.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United Kingdom
- Availability: United Kingdom
- Contact: WIPO GREEN Database

Storm-resilient infrastructure: watertight concrete system

Sika Group

Source: Getty Images/Vesnaandjic

Sika Group's watertight concrete system is designed to prevent water penetrating into concrete structures. It utilizes a combination of specialized products, including waterproofing additives, admixtures and surface treatments, to enhance the durability and resistance of concrete against water infiltration. The system works by incorporating hydrophobic agents and crystalline technology, which react with water to form a waterproof barrier within the concrete itself. This ensures long-lasting protection against water damage, reducing the risk of leaks and structural deterioration. Sika's watertight concrete solutions are widely used in underground structures, basements, tunnels and water retention areas to prevent water ingress in concrete construction projects.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Switzerland
- Availability: Worldwide
- Contact: WIPO GREEN Database

Storm-resilient infrastructure: self-healing concrete

Basilisk

Source: Getty Images/Ruslan Sidorov

Basilisk Healing Agent is a bio-based granular additive that can convert any concrete mix into self-healing concrete. The technology uses microorganisms that produce limestone, allowing cracks in concrete structures to be repaired autonomously and enhancing durability. This self-healing system can be applied to both new and existing construction, and currently repairs cracks up to 1 mm, filling them with limestone and effectively waterproofing the concrete. Beyond waterproofing, self-healing concrete reduces the need for additional reinforcement in concrete structures to compensate for the shrinkage that occurs as concrete cures and hardens. It also creates a lower CO_2 footprint and minimizes maintenance.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Kingdom of the Netherlands
- Availability: Worldwide
- Contact: WIPO GREEN Database

Storm-resilient infrastructure: Alutech Smart Mobile for roller shutters

Alutech

Source: Getty Images/vlado85rs

The ALUTECH Smart mobile app allows the remote control of roller shutters, allowing their opening or closing from anywhere and the setting of schedules based on weather conditions like temperature or wind. During extreme weather, the shutters can automatically close for added protection. Instead of Wi-Fi or radio, the system uses the Zigbee protocol, which creates a mesh network wherein devices communicate directly, even if out of range. It also reconnects devices if there is interference or failure. Additionally, it tracks device status and energy use, and updates automatically without needing an installer.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: Russian Federation
- Availability: Russian Federation
- Contact: WIPO GREEN Database

Storm tracking, research and prediction: lightweight weather sondes

Skyfora

Source: Skyfora

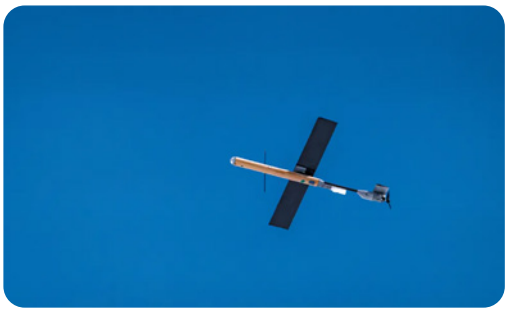
Skyfora's StreamSonde technology is a highly accurate atmospheric data collection device that builds on prior weather sondes. StreamSondes are lightweight, small and parachute-free versions of dropsondes that can be deployed in large numbers. They are designed to stay in the air longer and gather more data, increasing the volume and accuracy of weather information collected. Deploying multiple StreamSondes simultaneously helps create detailed and high-resolution atmospheric profiles. With improved data collection capabilities, Skyfora's technology supports more accurate weather monitoring and disaster prevention efforts, providing better insights for meteorologists and other professionals.

- Technological maturity: Frontier
- Contracting type: For (limited) sale
- Technology level: High
- Place of origin: Finland
- Availability: Partnerships with government agencies, research institutions, and meteorological organizations
- Contact: WIPO GREEN Database

Horizon technology solutions

Hurricane research: air-deployed unmanned aircraft system (UAS)

Black Swift Technology



Source: Black Swift Technology

NOAA and the US Air Force sought a low-cost, air-deployed UAS to sample the lower boundary layer of a hurricane for atmospheric research. They selected Black Swift's S0 Air Deployed UAS for the task, a lightweight and compact platform weighing just 1.2 kg, making it the lightest platform to successfully sample a tropical cyclone. The S0 can operate in dangerous parts of the storm, with the ability to transmit data within a 125 nautical mile range and fly for over 100 minutes. Its sensor suite captures 3D wind measurements, pressure, temperature, humidity and sea surface temperature – all critical for understanding tropical cyclones. The S0's autonomous, "launch-and-forget" design aims to ensure reliable, low-cost missions for hurricane research.

- Technological maturity: Horizon
- Contracting type: Under development
- Technology level: High
- Place of origin: United States
- Availability: Under development
- Contact: WIPO GREEN Database

Flood protection and modeling: digital twin

TU Dresden

Source: TU Dresden

In 2024, the Institute of Hydraulic Engineering and Technical Hydromechanics (Institut für Wasserbau und Technische Hydromechanik, IWD) started developing an "Urban Digital Heavy Rain Twin." It consists of a virtual model of the city, for which data can be visualized and accessed via a 3D web app on desktop and mobile devices. Then, users can conduct heavy rain simulations in urban areas and track the results in real time, ultimately assessing flood risk, even for specific individual buildings. The prototype offers fully automated creation of 2D simulation models based on free and open software, which can be complemented by precipitation forecasts from the German Weather Service. Flood simulations intersect with urban infrastructure features like roads to assess potential hazards and calculate potential damage of residential buildings. The platform will be publicly accessible at the end of 2025, while the full completion of the Urban Digital Heavy Rain Twin is scheduled for the end of 2026.

- Technological maturity: Horizon
- Contracting type: Under development
- Technology level: High
- Place of origin: Germany
- Availability: Under development
- Contact: WIPO GREEN Database

Flood protection and modeling: digital twin

Destination Earth

Source: European Space Agency

Destination Earth (DestinE) is an EU initiative to build a highly accurate digital twin (DT) of the Earth to simulate, monitor, and analyze natural and human-driven processes. It is implemented jointly by the European Space Agency (ESA), the European Centre for Medium-Range Weather Forecasts (ECMWF), and EUMETSAT under the Digital Europe Programme. DestinE builds upon three main components: the DestinE Platform, providing access to data, services, and applications; the Data Lake, harmonizing and enabling big data processing across sources such as ESA, ECMWF, EUMETSAT, and Copernicus; and the DT Engine, the software infrastructure that powers extreme-scale simulations. The first two operational digital twins are the Climate Change Adaptation DT, which produces multi-decadal, km-scale climate scenario simulations, and the Weather-Induced Extremes DT, which delivers high-resolution forecasts and interactive on-demand simulations of extreme weather. Both began demonstrations in 2024, with full-scale expansion of the system planned through 2030.

- Technological maturity: Horizon
- Contracting type: Under development
- Technology level: High
- Place of origin: United Kingdom
- Availability: Under development
- Contact: WIPO GREEN Database

Coastal erosion

The world's coasts are vanishing before our eyes, but a wave of innovation is fighting back. Hybrid defenses now merge engineering with nature: 3D-printed seawalls incorporate oyster habitats, while AI-guided drones map erosion in real time. From living breakwaters that tame storm surges to geotextiles that knit shorelines together, these solutions protect both communities and ecosystems and buy time for 600 million coastal residents on the climate frontline.

Technological developments and trends

Coastal erosion is an escalating threat to the 600 million people living in low-elevation coastal areas worldwide (Ronglan *et al.*, 2024). Human activities like coastal development, dam construction and ecosystem destruction contribute significantly to erosion, and are exacerbated by severe storms and climate change. Rising sea levels and more frequent extreme weather events are increasing the threat to infrastructure.

It is important to recognize the source-to-sea connections in coastal systems. Sediment management upstream, including dam operation, plays a key role in coastal erosion by disrupting the natural flow of sediments that replenishes beaches and shorelines. Without adequate sediment supply, beaches become depleted, accelerating erosion and weakening natural coastal defenses.

> Human activities like coastal development, dam construction and ecosystem destruction contribute significantly to erosion

A recent global study using the Global Surface Water Explorer dataset estimates that from 1984 to 2015, around 28,000 km^2 of land was lost to erosion – the size of Haiti. Additionally, 24 percent of sandy beaches worldwide eroded at a rate of more than 0.5 meters per year during this same period, above what is typically considered normal for coastal erosion (Mentaschi *et al.*, 2018). This trend is most pronounced in areas like the Amazon River mouth, where erosion rates have reached up to 50 percent (Luijendijk *et al.*, 2018). Alarmingly, most sandy shorelines within marine-protected areas are also eroding, posing a risk not only to human communities, but also to the marine ecosystem (Luijendijk *et al.*, 2018).

Coastal erosion threatens lives and livelihoods

As urban development expands, an increasing number of people living in low-lying cities are becoming exposed to erosion. By 2030, rising sea levels are projected to expose over 100 million people in sub-Saharan Africa to flooding, with that number growing to 135 million by 2050 (WMO, 2021a; Opperman *et al.*, 2021). The economic and social costs of coastal erosion are already substantial. For example, in 2018, coastal erosion, flooding, and pollution in Nigeria's Cross River, Delta, and Lagos states caused an estimated loss of USD 9.7 billion, equivalent to about 8.1% of the combined GDP of those states (Croitoru *et al.*, 2020).

Importantly, global port activities – crucial to international trade – are at considerable risk. Between 1980 and 2020, approximately 38 percent of global container port activity occurred in hurricane-prone areas, with damages estimated at USD 7.5 billion annually (UNDRR, 2023). Seaports are increasingly vulnerable to sea levels that are expected to rise by 0.6 to 1.1 meters by 2100 (IPCC, 2019). The impact of extreme events, like Hurricane Sandy's USD 60 billion toll on the US eastern seaboard, underscores the urgency of addressing these vulnerabilities.

> By 2030, rising sea levels are projected to expose over 100 million people in sub-Saharan Africa to flooding, growing to 135 million by 2050

Since 20 percent of the world's population lives within 25 km of the coast, such populated areas tend to be more developed than other coastal locations, which contributes to greater coastal deterioration (Das Adhikari *et al.*, 2025). Artificial structures constructed along coastlines to prevent erosion do not fully stop erosion, instead often relocating it to other areas or even accelerating the process (Das Adhikari *et al.*, 2025).

In addition to erosion, coastal subsidence – the sinking of coastal areas – compounds the challenges faced by low-lying coastal areas, making them even more vulnerable to the impacts of rising sea levels. Coastal subsidence is commonly overlooked in both coastal-management policies and longer-term urban planning (Ohenhen *et al.*, 2024). However, coastal managers are becoming increasingly focused on understanding the effects of extreme weather events and ongoing ground subsidence on coastal areas (Vitousek *et al.*, 2017; Sengupta *et al.*, 2020).

Saltwater intrusion is another serious consequence of coastal erosion and rising sea levels. This occurs when saltwater infiltrates freshwater sources, such as rivers, aquifers and lakes, and is also caused by the over-pumping of groundwater. Such intrusion can render water undrinkable, reduce soil fertility and disrupt ecosystems by altering soil composition and aquatic habitats. It also threatens human activities, with freshwater scarcity affecting drinking water and agriculture. To address this issue, reverse osmosis (RO) water filters and other technologies have emerged to remove salt and impurities and provide safe water for consumption and irrigation. See the *Green Technology Book* Adaptation edition for more information on desalination technologies.

Coastal communities losing natural protection

The loss of coastal ecosystems, such as wetlands, mangroves and coral reefs, is further compounding risk. These ecosystems play a vital role in mitigating the impacts of tropical cyclones and storm surges by attenuating wind impacts, retaining water and acting as natural barriers. Coral reefs dissipate up to 97 percent of wave energy, offering both coastal protection

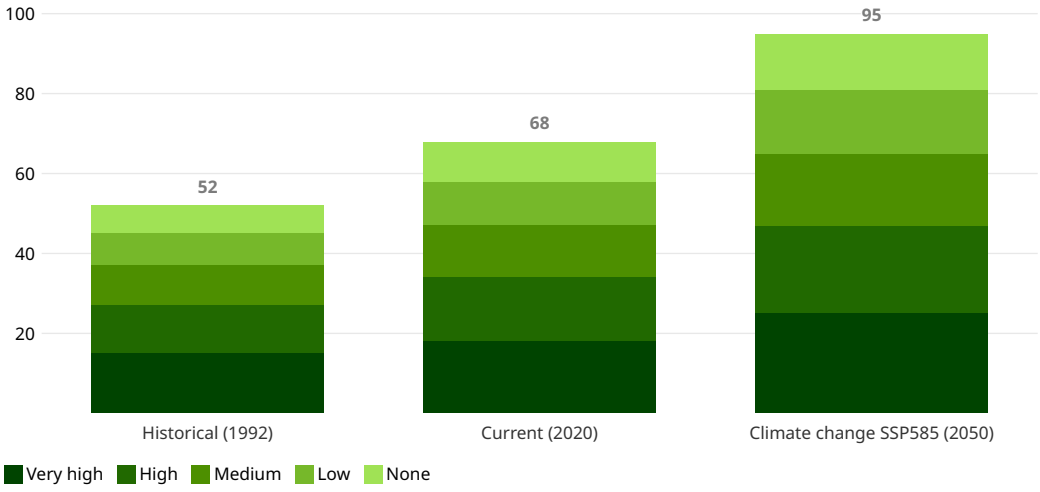
and ecosystem services (Ferrario *et al.*, 2014). However, rising ocean temperatures and other stressors threaten 60 percent of the world's reefs, with projections suggesting nearly all could be at risk by 2050.

> Over the last 30 years, the destruction of these ecosystems has contributed to the loss of natural protection for 1.4 million people

Over the last 30 years, the destruction of these ecosystems has contributed to the loss of natural protection for 1.4 million people (The Nature Conservancy, 2023). Restoration efforts are critical, especially in smaller countries and island states where the potential for enhancing coastal protection is high (Hülsen *et al.*, 2023).

Figure 3.1 depicts the global total population impacted annually by tropical cyclones and the degree of protection provided by natural ecosystems in the past and present and in a climate-altered future (Hülsen *et al.*, 2023). While coastal ecosystems currently protect the largest share of people from cyclones, their relative capacity is falling, projecting that 14 million people will be completely unprotected by 2050.

Figure 3.1 Global total number of people impacted annually by tropical cyclones and level of protection provided by coastal ecosystems, 1992, 2020 and 2050



Source: Hülsen *et al.*, 2023

A diverse range of coastal protection methods for erosion

Coastal protection methods combat erosion, protect communities and preserve coastal ecosystems. They range from traditional infrastructure, such as seawalls and groynes, to innovative bioengineering solutions that enhance coastal resilience and support ecological restoration.

Traditional "hard engineering" methods: proven and reliable

Coastal structures like groynes, jetties and gabions have been used for decades to manage water flow and reduce erosion.

Groynes are structures extending from the shore into the sea. They are designed to reduce longshore drift and trap sediment, preventing beach erosion and maintaining beach width. Made of rock, wood, steel or concrete, they are often arranged in groyne fields, so as to work together in protecting the beach.

Gabions are wire mesh containers filled with rocks, commonly used in engineering projects to stabilize banks and prevent soil loss. They can also be used as levees, retaining walls or in drainage systems to reduce water pressure buildup. Gabions are durable and cost-effective, and can also support the growth of vegetation between the rocks.

Sea walls, especially concrete ones, are being reengineered to handle rising sea levels. Innovations like flap-gate seawalls, which automatically open and close in response to water level, help maintain natural water flow during fluctuations such as at high tide and during storm surges.

Breakwaters and revetments serve as barriers against wave energy. Whereas breakwaters reduce wave impact and protect vessels, revetments are sloped structures that absorb wave energy and blend more naturally into the landscape.

Hybrid solutions for coastal resilience: combining nature and engineering

Hybrid solutions combine human-engineered structures with natural processes to provide both coastal protection and ecological benefits.

Artificial reefs. Coastal defense strategies have traditionally relied on hard engineering structures like seawalls and breakwaters to mitigate erosion. While effective at reducing wave impact, these methods can be costly and ecologically disruptive, and can moreover worsen erosion elsewhere. Artificial reefs offshore mimic natural reefs by reducing wave energy, thereby protecting beaches from erosion and supporting marine life. For example, in 2020, the Sarawak government in Malaysia allocated RM 70 million to deploy 17,200 reef balls – artificial reef structures made of concrete designed to mimic natural coral reefs by providing habitat – along its coastline as part of the Sarawak Reef Ball Project. The initiative aimed to enhance marine resources, protect fishing grounds from illegal trawling, and improve local fishermen's livelihoods (Sarawak Tribune, 2020).

Innovations such as the USD 67.6 million Reefense program (launched by the U.S. Department of Defense) are developing hybrid reefs that combine man-made structures with natural elements like oysters and corals, with the aim of protecting coastal areas from extreme weather events and rising sea levels (Wired, 2024).

Hybrid solutions combine human-engineered structures with natural processes to provide both coastal protection and ecological benefits

Sea wall innovations incorporate advanced designs such as the Smart Seawall wave diversion system, which diverts waves and supports the growth of aquatic habitats. 3D-printing technology is also being used to create custom seawall tiles and structures more efficiently, incorporating biomimicry and reducing environmental impact.

Geosynthetics, such as geogrids and nonwoven textiles, are increasingly used alongside other erosion control measures to stabilize shorelines and reinforce seawalls. These materials provide durability, allow water to flow and prevent sediment loss. *Geogrids* are typically made from polymers, while *nonwoven textiles* are made by bonding fibers either mechanically, thermally or chemically to create a porous and durable material that allows water to pass through, while retaining soil particles, thus preventing sediment loss.

Rebuilding coastal resilience with bioengineering, restoration and stabilization techniques

Bioengineering technologies use natural processes and materials to stabilize coastal areas, reduce erosion and promote ecological restoration. These techniques are environmentally friendly and help enhance biodiversity, while offering protection.

Hydroseeding and hydroblankets. Hydroseeding involves spraying a mixture of seeds, mulch and fertilizer to stabilize large areas. More affordable than sodding (laying down pre-grown grass) for large areas, hydroseeding provides for the uniform distribution of seeds and allows tailoring to specific site conditions. Hydroblankets add a protective biodegradable mat to enhance stabilization.

Erosion control mats, made from natural fibers like jute and coconut, help trap sediment and reduce wave impact when combined with vegetation planting for longer-term stabilization.

Mangrove restoration in tropical regions reduces wave energy, stabilizes sediments and improves water quality by filtering pollutants and trapping runoff.

Wetland restoration using plants such as sedges (*Carex* spp.), cattails (*Typha* spp.) and bulrushes (*Schoenoplectus* spp. or *Scirpus* spp.) helps control erosion by absorbing excess water and providing a natural barrier to water flow.

Seagrass restoration in shallow coastal waters reduces wave energy, stabilizes sediments and provides vital habitats for marine life.

> Bioengineering technologies use natural processes and materials to stabilize coastal areas, reduce erosion and promote ecological restoration

Dune restoration focuses on rebuilding coastal sand dunes by removing invasive species, planting dune grasses and reducing beach grooming to facilitate natural sand processes. It differs from beach nourishment in that it builds vertically instead of horizontally. This is accomplished by dredging sand from offshore sources and transporting it through piping, or else sand can be placed and sculpted using heavy machinery. Other methods include the removal of the invasive species that often alter natural sand flow processes, planting dune grasses to stabilize the sand, installing fences around the dune and reducing beach grooming, that is, the use of tractors to grade the sand to smooth for beach recreation (Warnell *et al.*, 2023).

Beach nourishment involves adding sand to restore beach size and function, with periodic replenishment to counter ongoing erosion. Innovations in sand deposition technologies are advancing rapidly. A deeper understanding of coastal fluvial processes, along with improved hydrological modeling, is helping to optimize how and where sand is placed – maximizing effectiveness, while reducing environmental impact. This knowledge also supports the further development of nature-based solutions. Nourishment is typically carried out by pumping sand from shallow waters onto the beach or transporting it from further away on barges. The collection of source material may have negative impacts on marine life.

Combining beach nourishment with vegetation planting enhances stability and prevents further erosion. A variety of plants can be used in this process (Warnell *et al.*, 2023), including:

- Beach Morning Glory (*Ipomoea pes-caprae*): a creeping, salt-tolerant vine found in tropical and subtropical regions.

- Beachgrass (*Ammophila* spp.): salt-tolerant with a deep root system; often used for stabilizing sand dunes and preventing the intrusion of saltwater into the freshwater ecosystem.
- Cordgrass (*Spartina patens*): a perennial grass that forms a dense mat, tolerates salt and stabilizes sandy soils.
- Sea oats (*Uniola paniculata*): tall grasses with extensive root systems.
- Seashore paspalum (*Paspalum vaginatum*): a perennial creeping grass common in tropical and subtropical coastal regions.

Coastal monitoring and mapping: drones, LiDAR and specialized software

Several techniques, such as direct measuring of distance and monitoring with cameras, lasers or aerial photography, are used to monitor coastal morphology dynamics (Mentaschi *et al.*, 2018). Advanced technologies for monitoring coastal erosion have been widely used at the local and regional scale. These provide high-resolution data for smaller areas only, which limits their ability to support comparative and global analyses. As a result, satellite-based remote sensing has emerged as a more effective option for broader studies.

> LiDAR-equipped drones are revolutionizing coastal monitoring through their ability to quickly survey large areas and provide high-resolution imagery

LiDAR-equipped drones are revolutionizing coastal monitoring through their ability to quickly survey large areas and provide high-resolution imagery. LiDAR sensors help generate the digital elevation models (DEMs) useful for 3D representation of coastal landscapes and erosion patterns and tracking topographical changes over time. They are more economical and efficient compared to traditional methods like ground surveys. This is because they are able to rapidly survey large areas, and the data generated can be combined with ground surveys and satellite imaging to create models that help in understanding the spatial distribution of erosion. Software specifically designed for coastal monitoring, such as Pix4D, allows for the creation of detailed maps, 3D models and the time-lapse visualization of coastal changes, providing insights into how erosion is progressing and where damage has occurred.

Software tools have also been developed to support engineers in designing geotechnical and erosion control solutions. Maccaferri, for example, has developed a versatile suite of tools to help develop efficient drainage systems and design flexible pavement, road subgrade stabilization, reinforced soil slopes, retaining walls and hybrid structures.

Innovation examples

Dune restoration in Catalonia: simple sand traps and drone-assisted monitoring

Source: Getty Images/Roberto Michel

Along the Catalan coast in Spain, 50 meters of beach was lost between 1974 and 2024, partly due to the disruption of natural sediment flows caused by port and dam construction. Manually replenishing the beaches with transported sand proved to be costly and unsustainable. In response, the Government of Catalonia, the Natural Park of Costa Brava, and residents and businesses initiated a project to restore the beach's dune system. Beginning in 2020, they installed cane fences – known as sand traps – to capture sand and increase dune height and volume. These sand traps act as filters, allowing wind to pass through, while at the same time trapping the sand. In 2021, researchers introduced drones equipped with advanced sensors and radars to monitor changes. The drones were used to create DEMs with centimeter-level accuracy. Measurements revealed a remarkable 40 percent increase in dune height over the course of three years, with an average 2-meter rise. Building on this success, project managers are now applying these same techniques in urban areas where natural dunes have been replaced by buildings and promenades. In Calafell, the city council has removed sections of the promenade to make way for natural sand deposits, using the same sand-capturing methods to reshape the beach and improve its storm resilience. The project highlights the lasting power of nature-based solutions as a sustainable and long-term approach to coastal resilience (Impetus, 2024).

Multiple wins for living shorelines in Tampa Bay, Florida

Source: Getty Images/Norm Lane

Hurricanes are a major concern in Florida, making coastal protection a priority. In 2024, Tampa Bay Watch, an environmental nonprofit organization, built 500 feet of living shorelines along Tampa Bay. These shorelines help prevent erosion, storm surge and flooding using native plants, sand and natural materials. The project used concrete structures called reef balls, which were placed alongside mesh bags filled with oyster shells. These shells were collected through the Shells for Shorelines program, which gathers discarded oyster shells from local restaurants. The shell bags serve to replace eroded sediment and trap sand, while the reef balls provide a surface on which oysters can grow. It takes about 6 months for oysters to settle, and each oyster can filter up to 50 gallons of water daily. Over two years, a reef ball can support around 1,000 oysters, thereby helping stabilize the shoreline, attract marine life and support plant growth such as marsh grass. Oysters now cover 200 acres of Tampa Bay spread across 20 similar projects (Axios Tampa Bay, 2025).

Proven technology solutions

Coastal erosion protection: gabion (groyne)

Maccaferri

Source: Getty Images/mtcurado

Maccaferri gabions are wire baskets made from double-twisted hexagonal steel mesh designed for erosion control, slope stabilization and retaining structures. They are filled with locally sourced stones and recycled materials. Gabions are highly permeable, allowing water to flow through, while preventing soil erosion, making them ideal for riverbank protection, coastal defenses and landslide mitigation. Maccaferri's PoliMac® polymer coating is applied on gabions to enhance durability against chemicals and cold. Bio PoliMac, which is made from bio-naptha derived from sustainable raw materials and biobased feedstock, is also available.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Italy
- Availability: Worldwide
- Contact: WIPO GREEN Database

Coastal erosion protection: TECCO CELL

Geobrugg AG

Source: Geobrugg AG

TECCO® CELL is an engineered solution for coastal protection, built from marine grade high tensile stainless-steel mesh, geotextile, and locally sourced rock fill. Together, these components form a porous revetment that stabilizes slopes and mitigates erosion. The system responds to beach geometry, tidal variations, and wave dynamics, while its flexible structure accommodates changing shoreline levels over time. Compared to conventional rock armor, the open structure of TECCO® CELL offers higher wave energy dissipation and reduced wave run-up. Stability is ensured by the interlocked cell compartments, which create a monolithic system. The modular design of TECCO® CELL is suitable for both small- and large-scale coastal projects. Stainless-steel materials guarantee durability under continuous wave exposure, making it effective for both temporary and permanent applications. In addition, the system can be adapted to site-specific needs, including beach access and the integration of vegetation. All components are non-toxic and recyclable, and the company also offers variants for fully submarine applications.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Switzerland
- Availability: Worldwide
- Contact: WIPO GREEN Database

Coastal erosion protection: Triton marine mattresses

Tensar

Source: Tensar

Tensar Triton marine mattresses are commonly used for revetment, scour protection and channel linings, especially in difficult conditions involving saltwater, soft soils or steep slopes. They come in different styles and thicknesses to meet various project needs. The mattresses are perfect for environments where erosion is high, such as areas with strong waves and fast-moving water, where geotextile fabric alone is unable to remain in place. The stones inside the mattresses provide ballast that helps the geotextile fabric remain secure. The mattresses serve two main functions: deploying geotextile in fast-moving water and protecting the foundations for armor stone riprap (a type of rock or other material that is placed along shorelines, riverbanks or on slopes to prevent erosion). Additionally, Triton mattresses are used in modular capping systems to treat contaminated sediment and can hold materials like sand or carbon for specific remediation needs.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO GREEN Database

Coastal erosion protection: Secumat Green mats

Naue

Source: Naue

Secumat® Green mats, made from biodegradable materials like jute and coconut fibers, are designed to prevent surface erosion and enhance the stability of slopes and shoreline areas. They stabilize soil, preserve nutrients and promote vegetation growth, making them ideal for environmentally-sensitive areas. Easy to install, Secumat® Green decomposes naturally, leaving no ecological footprint, offering a sustainable solution for landscaping projects. Secumat® Green Jute N provides a temporary solution made from 100 percent untreated jute fibers. The mat is biodegradable and features a woven net. Secumat® Green Coco N is made from 100 percent untreated *coir* (coconut) fiber woven into a net. Secumat® Green PinW is a 30 cm wooden pin used for securing the mats, made from untreated, high-strength hardwood. Each variant offers a different tensile strength.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Germany
- Availability: Worldwide
- Contact: WIPO GREEN Database

Coastal erosion protection: split barge

Rohde Nielsen

Source: Rohde Nielsen

Most of Rohde Nielsen's hopper barge vessels are self-propelled split hopper barges, built to transport materials like sand, silt and clay. Their split-hull design allows for rapid bottom discharge, unloading cargo within minutes and making them ideal for beach nourishment, land reclamation and offshore disposal. These barges provide continuous, reliable service to stationary dredgers, enhancing overall project efficiency. Additionally, polluting or sensitive materials can be safely managed using sealed tank barges, which ensures environmental protection during operations.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Denmark
- Availability: Worldwide
- Contact: WIPO GREEN Database

Slope stabilization/ recovery: hydroseeding

GeoGrow

Source: GeoGrow

Hydroseeding is a process whereby a mixture of seeds, water, mulch and additives such as fertilizer or biostimulants are blended into a slurry and sprayed directly onto an area. This method combines high-performance, thermally-refined wood fiber, seeds, fertilizers and binding agents inside a hydroseeding machine to create a slurry that is then sprayed onto surfaces, so as to encourage rapid vegetation growth. Sometimes referred to as hydro-mulching, this technique ensures faster germination and establishment of plants by providing an ideal environment for seed growth. GeoGrow's materials are 100 percent organic, biodegradable and non-toxic. Grass seed mixes that are appropriate for hydroseeding large open spaces and erosion control areas are available, including low-maintenance, shade and drought tolerant riverbank and wildflower mixes.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United Kingdom
- Availability: Europe and United Kingdom
- Contact: WIPO GREEN Database

Breakwater system: moveable flap gate-type breakwater system

Kanadevia

Source: Kanadevia

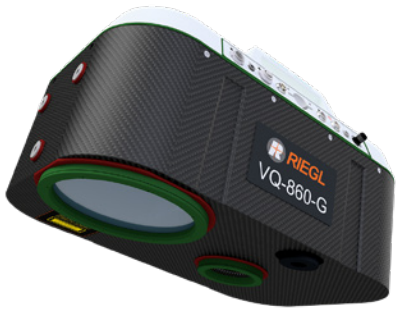
A movable flap-gate breakwater system is a dynamic coastal or harbor protection structure designed to reduce wave energy and protect shorelines, ports or harbors from wave impact. Unlike traditional fixed breakwaters, this system can be either adjusted or relocated to suit changing wave conditions. It can also be opened to allow ships to pass through or maintain natural tidal flows. The system is versatile and can be used on rivers, seabeds or as a land-based solution with the neo RiSe series. The series name, “neo RiSe®,” stands for “No Energy, No Operation, Rising Seawall,” a design that enables automatic gate closure during an emergency without the need for external power or human intervention, using buoyancy. The neo RiSe-A blends with building exteriors, while neo RiSe-L can be integrated into existing structures. The neo RiSe-SL Super Long Span Flap-gate Seawall offers continuous water retention over long distances.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: High
- Place of origin: Japan
- Availability: Japan
- Contact: WIPO GREEN Database

Frontier technology solutions

Coastal erosion mapping: topo-bathymetric laser scanning system with LiDAR

RIEGL



Source: RIEGL

The RIEGL VQ-860-G is a lightweight topo-bathymetric laser scanning system designed for integration on crewed aircraft or drones. Providing up to 100 high-resolution scans per second at altitudes ranging from 75 to 300 meters, it maps both land and underwater topography for applications such as coastline cartography, river mapping, and detection of submerged and floating targets. The scanner can be optionally integrated with a factory-calibrated IMU/GNSS system and a digital camera to supplement the acquired data, and the system also features a reduced laser power mode for eye-safety during operation in sensitive areas. In addition to online echo waveform processing, the gathered data gets stored internally or on a removable storage card, enabling offline full waveform analysis.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: Germany
- Availability: Worldwide
- Contact: WIPO GREEN Database

Coastal erosion mapping: Mavic 3 Enterprise drone

DJI

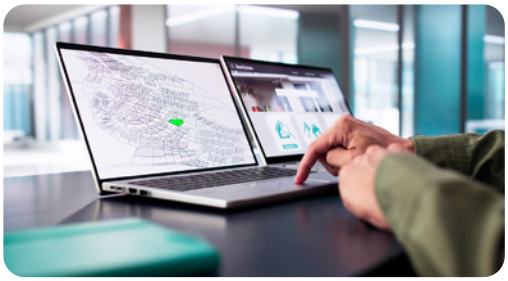
Source: Getty Images/simonkr

Mavic 3 Enterprise Series drones are optimized for detailed land and coastal zone mapping. They feature a mechanical shutter, a 56× zoom camera, and an real-time kinematic (RTK) module for precise centimeter-level accuracy. The Mavic 3E model is designed to enhance mapping and mission efficiency. A thermal version is also available, making it suitable for search and rescue, inspections and nighttime operation. The Mavic 3E is equipped with a 20MP, wide-angle 4/3 CMOS sensor and a mechanical shutter to prevent motion blur. It supports rapid 0.7-second interval shooting, making mapping missions faster without the need for Ground Control Points. Its wide camera, with large 3.3 µm pixels and intelligent low-light mode, performs well in low-light conditions. With a 45-minute flight time, the Mavic 3E can cover up to 2 square kilometers in one flight, maximizing survey efficiency.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Coastal erosion mapping: DJI Terra software

DJI



Source: Getty Images/AndreyPopov

DJI Terra is 3D modeling software that uses photogrammetry to create precise 2D and 3D reconstructions from visible light imagery and data processed through DJI LiDAR. It is fully compatible with DJI Enterprise drones, offering comprehensive solutions for various industries like land surveying, power transmission, emergency services and construction. The software enables the rapid generation of realistic 3D models and point clouds from photographs, with AI technology that automatically optimizes water surfaces in the models. DJI Terra can also produce vegetation index maps (e.g., normalized difference vegetation index (NDVI) and normalized difference red edge index (NDRE)) to assess plant growth and health. It supports radiometric correction (the process of adjusting raw data from an image to account for atmospheric conditions and sensor inconsistencies) and generates reflectance maps, ensuring accurate data for remote sensing research.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Coastal erosion protection: 3D living seawalls, kind tiles and living shorelines

KindDesigns

Source: KindDesigns

KindDesigns develops sustainable coastal infrastructure solutions using cutting-edge robotics and advanced materials. The technology includes high-resolution 3D concrete printers that enable on-site, custom designs to be printed 20 times faster than traditional construction methods. The materials used are marine-grade concrete and custom reinforcement, which are eco-friendly, non-toxic and pH-neutral, ensuring safety for marine ecosystems. KindDesigns offers over 1,000 custom 3D-printed designs to improve coastal infrastructure. Their Kind Tiles™ can be added to any existing seawall (concrete, steel or vinyl) to dissipate wave energy, promote species colonization and enhance water quality by supporting marine life attachment.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United States
- Availability: United States
- Contact: WIPO GREEN Database

Coastal erosion protection: smart seawall aquatic and wave diversion models

Smart Seawall Technologies

Source: Getty Images/gmc3101

Smart Seawall's patented wave diversion shoreline technology and solutions integrate utilities, enhance aquatic habitats and provide luxurious waterfront options for municipalities and residential areas. All Smart Seawall models are suitable for both intercoastal and coastal locations, and designed for private, commercial and governmental projects. The aquatic and wave diversion series incorporates aquatic features to support native marine life. The aquatic series is ideal for calmer waters, such as bays and canals, and provides a range of options such as full frontage seawalls, permanent dock systems, floating dock systems and single pylons for anchorage. The wave diversion series is designed for more turbulent areas with larger waves and uses proprietary technology to divert up to 70 percent of wave energy back into the water. The system is customizable and adaptable to any coastline.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: Germany
- Availability: Worldwide
- Contact: WIPO GREEN Database

Coastal erosion protection: software for erosion control planning

Maccaferri

Source: Getty Images/Wirestock

Maccaferri's software programs are designed to support engineering solutions and design processes. Newer tools, such as MAC.R.O. (Maccaferri Automatic Calculation of Rockfall) and Maccaferri Slope Stability Software, were developed to provide engineers with advanced, user-friendly platforms for analyzing and designing solutions for geotechnical, hydraulic and erosion control challenges. Several different downloadable design software programs are available, including MACFLOW Studio for the design of effective drainage solutions, MACREAD AASHTO for the design of flexible pavement layers, MACREAD Studio for the design of road subgrade stabilization solutions, MacStars 4.0 for the design of reinforced soil slopes, walls and complex hybrid structures, and GAWAC for the design of gabion retaining walls.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: Italy
- Availability: Worldwide
- Contact: WIPO GREEN Database

Coastal erosion protection: soil and water treatment

Planet Horizons Technologies SA

Source: Planet Horizons Technologies SA

AQUA4D® is an advanced water treatment technology using resonance fields to alter the physical structure of water molecules. This process improves water's interaction with soil by dissolving crystallized salts that block soil pores, addressing salinity issues common in agriculture. By opening these pores, AQUA4D® increases soil moisture retention, reduces the need for frequent irrigation, and enhances nutrient uptake and root development. The treatment also helps leach harmful salts away from plant roots, thereby regenerating soils and promoting healthier crop growth.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Switzerland
- Availability: Europe, North America, South America
- Contact: WIPO GREEN Database

Coastal restoration: multidisciplinary program on restoration and regeneration

BESE and Blue Carbon Lab

Source: Peter Macreadie/Blue Carbon Lab

Regenerating Our Coasts is a program that tests biodegradable structures to help restore coastal areas and explore their potential across Australia. The program also aims to educate the public, stakeholders and industry on the benefits of such restoration techniques for local ecosystems. It has trialed direct seeding into BESE-elements® structures, which are 3D lattice forms made from biodegradable potato starch that degrade within 2–10 years. These structures mimic coastal soil conditions, slow down water movement and aid seeds in establishing roots. The program is now testing seagrass seed injection into such structures in order to restore intertidal seagrass in lost areas. It also uses wave sensors to monitor environmental factors, such as wave energy, sediment and elevation, which affect plant growth. Ongoing data collection helps compare plant and soil responses to different restoration methods.

- Technological maturity: Frontier
- Contracting type: For collaboration
- Technology level: Medium
- Place of origin: Kingdom of the Netherlands
- Availability: Worldwide
- Contact: WIPO GREEN Database

Artificial reefs: modular breakwater units

Reefy

Source: Reefy

Reefy's Reef Enhancing Breakwater (REB) is a modular artificial reef system built from large interlocking concrete ReefBlocks. The structure dissipates wave energy, providing erosion control and protecting shorelines and infrastructure such as dikes and seawalls. The blocks are assembled underwater, forming a stable breakwater that allows controlled return flow through the structure for sediment stabilization. The system was tested in wave flume experiments at Deltares, where it dissipated up to 90% of wave energy under hurricane conditions. In 2023, Reefy installed a REB system in Rotterdam as part of a pilot project. It was monitored for engineering and ecological performance and the findings validated the design. The next-generation ReefBlocks feature a fully textured surface and optimized hydrodynamics, with installations planned for late 2025 and early 2026.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Kingdom of the Netherlands
- Availability: Worldwide
- Contact: WIPO GREEN Database

Horizon technology solutions

Artificial reefs: architected wave-breaking reefs

Massachusetts Institute of Technology (MIT)

Courtesy of the researchers, edited by MIT News

A team from MIT is developing “architected” reefs – offshore structures designed to mimic the wave-buffering effects of natural reefs, while creating habitats for marine life. These reefs feature cylindrical cores surrounded by slats that break incoming waves into turbulent jets, thereby dissipating their energy. The new design could reduce wave energy as effectively as current artificial reefs using 10 times less material. The team plans to use sustainable cement molded into “voxel” patterns to create these cylinders, which can be easily assembled. The cylinders can form a semi-permeable wall about half a mile off the coast, offering pockets for fish and marine species to inhabit. Early lab-scale tests show that this reef could reduce wave energy by over 95 percent.

- Technological maturity: Horizon
- Contracting type: Under development
- Technology level: High
- Place of origin: United States
- Availability: N/A
- Contact: WIPO GREEN Database

Artificial reefs: carbon neutral artificial reef structures

Holcim

Source: Holcim

Xstone is Holcim’s modular concrete armor block designed to support coastal defense systems such as groynes and embankments. The blocks are porous and reduce the force of incoming waves, helping reduce scouring and erosion as water levels rise. Their shape and textured surface provide habitat and sheltered zones for marine organisms, allowing the Xstone to double as an artificial reef structure. In 2025, Holcim initiated a multi-year program piloting a new, carbon-neutral Xstone made using bioactive concrete and biochar. Around 400 Xstones were installed to establish an artificial reef at the Friedrichsort pier in Germany. The program will monitor the Xstones performance in terms of marine conservation and compare it with other material installed simultaneously at the same site.

- Technological maturity: Horizon
- Contracting type: For collaboration
- Technology level: Medium
- Place of origin: Germany
- Availability: Germany
- Contact: WIPO GREEN Database

Artificial reefs: breakwater structures made from local silt

NETICS

Source: NETICS

GEOWALL® Reef Blocks are made from locally sourced dredged sediment compressed to form solid units of substrate for marine life attachment. Each block consists of about 90% dredged material and is produced on-site using the electric GEOWALL® press, reducing the need for material transport and providing a low-carbon alternative to conventional concrete reef units. In 2021, NETICS initiated a five-year trial with the Royal Netherlands Institute for Sea Research and the University of Groningen, installing 400 GEOWALL® Reef Blocks made from local sediment along the coast between Delfzijl and Eemshaven in the Netherlands. The trial investigates how these blocks perform under tidal and saline conditions, and whether they provide suitable habitat for oysters, mussels, and other marine species. The project hopes to improve the water quality by supporting water-filtering fauna while simultaneously preventing sediment scouring with the blocks acting as breakwaters. The blocks were installed at different heights and compressed to varying hardness levels to compare durability and colonization rates.

- Technological maturity: Horizon
- Contracting type: For collaboration
- Technology level: Medium
- Place of origin: Kingdom of the Netherlands
- Availability: Kingdom of the Netherlands
- Contact: WIPO GREEN Database

Artificial reefs: 3D-printed reef structures made from invasive algae-based ceramic material

Thrasos 3D

Source: Thrasos 3D

Domosfera is a modular 3D-printed reef structure made from clay and converted sargassum waste, an invasive algae in the Caribbean Sea. The material is carbon-negative, removing 476 kilograms of CO_2e per square meter, and is produced through a low-energy sintering process. The structures provide surfaces for coral polyps to colonize and chemically attract coralline algae to settle, while dissipating up to 50 percent of wave energy and protecting coastal communities from erosion. The surface is algae-resistant, helping increase coral survival by up to 85 percent during bleaching events compared to concrete structures. The structures use a mussel-inspired, coral-safe adhesive that has kept coral fragments intact during seismic activity while giving the modules a natural appearance. In collaboration with the Cozumel Coral Reef Restoration Program and commercial partners - local dive shops, resort operators, and ceramic industry players - Thrasos 3D deployed pilot installations off the coast of Cozumel, Mexico.

- Technological maturity: Horizon
- Contracting type: For collaboration
- Technology level: Medium
- Place of origin: Mexico
- Availability: Mexico
- Contact: WIPO GREEN Database

Coastal protection: coastal carbon capture with carbon-removing sand

Vesta

Source: Getty Images/STELLA NEDELCHEVA

Vesta is developing "Coastal Carbon Capture", a solution that accelerates the natural weathering of olivine to remove carbon dioxide from the atmosphere and has the added benefit of counteracting coastal erosion. By placing olivine sand in coastal waters, the sand gradually dissolves over the course of years to decades, increasing ocean alkalinity, reducing seawater acidity, and permanently storing CO_2. Vesta has conducted field pilots in the United States, placing up to 7,000 cubic yards of olivine sand in intertidal and nearshore zones. The projects are monitored by independent research organizations, with data collected on water quality, sediment, marine organisms, and carbon removal efficiency.

- Technological maturity: Horizon
- Contracting type: For collaboration
- Technology level: Medium
- Place of origin: United States
- Availability: United States
- Contact: WIPO GREEN Database

Landslides

As climate change intensifies rainfall and thawing permafrost triggers more landslides, innovative safeguards are emerging. Models now predict landslide risks globally every 30 minutes, while AI analyzes real-time data from tiltmeters, InSAR satellites, and drone-mounted LiDAR. On unstable slopes, bioengineered solutions like bacteria-made biogrout strengthen soil, and smart barriers deploy automatically when sensors detect movement, protecting communities before the first rocks fall.

Technological developments and trends

Landslides – the sudden or slow downhill movement of rock, soil or debris – are powerful natural events that shape landscapes and threaten communities worldwide. They come in many forms, such as falls, topples, slides, spreads and flows (UNDRR, 2024b), and range from small rockfalls to large, fluidized debris flows. Landslides are typically triggered by geological and physical factors, including heavy rainfall, snowmelt, water pressure, volcanic eruptions, earthquakes and steep slopes. Rainfall-triggered landslides, which can lead to debris flows, are common. Prolonged rainfall or intense storms can both cause slope failure. Topography plays a key role in landslide risk, with steeper slopes being more prone to failure, though other factors like slope aspect, relief, vegetation type and position on the slope also influence susceptibility. Human activity, such as deforestation, urbanization and wave-driven erosion, can also contribute to landslide occurrence.

> Landslides can move rapidly, with debris flows reaching speeds of 60–80 km/h, or slowly at rates of millimeters to centimeters per year

When a landslide occurs there is not much that can be done to remedy the situation for those affected people or infrastructure. Most of the technologies discussed in this section are therefore related to prevention and early warning systems.

Landslides can move rapidly, with debris flows reaching speeds of 60–80 km/h, or slowly at rates of millimeters to centimeters per year (ARSET, 2025a). They can cause injury, death, infrastructure damage, displacement, long-term economic impacts and harm ecosystems. Although landslides cannot be precisely predicted, warning systems that monitor rainfall can alert those living in prone areas (UNDRR, 2024b). According to the World Health Organization (WHO), landslides are more widespread than any other geological event. During the period 1998–2017, they impacted roughly 4.8 million people and caused 18,000 deaths (WHO, 2024b). The International Disaster Database (EM-DAT) reports that landslides accounted for 4.9 percent

of all disaster events and 1.3 percent of all fatalities between 1990 and 2015, with 54 percent of these events occurring in Asia (Guha-Sapir *et al.*, 2018).

Climate change is expected to trigger more landslides, particularly in mountainous regions, largely driven by an increase in extreme rainfall. Warming can also lead to permafrost melting and associated landslides in higher mountain ranges (European Climate and Health Observatory and ADAPT, 2025).

Innovative landslide monitoring technologies to detect and analyze landslide activity

Landslide monitoring technologies range from instrumental ground sensors and devices to global positioning systems (GPS), aerial photography, satellite images and LiDAR. Surface and subsurface monitoring technologies work together to provide a comprehensive understanding of both surface and subsurface conditions, which is critical to the evaluation and prevention of landslides (Ebrahim *et al.*, 2024; Neuroject, 2024).

Surface monitoring

Tiltmeters measure changes in slope angle or inclination in order to provide information on ground movement and are usually installed at multiple locations along a slope to detect potential landslide activity. These instruments are sensitive to ground movements at or near the surface, allowing early detection of shifts in slope stability.

Extensometers measure the change in distance (or elongation) between two fixed points on a material or structure, typically over larger distances. In the same way as for tiltmeters, observed changes may indicate movement as a precursor to a landslide event.

Subsurface monitoring

Inclinometers measure the angle of inclination or slope deflection below the ground surface. They are typically installed in boreholes or inclinometer casings to track subsurface movements and evaluate slope stability.

Strain gauges measure the strain or deformation within a structural element, such as a retaining wall, providing data on the mechanical behavior of materials and helping assess slope stability from within the ground or structure.

Piezometers or *pore pressure sensors* measure groundwater or pore water pressure within soil or rock formations, enabling the monitoring of groundwater levels and the identification of potential slope failure triggers.

Seismic sensors detect the seismic waves and ground vibrations generated by landslides and earthquakes, and play a role in providing early warnings.

Earth pressure cells monitor the pressure within earth-fill dams, embankments or at the interface between a structure and excavation walls. They consist of two welded stainless-steel plates with a vacuum-sealed gap filled with de-aired oil. A pressure pad connected to a transducer forms a closed hydraulic system, generating an electrical signal that can be read remotely. Vibrating wire technology is often used in these systems to measure strain, displacement or pressure. A wire attached to the sensor vibrates under stress, and the frequency change is converted into an electrical signal proportionate to the pressure. This signal is then sent to a readout unit or data logger for monitoring.

Revolutionizing landslide monitoring, modeling and risk mapping with satellites and remote sensing

In addition to ground-based monitoring, satellite-based or other platforms for remote sensing technologies have become crucial for detecting and tracking landslides. These technologies enable large-scale monitoring with minimal environmental disruption.

Global navigation satellite systems (GNSSs) help monitor ground movements and detect landslides. They use a network of satellites orbiting the Earth that send signals to receivers on the ground. A GNSS includes global coverage systems such as GPS (United States), Galileo (European Union), GLONASS (Russian Federation) and BeiDou (China). These technologies enable the precise measurement of ground movement and displacement by tracking changes in the position of receivers.

> In addition to ground-based monitoring, satellite-based or other platforms for remote sensing technologies have become crucial for detecting and tracking landslides

Synthetic aperture radar (SAR) is a remote sensing technology that uses radar waves from satellites to capture images of the Earth's surface, as defined in the chapter on storms and flooding. SAR uses microwave signals to capture high-resolution images of the Earth's surface, enabling the detailed monitoring of landscapes, weather patterns and disasters, even through cloud cover. In dry conditions it can also reveal shallow subsurface features. SAR captures images of the Earth's surface before and after a landslide event and tracks changes in surface elevation. If there is a shift in terrain due to a landslide, the phase difference in the SAR images can reveal the quantity of displacement and show the precise area affected. Repeated SAR scans can monitor stability over time. SAR can also help map an area and assess damage.

Interferometric synthetic aperture radar (InSAR) is a more advanced remote sensing technology that uses SAR satellites for monitoring and detecting ground deformation. InSAR enhances SAR by processing multiple SAR images taken at different times in order to detect subtle changes to the Earth's surface such as land subsidence or movement related to landslides. It has millimeter precision, enabling the early detection of land movement, and the ability to cover large areas. It provides abundant archive data enabling time-series analyses of change (Geostock, 2022). Remote sensing technologies do not interact with the environment and are often less costly than aerial surveillance or in situ measurements, especially when covering large areas of land.

From space to surface: high-tech tools for landslide tracking

NASA's landslides team has developed the Landslide Hazard Assessment for Situational Awareness (LHASA) model, which provides timing and location information on potential landslide occurrences every 30 minutes. NASA has also developed the Landslide Susceptibility Map, a tool to identify and map regions at risk, and the Global Landslide Catalog, a global database that tracks and records landslides worldwide by compiling information from satellite data, ground observations and scientific reports to create a detailed record of landslide events. The landslide project is part of NASA's Global Precipitation Measurement (GPM) mission (explained in the storms and flooding chap) utilizing satellite data and citizen science contributions in order to model and record landslides worldwide.

For decades, optical data has been the primary tool for landslide modeling. Optical satellites, including the Landsat series and Sentinel-2, have enabled large-scale assessments with increasingly higher temporal and spatial resolution analysis. The use of multiple spectral bands also allows for the analysis of higher-contrast data, including NDVI, a combination of spectral bands used to assess and monitor vegetation health and density. However, cloud cover poses a challenge to optical data from satellites (ARSET, 2025a).

Hyperspectral remote sensing – also called imaging spectroscopy – analyzes reflected radiation across many narrow spectral bands, allowing for more advanced analyses of spectral signatures of land and vegetation features, which helps determine bio- and geochemical information about an area (GFZ Helmholtz Centre for Geosciences, 2025).

The terrestrial laser scanner (TLS) is a specific type of LiDAR system designed to be used on the ground. TLS are used to create precise 3D maps of damage, monitor slope stability, plan debris removal and reconstruction, support search and rescue efforts, and analyze the causes and mechanics of a landslide. Whereas LiDAR is used in a variety of settings, including aerial or satellite-based scanning, TLS is typically stationary and placed at various points on the ground to obtain high-resolution scans of smaller, more localized areas such as landslides, steep slopes, damaged infrastructure and collapsed tunnels. TLS works by sending laser pulses that are reflected back from the first solid surface they encounter, such as soil, rock, vegetation or a man-made structure. This means it cannot penetrate the ground, unlike ground-penetrating radar, but can capture detailed surface geometry.

> The growing availability, reliability and cost efficiency of remote-controlled drones has made it easier to access real-time aerial images in remote, unsafe or otherwise unreachable locations

Like with other extreme weather events, drones are useful in the aftermath of a landslide. Aerial photographs have long been a useful tool, and the growing availability, reliability and cost efficiency of remote-controlled drones has made it easier to access real-time aerial images in remote, unsafe or otherwise unreachable locations. This has significantly raised the importance of drones for conducting landslide assessments (Alsop and Palastanga, 2023). They can capture higher resolution imagery that is integrated into hardware and software for processing.

AI and big data: integrating multiple data sources for landslide monitoring

As is the case with flooding, advancements in big data and AI have improved landslide monitoring and prediction systems. The latest technologies use real-time data collection, advanced computation techniques and dynamic risk assessment to predict landslides with greater accuracy, issue early warnings and reduce loss of life and property.

The combination of big data and AI has improved data analysis, occurring alongside the increased use of drones, satellites, remote sensing and IoT sensors, ground sensor networks and meteorological data. Big data can help process this in real time. Additionally, AI algorithms analyze volumes of historical data to identify patterns. Importantly, AI models can dynamically adjust predictions based on feedback concerning changing conditions delivered by ground sensors (Qin *et al.*, 2024).

Prepare for the future or recover from past landslides – soil stabilization

A variety of methods are employed to stabilize slopes and improve soil stability, ranging from traditional engineering techniques to innovative, eco-friendly solutions.

Retaining walls constructed out of concrete, steel or geosynthetic materials are commonly used to stabilize slopes, alongside gravity walls, which rely on their own weight to hold back soil. To enhance soil stability and address issues like erosion and foundation weaknesses, innovative methods such as biogrout, soil nailing and ground improvement techniques are gaining popularity. These techniques offer sustainable, efficient and cost-effective solutions compared to traditional methods.

Biogrout is an eco-friendly material that serves as an alternative to conventional chemical soil stabilization methods. Bacteria, such as *Sporosarcina pasteurii*, are inserted into the soil in order to produce calcium carbonate (limestone) which fills the soil pores and binds particles together, thereby improving soil stability and strength. Not only does this process strengthen weak soils,

it also reduces water seepage in landfill and seals underground water channels. This process can augment the load-bearing capacity of foundations and provide improved structural support.

> A variety of methods are employed to stabilize slopes and improve soil stability, ranging from traditional engineering techniques to innovative, eco-friendly solutions

Soil nailing is an engineering technique used to stabilize slopes and excavations by installing closely spaced steel bars in the soil, so as to stabilize either a natural slope or reinforce an over-steepened slope. It involves drilling or launching steel bars to a specified depth. Systems like the GeoStabilization Soil Nail Launcher™ use compressed air to drive nails at high speed for increased efficiency.

In addition, *rock bolting* involves inserting steel bolts into a rock face for stabilization. *Shotcrete* is a method of spraying concrete onto an unstable rock or soil surface using compressed air at high velocity to provide a protective layer.

Ground improvement techniques are methods used to compact the soil and increase its density and strength through the use of *mechanical vibration* (using vibratory rollers or vibrating plates), *dynamic compaction* (dropping a heavy weight, e.g., a large steel block or hammer, from a significant height onto the soil surface), *vibroflotation* (using a high-frequency vibrating probe, called a vibroflot, to compact granular soils) or the addition of cementitious materials. These techniques are often used in conjunction with soil stabilization methods like biogrout and soil nailing.

Geosynthetic clay liners (composed of a layer of bentonite (very absorbent) clay sandwiched between two layers of geosynthetic fabrics) can also be used in soil stabilization to prevent water seepage and improve the load-bearing capacity of soil. When applied in conjunction with biogrout or another stabilization method, they can reduce water flow and prevent erosion, thereby contributing to long-term slope stability.

As explained in the coastal erosion chapter, geogrids reinforce soil by adding tensile strength to the soil mass. They are often used either in conjunction with soil nailing or as part of a retaining wall system. Finally, planting deep-rooted plants and grasses can help stabilize soil naturally. Biodegradable erosion control mats protect soil during the establishment of vegetation, preventing erosion until the plants take root.

Dealing with debris and damage

In areas prone to rockfalls, *protection nets and barriers* can be installed to capture falling rocks before they impact roads or infrastructure. Typically made of high-tensile steel cables or mesh, these rockfall protection nets absorb the impact of falling rocks and safely direct them to the ground.

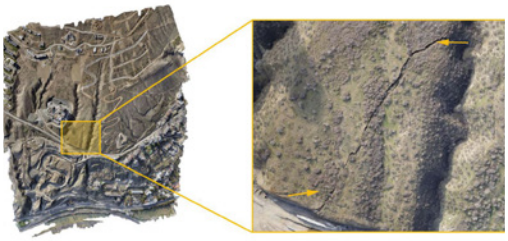
Debris flow barriers, slurry pumps and other technologies used for landslide debris cleanup are essential for managing and mitigating the aftermath of a landslide. Debris flow barriers block the flow of landslide debris, including mud, rocks and trees, before it can damage infrastructure. They can be passive (in the case of permanent structures) or active (meaning they can be adjusted to handle varying flow volumes) and are constructed from steel, concrete or mesh materials.

Slurry pumps are heavy-duty pumps designed to handle thick, viscous mixtures of water, mud, debris and sediment using a combination of high pressure and specialized impellers to move debris-laden liquids. They remove and transport mud and other loose materials to either safer locations or treatment facilities.

Additionally, excavators, bulldozers, vacuum trucks and hydraulic excavation using waterjets combined with excavation machinery can all be used in debris clean-up efforts. Sediment removal and screening using classifiers, screens and separators are also employed to remove large debris particles.

Innovation examples

Aerial mapping with drones in Tbilisi, Georgia



Source: Pix4D

In 2021, a fissure opened on a hillside near two residential areas in Tbilisi, Georgia, prompting local authorities to assess the potential damage. To safely carry out this operation, the National Environmental Agency of Georgia turned to drones and the PIX4Dmapper. They selected the eBee X fixed-wing drone for its long flight time and battery efficiency (see also *Green Technology Book* Mitigation edition, agriculture section). Using photogrammetry, the eBee X captured data across various parameters, which were then analyzed with the help of PIX4D's specialized mapping software. The PIX4Dmapper allowed the team to measure and quantify key features of the landmass, including volume and movement. Over two flights, they collected more than 800 images, creating a digital surface model (DSM) that provided an in-depth analysis of the fissure's depth, volume, curvature, potential movement and flow accumulation. The fissure measured 14 meters in depth with a displaced volume of half a million cubic meters of land. Thanks to these advanced technologies, stabilization measures were quickly implemented to protect residents and their property (PIX4D, 2022; AgEagle, 2021).

Soil nailing and rock bolting stabilize active landslide zones in India

Source: Getty Images/Muhammed Zeynel Ozturk

In Uttarakhand, landslides frequently disrupt roads, particularly during the monsoon season, presenting a major challenge for Char Dham pilgrims. To address this, the Border Roads Organisation (BRO) is employing Australian rock bolt technology to stabilize landslide-prone areas along the Gangotri and Yamunotri highways. This proven technology involves removing loose debris and reinforcing bedrock through soil nailing and rock bolting. Specialized drilling is used to secure fractured rocks by inserting bolts at critical fracture points, enhancing the stability of the formations. The technique has been shown to be 90 percent effective in preventing future landslides. According to BRO officials, using this method has significantly improved the safety of the roads in question for both pilgrims and tourists. After stabilizing the area, excavation tunnels were constructed, and treatments started in two additional landslide

zones, with the goal of completing stabilization efforts by spring 2025. This initiative is part of a broader effort to improve road safety and resilience within Uttarakhand's challenging mountainous landscape (Sethi, 2024).

A drone in the dark: assessing a collapsed tunnel

Source: Flyability

In 2024, several landslides collapsed a tunnel in Switzerland, cutting off access between villages and a ski resort. Safe entry was impossible, so the local authorities employed Flyability's Elios 3 indoor drone to assess the collapsed tunnel. The drone collected data via LiDAR, photos and videos, and the point cloud datasets from the LiDAR scan provided a clear view of the damage. It also helped show how the tunnel's design, specifically a small and unnecessary window, contributed to its vulnerability. Cold air flowing through the window since the tunnel was built in the 1960s had caused a type of freeze–thaw weathering effect (where water freezes and expands, causing cracks and faults over time) inside the tunnel. The surrounding rock had also developed faults due to weathering, traffic vibration and minor seismic events. The Elios 3 drone's key features – its autonomous stabilization, protective cage, ability to survive colliding with walls, advanced processing, 4 K cameras for clear visualization in low light, thermal cameras to detect structural weaknesses and laser distance measurement – made it essential for investigating the accident. Thanks to these capabilities, the tunnel was reopened within months, demonstrating how drone technology can enhance emergency response and prevent future incidents (Flyability, 2024).

Proven technology solutions

Slope stabilization: soil nail launcher

Geostabilization International

Source: Getty Images/Juan-Enrique

The Soil Nail Launcher™ was originally developed by the British military and is a compressed air cannon that shoots a 6-meter steel or fiberglass tube at speeds of up to 400 km/h. The high-speed launch creates tensile stresses that prevent the nail from buckling and helps it penetrate the ground efficiently. The shockwave at the tip displaces soil during installation, and the process stops when friction at the nail tip absorbs the cannon's energy. Unlike traditional methods, this system minimizes wear and preserves the nails' corrosion protection, leading to higher pullout capacities (the maximum force or resistance a soil nail can withstand before it starts to be pulled out or displaced from the ground). It also increases soil density in the nailed area, unlike open-hole drilling, which can weaken the connection between the soil nail and the surrounding soil.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United States
- Availability: Canada, New Zealand, United States
- Contact: WIPO GREEN Database

Slope stabilization: 2D-Geo system

GEOIZOL Project

Source: GEOIZOL Project

The 2D-Geo is a high-strength steel net with diamond-shaped meshes designed to stabilize slopes and prevent erosion. It is anchored to the ground using special plates and can be combined with anti-erosion fabric for added protection. Supplied in rolls and connected with steel spirals, the net can cover a large area. It is effective for stabilizing mudslides, rockfalls and landslides, as well as protecting against erosion. Key benefits include stabilizing slopes of up to 70–80 degrees, saving up to 40 percent compared to lower-strength nets. It also offers high tear strength, has minimal environmental impact and encourages grass seed germination by creating a fertile soil layer. Additionally, its large mesh size helps preserve the landscape's aesthetic appearance.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Russian Federation
- Availability: Russian Federation
- Contact: WIPO GREEN Database

Landslide monitoring: wireless tilt sensor

Next Industries

Source: Getty Images/Aleksandr Kondratov

The NI310-TIL Wireless LoRa Tilt Sensor is a compact device that measures tilt angles in real time. It has a built-in micro-electromechanical systems (MEMS) accelerometer (to detect changes in movement or tilt by measuring the displacement of a mass suspended on a spring, which is then converted into an electrical signal) for accurate readings and can be set up quickly with customizable angle thresholds. The sensor is waterproof. Users can create up to 36 trigger rules, so the sensor sends an alarm when a certain tilt angle is reached. It is easy to install and can be wirelessly connected to other systems, allowing data to be transmitted to an IoT cloud platform for remote monitoring and analysis.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Italy
- Availability: Worldwide
- Contact: WIPO GREEN Database

Landslide monitoring: extensometers (clip-on, sensor arm, video and laser)

ZwickRoell

Source: Getty Images/tracielouise

Extensometers are devices used to measure the displacement or strain of an object, and they come in various types. Sensor arm extensometers are mounted directly onto the object using knife edges attached to sensor arms, measuring strain by detecting changes in the arms' angle or travel distance. They are modular and adaptable. Clip-on extensometers are also directly attached, offering high accuracy, but limited flexibility. Video and laser extensometers are contactless: laser extensometers use a laser beam directed at a target on the object to measure the distance, while video extensometers use high-resolution cameras to track the movement of markers placed on an object, with software analyzing the images to calculate the displacement.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Germany
- Availability: Worldwide
- Contact: WIPO GREEN Database

Landslide monitoring: earth pressure cell

Sisgeo

Source: Sisgeo

Earth pressure cells measure total pressure in embankments, retaining walls and diaphragm walls. They consist of two stainless steel plates welded together, filled with de-aired oil and connected to a transducer via a tube, forming a closed hydraulic system. Pressure applied to the cell generates an electrical signal that is readable remotely using portable units or data loggers. Vibrating wire technology – often integrated into these systems – measures strain, displacement or pressure by detecting changes in a wire's vibration frequency under stress. This frequency shift is converted into an electrical signal. Vibrating wire systems – known for their accuracy and environmental resilience – are ideal for long-term geotechnical monitoring, providing reliable data for pressure monitoring applications.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Italy
- Availability: Worldwide
- Contact: WIPO GREEN Database

Landslide debris clean-up: mobile debris crushers

Metso

Source: Metso

Metso crushers are designed to process debris generated in disasters or demolitions. Available in mobile and stationary configurations, they are effective for medium-hard and hard materials such as concrete, asphalt, and bricks. Mobile units are easy to relocate as work progresses and have been used in disaster recovery operations, where crushers helped manage rubble and produce aggregates for reuse in, for example, road bases, reclaimed asphalt, or erosion control.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Finland
- Availability: Worldwide
- Contact: WIPO GREEN Database

Landslide debris clean-up: grinding machine

Rotochopper

Source: Getty Images/ezoom

Rotochopper's electric and diesel grinding machines are designed for the high-efficiency, high-volume processing of organic materials like wood, construction debris and green waste. They use a rotating drum with sharp, heavy-duty knives to shred and grind the material into a consistent, finely processed output. They are designed to feed logs, whole trees and brushy material into the powerfeed. The StopWatch Monitoring System can detect ungrindable objects and vibration in the rotor and stop and reverse the infeed. The electric-powered models provide a quieter, cleaner operation with less maintenance, whereas the diesel-powered models offer greater mobility for on-site operations, especially in rugged areas. Both systems have advanced features, such as adjustable screens to control particle size, and quick-change blades for minimal downtime.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: High
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO GREEN Database

Landslide damage assessment: 3D terrestrial laser scanner (TLS)

Leica Geosystems

Source: Leica Geosystems, part of Hexagon

The RTC360 is a high-precision 3D laser scanner with quick scanning capabilities (up to 2 million points per second) that captures detailed 3D topographical data for precise mapping of the displacement of land to assess the extent of damage. It is compact and captures detailed terrain data in rugged areas, such as landslide-prone slopes, with high accuracy. It offers software integration for processing large datasets quickly. It is small and lightweight with a collapsible tripod and therefore can be taken anywhere. It has a one-button operation for simple scanning. The Cyclone FIELD 360 app is also part of the RTC360 solution, enabling the on-site automatic capturing, registration and examination of scan and image data. The app can also connect the 3D data acquired in the field with the laser scanner and data registration back at the office.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: High
- Place of origin: Switzerland
- Availability: Worldwide
- Contact: WIPO GREEN Database

Frontier technology solutions

Landslide monitoring: vibrating wire multi-level piezometer

Roctest

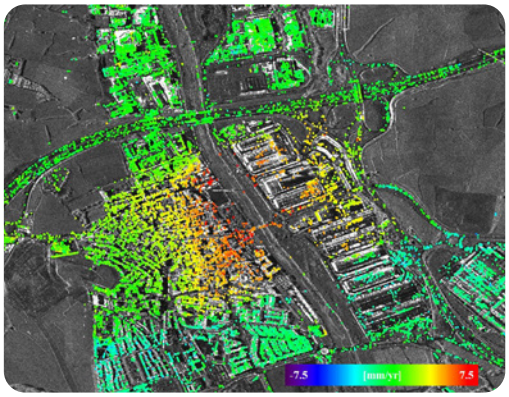
Source: Smartec / Roctest

A multi-level piezometer is used to measure pore water pressure in the ground at different depths, so as to understand how water pressure changes. A wire inside vibrates at a specific frequency, and when water pressure changes, it affects the wire's tension, which changes the vibration frequency. This change is then used to measure the pressure. The PW-ML multi-level piezometer features multiple piezometers connected to a single communication cable, which links to a data acquisition system (SENSLOG) or readout device (MB-3TL). The multi-level piezometer is installed using direct grouting with piezometer string and a grout injection tube. Once the grout hardens, the piezometers are sealed off from one another, allowing for accurate measurements of pore water pressure at different depths. This system lets the user customize sensor spacing along the cable, ensuring precise depth control based on site-specific needs. The connections between each piezometer and the main cable are reinforced with epoxy resin.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: Canada / Switzerland
- Availability: Worldwide
- Contact: WIPO GREEN Database

Landslide monitoring: land deformation monitoring services using satellite radar data (InSAR)

GeoKinesia



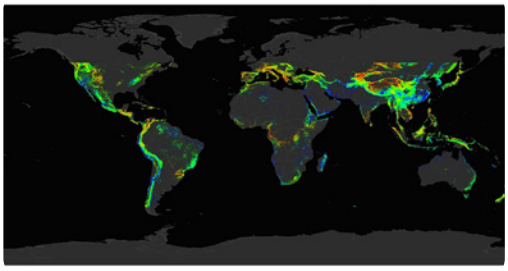
Source: GeoKinesia

GeoKinesia is highly experienced in land deformation monitoring, specializing in SAR, InSAR, and other remote sensing techniques. InSAR (Interferometric Synthetic Aperture Radar) is a remote sensing method that detects land and structural displacement with millimeter precision by comparing satellite images taken at different times. GeoKinesia uses a proprietary Persistent Scatterer Interferometry (PSI) InSAR processing technique with a high level of automation and reliability. It helps estimate key factors like residual topographic error (the remaining discrepancies in height or elevation after accounting for topographic variations in data), which is crucial for accurate modeling. With this technique, GeoKinesia can create deformation velocity maps, cumulative deformation maps, time series, and analyze both horizontal and vertical movement.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: Spain
- Availability: Worldwide
- Contact: WIPO GREEN Database

Landslide monitoring: Landslide Hazard Assessment and Model for Situational Awareness (LHASA)

National Aeronautics and Space Administration (NASA)



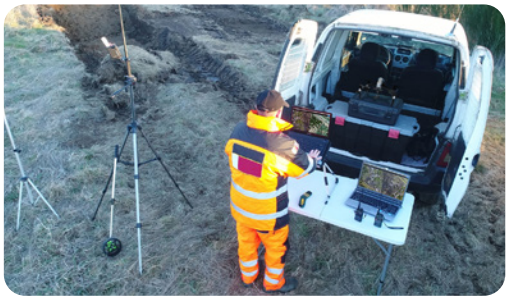
Source: NASA's Scientific Visualization Studio

The Landslide Hazard Assessment and Model for Situational Awareness (LHASA) provides near real-time global landslide hazard forecasting to support disaster preparedness and response efforts. LHASA version 2.1 combines multiple data sources including satellite-based estimates of precipitation and soil moisture, terrain, and seismicity to predict where rainfall-triggered landslides are most likely to occur. The system uses XGBoost machine learning algorithms trained on historical landslide data to generate daily nowcasts that are publicly accessible through NASA's Landslide Viewer. By integrating forecasts from NASA's Goddard Earth Observing System (GEOS) Forward Processing system and incorporating new landslide inventory data, LHASA helps emergency managers, researchers, and communities worldwide better prepare for and respond to landslide hazard.

- Technological maturity: Frontier
- Contracting type: Open source (freely available)
- Technology level: High
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO GREEN Database

Landslide monitoring: 2D drone mapping software

Pix4D



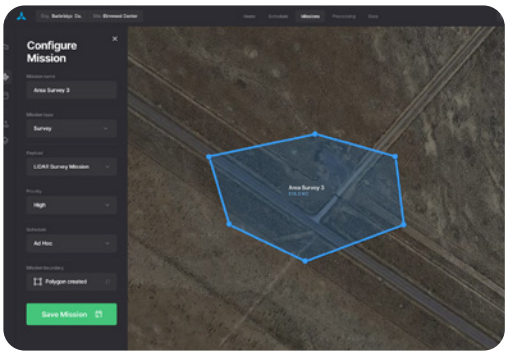
Source: Pix4D

Pix4D develops end-to-end mapping solutions that transform images into survey-grade maps, 3D models, and actionable insights, using photogrammetry and machine learning. Developed for emergency response, PIX4Dreact enables the creation of 2D maps from aerial imagery within minutes and without relying on the internet or a cloud for processing. It contributes to rapid and accurate damage assessment and subsequent planning of resources. For landslide monitoring, PIX4Dmatic combines photogrammetry and LiDAR technology to process thousands of images while maintaining survey-grade accuracy, cutting the processing time in half. The result can be viewed online using PIX4Dcloud, enabling collaborative and user-friendly progress tracking and site documentation.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: Switzerland
- Availability: Worldwide
- Contact: WIPO GREEN Database

Landslide monitoring: drone capture automation, drone data processing and analysis

Skycatch



Source: Skycatch

High-resolution aerial images captured by drones can be used to create detailed 3D terrain models. This data can be used for pre- and post-event comparison wherein drones can quickly map landslide areas to assess the extent of movement, erosion or deformation. Data can also be gathered from regular drone flights over landslide-prone areas to provide real-time updates on ground movement and help identify early signs of instability. Drones provide quick access to hard-to-reach areas, reducing the need for manual inspections and offering a safer, more efficient way to monitor dangerous or unstable terrain. Skycatch's drone technology is valuable for monitoring landslides and other geohazards in real-time, providing crucial data for risk mitigation and decision-making. Skycatch works with a variety of drone hardware manufacturers, integrating its software with their drones to ensure seamless capture, data processing and analysis.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO GREEN Database

Rockfall protection system: monitoring and alert system

Logistics and Supply Chain MultiTech R&D Centre (LSCM)

Source: Getty Images/beekeepx

The Smart Barrier System by LSCM provides real-time monitoring of falling debris. It is a low-cost system that uses IoT sensors to first detect landslide impacts on barriers and then instantly notify authorities for follow-up actions via a web platform and mobile app. An integrated infrared camera transmits images, while an on-site warning message system (WMS) delivers landslide warnings. The system is designed to withstand extreme weather and has been used to enhance the effectiveness of remote barriers built by Hong Kong's Civil Engineering and Development Department (CEDD).

- Technological maturity: Frontier
- Contracting type: For licensing
- Technology level: High
- Place of origin: Hong Kong, China
- Availability: Hong Kong, China
- Contact: WIPO GREEN Database

Rockfall protection system: monitoring and alert system

Maccaferri

Source: Getty Images/Sebastian_man

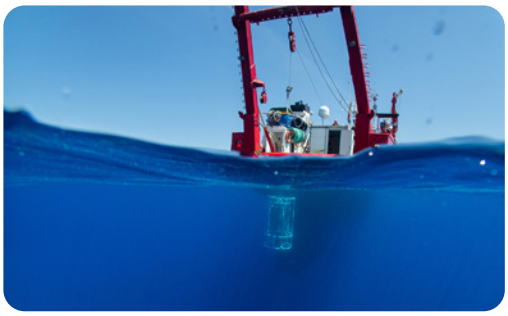
HELLOMAC is an advanced alert system designed to monitor rockfall protection systems, especially in remote areas. It detects boulder movement, stress and sagging, sending real-time notifications via mobile app, email and SMS for every section of the rock barrier. Built from durable metal alloys, its compact and robust structure is engineered to withstand harsh conditions and heavy loads. With continuous monitoring capability, it operates without external power sources, relying on batteries that last up to five years, and functions even in areas with no cell coverage.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: Italy
- Availability: Worldwide
- Contact: WIPO GREEN Database

Horizon technology solutions

Landslide research: benthic event detector (BED)

Monterey Bay Aquarium Research Institute



Source: Getty Images/Marta Masdeu

Underwater and terrestrial landslides share similar drivers, including gravity, soil composition and slope angle, and both involve the movement of sediments, rocks and debris. Studying underwater landslides helps researchers understand slope stability, which can inform landslide technology and engineering on land. A benthic event occurs near the ocean or lake floor, within the benthic zone, and benthic event detectors (BEDs) are designed to measure near-seafloor conditions in sediment gravity flows. Deployed by the Monterey Bay Aquarium Research Institute (MBARI), BEDs were used in the Coordinated Canyon Experiment to monitor sediment movement across 50 km of Monterey Canyon at depths of 200, 300 and 400 meters. These motion-sensing instruments rest on the seafloor, capturing data within the densest part of the sediment flow. Over 18 months, the BEDs recorded 10 sediment gravity flows, revealing that these flows can mobilize the top three meters of the seafloor. This research provided valuable insights into the dynamics of sediment flows. BED technology is still under development, but close to commercialization.

- Technological maturity: Horizon
- Contracting type: Under development
- Technology level: High
- Place of origin: United States
- Availability: N/A
- Contact: WIPO GREEN Database

Landslide research: meta-model and novel feature selection technique for understanding landslides

Leibniz Centre for Agricultural Landscape Research (ZALF)

Source: Getty Images/Josephine Jullian

Building upon six advanced machine learning models, researchers in Germany and India have developed a meta-model and framework to better understand and forecast landslides using data from West Bengal, India. The researchers converted spatialized features, such as geology, lithology, soil texture, land-use and land cover, into binary vectors, making them compatible with a machine learning algorithm. Then, an ensemble geospatial feature selection technique was employed, finding and including only the most influential causative aspects of landslides. The resulting meta-model stacks the predictions made by the six foundational models. It demonstrated superior accuracy as compared with the individual models due to its integration with the ensemble feature selection process. The findings have implications for both disaster management and land-use planning, and the methodology, which can be extended to other regions, is open access.

- Technological maturity: Horizon
- Contracting type: Under development/ open access
- Technology level: High
- Place of origin: Germany/India
- Availability: N/A
- Contact: WIPO GREEN Database

Landslide monitoring: AI routing system for weather-affected unpaved roads

HeiGIT

Source: Croix-Rouge Malagasy

The AI Logistic Awareness System (AILAS) is an AI-supported, weather-adaptive routing system designed for regions with unpaved roads. It is intended to assist planners in road development, maintenance, and humanitarian logistics, where uncertain road conditions can cause life-threatening delays. HeiGIT is currently developing and testing AILAS through a pilot project in Madagascar, where dashcams mounted on emergency vehicles capture street-level imagery to train a deep learning model. This imagery is combined with secondary weather and environmental data within a probabilistic framework to evaluate how weather conditions influence road passability. As the system evolves and sufficient imagery becomes available, AILAS will predict passability across the entire unpaved road network, including areas without direct image data. The predictions will be integrated into routing software or a web-based map tool, enabling reliable logistical planning based on both current and anticipated road conditions. HeiGIT is looking to scale the system to other regions and integrate extreme events, such as floodings or landslides.

- Technological maturity: Horizon
- Contracting type: Under development/ for collaboration
- Technology level: High
- Place of origin: Germany
- Availability: Madagascar
- Contact: WIPO GREEN Database

Landslide monitoring: ground-penetrating radar and hyperlocal landslide nowcasting

Augsense Lab

Source: Getty Images/Halfpoint

Augsense Lab develops quantum and remote sensing technologies for subsurface and atmospheric monitoring related to landslide risk. The company is focused on developing two core systems: a ground-penetrating radar (GPR) and a GNSS-based atmospheric sensing platform. The GPR, an antenna-less radio-frequency receiver, detects low-frequency radio signals by leveraging the quantum properties of Rydberg atoms. It enables subsurface imaging through soil, rock, and debris without a conventional large antenna. Augsense Lab is currently focused on miniaturizing the system, with the aim of mounting it on drones for use in search-and-rescue operations. The company recently signed an iDEX contract with India's Ministry of Defence to advance its work on next-generation quantum sensors and collaborates with Kerala-based mistEO on sensor miniaturization and AI-driven real-time forecasting. Meanwhile, the N-Sonde platform employs GNSS tomography and radio occultation to generate 3D refractivity profiles for hyper-local weather forecasting. This technology is part of a pilot project deployed by the Kerala State Disaster Management Authority, which will integrate N-Sonde data into a landslide prediction model developed by IIT Roorkee.

- Technological maturity: Horizon
- Contracting type: Under development
- Technology level: High
- Place of origin: India
- Availability: N/A
- Contact: WIPO GREEN Database

Part 2: Dry weather-related disasters

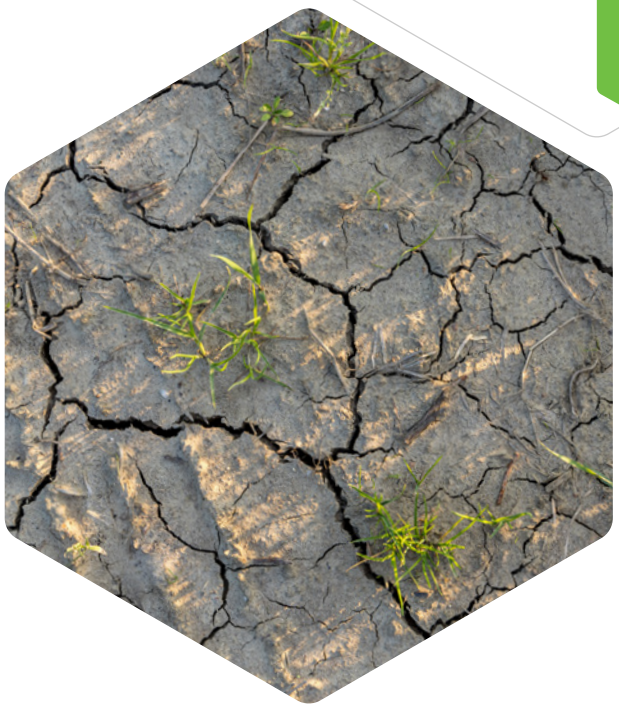


Photo: Getty Images

Wildfire and droughts are escalating from seasonal hazards into full-blown crises, threatening ecosystems, economies and lives. Wildfires, fueled by hotter temperatures and drier landscapes, now rage with unprecedented ferocity. Fortunately, innovation is rapidly advancing technologies for early detection, from artificial intelligence (AI)-powered satellites to thermal drones and digital twins (virtual models that simulate real-world systems or processes) that predict fire behavior. Meanwhile, prolonged droughts are destabilizing food and water systems, pushing communities to innovate with drought-resistant crops, atmospheric water harvesters and smart irrigation networks.

The chapters in this section explore cutting-edge solutions, from firefighting robots and biodegradable retardants to CRISPR (clustered regularly interspaced short palixndromic repeats)-engineered crops and underground water mapping. These solutions enable us to confront the growing challenges of dry-weather extremes in a changing climate.

Wildfire

Cutting-edge technologies are transforming wildfire management. AI-powered satellite networks and thermal drones enable early detection, while digital twins improve fire behavior modeling. Aerial fleets deploy innovative retardants and autonomous drones for precision suppression. On the ground, fire-resistant materials protect homes, while IoT sensors and mobile Doppler radar track fire weather. Robotics assist dangerous firefighting operations, and virtual reality systems enhance responder training. These innovations work together to detect, predict, and combat increasingly severe wildfires in an era of climate change.

Technological developments and trends

Wildfires and climate change converge to form a vicious cycle: rising temperatures and shifting humidity and wind patterns fuel more severe fire seasons, while wildfires cause greenhouse gas (GHG) emissions and damage ecosystems, contributing further to global warming (Columbia Southern University, 2025). The reality is stark – fires are escalating from seasonal hazards into full-blown disasters, growing more frequent, intense and destructive with each passing year. To complicate matters, some level of fire activity is often necessary to prevent more catastrophic fires and can even be beneficial for certain ecosystems. Therefore, wildfire response requires a tailored approach, as there is no single solution that fits all situations.

Wildfires: a growing global threat

A wildfire is any fire occurring in wildland areas, including forests, grasslands and other natural landscapes. Wildfires are different than structural fires, i.e., those occurring in buildings and urban areas (FAO, 2002). This chapter covers wildfires that extend into the wildland–urban interface (WUI), locations where urban development meets wildland areas. Wildfires are caused by arson, unattended campfires and natural causes, such as lightning strikes. Their spread is influenced by several factors, including wind conditions, types and quantity of dry vegetation nearby, moisture levels and heat. The extent of land burned and effects on ecosystems are shaped by a mix of human activities, weather patterns, vegetation management and suppression efforts (Samborska and Ritchie, 2024).

Wildfires are rapidly becoming a global threat, profoundly impacting societies, ecosystems and economies. They cause increasing loss of life, displacement and evacuations each year. Besides carbon dioxide, wildfires also emit harmful pollutants such as black carbon, carbon monoxide, particulate matter, volatile organic compounds (VOCs) and nitrogen oxides, which pose serious health risks, including respiratory problems and higher premature mortality (Alexeeff *et al.*, 2021; Murray *et al.*, 2020).

Wildfires are rapidly becoming a global threat, profoundly impacting societies, ecosystems and economies

Climate change is fueling wildfires

In recent decades, the combined effects of global warming and land-use changes have led to more frequent heatwaves, droughts and infestations of wood-eating insects. These factors have weakened ecosystems and increased wildfire risk. Heatwaves, often occurring alongside dry conditions, significantly increase the likelihood and intensity of wildfires. Heat dries out vegetation, creating perfect conditions for fires to ignite and spread. The rapid spread of many fires, in some cases driven by winds but also the rising availability of these dry fuels, often outpaces both evacuation efforts and firefighting responses, and heightens the direct threat to life and safety. Recent attribution studies found climate change made extreme events, such as Los Angeles's catastrophic fires in January 2025, 30 percent more likely (World Weather Attribution, 2025).

The combined effects of global warming and land-use changes have led to more frequent heatwaves, droughts and infestations of wood-eating insects

Burning the expanding WUI

Land-use changes have paradoxically reduced total burned area in grasslands due to agricultural expansion, even as forest fires intensify (Andela *et al.*, 2017). Nevertheless, fires can severely damage and alter ecosystems, as observed between 2001 and 2023, when they were responsible for 28 percent of tree cover loss globally. The hardest hit countries were Australia, Brazil, Canada, the Russian Federation and the United States of America (Global Forest Watch, 2025).

Nearly 12 million hectares burned globally in 2023, roughly corresponding to the land area of Bangladesh, surpassing the previous record by approximately 24 percent. Extreme wildfires in Canada were responsible for about two-thirds of the fire-related tree cover loss, contributing 27 percent of global tree cover loss (WRI, 2024b). Wildfires are a growing threat to human activities, particularly due to urban sprawl in the WUI (Radeloff *et al.*, 2005). In California, the expansion of low-density housing near wildlands has fueled a sharp increase in the number of structures destroyed by wildfires: 3,533 between 1955 and 1985, 7,467 between 1985 and 2000 and 3,710 in 2003 alone (Hammer *et al.*, 2007).

In the WUI, large flames are often mistakenly identified as the primary threat, when in fact wind-driven embers – which ignite structures far from the original fire – pose the greater danger. It is also common for houses to catch fire after the main fire has passed due to embers that have landed in vents. This turns wildfires into "urban disasters" (Curwen, 2025) and highlights the imperative to focus on bolstering homes and communities with fire-resistant construction materials and community-driven landscaping efforts to prevent fire spread.

Power grids and power lines – increasing fire hazards in an era of climate change

Wildfires can impact critical parts of the power grid, including transmission and distribution lines, and even power plants. Power lines, especially those that are older or in poor condition, can spark fires, and have become a significant concern in dry or windy places with high fire danger. Electricity can arc and ignite surrounding vegetation, while equipment such as transformers and electrical insulators can overheat, causing sparks. Grid failures can cause fires, and therefore wildfires and grid failures have begun to exacerbate each other (Arbaje, 2024).

Argentina, Australia, Chile and the western United States face these risks, and their governments are focused on hardening power grids, improving maintenance, and transitioning

to using underground cables. In California, Pacific Gas and Electric (PG&E, a public utility company) equipment was linked to several fire starts, and in response the state imposed stricter regulations, including public safety power shut-offs during extreme weather events to prevent fires (California Public Utilities Commission, 2025). Table 5.1 depicts the number of wildfires caused by electrical power in California, where they constituted 19 percent of Cal-Fire-reported acres burned between 2016 and 2020.

Table 5.1 Wildfires caused by electrical power account for 19% of Cal-Fire-reported acres burned, 2016-2020

	Wildfires		**Wildfires caused by electrical power**			
Year	Total wildfires	Total acres burned	Number	Percent	Acres burned	Percent
2016	2816	245,000	270	10	3000	1
2017	3470	467000	408	12	250000	54
2018	3504	1063000	297	8	247000	23
2019	3086	130000	304	10	84000	65
2020	3501	1459000	335	10	59000	4
Totals	16377	3364000	1614	10	643000	19

Source: California State Auditor (2022). Electrical system safety: California's oversight of the efforts by investor-owned utilities to mitigate the risk of wildfires needs improvement. Available at: https://information.auditor.ca.gov/pdfs/reports/2021-117.pdf.

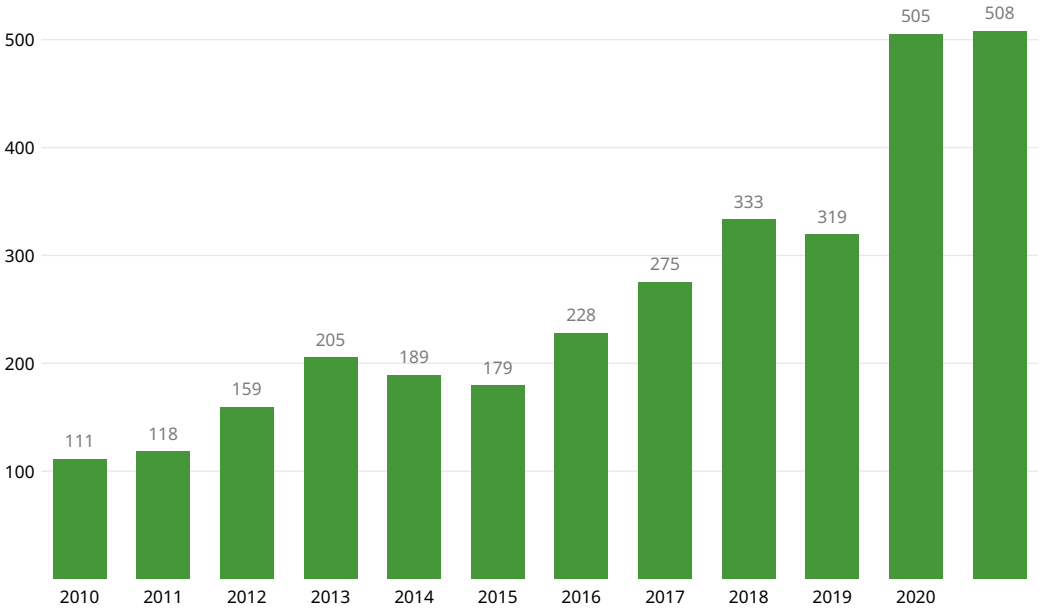
California utilities are now investing heavily in measures to reduce the risk of ignitions. However, this is a costly endeavor. Innovations such as GE Vernova's SPEEDWORM robot, which tunnels 300 m in two hours, and Prysmian Group's automated splicing machine (which reduces cable splicing failures that occur when two sections of cable are damaged at the point where they are spliced), aim to cut costs and boost grid safety. AI is helping analyze vegetation near lines, while Gridware's sensors, deployed by PG&E, detect faults and fire risks in real time.

Innovation in firefighting has advanced rapidly in the last decade

Since 2020, the number of patent applications related to forest fires has substantially increased globally. While Australia, the Russian Federation and Spain may not be the leading patent filing offices worldwide, they are notable for their contributions in the field of forest fire technologies, surpassing other offices such as Japan or the European Patent Office. Increasingly, innovations focus on the use of AI and drones in combating and managing forest fires. Portugal is actively involved in research and development projects aimed at fire prevention and detection, including aerial technologies, AI and sensors. The field of fire extinguishing technology leads in patent filings, surpassing detection and prevention or protective equipment. Post-fire restoration is the least patented sector, leaving significant opportunities for innovation (OEPM and INPI, 2022).

Figure 5.1 shows total global patent documents on forest fires between 2010 and 2021, during which a total of 3,129 patent and utility model documents related to forest fires were published.

Figure 5.1 Total patent documents on forest fires, 2010-2021



Source: OEPM and INPI (2022). Patents and forest fire control. Oficina Española de Patentes y Marcas (OEPM), Instituto Nacional da Propriedade Industrial (INPI). Available at: https://www.oepm.es/export/sites/oepm/comun/documentos_relacionados/Publicaciones/Estudios-Articulos/Patentes_y_control_de_incendios_forestales_ingles.pdf

Early fire detection: catching fires before they spread

Early fire detection systems are critical for minimizing wildfire damage and danger to human life and the environment. Technologies such as satellite imaging, drones with infrared cameras, and AI-driven predictive analytics have drastically improved the speed and accuracy of detecting fires at their earliest stages. By using real-time monitoring systems, fire response teams can quickly assess new ignitions and respond with minimal delay, often before a fire spreads.

Key innovations in fire detection include real-time environmental monitoring through internet-of-things (IoT) sensors that track conditions such as temperature, humidity and smoke levels. These sensors, combined with AI algorithms, help forecast potential fire risks and send alerts to emergency managers when danger is imminent. Integrated communication networks such as mobile apps and crowdsourcing further enhance situational awareness, alerting both responders and the public about fire events as they unfold. A key example is Pano AI's high-resolution, 360°Cameras on mountaintops and cell towers that use AI to detect smoke and fire around the clock. Other systems combine multispectral sensors with advanced geographical information system (GIS) models to monitor fire progression.

Thermal cameras provide real-time information even in darkness

Among the most critical tools in wildfire monitoring are thermal cameras. These systems provide real-time information about fire hotspots, even in low-visibility conditions such as smoke or darkness. Thermal cameras are particularly effective at detecting heat signatures, helping firefighters pinpoint smoldering areas that may reignite.

Thermal cameras are particularly effective at detecting heat signatures, helping firefighters pinpoint smoldering areas that may reignite

For instance, UC San Diego's ALERT California program uses a network of over 1,000 wildfire-monitoring cameras paired with advanced sensors to provide real-time data on ongoing fires and other hazards (UC San Diego, 2023). Thermal cameras also work effectively in conjunction with aerial units such as drones and aircraft, which can scan large areas while ground crews use the thermal data to focus on specific threats. As technology advances, researchers are combining various fire detection tools such as unmanned aerial vehicles (UAVs), satellites and manned aircraft to create more comprehensive systems.

Satellites for fire detection, mapping and post-fire recovery

Satellites have become a vital tool in wildfire monitoring and management. Equipped with advanced sensors, they provide information on fire behavior, intensity and the surrounding environment. Earth observation satellites have evolved dramatically over the last few decades via a mix of public programs and private entrepreneurs. Together, they offer a wide range of products for specialized tasks such as wildfire detection and monitoring, often at competitive prices.

MODIS (moderate resolution imaging spectroradiometer) is a sensor on the National Aeronautics and Space Administration's (NASA) Terra and Aqua satellites that provides frequent global coverage (250 m–1 km resolution) and near real-time wildfire detection (1–3 hours), mapping fire intensity, progression, smoke plumes and atmospheric impacts. *Landsat* is a series of Earth-observing satellites operated by NASA and the United States (US) Geological Survey that provide high-resolution imagery (30 m) for detailed post-fire analysis, such as land-cover changes and ecosystem recovery. Sentinel satellites, operated by the European Space Agency (ESA), have high spatial resolution (up to 10 m). Sentinel-1 uses synthetic aperture radar (SAR) to detect fire damage through smoke and clouds, while Sentinel-2 provides optical imagery to assess fire effects on vegetation.

NASA's *Fire Information for Resource Management System* (FIRMS) provides multiple sources of active fire detection data products and low-latency (available almost immediately) satellite imagery. FIRMS uses 15 satellites – 10 polar-orbiting and five geostationary. Polar orbiting satellites are low (<1000 km), sun-synchronous, collect one or two observations daily, and have relatively high spatial resolution. Geostationary satellite orbits are locked on a fixed point above the equator while Earth rotates, using a higher orbit (35,000 km). They collect multiple observations per hour but have lower spatial resolution. FIRMS uses 16 sensors implemented by five different space agencies: NASA, the National Oceanic and Atmospheric Administration (NOAA), ESA, the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) and the Japan Aerospace Exploration Agency (JAXA), as no one satellite sensor meets all requirements (high spatial resolution, frequent observations, global coverage, consistency, accuracy, and reliability) (ARSET, 2025b). See proven technologies for more information.

Satellite surveillance enhanced by AI pattern recognition can quickly and accurately detect wildfires. German startup OroraTech uses mini satellites in low orbit to capture thermal images. OroraTech's algorithms factor in vegetation and humidity, enabling firefighting agencies to prioritize resources and focus on fires with large growth potential.

SAR for wildfire detection

SAR is a remote sensing technology that also operates in conditions of cloud cover, haze and smoke, overcoming the limitations of traditional optical sensors as well as light detection and ranging (LIDAR)-based systems. SAR is further discussed in the storms and flooding chapter. Researchers at Ohio State University are experimenting with SAR for wildfire detection by integrating it into predictive models to improve early warning systems and wildfire management strategies (Ohio State News, 2023). Researchers believe SAR holds potential as an additional wildfire monitoring method to track the fire and its aftermath, since it can discern additional factors contributing to the creation of flame-prone areas, including soil moisture levels and vegetation types.

Mobile Doppler radar systems – not just for storm tracking

Doppler radar systems provide critical information about atmospheric conditions that impact wildfire behavior and suppression efforts. Importantly, Doppler radar can detect and track fire-generated weather patterns. For example, wildfires sometimes generate pyrocumulonimbus clouds (fire-induced thunderstorms) that produce lightning and strong winds. Doppler can provide wind speed and direction data to help predict fire behavior, smoke plumes and ash clouds (especially if smoke reaches higher altitudes). Doppler can also be integrated with satellite imagery and ground-based sensors for better modeling of fire behavior.

Fire behavior models guide wildfire strategy worldwide

Fire behavior modeling is essential for understanding and predicting wildfire spread. Several advanced systems integrate satellite, weather and ground data to create accurate models. The Rothermel spread model (1972) remains the foundation for many systems, powering tools such as FARSITE – the US standard for tactical fire spread prediction, Canada's Fire Behavior Prediction System, Australia's PHOENIX RapidFire and FIRECAST, and Europe's ELMFIRE for cross-border wildfire scenarios. These models predict fire spread by simulating how factors such as terrain, wind and fuel affect fire behavior, and are often combined with satellite data and AI-powered platforms.

Emerging models that integrate machine learning are improving our ability to predict fire risks and damage. Some models predict lightning-induced fire risk. AI-powered applications are also leveraging crowdsourcing through analysis of user-submitted photos documenting fire-prone areas. Platforms such as Google Earth Engine provide powerful geospatial analysis capabilities to track active fires and predict fire spread.

Models predict fire spread by simulating how factors such as terrain, wind and fuel affect fire behavior, and are often combined with satellite data and AI-powered platforms

When models fall short. Fire behavior models face limitations such as outdated fuel maps, computational bottlenecks, and difficulties predicting extreme fires (e.g., ember storms, crown fires) (Cardil *et al.*, 2021). Many models underweight human factors and firefighter suppression efforts (e.g., dozer lines, retardant drops), while climate change exposes new challenges as well. Models calibrated to historical data may fail under novel climates – and traditional metrics such as fuel moisture thresholds may not reflect current climate-driven aridification. Emerging solutions include satellite updates, hybrid AI-physics models and edge computing (processing data locally near its source instead of in a distant cloud), but interoperability and trust in AI among fire personnel remain hurdles. The path forward will require dynamic data integration, global standardization, and adaptive modeling to keep pace with the rising unpredictability of wildfires.

Digital twins for wildfires. Using AI and machine learning, digital twins) merge data from sensors located on the ground, in air, and in space to produce highly accurate global wildfire models. Unlike current models with spatial resolution of 10 km per pixel, NASA's Wildfire Digital Twin project is developing models with a resolution of 10–30 m per pixel. These models can be generated in minutes, while current global models take hours. The NASA digital twin project aims to improve global wildfire forecasting and better understand the health impacts of wildfire smoke, particularly fine aerosols such as particulate matter 2.5.

Fighting fires from above – aerial innovations

Aerial firefighting technologies enable fire suppression in difficult-to-reach areas such as remote forests, rugged terrain, or areas with limited road access using aircraft that drop water, fire retardants, or other fire-suppressing agents such as foam, gel agents, powder or dry chemical agents onto the wildfire. They can also be used for monitoring, reconnaissance and coordination.

Fixed-wing aircraft are primarily used for large-scale aerial water or retardant drops. Aircraft such as the DC-10 or C-130 Hercules are modified for firefighting, carrying more than 37,000 liters of retardant and covering large areas. Fixed-wing aircraft also create firebreaks by dropping retardant ahead of the fire's path to prevent it from spreading. *Air tankers* are specialized aircraft designed specifically for dropping water or fire retardant. They are large, high-performance aircraft converted for firefighting use. The Canadair CL-215 and CL-415 are iconic firefighters, now produced by De Havilland Canada with the model name DHC-515. Other examples include the Lockheed P-3 Orion, Boeing 737, and the Air Tractor AT-802. They typically carry between 3,785 and 11,350 liters of fire retardant or water.

Canadair CL-415. Source: Getty Images/orestegaspari

Helicopters are more versatile than fixed-wing aircraft, primarily used for precision drops. The CH-47 Chinook or the Kaman K-MAX can carry large buckets (often referred to as "bambi buckets") that scoop water from nearby water bodies and dump it directly on the fire. Helicopters can access areas that are difficult for fixed-wing aircraft to reach. Their flexibility allows them to make multiple precise drops, and they can hover in place to directly target hotspots.

> Drones are becoming more prominent in wildfire management, equipped with thermal imaging, infrared and high-definition cameras, sensors and small fire suppression systems

UAVs or drones are becoming more prominent in wildfire management, equipped with thermal imaging, infrared and high-definition cameras, sensors and small fire suppression systems. They track fire movement, locate spot fires, assess fire behavior, coordinate firefighting efforts, and can ignite prescribed fires by dropping incendiary devices. Drones also support post-fire reforestation by dropping seeds in inaccessible areas. Advanced drones provide real-time aerial footage and live feeds. High-capacity industrial models, such as those developed by Drone Hopper, operate at night to create firebreaks or tackle small fires. Emerging systems combine manned and unmanned aircraft for autonomous nighttime firefighting with automated return after retardant drops.

Fire retardants. Water has been the most used fire suppressant due to its ability to cool, suffocate and interrupt the combustion process. Inorganic compounds such as phosphorus and nitrogen salts are used as flame retardants. However, these salts can contribute to pollution if they enter

water sources. Another common retardant is foam, which enhances water's ability to penetrate and cling to surfaces. However, foam is still a short-term solution since it relies on water, and its effect ends once the water evaporates (OEPM and INPI, 2022). Follow-up line construction usually remains necessary after retardant drops. Also, some foams are carcinogenic.

Innovations are focused on improving aqueous solutions that are more effective than water, such as mixtures of surfactants (trisiloxane–polyether) and salts, along with biodegradable and low-toxicity options such as organic components, nitrification inhibitors or gelling agents (OEPM and INPI, 2022). Some studies suggest that fire retardants, particularly those containing ammonium phosphate, can harm aquatic life and hinder post-fire land restoration (UNDRR GFMC, 2025a). As ammonium phosphate acts as a multi-nutrient fertilizer, its large-scale use may promulgate invasive plant species while negatively impacting native vegetation that struggles in fertilized environments (Tufts Now, 2020).

Fighting fire with fire

"Fighting fire with fire" is a containment tactic to eliminate some or all of the fuel – such as dry grasses or woodland – ahead of a spreading fire in a targeted way. This is a frequent component of fire suppression efforts by fire crews on the ground.

> Prescribed fires are carefully planned to ensure that the fire stays contained and achieves the desired ecological benefits without threatening nearby communities

Prescribed or controlled fires are conducted separately from fire suppression activities. They are intentionally ignited under carefully managed conditions to reduce the risk of uncontrolled wildfires and improve ecosystem health. These fires help clear dead vegetation, excess fuel, and underbrush, which can otherwise contribute to larger, more dangerous wildfires. They also promote the regeneration of certain plant species that rely on fire for regeneration, such as sequoia trees, longleaf and jack pines, Kowhai trees and Banksia species. Conducted by trained professionals, prescribed fires are carefully planned to ensure that the fire stays contained and achieves the desired ecological benefits without threatening nearby communities.

Sequoia tree fire scar. Source: H. Jacobs.

Note: Sequoia trees rely on fire for seed germination and thus are fire-tolerant, able to survive moderate burns and bear visible fire scars.

In addition to prescribed fires, *mechanical thinning* is another important method for reducing fuel loads. This technique involves removing trees, shrubs and underbrush to lower fire intensity, create defensible spaces and improve forest health.

Fuel breaks are cleared areas that reduce flammable vegetation to slow or stop wildfire spread. Placed strategically around communities and infrastructure, they interrupt continuous fuel, protecting against fire damage. Fuel breaks create safer zones for firefighters, improve fire control and buy response time. They are made using heavy machinery such as bulldozers or chainsaws, and also by grazing, manual clearing, controlled burns, or sometimes chemical treatments in hard-to-manage areas.

Safer, more efficient firefighting on the ground

As technology continues to evolve, innovative solutions are being developed not only to improve the effectiveness of firefighting but also to prioritize the safety and efficiency of responders.

Robots are increasingly being used in firefighting, equipped with heat-sensing cameras and fire retardants to fight fires in dangerous areas. While many are controlled remotely, advancements in AI are allowing robots to make independent firefighting decisions by using thermal and infrared cameras, either on the ground or in the air. Robots can also carry equipment and evacuate people, ensuring firefighter safety. However, their high cost remains a major barrier to widespread adoption.

Virtual reality (VR) is being explored to improve firefighter training since it helps firefighters practice various skills, such as rescue techniques, in a controlled environment. The addition of haptic technology – systems that use tactile feedback to simulate the sense of touch, involving sensations of vibration, force or motion that can be felt by users through devices such as wearable suits, gloves or handheld controllers – enhances the experience. Some companies, such as FLAIM Systems, combine VR with real-world heat simulations for more realistic training.

Firefighting gear reinvented

Innovations in personal protective equipment (PPE) and firefighting gear are revolutionizing firefighter safety and convenience, and making gear lighter, more durable, and better at protecting against extreme heat, toxic smoke and physical hazards.

Fire-resistant fabrics made with poly(p-phenylene-2,6-benzobisoxazole) (PBO) provide exceptional heat resistance and durability. Recent innovations in “smart PPE” feature wearable physiological monitoring devices that measure temperature, relative humidity and heat index, and assess safety and send alerts. Some monitor carbon monoxide, nitrogen dioxide, temperature, humidity, firefighter heart rate and smoke density. Kestrel weather devices enable firefighters to gather critical on-site weather observations. New generation fire shelters are now used across the globe. Box 5.1 provides a brief history of the wildfire shelter.

Box 5.1 The ongoing quest for a better wildfire emergency shelter

Emergency wildfire shelters are lightweight, heat-reflective tents that firefighters carry and deploy as a last resort to protect themselves if trapped by wildfire. They were first developed in 1959 by the U.S. Forest Service, with the first documented use in 1964, saving 36 lives. By 1967, shelters were mass-produced with an A-frame design using aluminum foil, fiberglass and kraft paper. In 2002, the U.S. Forest Service introduced the New Generation Fire Shelter, which incorporated woven silica and fiberglass for better protection, though it still wasn’t sufficient for extreme conditions.

The Fire Shelter Project Review began in 2014, with NASA Langley Research Center developing the Convective Heating Improvement for Emergency Fire Shelters (CHIEFS) project to test over 300 material combinations for better heat resistance without adding bulk. By 2015, full-scale tests showed promising results. However, shelters haven’t changed significantly since the 2002 design, as the CHIEFS prototype has not yet been widely adopted. Key challenges remain: no material can withstand extreme fire temperatures without becoming too bulky or fragile, and the materials are too expensive for field use. Until a breakthrough material is found, the 2002 design will likely remain in use.

Fireproofing homes – materials that withstand heat

First, creating a defensible space by clearing vegetation around the home helps reduce the risk of direct flame contact. Addressing the threat of embers and radiant heat is also essential for safeguarding homes (International Association of Fire and Rescue Services (CTIF), 2025).

Concrete is highly fire-resistant, providing strong heat protection and a thick barrier against flames. Insulated concrete forms, combining reinforced concrete with foam panels, enhance thermal insulation. Other common fire-resistant materials include bricks, clay, fire-resistant and tempered glass (including wired glass), and stucco, which offers a one-hour fire rating at 2.5 cm thickness (i.e., can resist fire for one hour at this thickness) (howstuffworks, n.d.). Gypsum board, or drywall, burns slowly due to its noncombustible core. FireCoat, a fire-retardant acrylic undercoat, also helps reduce surface temperatures during fires (Fire & Safety Journal Americas, 2024).

> Creating a defensible space by clearing vegetation around the home helps reduce the risk of direct flame contact

Stainless steel rebar and fire-resistant coatings provide durability, while glass-fiber-reinforced polymer combined with lightweight concrete is ideal for fire-prone areas due to its rust resistance, non-conductivity and high strength-to-weight ratio (UNDRR GFMC, 2025b). Intumescent coatings expand when heated to form an insulating layer. Modern formulas include additives such as ammonium polyphosphate, pentaerythritol and melamine, with nanotechnology (nano-clays, carbon nanotubes, graphene) enhancing char strength and thermal stability (Fire & Safety Journal Americas, 2024). Natural materials such as adobe and cob are sustainable alternatives that can be engineered for fire resistance using bio-based resins with natural fibers. For example, Duplicor's 100 percent bio-based composite made from crop residues and natural fibres such as flax, jute or hemp, and hempcrete – fire resistant due to lime – also regulate both temperature and humidity (Jean Lotus, 2025).

Innovation examples

NASA FireSense deploys drone technologies on a prescribed fire, Alabama, USA

Source: Getty Images/gorodenkoff

A team from NASA's Armstrong Flight Research Center demonstrated drone technology during a prescribed burn in Geneva State Forest, Alabama, as part of its FireSense project. The team installed two instruments from NASA's Langley Research Center on the Alta X drone: a 3D wind sensor and a radiosonde to measure temperature, pressure and humidity. The collected data helped predict smoke dispersion and mixing height (the extent or depth to which smoke will be dispersed), which can be difficult to forecast for prescribed burns. The Alta X drone's vertical flight path and autonomous data collection allowed the team to monitor fire behavior from 3,000 feet (0.91 km), while NASA Armstrong's B200 King Air flew over actively burning fires at

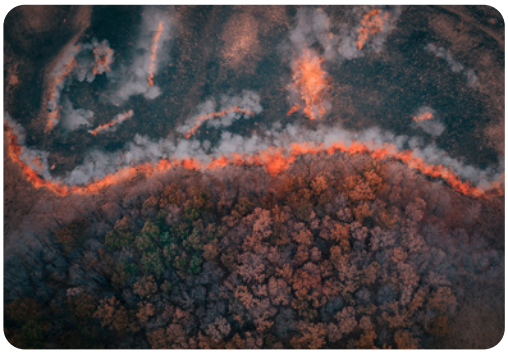
6,500 feet (1.98 km) with sensors gathering data at varying altitudes during and after the fire. This mission not only aimed to showcase the technology as an improved method of monitoring the variables for a prescribed burn, but also to refine burn forecast models. In August 2024, similar drone technology was tested in Missoula, Montana, for further refinement of fire forecasting (NASA, 2025).

Watch Duty: an app for the ages

Source: Getty Images/f00sion

When Southern California's wildfires erupted in January 2025, Los Angeles County's alert system failed, prompting residents to turn to the nonprofit app Watch Duty. The app provides real-time updates on fire perimeters, wind direction, and evacuation routes. It quickly gained over 2 million new users in its first week alone, and the city's emergency operations center began using its live map to track developments. Watch Duty works by collecting real-time data from various sources, including radio broadcasts from emergency responders and other official channels, but also inputs from citizens. It was founded in 2021 by John Mills, a tech entrepreneur, after experiencing his own difficulty finding information during a wildfire. His development team includes former firefighters, which has helped the app gain trust among both citizens and professionals. Watch Duty is now available in 22 North American states, and a paid version has been launched with additional features such as data on electric and gas lines and land ownership. In Los Angeles County, home to nearly 10 million people, Watch Duty has become a vital tool, providing faster, more reliable updates than the county's buggy alert system. It is supported by a team of 200 volunteers and 15 employees. Next, Watch Duty plans to launch a flood-warning system (Peters, 2025).

FireAId's AI-supported maps predict wildfires with 80 percent accuracy in Türkiye

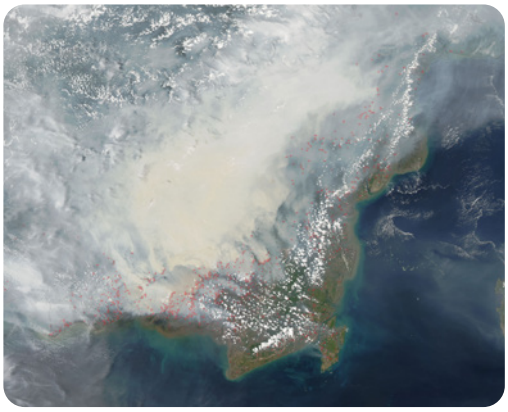


Source: Getty Images/Andrii Chagovets

The FireAId initiative, launched in January 2022, is aimed at reducing wildfire risks in Türkiye through a global collaboration involving tech giants such as Microsoft, Google, NASA and other key organizations. In response to the rising frequency of wildfires, the World Economic Forum Centre for the Fourth Industrial Revolution, Koç Holding, the Turkish Ministry for Agriculture and Forestry, and Deloitte spearheaded this initiative, using AI to enhance wildfire prediction and prevention. The pilot program has successfully created an interactive wildfire risk map utilizing AI and machine-learning algorithms. The map integrated more than 400 variables from 14 different data sets, including historical, meteorological and geographical data, to optimize

resource allocation and predict wildfire starts. After its implementation in Türkiye, the system achieved an impressive 80 percent accuracy rate in forecasting wildfires 24 hours in advance. The FireAId initiative's success in Türkiye has inspired other countries such as Portugal and South Africa to join the effort, promoting global knowledge exchange and the integration of emerging technologies into wildfire prevention and response (WEF, 2024a).

AI model helps predict and prevent peatland fires in Indonesia



Source: Jeff Schmaltz, LANCE/EOSDIS Rapid Response / NASA

Peatlands, often drained for agriculture and urban expansion, are highly vulnerable to recurring fires, which not only endanger lives and livelihoods but also release significant carbon dioxide. Researchers from Aalto University have developed a neural network model to predict the occurrence of these fires in Central Kalimantan, Indonesia, an area severely impacted by peatland fires. The model uses measurements taken before each fire season in 2002–2019 to predict the distribution of peatland fires, and a neural network analyzes 31 variables including land cover, vegetation and drought indices to predict fire likelihood. While the model's predictions were accurate 80–95 percent of the time, it still missed many isolated fires, showing the need for further refinement. Researchers simulated various fire management strategies and discovered that converting scrubland to swamp forests could reduce fires by 50 percent, and blocking drainage canals could reduce it by 70 percent. However, these strategies could disrupt the local economy, which relies on stable cultivation. Alternative strategies, such as establishing plantations, could reduce fire risks but often lead to forest loss and minimal local economic benefits. Ultimately, the study provides valuable insights for policymakers to balance fire prevention with economic and environmental considerations (Aalto University, 2022).

Proven technology solutions

Detection: multispectral sensors for fire detection and early-stage fire suppression

IQ Technologies for Earth and Space

Source: IQ Firewatch

IQ FireWatch is an advanced wildfire detection system that combines multiple sensors and AI to outperform traditional methods such as closed-circuit television (CCTV), spectroscopy and thermal infrared. It uses a multispectral sensor suite, including monochrome, near-infrared, red–green–blue and optional thermal infrared sensors, to detect fires across all conditions and regions. With a large spectral range, it captures more light than standard color cameras, enhancing information. The system integrates classic feature-based detection with AI, reducing false alarms and increasing detection speed. Real-time raw data processing ensures optimal performance without loss of information, even in poor weather. Unlike compressed image formats used by conventional cameras, IQ FireWatch delivers clearer, more detailed data, enabling faster and more accurate wildfire detection.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: High
- Place of origin: Germany
- Availability: Worldwide
- Contact: WIPO GREEN Database

Firefighting PPE: fire-resistant fabric made with PBO

TAIWAN K.K. CORP

Source: Getty Images/Ceri Breeze

KANOX PBO Pioneer is an advanced, inherently fire-resistant material designed for firefighter protection. PBO is a high-performance synthetic fiber, offering heat resistance up to 650 degrees Celsius (°C) and surpassing materials such as Nomex and Kevlar. It is lightweight (PBO is twice as strong as Kevlar at the same weight) and made with a durable twill weave, offering exceptional tensile strength and tear resistance, enabling firefighters to work in extreme conditions.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Taiwan
- Availability: Worldwide
- Contact: WIPO GREEN Database

Firefighting equipment: weather devices for firefighters

Kestrel

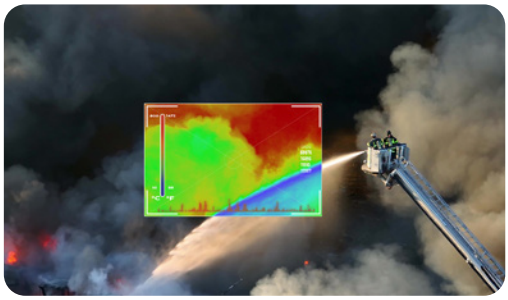
Source: Kestrel

Kestrel weather meters are essential tools for firefighters, providing accurate, real-time weather data that are critical for fire behavior analysis and safety. Meters measure key variables such as wind speed, temperature, humidity and pressure, with advanced models featuring built-in calculations of probability of ignition and fine dead fuel moisture.
The Kestrel PRO line includes wireless data transfer via the Kestrel LiNK app, making it easier to share real-time conditions. The meters also track environmental trends and provide instant access to critical fire behavior data, eliminating the need for paper lookup tables. Additionally, Kestrel's Fire Weather Meters help predict heat stress and prevent injuries during training and operations by measuring wet bulb globe temperature (WBGT). The Kestrel DROP D3FW loggers allow for continuous monitoring of temperature and humidity, which is useful for prescribed burns.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO GREEN Database

Firefighting equipment: thermal camera

SeekThermal



Source: Getty Images/Crovik Media

The FirePRO Series provides cost-effective, lightweight thermal cameras that enhance firefighter safety and efficiency. The FirePRO 300 features a 320 × 240 resolution sensor, while the FirePRO 200 offers 200 × 150 resolution. Both models use Seek's Mixed Gain Mode, allowing firefighters to observe both hot and cool areas in a single image, making thermal imaging more intuitive.
The cameras are useful in low-visibility conditions, detecting heat signatures through smoke, darkness or haze to locate hotspots and people, and monitor fire progression. Thermal cameras also support coordination with aerial units such as drones, improving firefighting efficiency, and can help in post-fire assessments to identify remaining heat sources and prevent reignition.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO GREEN Database

Firefighting equipment: thermal camera

Exosens

Source: Getty Images/OLJensa

Exosens designs advanced thermal imaging systems for firefighting and critical infrastructure, including handheld and wearable (helmet/jacket-mounted) cameras. These tools provide real-time visibility in smoke-filled environments, aiding in victim rescue, hotspot detection and structural integrity assessment. Equipped with Photonis' shutterless infrared cores, they maintain image clarity amid rapid temperature changes. While primarily tactical, their high-resolution thermal data also support wildfire research – such as prescribed burn monitoring – improving fire behavior models over time.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: High
- Place of origin: France
- Availability: Worldwide
- Contact: WIPO GREEN Database

Firefighting equipment: firefighting turbine

EmiControls

Source: EmiControls

A firefighting turbine uses highly efficient fire safety technology that atomizes water, foam or a mixture of the two into fine droplets, creating a large surface area for enhanced heat absorption. This mist envelops objects and reaches hidden fire sources, making it more effective than conventional water jets. The technology offers high cooling capacity with low water consumption and can deliver water mist with pinpoint accuracy at low pressures. Available in both stationary and mobile set-ups, the turbines can integrate with any fire detection system for fully automatic deployment, or be incorporated into a firefighting robot or fire truck. They can also be remotely controlled at distances up to 300 m.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Italy
- Availability: Worldwide
- Contact: WIPO GREEN Database

Aerial firefighting: helicopter firefighting bucket with refill pump

Kawak Aviation Technologies

Source : Getty Images/millsrymer

The Cascade helicopter firefighting bucket is designed for efficient aerial firefighting. The bucket's rapid dip-fill capability reduces turnaround time. Its compact, collapsible design allows for easy storage, transport and deployment. The KJet series helicopter bucket refill system offers simplified faster filling. Designed for bottom-filling buckets, it can fill from shallow streams, ponds and tanks, reducing cycle times and increasing flexibility in dip sites. Its corrosion-resistant construction ensures durability in harsh environments with minimal maintenance.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO GREEN Database

Aerial firefighting: amphibious aircraft

Beriev Aircraft Company (part of PJSC UAC of Rostec State Corporation)

Source: Getty Images/Dushlik

The Be-200ES is the world's only amphibious jet aircraft. It can drop up to 270 metric tonnes in a single refueling, making it highly effective for large-scale firefighting operations. The Be-200ES has garnered international attention, with its first foreign contract in 2020 receiving positive feedback. Manufactured by the Beriev Aircraft Company (part of PJSC UAC), this aircraft has proven its effectiveness in combating fires in the Russian Federation and is expanding its presence in global markets for firefighting services.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Russian Federation
- Availability: Worldwide
- Contact: WIPO GREEN Database

Fire monitoring: provision of real-time data on wildfire activity

NASA

Source: Getty Images/janiecbros

NASA's Fire Information for Resource Management System (FIRMS) provides near real-time satellite-based global wildfire detection and monitoring tools. Originally developed in 2007 by the University of Maryland with NASA and UN support, FIRMS delivers fire location, extent and intensity data using MODIS and VIIRS satellite sensors. In 2021, NASA and the US Forest Service launched FIRMS US/Canada, a modernized platform combining data from NASA, NOAA and other agencies to support wildfire response and decision-making. New features include the static thermal anomalies mask, helping distinguish fire types. The system aids fire managers and the public by visualizing active fires and hotspots. Users can access FIRMS through its Fire Map Viewer, an interactive tool for visualizing active fire locations globally. Data downloads are available in shapefiles, keyhole markup language or text files. FIRMS also offers web map service capabilities for integrating fire data into other applications.

- Technological maturity: Proven
- Contracting type: Data is open access
- Technology level: High
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO GREEN Database

Fire retardant: Instant Foam for Fighting Forest Fires (I4F)

R-Fire and TFEX Engineering Ltd

Source: Getty Images/mysticenergy

Unlike traditional water or foam-based methods, I4F uses a unique foam technology that stays on the branches of trees, preventing fire from spreading. This foam can be carried in smaller volumes, reducing the risk to pilots by minimizing the need to fly directly over the fire. The technology provides up to three times the extinguishing capacity of water, with a cooling effect that can last up to 60 minutes, compared to conventional foams that last only 25 minutes. I4F foam is also more cost-effective than long-term retardants, reduces water waste, lowers carbon dioxide (CO_2) emissions, protects flora and fauna, and helps safeguard human lives in WUIs.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Hungary
- Availability: Worldwide
- Contact: WIPO GREEN Database

Fire-resistant building materials: bio-based composite

Duplicor

Source: Getty Images/Wirestock

Duplicor® resin is a 100 percent bio-based composite material made from crop residues. When combined with natural fibers such as flax, jute or hemp, it forms an eco-friendly, fire-resistant material. Duplicor® is extremely fire-resistant, achieving Euro fire class B without requiring additional fire retardants. It emits minimal smoke and does not release hazardous particles. Beyond fire resistance, it offers a sustainable alternative for the construction industry, significantly reducing CO_2 emissions compared to traditional materials.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Kingdom of the Netherlands
- Availability: Europe
- Contact: WIPO GREEN Database

Frontier technology solutions

Power-line fire mitigation: AI-driven platform for vegetation management

Overstory

Source: Getty Images/Leonid Sorokin

Overstory's AI-driven platform helps utility companies manage vegetation near power lines to reduce wildfire risks. By processing satellite images, it extracts detailed data on tree and shrub health, height and species. The system then generates risk assessments to pinpoint which vegetation poses a fire threat, recommending pruning or removal for mitigation. With actionable insights and optimization guidelines, Overstory enables utilities to proactively manage fire hazards, integrating smoothly with their existing systems for effective, real-time risk management.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: Germany
- Availability: Brazil, Canada, Europe, United States
- Contact: WIPO GREEN Database

Power line fire mitigation: sensor system for real-time grid monitoring

Gridware

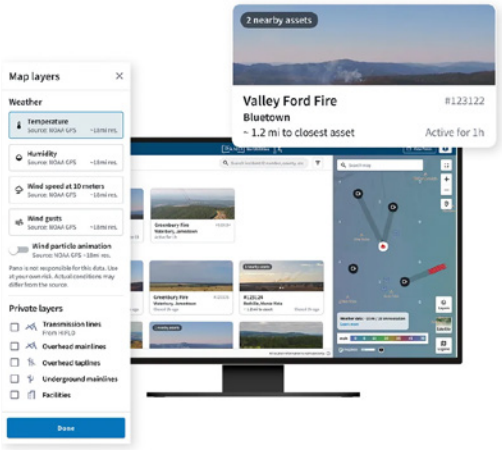
Source: Getty Images/metamorworks

Gridware uses advanced sensors placed on power poles to continuously monitor grid infrastructure, alerting operators in real time to hazards and faults. The sensors detect wildfire threats, such as equipment failures, downed lines, or contact with vegetation, enabling rapid response and repairs. Since the devices run on solar power, they remain operational during power outages. In 2023, the Californian power utility company PG&E deployed 1,875 sensors, and planned to expand to 10,000 in 2024, monitoring thousands of kilometers of power lines.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: United States
- Availability: United States
- Contact: WIPO GREEN Database

Detection: intelligent platform for fire detection

Pano AI



Source: Pano AI

Pano Rapid Detect is an advanced platform designed to help fire professionals detect and respond to wildfires faster and more accurately. Utilizing 360° ultra-high-definition cameras and AI-driven analysis, Pano stations are deployed on high vantage points to scan landscapes and spot wildfire activity within a 16 km radius. The platform integrates satellite data, emergency alerts and communication tools, ensuring real-time information sharing with responders, while using deep learning to automatically detect, verify and classify fire events in real time. Once a fire is detected, Pano sends rapid alerts to fire-monitoring teams.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO GREEN Database

Fire modeling: satellite-based mapping and monitoring of fire damage

OroraTech

Source: Getty Images/rakchai

The Burnt Area solution provides burnt area mapping and fire progression tracking using satellite data. It provides detailed insights into fire damage globally, supporting decision-making and recovery efforts in the aftermath of wildfires. Its high-resolution fire data have 20 m precision and can provide fire damage data within 2–3 days of a fire event. The system maps burnt areas and assesses damage severity more quickly than aerial mapping. It can provide continuous updates on fire movement and impacts and is scalable and adaptable for both small fires and large-scale fire events.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: Germany
- Availability: Worldwide
- Contact: WIPO GREEN Database

Fire retardant: non-toxic fire retardant and pump proportioner

FireRein

Source: FireRein

Eco-Gel™ is a non-toxic and biodegradable plant-based firefighting water additive. It is the first firefighting gel to be Underwriters Laboratories listed for both Class A (ordinary combustibles – wood, paper, vegetation) and Class B (flammable liquids – gasoline, oil, chemicals) fires, making it effective for a wide range of fire scenarios. When mixed with water, Eco-Gel™ creates a hydrogel that clings to surfaces – vertical, horizontal, and overhead – providing protection for firefighters and preventing fire re-ignition. Its food-grade ingredients make it exceptionally safe, and it has been certified by the United States Department of Agriculture's BioPreferred Program. FireRein also offers the FireRein TPP™ (Through Pump Proportioner) system, which enables users to introduce Eco-Gel™ into a firefighting water stream, adjusting its viscosity as needed. The product has a shelf life of five years.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Canada
- Availability: North America (limited availability in Australia, EU, Middle East)
- Contact: WIPO GREEN Database

Firefighting UAV: drone for nocturnal operations

Drone Hopper

Source: Getty Images/sarawuth702

Drone Hopper specializes in manufacturing high-load capacity industrial drones with thermal engines. Their product line includes both heavy-duty drones with high autonomy and lighter drones with industrial features. The company's WILD HOPPER project focuses on creating drones specifically for firefighting applications, aiming to complement existing aerial resources. Drone Hopper's drones are particularly useful in areas where conventional piloted aircrafts cannot operate. The drones are employed in indirect attack methods (e.g., creating firebreaks) and direct interventions to combat smaller fires or provide quick response.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: Spain
- Availability: Spain
- Contact: WIPO GREEN Database

Firefighting robot: forest mulcher

Vallfirest

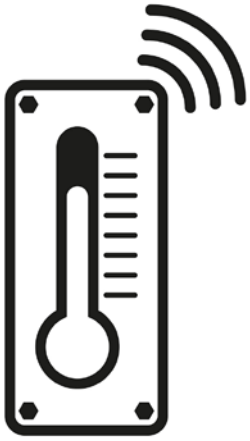
Source: Getty Images/Vadzim Sheleh

Dronster is a remote-controlled emergency robot designed to improve safety and efficiency in wildland firefighting, structural fires and rescue operations. The Dronster can operate multiple attachments such as trenchers, snowplows and extinguishing monitors, allowing it to adapt to various emergency scenarios. Remotely controlled from up to 150 m, it enables firefighters to handle dangerous tasks from a safe distance. It can navigate difficult terrain, including slopes of over 30° and dense vegetation. Weighing about 850 kg, the Dronster can be transported by pickup trucks, vans, or helicopters, ensuring quick deployment to emergency sites.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: Spain
- Availability: Worldwide
- Contact: WIPO GREEN Database

Firefighting equipment: smart personal protective equipment

SlateSafety



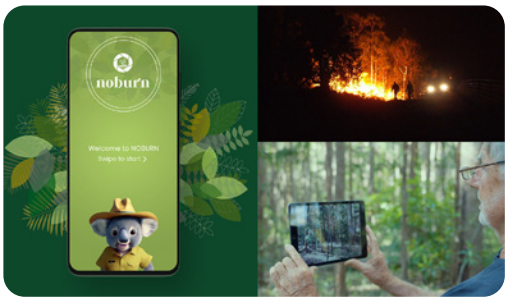
Source: Getty Images/Serhii Poliakevych

The BEACON V2 is an advanced environmental monitoring system designed to measure real-time temperature, relative humidity, heat index and effective WBGT. It serves as a hyperlocal monitor for heat tracking and can also be integrated with the BAND V2 wearable device, creating a comprehensive safety system for teams in physically demanding roles. The BAND V2 is a safety wearable that continuously monitors physiological data and sends real-time alerts to ensure worker safety. The data collected from both devices are processed and stored securely in the cloud. Additionally, BEACON V2 provides coarse real-time location system capabilities.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO GREEN Database

Fire prevention: user-driven app for assessing potential bushfire fuel loads

NOBURN



Source: NOBURN

The NOBURN app, developed by researchers at the Universities of Adelaide and the Sunshine Coast, uses AI and computer vision to analyze user-submitted photos of fire-prone areas. It assesses bushfire fuel loads and predicts potential bushfire severity and spread. The app aims to raise awareness about the role AI can play in preventing devastating bushfire losses and in providing situational awareness for bushfire commanders. By enabling thousands of citizens to contribute data through photos, the app facilitates a broader approach to bushfire prevention. The app has the potential to expand into real-time resource deployment tracking and even AI-assisted communication with firefighters.

- Technological maturity: Frontier
- Contracting type: Open access
- Technology level: High
- Place of origin: Australia
- Availability: Australia
- Contact: WIPO GREEN Database

Fire-resistant building materials: fire protection coating

Flame Security International

Source: Flame Security International

FIRECOAT Interior is a water-based, fire-resistant coating tested to Bushfire Attack Level (BAL-29) under Australian Standard AS 3959. Designed for homes and commercial interiors, it reacts to heat by forming an insulating char layer, delaying ignition and flame spread while reducing smoke. Ideal for ceilings, kitchens and areas with electrical equipment, it provides critical evacuation time. Applied via brush, roller or spray (2–3 coats required), it meets stringent safety standards for radiant heat and ember exposure. Exterior and structural fireproofing require FIRECOAT's specialized variants.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: Australia
- Availability: Australia, Sweden, United States
- Contact: WIPO GREEN Database

Fire-resistant building materials: bio-based alternative for ecological construction

Nordtreat

Source: Nordtreat

NORFLAM® is a flame-retardant treatment for wood-based products offering fire protection and unlimited color selections in one. Applied either industrially or manually on-site, NORFLAM® provides fire protection ranging from Euroclass standards B-s1, d0, to D-s1, d0, making it suitable for various applications in construction. The solution is commonly used for materials such as solid wood cladding, thermally modified timber, interior paneling and wood-based panels. Over 95 percent of the raw materials used in NORFLAM® are non-fossil, and more than 40 percent are bio-based. This helps the product meet certifications such as LEED, M1 and A+ emission ratings.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Finland
- Availability: Europe
- Contact: WIPO GREEN Database

VR: firefighter training system

FLAIM

Source: Getty Images/kzenon

FLAIM technology provides advanced VR firefighter training solutions, designed to deliver immersive, high-fidelity fire scenarios that simulate real-world emergencies. Their platform includes FLAIM Trainer, which combines VR fire simulations with firefighting equipment to create realistic training experiences. This helps firefighters develop crucial skills, such as situational awareness and quick decision-making, all while maintaining safety during training. FLAIM also integrates with Capture, a web-based learning and analytics platform that securely tracks and reports on performance and competency during training sessions. The platform records key data, which are then used to evaluate and improve training strategies and outcomes.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: Australia
- Availability: Worldwide
- Contact: WIPO GREEN Database

Horizon technology solutions

Place-of-origin detection and response: autonomous drones for ultra-early wildfire response

Dryad

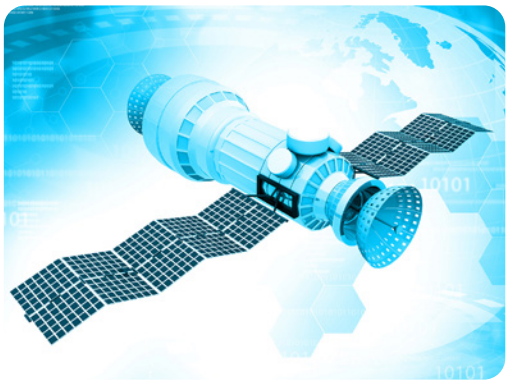
Source: Dryad

The Silvaguard drone system integrates with Dryad's Silvanet ultra-early fire detection system, using solar-powered gas sensors to detect wildfires at the smoldering stage. Upon detection, Silvaguard drones autonomously deploy, providing real-time aerial observation and pinpointing fire location and size. In the future, Silvaguard drones will use suppression technologies, such as acoustic waves (a novel suppression method whereby high-intensity sound waves vibrate air molecules and separate oxygen from fuel vapors), to extinguish fires in their early stages. As of 2025, the system is a fully functional prototype and is undergoing testing to enhance suppression capabilities and refine drone autonomy. The Silvaguard system represents a significant step toward automated, real-time wildfire detection and suppression, with the long-term vision of deploying fleets of drones for widespread wildfire management.

- Technological maturity: Horizon
- Contracting type: Under development
- Technology level: High
- Place of origin: Germany
- Availability: N/A
- Contact: WIPO GREEN Database

Detection: CubeSat AI model

University of South Australia (UniSA)



Source: Getty Images/Rasi Bhadramani

Researchers from UniSA, Swinburne University of Technology and Geoscience Australia have developed an energy-efficient AI model for detecting bushfire smoke using onboard image processing in cube satellites (standardized and miniaturized, lightweight, low-cost satellites). Part of the broader Kanyini CubeSat mission managed by SmartSat CRC, the project addresses the challenge of processing large volumes of data within the strict power, storage and transmission capabilities of small satellites. By processing imagery in orbit rather than after downlink, the system reduces data volumes by 84 percent while consuming 69 percent less energy. In one simulated event, it took 14 minutes for the onboard AI to detect smoke and send the data to the ground station. This approach enables fire smoke detection at rates up to 500 times faster than that of conventional on-ground processing. Once operational, the technology could be commercialized and used in a CubeSat constellation.

- Technological maturity: Horizon
- Contracting type: Under development
- Technology level: High
- Place of origin: Australia
- Availability: N/A
- Contact: WIPO GREEN Database

Detection and response: autonomous vase/vessel fire protection system

Hephaesnus

Source: Hephaesnus

The Sallus® Guard is an autonomous fire protection system designed to detect and suppress fires around properties. The system independently identifies flames from up to 10 m away and releases a retardant to cover approximately 30 m^2. It operates without electrical, water or other external connections. Beyond fire protection, the Sallus® Guard serves as a decorative element, featuring optional enhancements such as CCTV systems and device-charging capabilities.

- Technological maturity: Horizon
- Contracting type: Available for pre-order
- Technology level: High
- Place of origin: Portugal
- Availability: N/A
- Contact: WIPO GREEN Database

Aerial firefighting: autonomous aircraft for wildfire response

Rain

Source: Getty Images/jpgfactory

Rain has developed a wildfire mission autonomy system that enables uncrewed and optionally piloted aircraft to autonomously detect and suppress wildfires. The system integrates onboard sensors, infrared and visual cameras, global positioning system (GPS) and inertial navigation systems with software for wildfire mission management, path planning, fire perception, suppression strategy and suppressant targeting. It enables autonomous mapping of fire size and behavior, and uses the data to design a suppression strategy. A handheld control interface, the Rain tablet, allows operators to command tasks such as area searches, water drops, and bucket refills. In partnership with Sikorsky, Rain demonstrated the technology in California, where a tablet-controlled Black Hawk helicopter performed autonomous fire suppression, including drops in high winds and real-time path adjustments.

- Technological maturity: Horizon
- Contracting type: Under development
- Technology level: High
- Place of origin: United States
- Availability: N/A
- Contact: WIPO GREEN Database

Fire modeling: AI-enabled lightning strike prediction model

Bar-Ilan University

Source: Getty Images/Jian Fan

Researchers from Bar-Ilan University are developing a machine-learning model that predicts lightning-induced wildfire risk globally. Unlike previous models, it uses seven years of high-resolution satellite data, considering factors such as lightning strikes, vegetation, weather and topography. The AI model was tested on 2021 wildfire data, achieving over 90 percent accuracy. Testing also revealed that lightning-induced wildfires behave differently from those caused by humans, highlighting the need for specialized prediction models. The model shows that climate change is increasing lightning fire risks, driven by more frequent extreme weather. While not yet implemented in real-time forecasting systems, this AI model demonstrates how big data and AI can improve wildfire management.

- Technological maturity: Horizon
- Contracting type: Under development
- Technology level: High
- Place of origin: Israel
- Availability: N/A
- Contact: WIPO GREEN Database

Drought

As droughts grow longer and more severe, a wave of innovation is reshaping how we manage water. AI-powered forecasting and satellite-based monitoring to smart irrigation and atmospheric water harvesters are enabling more efficient use. Emerging solutions like fog nets, hydrogel-enhanced soils, wastewater recycling, desalination, and leak detection sensors are helping communities capture and conserve water in arid environments.

Technological developments and trends

Droughts are prolonged dry periods in the natural climate cycle caused by a lack of rainfall. Although they are historically part of the natural climate cycle, human-driven climate change is now making them longer, more severe and less predictable (WMO, 2020). This intensification is driven by rising temperatures and changing precipitation patterns. Rising temperatures accelerate water evaporation, while reduced rainfall and growing water demand strain surface and groundwater supplies. In July 2024, the global average temperature reached a record high of 17°C, increasing soil evaporation. Combined with unusually low rainfall, this led to reduced water flows in major river basins such as the Amazon, La Plata and Zambezi (European Commission, 2024). Today, water scarcity affects 40 percent of the global population, with up to 700 million people at risk of displacement by 2030 (WMO, 2020). In 2022 and 2023 alone, 1.84 billion people – roughly one out of four people worldwide – were affected, with about 85 percent of those in low- and middle-income countries (EC-JRC and UNCCD, 2024).

Droughts are not just disasters – they are slow-burning crises that destabilize food, energy and health systems. This means they disrupt the water–energy–food nexus, a framework that highlights the critical interdependence between these sectors, showing how pressure on one (such as water) can ripple across the others (such as food production and energy supply) (Matthew, 2014). In agriculture, water shortages reduce crop yields, driving up food prices and worsening food insecurity and foodborne disease risks (European Commission and Climate ADAPT, 2025). Droughts also strain energy production and exacerbate malnutrition and waterborne diseases such as cholera and diarrhea. Health services often struggle with staff displacement and insufficient water supplies (WHO, 2024a).

As droughts typically unfold over extended periods, much of the discussion and solutions in this section focus on prevention and preparedness rather than immediate emergency response. In acute drought situations, emergency measures typically involve transporting water to affected areas and populations, conserving the sparse water resources available, or organizing evacuations. Prevention measures to optimize water use, along with surveying, recycling and managing water resources efficiently, are numerous and increasingly critical in a “new normal” marked by more frequent and severe climate-induced droughts.

Droughts are not just disasters – they are slow-burning crises that destabilize food, energy and health systems

Economically, one study estimated that up to 5 percent of global GDP will be exposed to severe droughts over the next 50 years, with losses rising from USD 4.7 billion in the 2030s to USD 10 billion by the 2050s (in 2005 prices). Despite these growing risks, droughts have received less attention than other disasters, and response efforts remain insufficient.

Sanitation and hygiene worsened by drought

As of 2022, 2.2 billion people lacked safe drinking water, while 3.5 billion lacked safe sanitation. Drought reduces water availability, hindering safe water management, especially in areas affected by conflict or unequal access. People may resort to unsafe water, increasing the risk of waterborne diseases. Limited water can also lead to poor hygiene, contributing to illnesses such as diarrhea and skin infections (EC-JRC and UNCCD, 2024).

Droughts also lower groundwater levels and strain water infrastructure, increasing reliance on untreated sources that may contain naturally occurring toxins such as arsenic (Sensorex, 2023). These conditions create environments where pathogens thrive, compounding health risks.

To address these risks, portable testing labs and rapid detection methods (e.g., membrane filtration) can help identify contamination, Purification tools such as solar-powered filters, ultraviolet (UV) disinfection with advanced oxidation processes (AOP) and reverse osmosis can treat high-risk water. AOP, for instance, combines UV light and oxidants (usually hydrogen peroxide) to form powerful hydroxyl radicals that break down difficult-to-remove contaminants, such as micropollutants, that are often resistant to traditional water treatment methods.

Drought conditions also further degrade water quality by concentrating pollutants such as heavy metals and overwhelming wastewater systems. They may also shift the distribution of disease vectors such as mosquitoes, raising the risk of disease infections such as Malaria, West Nile and Dengue virus, as they gather around limited or stored water sources often more prevalent in populated areas during water stress situations.

From sky to soil – predicting and monitoring drought with data

As droughts become more frequent and severe, early warning and monitoring systems are increasingly vital. Key drought indices, such as the Standardized Precipitation Index, which tracks precipitation deficits, and the Standardized Evapotranspiration Precipitation Index, which accounts for both precipitation and evapotranspiration, help assess drought risk (EDO & GDO, 2025). The Normalized Difference Vegetation Index, derived from satellite measurements, monitors changes in plant biomass. Dashboards integrating these indices provide real-time drought visualizations for governments, farmers, and disaster response teams. Machine learning enhances drought forecasting by analyzing complex data sets from satellites, weather stations and historical climate data to detect trends and improve predictions over time. These drought-monitoring technologies are in active use worldwide, supporting early warning, real-time assessment and proactive management of drought impacts across diverse climates.

Feeding the world in a drier future

Agriculture was the largest consumer of freshwater globally in 2024, accounting for approximately 70 percent of all water withdrawals (UNESCO, 2024). This sector's demand is projected to increase 15 percent by 2050, driven by the need to feed a growing global population and meet the rising demand for food (World Bank, 2017). Drought affects both large-scale industrial farms and smallholder farmers, disrupting a wide range of agriculture production systems.

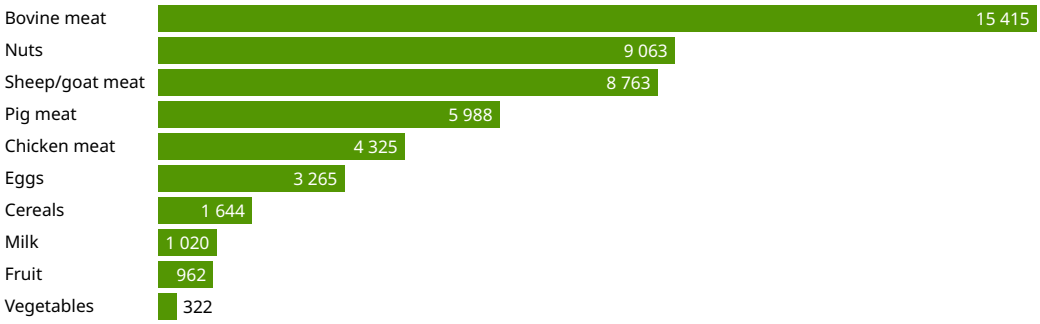
> Among the four main global crops – wheat, maize, rice, and soybeans – wheat is the most sensitive to drought, followed by soybean and maize

The impact of drought on crop yields is complex. Drought degrades soils by reducing moisture levels, diminishing fertility, causing erosion and lowering soil quality. Reduced water availability often leads to smaller, lower-quality harvests. Crop type and variety, location, irrigation, plant phenology, and drought severity and evolution all influence how agricultural systems respond to water stress (UNCCD, 2024).

Among the four main global crops – wheat, maize, rice, and soybeans – wheat is the most sensitive to drought, followed by soybean and maize. Rice appears to have been less affected by changes in drought severity over the past decade (EC-JRC and UNCCD, 2024). However, as climate change intensifies, these trends may continue to shift.

Water use varies dramatically with different food products. Figure 6.1 shows the water required to produce 1 kg of various agricultural products.

Figure 6.1 Liters of water required to produce 1kg of food



Source: EC-JRC and UNCCD, 2024

Genetic innovation in crops: CRISPR/Cas9 and GM

Drought tolerance is a complex trait influenced by multiple genes, making it one of the most difficult characteristics to study and categorize (Harin Song, 2024). Various modern techniques are being employed to enhance drought resistance in crops, each offering unique advantages to combat water stress.

The development of recombinant technology in the late 20th century led to the development of genetically modified (GM) crops, offering potential benefits in nutrition, yield and stress resilience. Despite ongoing controversy, GM crops are now grown on 190 million hectares by 17 million farmers across 29 countries, marking a 112-fold increase since 1996 (ISAAA, 2020). In 2024, the United States led global GM crop production with 75.4 million hectares (ha), followed by Brazil (67.9 million) and Argentina (23.8 million). Notable expansions among countries with over 100,000 ha include Vietnam (+93.2 percent), Uruguay (+49.8 percent), Spain (+40.3 percent) and Myanmar (+39.2 percent), driven by larger planted areas and higher GM adoption. Soybeans dominate (105.1 million ha, ~50 percent of the global total), followed by corn (68.4 million ha), cotton (24.8 million), and canola (10.4 million) (UkrAgroConsult, 2025).Nevertheless, GM crop cultivation and commercialization remain controversial and are tightly regulated in some countries (Hamdan and Tan, 2024).

Gene editing (via CRISPR/CRISPR-associated protein 9 (Cas9)) allows precise modifications to specific genes related to drought tolerance, such as those controlling water use efficiency and

stomatal regulation (Hamdan and Tan, 2024). CRISPR/Cas9 allows scientists to cut and edit DNA at exact spots, such as using precise scissors.

The CRISPR/Cas9 system has thus gained attention for its ability to edit plant genomes by creating precise DNA breaks. Unlike GM, CRISPR doesn't always require foreign DNA insertion, and thus presents a more efficient and accurate method than traditional breeding. Supporters view CRISPR/Cas9 as a powerful tool for developing crops with better resilience, higher yields and improved nutrition. It has been used to enhance nearly 120 crops (Cardi *et al.*, 2023; Yuyu *et al.*, 2020; Alam *et al.*, 2022).

Table 6.1 presents an overview of GM and CRISPR benefits and concerns.

	Benefits	Concerns
GM	Produces biofortified crops with enhanced nutritional value	Environmental impact, risk of antibiotic-resistant markers and gene flow into wild plants
	Increases crop yield and reduces pesticide/herbicide use	Potential toxicity and allergens in modified crops
	Can improve farmers' income and regional economic value	May be of temporary benefit only
		Can increase farmer dependency on seed suppliers
CRISPR	Allows specific, targeted gene editing with high precision	Off-target gene modifications may occur
	Perceived as less intrusive compared to GM, as it doesn't introduce foreign genes	Edited crops may be indistinguishable from conventional ones, raising concerns about food labeling and regulation
	More cost-effective and simpler than GM techniques	
	Shortens development time for crops with beneficial traits	
	Has broad applications, from crop improvement to gene therapy	

Source: Hamdan and Tan, 2024

Marker-assisted selection and genome-wide association studies help breeders identify plants with drought-tolerant traits, such as deep roots and efficient water use, speeding up breeding cycles by selecting for these traits without waiting for plants to express them in the field (Aleem *et al.*, 2024). Speed breeding shortens breeding cycles through controlled environmental conditions, allowing rapid testing and selection of drought-tolerant plants (Rai *et al.*, 2023).

Techniques such as somaclonal variation and tissue culture can discover new drought-tolerant plants or rapidly propagate those with desirable traits (Chaudhary and Sandhu, 2024). Hybridization combines traits from different varieties or species to develop hybrids with improved drought resistance. Transgenics introduces foreign genes for enhanced water retention and stress tolerance (Garland and Curry, 2022).

Specific crops leading the fight against drought

The global drought-resistant crops market is expected to grow at a 6.9 percent compound annual growth rate until 2032. Key segments such as oilseeds, pulses and conventional breeding methods will play a significant role in fostering market growth, with Europe slated to lead in research and development efforts (Global Market Insights, 2024).

Certain crops help farmers mitigate risks from changing weather patterns. Chilies and millets are drought-resistant alternatives to traditional corn farming. Chilies thrive in harsh conditions,

while millet is praised for its resilience in dry, poor soils (Farmonaut, 2025). Alongside these, five climate-resilient crops – amaranth, fonio, cowpeas, taro and kernza – are being revived or developed to build more sustainable agricultural systems.

HB4 wheat, a genetically modified wheat variety developed by Bioceres, an Argentinian crop productivity solutions company, is designed to address water shortages. By incorporating the HaHB4 gene from sunflowers, it helps plants survive dry spells through the production of antioxidants and osmoprotectants (small molecules that help plants retain water and protect cells during drought). Approved in Argentina in 2020, HB4 wheat has produced up to 38 percent higher yields in drought conditions and 23 percent more in optimal conditions (Harin Song, 2024). *Cañahua*, an ancient Andean crop related to quinoa, is gaining attention for its drought resilience, faster growth cycle and ability to thrive in harsh, salty soils in Bolivia's highland plateau (The Guardian, 2025).

> Crop wild relatives are wild plants related to domesticated crops, providing genetic diversity for breeding programs

Cutting-edge innovations are on the horizon. Australia's Grains Research and Development Corporation, led by the Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia's national science agency, is investing USD 12.7 million in a project to integrate long coleoptile wheat, which can be sown deeper, improving yield by up to 20 percent by better utilizing soil moisture (CSIRO, 2023). Swedish agtech startup OlsAro is developing salt-tolerant wheat using AI (see horizon technologies). Their technology speeds up breeding, offering a 52 percent yield increase in saline soils, making otherwise unfarmable land viable. And the EpiSeedLink project, a €2.69 million EU initiative, is developing drought-resistant crops through epigenetic research and molecular seed priming (where seeds are treated with specific substances or processes to enhance their germination, growth and resistance to stress such as drought) with renewable resources such as seaweed (European Union, 2022).

Crop wild relatives (CWRs) are wild plants related to domesticated crops, providing genetic diversity for breeding programs. The Dissemination of Interspecific International Center for Agricultural Research in the Dry Areas (ICARDA) Varieties and Elites through Participatory Research (DIIVA-PR) initiative enhances food security and resilience for wheat and barley farmers by evaluating CWR-derived lines in Ethiopia, Morocco and Tunisia, assessing landraces, and integrating the best germplasm into breeding. The project has released six drought-tolerant varieties and conducted trials in 23 countries (ICARDA, 2023).

Livestock vulnerability to drought

Drought reduces the availability of pasture and water, leading to malnutrition, dehydration and, in recurring cases, starvation and death for livestock – threatening the livelihoods of pastoralists (Sintayehu *et al.*, 2025). Livestock systems can adapt to drought by using locally adapted breeds, diversifying animal types and adopting alternative feed methods (Bekele, 2017). For rural farmers with limited resources, low-cost adaptations are essential, including the provision of natural shade and clean water to reduce heat stress, and improved water management through simple irrigation techniques such as drip irrigation and rainwater harvesting systems.

Practical strategies for livestock feed include extending grazing seasons through managed grazing and planting drought-tolerant forages such as sorghum, millet and brassicas. Drought-tolerant grains (which endure drought stress and survive despite water shortage) such as sorghum and millet are well-suited to arid climates, requiring much less water than crops such as corn. Crop residues, such as corn stover and soybean residue, can supplement feed. Cottonseed hulls (in parts of Africa, and in Australia and India), alfalfa pellets and cactus pads (Africa, Mexico and the Middle East) are region-specific alternatives that provide water-efficient feed in dry areas (Michigan State University Extension, 2021).

Enhancing drought resilience through water efficiency and climate-smart agriculture (CSA)

Drought is not merely a climatic event, but also a consequence of unsustainable land use. Its impacts are disproportionately borne by women and marginalized communities who often rely on degraded land for subsistence farming and lack access to early warnings or adaptive technologies. Deforestation, overgrazing and soil degradation amplify water scarcity and vulnerability. Transitioning to CSA, precision farming and improved breeding techniques can improve drought resilience, reduce environmental impacts, bolster food security and restore landscapes. Improved irrigation methods and precision agriculture have been covered in other editions of the *Green Technology Book*, including Adaptation, Mitigation, Energy and special EXPO editions.

Precision agriculture (PA), which is rapidly gaining popularity worldwide, is a farming approach that uses GPS, sensors and IoT devices to improve resource efficiency by applying site-specific inputs. The global market for PA is projected to grow from USD 9.8 billion in 2024 to USD 22.5 billion by 2034, reflecting a compound annual growth rate of 8.6 percent, driven by advancements in IoT, AI and data analytics (Globe Newswire Research and Markets, 2025).

In regions such as the United States, large-scale farms are leading the adoption of precision agriculture technologies. In 2023, 70 percent of large-scale crop-producing farms employed guidance autosteering systems, a significant increase from the single-digit adoption rates seen in the early 2000s (AgriTech Insights, 2024). While larger farms are increasingly integrating precision agriculture, smaller farms face challenges such as high initial costs, limited access to technology and a lack of technical expertise.

Agricultural drones are rapidly expanding worldwide, with China already using them to spray one-third of its farmland. These drones enable targeted irrigation, reducing overwatering and conserving water. So far, their efficient spraying and no-till operations have saved 210 million tonnes of water globally (Clean Technica, 2025). Drones with multispectral or thermal cameras can detect early signs of water stress in plants and assess soil moisture variations across fields, enabling precise, targeted irrigation that avoids wasteful overwatering. They can also inspect irrigation infrastructure, identify leaks and feed data into variable rate irrigation systems, applying water based on specific crop and soil requirements.

Drones with multispectral or thermal cameras can detect early signs of water stress in plants and assess soil moisture variations across fields

Conservation agriculture is a farming technique aimed at resource-efficient agriculture. It is based on minimal soil disturbance (e.g., zero or reduced tillage), permanent soil cover (e.g., crop residues or cover crops) and crop rotation or diversification. Zero or low-tillage systems help build drought resilience by improving soil health, conserving moisture and reducing erosion. CSA, as defined by the Food and Agriculture Organization of the United Nations (FAO), expands on conservation agriculture with a broader framework to address the triple challenge of sustainably increasing agricultural productivity and incomes; adapting and building resilience to climate change; and reducing or removing GHG emissions where possible (Lipper *et al.*, 2014). Scaling up CSA requires strong political commitment, inclusive institutions, supportive policies and access to finance and services for small-scale farmers (Matteoli *et al.*, 2021).

Box 35.2 The UNCCD's drought toolbox

The UNCCD's (United Nations Convention to Combat Desertification) proactive drought management approach is built on three key pillars: monitoring and early warning systems, vulnerability and impact assessments, and risk mitigation through sustainable land management. This approach is used by governments, agencies and communities to anticipate and reduce drought impacts before emergencies arise. The first pillar focuses on continuously monitoring climate, hydrology and water-supply conditions to provide timely information that helps anticipate drought events. The second pillar involves assessing the vulnerability of communities and ecosystems to drought, ensuring that interventions target those most at risk. The third pillar emphasizes risk reduction by promoting sustainable practices such as conservation agriculture, which improve soil health, retain moisture and reduce erosion. Together, these tools form a comprehensive drought toolbox designed to enhance preparedness, reduce impacts and build resilience against increasingly frequent and severe droughts.

Source: UNCCD, 2024.

Protecting the world's disappearing groundwater

Groundwater levels are influenced by increasing water demand and climate change. Rapid declines in groundwater levels (greater than 0.5 m per year) have been widespread in the 21st century, particularly in dry regions with large agricultural areas. Alarmingly, groundwater depletion has accelerated in 30 percent of the world's regional aquifers over the past 40 years (Jasechko *et al.*, 2024). Rising sea levels also cause saltwater intrusion into freshwater aquifers, further degrading water quality.

Groundwater monitoring is challenging due to the complexity of underground systems. Varying soil conditions, irregular flow of aquifers and the long timescales required for data to reflect significant changes complicate accurate assessment. However, technologies such as remote sensing, hydrological modeling, geophysical surveys and real-time data sensors are enhancing monitoring capabilities.

Ground penetrating radar (GPR) is an innovative, non-invasive technology used to monitor groundwater resources and detect contamination of migration pathways. By emitting high-frequency electromagnetic pulses into the ground, GPR creates cross-sectional images of subsurface structures, revealing potential contaminant zones, voids and migration pathways. It is useful for mapping water tables and aquifer characteristics.

> Groundwater depletion has accelerated in 30 percent of the world's regional aquifers over the past 40 years

NASA's unmanned aerial vehicle synthetic aperture radar (UAVSAR) technology uses advanced radar to track underground water movement, detecting surface elevation changes caused by snowmelt recharging groundwater and helping to identify and quantify aquifer replenishment. Satellite-based InSAR and airborne electromagnetic systems (such as the one described in the innovation examples) work together to map underground water pathways to identify recharge locations. The Gravity Recovery and Climate Experiment (GRACE), a joint mission between NASA and the German Aerospace Center (DLR), also works alongside the UAVSAR data to provide tools for monitoring water storage, recharge hotspots, and groundwater movement on both regional and global scales.

Airborne electromagnetic (AEM) surveys are another important geophysical tool for mapping groundwater. This method works by flying an aircraft equipped with a large wire coil that

generates a controlled electromagnetic field. This field penetrates the ground and interacts with subsurface materials, inducing secondary electrical currents whose strength depends on the conductivity of the underlying geology. Sensors on the aircraft measure these returning signals, which are then processed to map groundwater depth, salinity and aquifer structure without drilling.

To manage water scarcity, various storage techniques are being utilized, from rainwater harvesting to large reservoirs and nature-based solutions such as wetlands, which store water and replenish groundwater.

Managed aquifer recharge is a method that boosts and sustains natural groundwater recharge through various techniques such as spreading, recharge or injection. These approaches optimize water storage, enhance water security, restore aquifers, prevent seawater intrusion in coastal areas, stop land subsidence, improve water quality, and support ecosystems reliant on groundwater (IGRAC, n.d.). See also the water conservation and efficiency section in the *Green Technology Book* Adaptation edition.

Efficient water management in cities and at home

A wide array of technologies for efficient water management across communities and households is available. Smart water meters are advanced devices that measure water usage in real-time and transmit data digitally. Cutting-edge innovations feature remote monitoring, IoT integration and predictive analytics, which enable proactive leak detection, dynamic pricing and more precise water management. Household appliances include low-flow toilets, faucets and laundry machines. Water management technologies are addressed in both the *Green Technology Book* Adaptation and Energy editions.

Making every drop count – turning wastewater into water wealth

Recycling wastewater offers a promising solution to combat drought by providing a sustainable, alternative water source for agricultural, industrial and domestic use. Modern water treatment and wastewater reclamation have evolved significantly, improving water extraction, management and treatment for various uses such as drinking, irrigation and industrial processes. The global market for wastewater recovery systems was valued at approximately USD 37.3 billion in 2022 and is projected to reach USD 88.5 billion by 2032, growing at a compound annual growth rate of 9.1 percent (Globe Newswire, 2023). Graywater from baths, showers and sinks can be treated and repurposed for toilet flushing, laundry or garden irrigation. Additionally, industrial process water can be managed in closed-loop systems for temperature regulation or reused through industrial symbiosis. In addition to wastewater, alternative water sources such as brackish water, rainwater and desalinated seawater are increasingly being used, especially in water-stressed regions. Desalination, though energy-intensive and expensive, is vital in areas such as the Middle East that lack freshwater, with innovations aimed at using renewable energy. These are covered in the *Green Technology Book* Adaptation edition.

Zero liquid discharge (ZLD) is an advanced wastewater treatment approach that enables industrial facilities to recover and reuse most water – often over 95 percent – while converting the remaining contaminants into solid waste. Although ZLD significantly reduces freshwater intake and eliminates liquid effluent discharge, it still requires some make-up water and is energy- and cost-intensive, making it most practical in water-scarce regions or where strict environmental regulations apply.

Harvesting water from the air

Around 2 billion people experience daily water stress, with 1.1 billion – mainly in urban slums or remote arid regions – having access to just 5 liters per day (AZoCleanTech, 2024). Emerging technologies offer solutions for producing potable water in water-scarce regions. Fog harvesting provides a sustainable supplementary water source for communities facing chronic or seasonal water scarcity. However, fog collectors are highly dependent on local conditions, working best in places with frequent dense fog, steady winds, and elevated terrain such as ridges or coastal hills where moist air is naturally funneled.

Passive fog harvesting systems use vertical fences of nanoscopic woven mesh to capture microscopic water droplets from fog. These systems yield between 5.3 and 13.4 liters/m^2 mesh per day, depending on factors such as fog moisture content, droplet size, mesh properties, wind speed and the season (AZoCleanTech, 2024). The FogCollector by aqualonis has collected 528 liters of water volume per fog day in Morocco.

> Fog harvesting provides a sustainable supplementary water source for communities facing chronic or seasonal water scarcity

To address contamination from pollutants in the water from fog collectors, researchers have developed polymer coatings with photocatalytically active nanoparticles such as titanium dioxide that break down contaminants when exposed to sunlight. Recent advancements allow the coatings to remain reactive even in cloudy conditions, enabling passive purification.

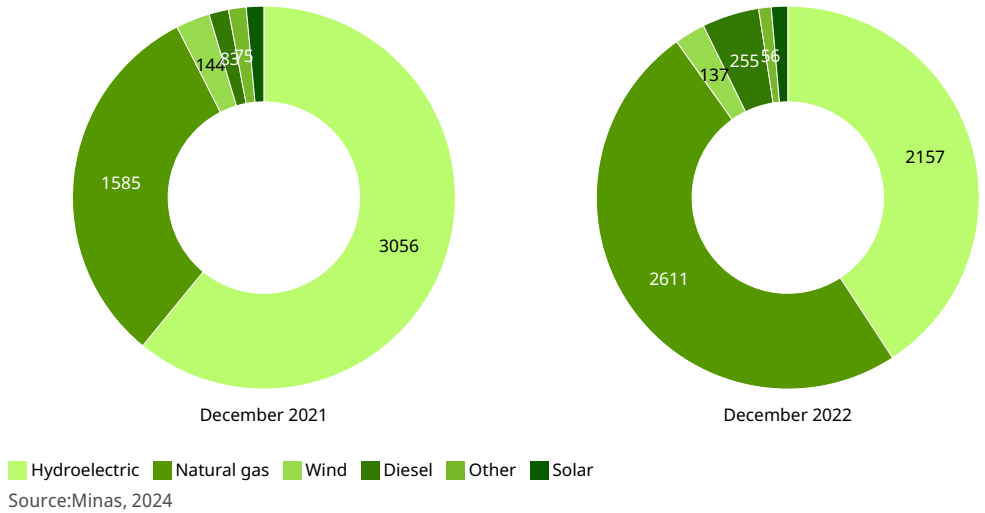
Metal–organic frameworks (MOFs) are highly efficient in capturing water vapor from the air, even in low humidity, due to their porous structures that provide an exceptionally high surface area. MOFs, such as those used in AirJoule® (described in frontier technology solutions), enable atmospheric water harvesting with minimal energy input and reduce reliance on traditional dehumidification methods, which consume more energy and may use climate-harmful refrigerants.

Hydropower in hot water

Droughts reduce water flow and reservoir levels, significantly limiting hydropower generation and sometimes causing shutdowns. This forces increased reliance on costly and carbon-intensive fossil fuels, leading to power disruptions and economic strain in agricultural and industrial operations, and across communities (Montel, 2025a; Shuai *et al.*, 2024).

Regions such as Brazil, Ghana, Peru, Uganda and the western United States have all faced power shortages due to drought-induced hydropower declines, resulting in higher fossil fuel use and emissions (Qiu *et al.*, 2023; Adu-Poku *et al.*, 2024; Ndayishimiye *et al.*, 2022). For instance, Peru's hydropower dropped by 29 percent in December 2022 compared to the previous year, triggering a 76 percent increase in natural gas generation and a 208 percent rise in diesel-based electricity generation, as depicted in figure 6.2 (Minas, 2024), causing rare outages and rising costs.

Figure 6.2 Electricity generation in Peru (gigawatt hours)



Source:Minas, 2024

Advances in hydropower technology, such as more efficient turbines and floating solar panels on reservoirs (that reduce evaporation losses), can maximize energy generation even with reduced water (Shuai *et al.*, 2024; Qiu *et al.*, 2023).

Keeping power flowing when water runs low

Beyond hydropower, droughts also challenge thermal power plants that rely on water for cooling, forcing reduced output or shutdowns to avoid overheating. Reduced water availability lowers their cooling efficiency, which can lead to a decrease in their overall electricity generation. Underground water storage can help maintain cooling supplies during droughts, supporting continued plant operation.

Mitigating these impacts requires diversifying energy sources and modernizing the grid. Incorporating renewable energy technologies (e.g., solar, wind) reduces dependence on hydropower and fossil fuels, bolstering resilience. Pumped storage hydropower, a form of energy storage that uses stored water rather than continuous river flows, improves grid stability by storing excess energy for later use (Shuai *et al.*, 2024).

Smart grids, demand response and energy storage (e.g. batteries) help balance electricity supply and demand during drought-induced stresses. Advanced cooling methods such as closed-loop systems and air-cooled condensers reduce water use in thermal plants (Byers *et al.*, 2020). Unlike hydropower and thermal plants, geothermal energy remains stable during droughts, offering a drought-resistant power source.

Innovation examples

Satellite-powered forecasting system tackles drought in Saint Kitts and Nevis

Source: UNEP/Duncan Moore

Saint Kitts and Nevis, a twin-island Caribbean nation, is becoming more vulnerable to climate change impacts, including drought. With rainfall being the only source of potable water, decreasing precipitation has led to regular water outages affecting 80 percent of the population. This is a recent challenge for Saint Kitts and Nevis, with the first occurrence in 2015. To address this, the United Nations Climate Technology Centre and Network (CTCN), in collaboration with HR Wallingford and the Department of Environment, developed a system that uses satellite and remote monitoring data to forecast droughts and predict groundwater availability. This system generates drought risk maps and provides forecasts to farmers via WhatsApp through the island's Met Office. Extension officers then visit farmers to advise them on optimal planting and harvesting times. This timely information helps farmers better manage water resources and adapt to changing conditions, especially as tourism and housing continue to increase water demand. This technology could also be adapted for use in other regions facing similar climate challenges. While small island nations need over USD 5 billion annually for climate adaptation, scalable tools such as this offer a cost-effective way to build resilience (UNEP, 2025).

Unlocking hidden water: aerial mapping transforms groundwater recharge in California

Source: California Department of Water Resources / Ramboll / SkyTEM

Tulare County, a heavily agricultural region in California's Central Valley, faces severe groundwater depletion due to prolonged over pumping. Declining water tables, dry wells and land subsidence have threatened both farms and communities. Under California's Sustainable Groundwater Management Act, local agencies must achieve aquifer sustainability by 2040 – therefore requiring smarter water storage solutions. AEM, a new underground mapping technology, is helping identify the best locations for storing surplus water. Helicopters equipped with electromagnetic sensors map underground geology, identifying paleo valleys – ancient riverbeds of porous gravel and sand ideal for rapid water recharge. These high-resolution 3D maps allow agencies such as the Tulare Irrigation District to target floodwater capture and groundwater banking precisely. AEM mapping is also being used in Denmark and other countries, where it has helped identify areas with significant water storage potential. In California, the Department of Water Resources has surveyed over 11,000 miles (17,703 km). AEM revealed unexpected aquifer depths and recharge potential in Tulare's Kaweah Subbasin, which shifted pumping limits and guided new recharge projects. However, challenges persist in securing land, funding infrastructure and navigating water rights (Water Education Foundation, 2023).

Recharging the land: the promise of sand dams in Kenya

Source: Africa Sand Dam Foundation

In southeastern Kenya, sand dams are transforming water access in arid regions, especially in villages such as Kasengela. These concrete barriers built across seasonal rivers trap water and sand, creating artificial aquifers that store water during the rainy season, recharge groundwater and minimize evaporation. With only 5 percent of Makueni County's households having access to clean piped water, sand dams have significantly improved water availability. This sustainable solution has also alleviated the long, dangerous water collection journeys once faced by locals. The community-led construction of these dams, supported by organizations such as the Africa Sand Dam Foundation, has resulted in the creation of 680 dams since 2010. The dams also support the environment by revitalizing vegetation and replenishing groundwater, which can lead to the formation of springs and boreholes. The success of each dam, however, depends on factors such as rainfall patterns, soil composition and geological characteristics. The success of these sand dams, while reliant on careful site selection, has caught the attention of the international community as a model of sustainable water management that can be replicated in other drought-prone regions (The African Exponent, 2024).

Smart farming in Cabo Verde: harnessing IoT and AI to tackle drought

Source: Getty Images/Sakorn Sukkasemsakorn

Cabo Verde is adopting emerging technologies such as IoT and AI to address the agricultural challenges caused by recurring droughts. Traditional farming methods in the country, such as rainfed agriculture and terracing, have been limited by arid conditions. To combat this, smart agriculture techniques are being introduced, including wireless sensor networks for soil, weather, and water monitoring, as well as drones for crop growth tracking. These technologies enable farmers to make more informed decisions about irrigation and crop management. A pilot project, led by researcher Sónia Semedo and supported by Primebotics and the Ribeira de São Filipe Producers Association, aims to test these technologies' viability. The project focuses on optimizing agricultural production through smart irrigation systems and AI-driven strategies. It also emphasizes training, with farmers learning to operate drones and utilize the smart irrigation system. Notably, the project has involved female farmers to ensure that solutions meet the needs of all agricultural workers. With initial successes, including a working prototype and training for local farmers, the project is now exploring scalability and future expansion, potentially revolutionizing farming practices in the region (UNDP, 2024).

Proven technology solutions

Laundry water saving: NuTek Ozone Laundry Support System (OLSS)

NuTek International

Source: Getty Images/kjohansen

NuTek's OLSS technology provides water and energy savings as well as sanitation. By using ozone in both wash and rinse cycles, it effectively eliminates 99.99 percent of harmful microorganisms, including antibiotic-resistant bacteria in cold water. Unlike traditional systems that rely on hot water and multiple rinse cycles, OLSS reduces water consumption by using fewer cycles and lower temperatures. Additionally, the system enhances chemical efficiency, lowering chemical usage. The reduced water saturation also results in shorter drying times, further conserving energy. With proven results from third-party tests, NuTek's OLSS provides solutions for healthcare, hospitality, and commercial laundry operations.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO GREEN Database

Water quality: automated microbial measurement system

Vienna Water Monitoring Solutions

Source: Vienna Water Monitoring Solutions

The ColiMinder® CMI-02 is a device designed for continuous, automated monitoring of microbiological water quality in various applications. Available in three versions – the industrial standard, the low-energy, and the portable Emergency Response Unit – it measures microbiological contamination within 15 minutes using enzymatic activity and operates with fully automated sampling, measurement, cleaning and calibration. The system can perform up to 54 measurements per day. The ColiMinder® provides real-time data transfer and visualization and users can receive notifications via email or SMS. It supports up to two sample intakes, with additional options available, and can be remotely controlled. The system enables up to 1,000 measurements without staff intervention, ensuring efficient, remote and continuous monitoring.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Austria
- Availability: Worldwide
- Contact: WIPO GREEN Database

Energy systems: closed circuit cooling tower

Casen

Source: Getty Images/supakitmod

A closed cooling tower is a type of heat exchanger that cools water or process fluid by using air and a heat exchange coil. The KCH series features a multi-modular design with a condensing coil and PVC fill to enhance heat transfer efficiency. In this system, water is circulated over the fill, while air is drawn through it, causing evaporation to cool the water. The process combines evaporative and sensible cooling, reducing scale build-up and minimizing water evaporation. Unlike open cooling towers, which expose water directly to the atmosphere, closed cooling towers recirculate water in a closed loop. This reduces water loss and the need for a constant supply of fresh water, making them more water-efficient. Closed cooling towers are especially beneficial in industrial and HVAC applications, with available configurations such as crossflow and counterflow for different operational needs.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Energy systems: induced draft-air-cooled condenser

ENEXIO

Source: Getty Images/Amorn Suriyan

ENEXIO is the inventor of the air-cooled condenser. Their latest innovation, the InAIR, uses induced-draft fans, commonly found in wet cooling systems, now adapted for dry cooling. They pull ambient air through heat exchange coils, where the air absorbs heat from the hot fluid, cooling it down without the need for water, before discharging the heated air into the atmosphere. This process significantly reduces water usage by eliminating the need for water-intensive cooling towers. Additional benefits include up to 60 percent reduction in steel structure quantities and a 50 percent reduction in steel weight, which could result in a 10–25 percent cost reduction in construction costs. The InAIR also offers shorter delivery and construction periods, along with easier pre-assembly.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Germany
- Availability: Worldwide
- Contact: WIPO GREEN Database

Wastewater treatment: ZLD system

Vifluter

Source: Getty Images/Onuma Inthapong

Wastewater systems typically release some degree of effluent into external water sources. A ZLD system eliminates this problem by removing all suspended solids and converting them into solid waste. This way, the wastewater is treated to the point where it can be reused without causing issues such as clogging or corrosion downstream. Viflter's ZLD system begins with efficient pretreatment, using both physical and chemical methods such as screens, ceramic membranes, emulsion breaking and bag filters to remove large debris and impurities. Next, the system applies state-of-the-art membrane technologies to reduce the level of total dissolved solids and enhance concentration efficiency. This is followed by an evaporation crystallization process, which transforms the concentrated salts into solid waste. Finally, the residual brine is dried to separate any remaining solids from the water, resulting in only solid waste and clear, reusable water.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Household appliance: extremely low-flush toilet

Wostman Ecology AB

Source: Wostman Ecology AB

The EcoVac™ is an innovative toilet that flushes with only 0.2–0.6 liters of water per flush, offering up to 95 percent water savings. This highly efficient toilet can be used by septic tank owners, island residents, or in remote areas, with various tanks, containers or bio-containers. It is also suitable for buses, trains and boats. The vacuum-powered flushing system quickly transports waste into the container, saving both water and energy while maintaining the comfort of a flushing toilet. In a year, the EcoVac™ requires only about 5 kWh of energy, and the septic tank only requires approximately one instance of emptying.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Sweden
- Availability: Worldwide
- Contact: WIPO GREEN Database

Irrigation: driplines for landscaping

Netafim

Source: Netafim

Netafim's Techline family of driplines provides efficient, water-saving irrigation by delivering water directly to a plant's root zone. Unlike sprinklers, which can cause overspray, staining and wasted water, these driplines release water slowly and precisely, preventing evaporation and runoff. The system saves 30 percent to 70 percent of water compared to traditional sprinklers. It promotes healthier, fuller plant growth, reduces plant diseases by keeping foliage dry, and prevents stains on surfaces. The system provides the option to lay the tubing on the ground or bury it beneath the soil. Techline's flexible design adapts to various planting shapes, making it ideal for oddly shaped or hard-to-water areas.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Israel
- Availability: Worldwide
- Contact: WIPO GREEN Database

Water supply and management: Smart metering solution

Telefónica Tech

Source: Getty Images/Martin Prescott

Telefónica Tech's Smart Water supply and management solution optimizes the entire water cycle from collection to wastewater treatment. By integrating Narrowband-IoT water meters, the solution enables remote monitoring, automatic consumption readings, and a 40 percent reduction in leaks, saving 15–20 percent of total water consumption. Designed for public, private and mixed water companies, the solution detects leaks, controls unauthorized consumption and manages water loss efficiently. Its modular and scalable design allows customization for each customer.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Spain
- Availability: Worldwide
- Contact: WIPO GREEN Database

Water supply and management: AEM survey system

SkyTEM

Source: SkyTEM

SkyTEM uses airborne geophysics to map the top 600 m of the subsurface in 3D. Its system measures electrical conductivity (or resistivity) and can also include sensors for magnetic susceptibility and natural radioactivity (potassium, uranium, thorium). Variations in these parameters reveal changes in mineralogy, moisture content, stratigraphy, porosity, and salinity—critical factors for groundwater studies. Airborne electromagnetic (AEM) surveys detect conductivity and resistivity variations to locate aquifers, track water quality, and assess salinity. Magnetic surveys map variations in magnetite content, aiding geological interpretation, while radiometric surveys detect natural gamma radiation to identify soil and rock types. Sensors mounted close to the ground beneath the aircraft capture subtle variations with high resolution, enabling water managers to visualize and manage groundwater resources efficiently and sustainably without invasive drilling.

- Technological maturity: Proven
- Contracting type: For service
- Technology level: High
- Place of origin: Denmark
- Availability: Worldwide
- Contact: WIPO GREEN Database

Frontier technology solutions

Hydrogel: non-synthetic formulations for agriculture

AEH Innovative Hydrogel

Source: Getty Images/Aneduard

AEH Innovative Hydrogel's GelPonics technology, developed with support from Innovate UK's Transforming Food Production challenge, provides biodegradable, hydrogel-based substrates for agriculture. The technology includes soil improver granules, which mix with soil to improve water retention and reduce soil erosion; dry sheets, which are used in propagation trays in controlled environment agriculture, replacing traditional growth substrates such as peat and coir; and plugs, designed for pots and troughs in hydro- and aeroponic systems. The GelPonics products' high-water holding capacity enhances crop resilience in dry conditions, reducing the need for frequent irrigation, and contributing to boosted yields.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United Kingdom
- Availability: United Kingdom
- Contact: WIPO GREEN Database

Water quality: portable microbiological water-testing lab

Roshan Water Solutions

Source: Roshan Water Solutions

VeloCens™ uses a light-addressable potentiometric sensor (an electrochemical sensor technology that detects changes in voltage caused by the presence of target substances) combined with nanotechnology-sensor-based test cartridges to quickly test water for *E. coli* and total coliform within one hour. The nanostructures on the cartridges attract targeted species of bacteria and are highly sensitive to their activity, allowing for on-site, on-demand water quality monitoring. This provides real-time decisions about water safety, significantly improving turnaround time by 18 times compared to traditional methods. VeloCens™ follows stringent protocols, ensuring its performance matches that of standard microbiological lab equipment. All sample data is automatically logged into a cloud data center, offering 24/7 access, where results can be mapped by location and time.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Canada
- Availability: Worldwide
- Contact: WIPO GREEN Database

Early warning and monitoring: UAVSAR system

NASA

Source: Courtesy NASA/JPL-Caltech

NASA's UAVSAR is an advanced airborne radar system that uses differential InSAR techniques to detect tiny ground surface movements – often less than a centimeter – caused by subsurface water activity. By capturing repeat radar images with precision GPS-guided flight paths, UAVSAR monitors groundwater recharge and movement. It has been instrumental in mapping areas of aquifer replenishment, such as California's San Joaquin Valley, and supports groundwater modeling when combined with other data such as AEM readings. Operating across multiple radar bands, UAVSAR provides critical insights into root zone moisture and subsurface changes to support sustainable water management.

- Technological maturity: Frontier
- Contracting type: Not commercially available/for scientific collaboration and application
- Technology level: High
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO GREEN Database

Water supply and management: Smart water metering system using GSM and sensors

HydroIQ

Source: Getty Images/Thomas Faull

HydroIQ SmartGrid is the world's first virtual water network operator, transforming traditional water systems into smart, integrated grids. Using advanced IoT devices, it monitors water consumption, pressure, levels and quality at both the consumer level and throughout the network. This enables predictive maintenance, real-time data analytics and reporting for industrial, utility and smart city projects. HydroIQ's SmartBilling platform allows property managers to remotely monitor, manage, bill and collect payments. Additionally, HydroIQ Snap uses a mobile app to capture precise meter readings, while HydroIQ Pay ensures 100 percent utility bill collection and reduces operational costs by over 90 percent, guaranteeing no revenue loss and eliminating follow-up.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Kenya
- Availability: Guatemala, Kenya, Nigeria, South Africa, Tanzania
- Contact: WIPO GREEN Database

Water supply and management: AI-powered digital platform for industrial water management

Veolia Water Technologies

Source: Getty Images/Acumen86

Hubgrade Water Footprint is Veolia's AI-powered digital platform designed to help industrial clients reduce their water use, energy consumption and carbon emissions. Unlike traditional water audits, Hubgrade provides real-time insights into water operations by combining in-field data, advanced analytics, and Veolia's global expertise. It identifies water wastage events as they occur and offers customizable alerts, ensuring immediate action can be taken. The system estimates true water costs, usage ratios and balances, supporting strategic sustainability planning. In addition, Hubgrade integrates seamlessly with existing water management systems, helping clients optimize water reuse and recycling efforts. Hubgrade began expanding globally in 2024, helping companies meet water neutrality goals and regulatory demands.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: France
- Availability: Worldwide
- Contact: WIPO GREEN Database

Improved crop breeding: speed breeding system

Nexsel Tech

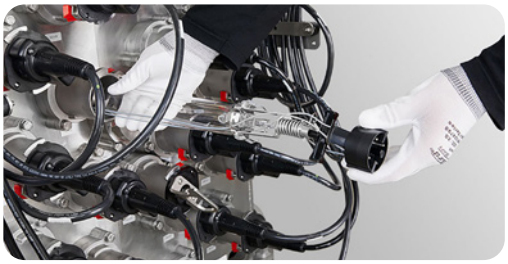
Source: Nexsel Tech

Nexsel has pioneered speed breeding solutions using the 7P control mechanism, which reduces breeding time by up to 60 percent. This advanced technique accelerates plant growth by optimizing seven environmental conditions, shortening breeding cycles for crops such as wheat, rice, cotton and okra. The company offers two types of 7P control speed breeding growth chambers: the portable chamber, designed for developing growing protocols with precise control over environmental parameters, and the walk-in chamber, which provides a comprehensive solution for commercial speed breeding with full control over light, temperature, humidity and CO_2 levels.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: India
- Availability: India, United Arab Emirates
- Contact: WIPO GREEN Database

Water treatment: UV advanced oxidation process (UV AOP)

Trojan Technologies



Source: Trojan Technologies

The TrojanUVFlex®AOP is a UV advanced oxidation solution designed to treat a wide range of contaminants in groundwater and surface water. Its cross-flow lamp orientation improves treatment efficiency, meaning that the water flows perpendicular to the path of the UV light to ensure that the water is exposed to the light more effectively. UV AOP works by using UV light (along with an oxidant) to break down chemical bonds in contaminants such as VOCs, pesticides, by-products, algal toxins and hazardous substances, including 1,4-dioxane, trichloroethylene and cyanide. The system's compact, modular design allows for easy installation and expansion, even in small spaces. Unlike filtration methods such as granulated activated carbon, UV AOP does not physically remove contaminants; instead, it chemically breaks them down, making it highly effective for treating complex pollutants that other methods may miss.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: Canada
- Availability: Worldwide
- Contact: WIPO GREEN Database

Wastewater treatment: modular all-in-one system for gray and black water

Big Red

Source: Getty Images/CUHRIG

Big Red is an all-in-one wastewater treatment system designed to convert black and gray water into recycled effluent for irrigation. It combines all necessary components of a treatment plant into a modular, scalable "plug-and-play" unit that is available for immediate installation in South Africa. The system processes wastewater through a multi-chambered septic tank for solids breakdown, followed by aerobic digestion in a bioreactor, and disinfection with an inline chlorinator. Made from 100 percent recyclable, durable polyethylene, the system can be installed underground, above ground, or containerized for export. It is solar-compatible, and suitable for various settings, including remote areas, schools, clinics and urban environments. The system can handle flow rates from 1 kliter/day to 500 kliter/day, with options for domestic (4–12 people) or commercial use (up to 2,000 people).

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: South Africa
- Availability: South Africa
- Contact: WIPO GREEN Database

Household appliance: water-saving automatic faucet

TOTO

Source: TOTO

TOTO's ECO CAP technology reduces water consumption by aerating the water flow. Their latest generation of touchless faucets, introduced in 2022, uses only 2 liters per minute while still providing a voluminous water flow and a comfortable handwashing experience. TOTO's automatic faucets also feature SELFPOWER technology, which generates energy from the water flow to operate the faucet's sensor, eliminating the need for external power sources or batteries.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Japan
- Availability: Worldwide
- Contact: WIPO GREEN Database

Horizon technology solutions

Improved crop breeding: CRISPR acceleration system

BetterSeeds

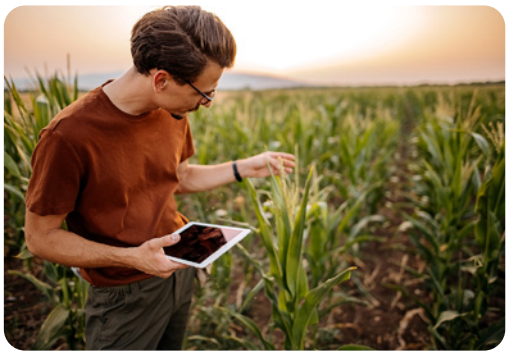
Source: BetterSeeds

CRISPR gene editing is a powerful tool for improving specific crops, but its use is limited by the time and resources required to develop edits for new crops. BetterSeeds is addressing these challenges with EDGE™ (Efficient Delivery of Gene Editing), a system designed to accelerate the process of introducing CRISPR-based traits across a broader spectrum of crops. With EDGE™, the time it takes to incorporate valuable traits – such as drought and heat tolerance – into crops is dramatically reduced, allowing for more rapid advancements. In addition to improving climate resilience, the EDGE™ system can also facilitate the development of crops with enhanced nutritional profiles, better disease resistance and improved yield.

- Technological maturity: Horizon
- Contracting type: Under development
- Technology level: High
- Place of origin: Israel
- Availability: N/A
- Contact: WIPO GREEN Database

Improved crop breeding: non-GMO hybrid wheat technology

Corteva



Source: Getty Images/Stefa Nikolic

In 2024, Corteva unveiled a proprietary non-GMO hybrid wheat technology. While hybrid technology has boosted yields in other crops, wheat has struggled to achieve the same benefits. Corteva's hybrid wheat could increase yields by 10 percent with the same resource usage and improve drought resistance, showing a 20 percent higher yield in water-stressed conditions. This technology also accelerates the development of elite germplasm by scaling up parent seed production. Corteva's hybrid technology is compatible with all wheat germplasm, enabling faster genetic improvements and commercial-scale seed production. The company plans to launch hybrid hard red winter wheat in North America by 2027, offering substantial benefits for farmers and global food security, similar to the impact of hybrid corn.

- Technological maturity: Horizon
- Contracting type: Under development
- Technology level: High
- Place of origin: United States
- Availability: N/A
- Contact: WIPO GREEN Database

Improved crop breeding: salt-tolerant wheat variety/ resilient cereals

OlsAro

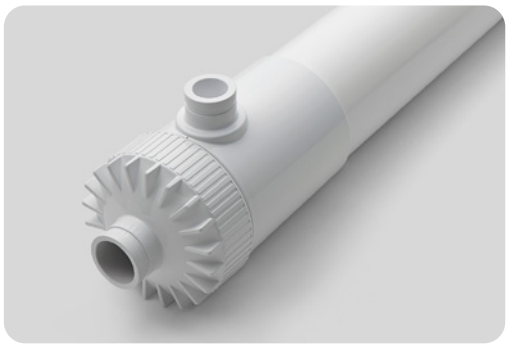
Source: Photo by Francesco Rucci and Francesco Marinelli from the FutureFood project

Swedish agtech startup OlsAro has raised €2.5 million in pre-seed funding to advance its development of climate-resilient wheat varieties. Backed by investors such as Future Food Fund, PINC (Paulig), and AgFunder, OlsAro uses an AI-driven breeding platform to accelerate crop development threefold. AI is used to analyze vast data sets and predict the best genetic combinations. Its first product – a salt-tolerant wheat – boosted yields by 52 percent in saline conditions in Bangladesh, enabling farming on degraded land. With over 830 million hectares of land globally affected by salinity, OlsAro's solution offers farmers new opportunities during dry seasons while supporting local food systems.

- Technological maturity: Horizon
- Contracting type: Under development
- Technology level: High
- Place of origin: Sweden
- Availability: N/A
- Contact: WIPO GREEN Database

Wastewater treatment: high-removal ultrafiltration (UF) membrane

Toray



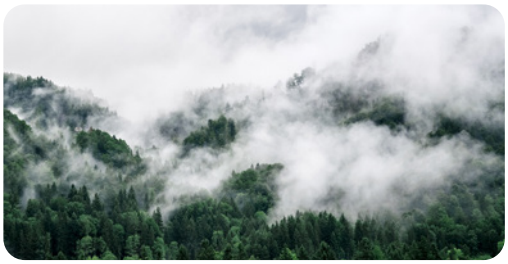
Source: Toray

Toray has developed a high-performance UF membrane that improves wastewater reuse by reducing the strain on reverse osmosis (RO) membranes. This innovation ensures consistent production of high-quality water for applications such as semiconductor manufacturing and potable water production. Featuring sub-10 nm nanopores, the new UF membrane effectively blocks biopolymers commonly found in wastewater, reducing RO membrane contamination. This leads to less frequent chemical cleaning, extending RO membrane lifespans, which lowers operational costs and reduces associated CO_2 emissions by over 30%. Toray's tests show the UF membrane can reduce the decline in RO membrane permeability by one-third. The technology is set for mass production and will launch in North America in mid-2025, followed by expansion into other markets.

- Technological maturity: Horizon
- Contracting type: Under development
- Technology level: High
- Place of origin: Japan
- Availability: N/A
- Contact: WIPO GREEN Database

Water harvesting: fog harvesting and treatment system

ETH Zurich/University of California – Berkeley



Source: Getty Images/EyeEm Mobile GmbH

Researchers have developed a passive system for harvesting and treating fog water, particularly in urban and industrial areas where fog droplets may contain harmful pollutants. The system uses polymer coatings embedded with photocatalytic metal oxide nanoparticles, such as titanium dioxide, to break down pollutants when exposed to sunlight, making the water safe for drinking. Unlike previous systems requiring UV light, this new approach allows the coating to remain active even under cloudy or foggy conditions, functioning similarly to how a battery stores charge. Two types of coatings were tested: hydrophilic (water-attracting) and hydrophobic (water-repelling). The hydrophilic coating proved more efficient at removing contaminants. In real-world tests, the system successfully reduced organic pollutants by over 90 percent, showing effective water collection performance. This method has the potential to be scaled in polluted regions, though challenges remain in adapting it to different types of air pollution.

- Technological maturity: Horizon
- Contracting type: Under development
- Technology level: High
- Place of origin: Switzerland
- Availability: N/A
- Contact: WIPO GREEN Database

Part 3: Extreme temperatures

Photo: Getty Images

As climate change intensifies, the world faces increasingly deadly heatwaves and cold snaps, demanding innovative solutions to protect lives, infrastructure and economies. New technologies are emerging to combat these extremes, from reflective roofs and wearable heat sensors to ultra-insulated building materials and precision frost protection for agriculture. While cities deploy smart ventilation, cooling centers and heat-resistant urban design, communities in cold regions rely on Arctic-ready electric vehicles (EVs), self-regulating heaters and winterized energy grids.

The chapters in this section explore these solutions, highlighting how technology is reshaping our ability to confront a world of rising temperatures and unpredictable freezes. From lifesaving early warning systems to energy-efficient cooling and heating innovations, these advances bolster resilience in an era of climatic extremes.

Extreme heat

Innovative cooling technologies combat extreme heat through urban and infrastructure solutions. Reflective cool roofs and permeable pavements reduce urban heat islands, while misting systems lower outdoor temperatures. Buildings integrate thermal mass materials, green roofs, and smart ventilation. Wearable sensors monitor worker heat stress in real-time, and AI-enhanced early warning systems target vulnerable populations. Community cooling centers and mobile apps provide heat relief, complemented by emergency backup systems during power outages.

Technological developments and trends

As heat extremes escalate, the need for smarter and more equitable solutions is becoming urgent. Traditional responses such as alerts, shade and hydration are no longer sufficient. Innovation is now central to building heat resilience, driving new solutions that help cities, communities and individuals identify and apply measures that prevent or reduce extreme heat risk before it manifests as heat shock. From construction materials design to wearable devices that detect early signs of heat stress, to satellite-driven heat-risk maps, technology is transforming how we understand, forecast, respond and adapt to, and survive extreme heat.

Innovation also supports inclusivity and equity, providing scalable, low-cost solutions for vulnerable populations who bear the greatest heat burden. Across sectors, innovators are integrating climate data, human and ecosystem health information, digital platforms, advanced materials, smart infrastructure and behavioral science to redefine responses to extreme heat. These solutions go beyond the purely reactive – they are preventive, dynamic and increasingly tailored to specific needs of different populations and environments.

The overlooked crisis of extreme heat in a warming world

As the planet warms, billions are being exposed to increasingly deadly extreme heat that strains economies, disrupts public health and education services, damages energy and transportation systems and threatens global development goals and the ecosystems upon which we depend. With over 489,000 deaths per year from heat-related causes and 2.41 billion workers exposed to excessive heat (Flouris *et al.*, 2024), resulting in heat- exposure-related potential income loss of USD 835 billion, this can no longer be ignored; it demands deep shifts in how we design and manage society.

With this in mind, the UN Secretary-General (UNSG) issued a Call to Action on Extreme Heat to combat the wide-ranging and growing threat of extreme heat. The UNSG's Call, developed with 10 UN agencies, urges global action in four key areas: protecting vulnerable people, safeguarding workers, strengthening resilience through science and data, and limiting warming to 1.5 degrees Celsius (°C) by phasing out fossil fuels and accelerating renewable energy (United Nations, 2024).

Following the record-breaking heat of 2024, scientists now project that global temperatures could rise nearly 3°C by the year 2100 if greenhouse gas emissions aren't drastically cut. Notwithstanding the risk of ecosystem collapse in some of our most precious biomes, it is cities that will bear the brunt of this warming. Due to heat-trapping urban features such as extensive pavement and limited green space, urban areas could experience an additional 1°C of localized heating, placing more than 4 billion city dwellers at heightened risk (Engel *et al.*, 2025). At the same time, population growth is pushing more people to live and work in areas vulnerable to high temperatures, increasing their exposure and placing greater strain on health systems, ecosystems and infrastructure (G20 DRR Working Group, 2025).

The challenge of heat stress is further compounded by fragmented institutional responsibilities, as heat impacts span across sectors such as health, labor, environment, energy, transportation and infrastructure – making coordinated action difficult. This urgent need to build robust, evidence-based governance approaches that mitigate heat risk holistically was the motivation behind the work of the United Nations Office for Disaster Risk Reduction (UNDRR), the Global Heat Health Information Network (GHHIN), World Meteorological Organization (WMO), World Health Organization, and national and international experts building integrated approaches to extreme heat-risk governance (UNDRR, 2025b).

Heatwaves: silent killers on the rise

A heatwave can be defined as a period where local excess heat accumulates over a sequence of unusually hot days and nights and can last from several days to months (WMO, 2025b). While the tendency is to focus on extreme heat incidence, the consequences of chronic heat (on public health, education, crop yields, etc.) are often less well understood or possibly even overlooked.

Heatwaves have earned the name "silent killers" because their deadly toll unfolds quietly and in a dispersed fashion across various locations, and through time. In recent years, they have expanded into new regions while also occurring at unexpected times of the year. With global warming, these extreme heat episodes are becoming more common and lasting much longer (IFRC Climate Centre, 2025b). Entire summers are now more likely to be defined by prolonged heatwaves, which can cause thousands of deaths from heat-related illnesses such as exhaustion, heatstroke and dehydration – especially among the elderly and those with pre-existing conditions. Even a 1°C temperature increase can raise mortality by 2–5 percent (Yazdani and Haghani, 2023).

> Heatwaves have earned the name "silent killers" because their deadly toll unfolds quietly and in a dispersed fashion across various locations, and through time

High-profile examples have illustrated this deadly trend: over 35,000 people died during the 2003 European heatwave (Hintz *et al.*, 2018), while China endured a record-breaking 70-day event in 2022. More recently, the 2025 European heatwave has triggered red alerts across multiple countries, setting records in Serbia and Slovenia (IFRC Climate Centre, 2025a). Meanwhile, over 4 billion people globally endured at least one extra month of extreme heat during the year prior to June 2025 (IFRC Climate Centre, 2025b). In many regions, homes lack cooling systems, leaving vulnerable residents at risk. Traditional emergency responses, such as assigning home visits by nurses, often fall short when demand surges – highlighting the need for scalable solutions such as relocation to designated cooling centers, despite their logistical complexity (Yazdani and Haghani, 2023).

Cooling the concrete jungle: battling the urban heat island

An urban heat island (UHI) occurs when cities experience significantly higher temperatures than surrounding rural areas due to dense buildings, asphalt, and limited green space (National Geographic, 2024; Yazdani and Haghani, 2023). In some cases, temperatures can be up to 10°C hotter. Three main factors amplify UHIs: urban geometry (tall, closely packed buildings), human and human-caused heat emissions, and heat-retaining urban materials. Lack of vegetation and water further worsen heat, while greenery can help cool neighborhoods. Though well-studied, UHI patterns vary by city and climate, and predicting future changes remains complex. Urbanization and climate-driven heatwaves will continue to increase heat risks, making cities hotter and more vulnerable (IPCC, 2021).

To combat the UHI effect, cities use passive cooling techniques such as cool roofs, shading and cross-ventilation. Cool roofs that are made with reflective materials or light colors reduce solar heat absorption, lowering indoor temperatures and energy use. Similarly, permeable pavements reflect heat while managing stormwater. Urban greening, including tree planting, creating mini-forests and shading parks, lowers temperatures through shade and evapotranspiration while also improving air quality (UNDRR, 2025b). Despite being highly effective, shade structures in parks remain underused in many United States (US) heat plans. Encouragingly, more cities are starting to integrate these strategies: Boston has implemented green roofs on City Hall and schools, while New York and Toronto use heat vulnerability maps to prioritize urban cooling efforts. Research shows that combining multiple cooling methods delivers the most effective results.

See Box 7.1 for a discussion and comparison of projected urban heat impacts in European cities at 1.5°C vs. 3°C warming.

In addition to infrastructure, affordable cooling solutions such as shaded windows, rooftop gardens and solar-powered fans can reduce reliance on air conditioning (AC). Strengthening energy policies – through tiered pricing, subsidies and renewable energy adoption – helps protect vulnerable populations. Community engagement via heat awareness campaigns, cooling centers and local partnerships is equally critical. For instance, Ahmedabad's "Cool Roofs" Program targets vulnerable groups through coordinated agency efforts, financing mechanisms and workforce training (AMC, 2019). See the *Green Technology Book* adaptation edition (cities chapter), mitigation edition (cities chapter), energy solutions edition (green urban energy solutions chapter), and EXPO25 special edition on energy solutions in the Asia-Pacific region (green urban energy solutions chapter) for further discussion on UHI solutions.

Box 7.1 The toll of warming on Europe's cities

Europe is the world's fastest-warming continent: at 1.5°C of warming, European cities would face challenging but manageable heat impacts, with Naples experiencing 25-day heatwaves and modest increases in cooling demand. However, as depicted in table 7.1, at 3°C, these impacts become severe and unmanageable: heatwaves in Naples would double to 50 days, southern cities would endure month-long extreme heat periods, and cooling demand would surge by 32 percent (reaching 60 percent in Barcelona) (WRI, 2024a). Northern cities like Amsterdam would face unprecedented 42°C temperatures, while Istanbul would see 40 percent more hot days above 29°C. The higher scenario would also dramatically worsen urban inequality, as low-income areas with limited cooling infrastructure and green spaces bear the heaviest burden (WRI, 2024a). This stark comparison shows how crucial it is to limit warming to 1.5°C to avoid catastrophic urban heat consequences.

Table 7.1 Estimated climate impacts on Europe's largest cities at 1.5°C and 3°C scenarios of global warming

	1.5°C	3°C	Percent change
Annual longest heatwave duration	15	20	(+) 32%
Annual number of days with high temperature at or above 35 °C	4	6	(+) 53%
Cooling degree days	142	187	(+) 32%

Source: WRI, 2024a

Protecting workers from heat stress

Protecting outdoor workers from extreme heat is increasingly urgent, as thousands die annually from heat-related illnesses. In 2020, 4,200 workers worldwide died from heatwaves, and 231 million were exposed, a 66 percent increase since 2000. The International Labour Organization (ILO) warns that more workers are being exposed to heat stress. Workers in Africa, the Arab states and Asia and the Pacific are most often exposed to excessive heat – where 92.9 per cent, 83.6 per cent and 74.7 per cent of the workforce are affected, respectively, compared to a global average of 71 per cent, according to the most recent figures available (2020). In its 2024 report, the ILO reported that between 2000 and 2020, Europe and Central Asia saw the fastest rise in excessive heat exposure for workers, increasing by 17.3 percent, nearly double the global average. The Americas and Europe/Central Asia also experienced the largest jumps in heat-related workplace injuries, up 33.3 percent and 16.4 percent respectively. Notably, most heat exposure and related injuries occur outside official heatwaves (Flouris *et al.*, 2024).

> Advanced wearable heat-stress sensors, cooling vests and environmental monitoring technologies provide real-time, non-invasive tracking of core body temperature, heart rate and hydration

Basic strategies to reduce heat danger include ensuring access to water, shade and rest breaks, promoting gradual acclimatization, and raising awareness about heat illness symptoms. Personal protective equipment (PPE) should be used only when other heat-stress controls aren't possible. Simple PPE is often more practical and cost-effective. Advanced cooling PPE – such as liquid-cooled or phase-change garments – can help but don't always prevent overheating (i.e., rising core body temperatures) and can be uncomfortable. While liquid cooling offers strong protection, phase-change vests or ice packs are usually more practical and affordable options (Flouris *et al.*, 2024).

As featured in the technology solution sections, advanced wearable heat-stress sensors, cooling vests and environmental monitoring technologies provide real-time, non-invasive tracking of core body temperature, heart rate, hydration and heat-stress indicators to protect workers from heat-related illnesses. Emerging wearable technologies, or "wearables," are developed to monitor core body temperature and detect early signs of heat stress – crucial since traditional skin temperature readings (such as those from consumer smartwatches) don't accurately reflect internal heat risk.

The US military leads this field with an algorithm, tested on 14,000 soldiers, that uses heart rate, skin temperature and movement to estimate the risk of heat-related illness (Swartz, 2025). This technology is now being adapted for public use. Companies such as Epicore have

introduced patches and sensors that track hydration and core temperature, while Sony's REON Pocket Pro offers localized cooling. By combining sensors, artificial intelligence (AI) algorithms and smart alerts, they enable early detection of dangerous heat strain and fatigue for workers across diverse industries such as mining, construction, manufacturing and emergency services. Many devices also integrate additional safety features such as lone-worker protection, helping organizations improve productivity and overall workplace safety.

Some tools still require more real-world validation to prove their effectiveness in preventing heat illness on worksites or in daily life (Swartz, 2025). The ILO finds that urgent targeted research is still needed to fill knowledge and policy gaps on heat stress. Importantly, heat-related illnesses are often under-reported, so standardizing data collection and reporting systems is essential to build comprehensive databases. At the workplace level, developing and evaluating new technologies – especially AI-driven alerts and cooling methods – is critical; however, these methods must meet the challenge of balancing practicality and cost for low-resource settings (Flouris *et al.*, 2024).

When heat won't let up: keeping cool in homes and communities

A multitude of home-cooling solutions helps people manage and survive extreme heat by enhancing personal hydration, improving air circulation and providing targeted cooling comfort. Hydration products such as Liquid I.V. use electrolyte mixes to quickly replenish fluids, while portable fans – handheld, neck, clip-on or stroller models – provide personal cooling on the go. Innovative cooling pillows and mattresses incorporate adjustable firmness and cooling technology to regulate temperature during sleep. For rapid relief, micro-cooling chairs circulate ice water to lower body temperature. Additionally, cooling fabrics and wearables help reduce core body temperature and boost endurance without chemicals.

Likewise, urban heat-management efforts, including heat-risk mapping and accessible cooling centers, complement these personal solutions by guiding people to cooler locations and safer routes. Heat-risk mapping involves combining environmental data such as temperature variability and urban heat islands with social and demographic information (e.g., age, income, housing quality) to identify populations most vulnerable to extreme heat. These maps – known as heat-vulnerability maps – visualize heat-vulnerability indices and help cities identify hotspots where residents face the greatest health risks during heatwaves. Several cities have developed public interactive heat-risk maps linked with the locations of cooling centers and safe spaces.

Digital platforms use these maps to inform authorities and the public, often including multilingual, mobile-accessible features that help users find nearby cooling centers, shaded areas, water fountains and spray parks. They can be multilingual and mobile-accessible. Crowdsourcing tools collect real-time user data on temperatures, personal heat experiences and resource availability (i.e., whether a cooling center is crowded or open). Apps such as Extrema consolidate these services, providing heat-risk notifications and safety alerts to users and their loved ones. Many platforms now also offer route planning for pedestrians or public transit users that prioritizes shaded streets, tree canopy cover and proximity to water fountains and cooling centers known as "cool routes" to reduce heat exposure during travel. Additionally, cities use satellite imagery, drones and AI to map tree cover and urban shade, guiding tree planting and green infrastructure projects that enhance cooling and improve air quality.

Cooling centers bring relief but AC is not a silver bullet

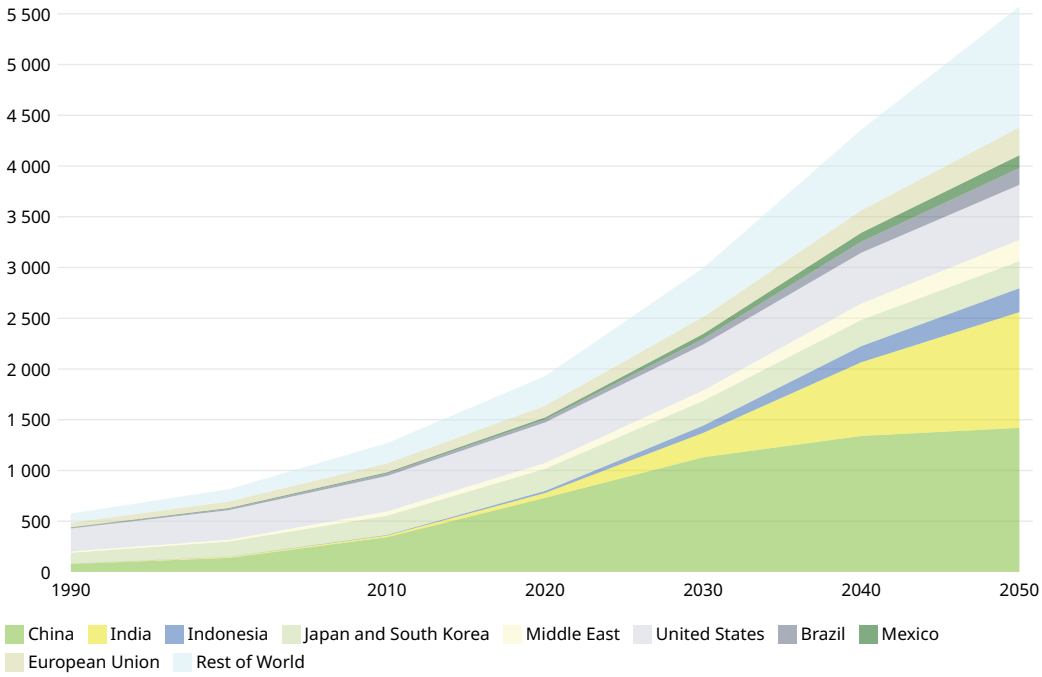
A *cooling center* is a designated air-conditioned or cooled location where people can find relief and safety during extreme heat. These centers can include government buildings (such as libraries or schools), community or religious centers, private businesses (such as shops or malls), and outdoor sites such as spray parks or pools. Temporary cooling spaces may also be set up for special events such as marathons or concerts (GHHIN, 2023).

They are a widely used, cost-effective way to provide relief from extreme heat, especially for low-income populations who may lack or avoid AC due to high electricity costs. They are often part of broader heat health warning systems (HHWS), which include alerts, public communication and emergency measures tailored to local needs. HHWS have been proven to reduce heat-related deaths.

It has been shown that spending time in cool environments, especially with AC, significantly reduces heat-related illness and death, with studies showing up to a 66 percent lower risk of mortality for those who use air-conditioned spaces during heatwaves (GHHIN, 2023). According to the International Energy Agency, annual AC unit sales nearly quadrupled between 1990 and 2016, reaching 135 million (Jay *et al.*, 2021). The projected number of AC units globally to 2050 is shown in figure 7.1. The total number of AC units is slated to increase sharply after 2020, with China and India being the two countries with the most units.

However, AC is not a sustainable long-term solution. It is expected to become the most widely used strategy for coping with heat worldwide, yet it remains inaccessible to many vulnerable populations, is highly energy-intensive, financially and environmentally costly, and can fail during power outages. A rapid increase in AC creates a self-reinforcing cycle: as the climate warms, demand for cooling grows, which – depending on how electricity is generated – can further contribute to climate change (Jay *et al.*, 2021).

Figure 7.1 Projected number of air conditioning units to 2050 (in million units)



Source: IEA, 2018

Super-efficient AC can drastically cut energy use

Innovation is improving the efficiency of AC units. Super-efficient ACs, optimized for real conditions with high-efficiency components, provide better dehumidification and comfort while being more energy efficient. A Global Cooling Efficiency Accelerator study in Palava City, India, tested super-efficient AC prototypes, finding they use 60 percent less energy than typical models while improving comfort and reducing peak demand. The study also revealed that current testing standards underestimate AC energy use in humid climates, highlighting the need for updated evaluation methods that account for humidity and user behavior (RMI, 2025).

Startups are developing technologies that significantly reduce energy use and environmental impact, including using liquid desiccants to reduce AC energy consumption, materials that remove humidity before cooling, and solid-state thermoelectric systems without refrigerants or moving parts. Other innovations use compressor-free, refrigerant-free designs with novel materials to lower power demand (ibid.). For more heating, ventilation and air conditioning (HVAC) technologies, see the Green Technology Book Adaptation edition (cities chapter), mitigation edition (cities chapter), energy solutions edition (green urban energy solutions and essential services chapters) and the EXPO25 special edition (green urban energy solutions and key service sectors chapters).

Mist, fog and ancient wisdom provide urban refreshment

Mist and fog cooling systems provide efficient, energy- and water-saving outdoor cooling by releasing ultra-fine water mist that lowers air temperature by up to 10°C. These systems work by turning water into an ultra-fine mist using high-pressure technology. As the tiny droplets evaporate, they absorb heat from the air, a process known as adiabatic cooling, which lowers the surrounding temperature (Raintime, 2024b). In parks, public squares and outdoor dining areas, misting systems create more comfortable microclimates where people can enjoy being outside, even during heatwaves. This is especially important for vulnerable groups such as the elderly and young children. Beyond comfort and safety, misting systems also consume much less energy than traditional AC (and some can even be powered by renewable energy). Additionally, the mist helps to remove dust and pollutants from the air, improving air quality.

In Seville, Spain, Cartuja Qanat is an innovative open-air public space erected in 2022, designed to combat rising urban temperatures. It uses ancient qanat cooling systems, tunnels dug to bring water to agricultural fields that were first documented in the present-day Islamic Republic of Iran 1,000 years ago. The Persians realized that the running water also cooled the air in the canals, so they built vertical shafts to bring that air to the surface through passive ventilation driven by wind pressure. By lowering ambient temperatures, the space offers a climate-resilient model for urban design. The project showcases how traditional knowledge and innovative design can come together to fight climate change in cities (Urban Innovative Actions Initiative, 2022; The Energy Mix, 2025).

Designing buildings to beat the heat

Buildings can reduce indoor heat through material and design choices. High-thermal-mass materials such as concrete, stone or earth absorb and gradually release heat, while insulation such as polystyrene and polyurethane foam helps reduce heat transfer. Breathable and sustainable options such as hempcrete or bamboo improve airflow, especially when paired with shading, sealed exteriors and smart ventilation systems (Sastry and Bhatt, 2025). These building modifications represent key adaptation strategies that enable occupants to better withstand rising temperatures without solely relying on energy-intensive cooling technologies.

> Insulation such as polystyrene and polyurethane foam helps reduce heat transfer

Cool-roof strategies vary depending on context and can be grouped into five main types (Sastry and Bhatt, 2025):

1. *Coated cool roofs:* Reflective paints (e.g., lime wash, acrylic) applied to existing surfaces.
2. *Membrane cool roofs:* Prefabricated reflective sheets made from polyvinyl chloride or bitumen.
3. *Tiled cool roofs*: High-reflectivity tiles or shingles installed over existing or new roofs.
4. *Alternative materials:* Options such as ModRoof, made from coconut husk and paper waste.
5. *Green roofs:* Vegetation-covered rooftops that reduce heat but can be cost- and water-intensive.

Choosing the right solution depends on roof type, cost, labor and maintenance needs. Especially when integrated with passive design, these strategies help buildings stay cool, reduce reliance on AC, and support broader urban heat resilience goals. For more detailed design and retrofit strategies, see Box 7.2.

Box 7.2 Key strategies to reduce heat absorption in buildings

Using mechanical or natural ventilation and materials with high thermal mass can reduce reliance on AC. Coupling cold storage with heat pumps, including geothermal systems, increases cooling flexibility. Indoor humidity control also improves thermal comfort. These combined measures reduce heat entering buildings and urban spaces, improving comfort and reducing cooling energy needs.

- *Windows and skylights:* Limit window size on east and west sides; avoid skylights or use alternatives; use windows with low solar heat gain; provide exterior shading (e.g., overhangs, shutters) and interior shading; ensure proper installation and air sealing.
- *Attics and roofs*: Use high insulation and air sealing; design for effective attic ventilation; install radiant barriers; choose reflective roof materials/colors; avoid placing ducts or HVAC in unconditioned attics; air seal all penetrations; avoid recessed lights in ceilings exposed to attic.
- *Walls:* Use high insulation with techniques that reduce thermal bridging (such as insulated panels); minimize unshaded east/west walls; select reflective exterior finishes; opt for compact house designs to reduce surface area; incorporate vegetative (green) walls to provide shading, evapotranspirative cooling and added insulation.
- *Foundations:* Air seal sill plates, rim joists and penetrations in foundation walls.
- *Site and landscaping*: Plant trees and vegetation to shade windows, roofs and pavements; avoid large unshaded concrete or asphalt areas; use light-colored, reflective pavements; encourage water retention with permeable landscaping.

Emergency cooling: simple techniques are surprisingly effective

In the face of extreme heat and increasingly frequent power outages, emergency cooling is becoming a critical consideration for home safety and comfort. Both full AC systems and passive cooling methods keep indoor temperatures low and maintain systems at a level low enough to be supported by backup sources such as batteries or generators. Emergency cooling often relies on existing HVAC systems, often complementing their use with simple strategies such as using fans and shading.

Mechanical AC remains the most direct method for emergency cooling. Full systems can be used, alongside smaller units such as mini-splits, window units or portable AC units. These systems also use less electricity, rendering them useful during outages. An energy recovery ventilator improves indoor air quality and reduces HVAC energy use by exchanging heat and moisture between incoming fresh air and outgoing stale air, making it especially effective in air-conditioned homes in warm, humid climates. Unlike traditional systems, ground-source heat pumps rely on the stable temperatures underground, performing better during extreme heat (DOE, 2022). However, they do require site-specific planning and installation. In dry climates, evaporative coolers are an effective and energy-efficient solution. Passive strategies, such as opening windows at night, using ceiling fans or designing with thermal mass (covered above), can be very effective without requiring any electricity at all.

> Emergency cooling is becoming a critical consideration for home safety and comfort

For emergencies, backup power systems are essential because grid failures often occur due to high demand during heatwaves. Generators or battery systems can meet needs, but loads must be prioritized, including refrigeration and lighting. Reducing the load on both the grid and the backup system can be done by choosing efficient appliances, shading windows or isolating a “cool room” within the home. A cool room is a simple, budget-friendly refuge during extreme heat that can improve survival during power outages by isolating the home’s naturally coolest space (DOE, 2022).

Innovating heat early warning systems: technology, equity, and integrated action

In February 2023, the Global Heat Health Information Network convened experts from around the world to discuss scaling heat health early warning systems (HHEWS), aligning with the goals of the global Early Warning For All (EW4All) initiative. The roundtable emphasized the urgent need to prioritize vulnerable populations who bear the greatest risks from extreme heat. Participants highlighted the importance of integrating social science and behavioral insights to tailor warning messages that resonate locally. The discussions also stressed the importance of cascading risk awareness to coordinate messaging and interventions during overlapping crises such as floods or pandemics. Crucially, the experts called for a shift from ad hoc, one-off risk responses toward building durable, community-based systems with multi-sectoral collaboration (GHHIN, 2023).

Developed countries such as Canada, the United States of America and several European nations have advanced heat warning systems integrating health data, behavioral models and real-time monitoring. The US National Weather Service issues heat-index-based alerts 3–7 days in advance via multiple platforms. Canada's Heat Alert and Response Systems combine forecasts with community protocols and cross-sector data sharing. Europe's HHEWS provide multi-day heatwave forecasts and vulnerability mapping to aid government preparedness. Germany uses a biometeorological model that accounts for urban heat islands, nighttime temperatures, and population acclimatization over 30 days, generating highly localized risk-based alerts (Matzarakis, 2024). France's Météo-France operates a color-coded vigilance system triggering public health actions, while Italy has used real-time heat-mortality risk modeling since 2004 (EEA, 2024). India's Heat Action Plan, pioneered in Ahmedabad, pairs meteorological forecasting with public health campaigns and cooling centers, serving as a model for rapidly urbanizing and vulnerable populations.

Innovation examples

Using weather forecasts to predict heat stress and protect workers in Europe

Source: HEAT-SHIELD

The HEAT-SHIELD project, funded by the European Union (EU), created Europe's first web-based heat stress warning platform to protect workers from extreme heat. Using data from the European Centre for Medium-Range Weather Forecasts, the platform provided weekly and monthly forecasts of heat stress risks across the continent. It mapped the likelihood of temperatures exceeding 27°C WBGT (Wet Bulb Globe Temperature), a key measure of heat stress. Anyone could access general heat forecasts on the website, while registered users received personalized advice tailored to their specific workplaces and needs. This included recommendations on clothing, hydration, and work/rest schedules to help prevent heat-related illness. The platform also sent email alerts about upcoming heat risks, giving workers, employers, and stakeholders time to plan preventive actions (Flouris et al., 2024). Although the HEAT-SHIELD project is currently inactive, it demonstrated a pioneering approach to combining scientific data with practical occupational health guidance. Its methodologies have been adopted and expanded within other international projects and tools (see e.g., ClimateCHIP) that continue to address workplace heat stress (Kjellstrom, 2025).

Saving the lives of workers on sugarcane fields in Nicaragua

Source: Ed Kashi/Talking Eyes Media

The Adelante Initiative, launched in 2017, tackles extreme heat risks faced by sugarcane workers in Nicaragua. Partnering with Ingenio San Antonio and Bonsucro, La Isla Network created a heat stress prevention program combining simple yet effective technological and logistical measures across a vast 75,000-hectare plantation. Key components include mandated breaks supported by mobile shaded tents, ensuring accessible rest spots equipped with purified water and isotonic drinks to maintain hydration and electrolyte balance. Sanitation facilities were added to accommodate increased fluid intake safely. The program's backbone is the PREP methodology—Prevention, Resilience, Efficiency, and Protection. It uses physiological data and heat exposure assessments to design tailored interventions that safeguard health without reducing productivity. Real-time monitoring of heat exposure and health outcomes guided ongoing adjustments (Flouris *et al.*, 2024). In just three years, the Adelante Initiative reduced acute kidney injuries by 94% in managed groups and by 72–80% mill-wide, eliminated fatal heat stroke, boosted worker productivity by 9–19% across working groups, and achieved a 60% return on investment by cutting accidents and absenteeism (Schlader *et al.*, 2025). Today, the initiative stands as a model—which La Isla Network calls the Center of Excellence—for protecting outdoor workers from extreme heat using practical technology and management strategies. La Isla Network's ambition is to create similar Centers of Excellence across industries worldwide, enhancing worker safety and boosting economic productivity (Flouris *et al.*, 2024)

Beating the city heat: Vienna's tech-driven urban refresh

Source: © raintimegmbh

Raintime has helped transform Vienna's Praterstern from a concrete-heavy traffic hub into a refreshing urban oasis, featuring 8,000 m2 of green space and 101 trees. At its heart lies a 500 m2 star-shaped water feature inspired by the original Praterstern design. This unique installation uses temperature-responsive water jets, sprinklers and foggers to cool the area, creating a pleasant microclimate that can be adjusted or turned off as needed. The project applies the "sponge city" principle, directing rainwater and water from the feature into the ground to nourish the trees and improve urban water management. The key technological highlight is the Raintime "Dry Mist" fog cooling system, which atomizes water into microscopic droplets via high-pressure nozzles (Raintime, 2024b;). These droplets evaporate quickly, extracting heat from the air and producing an efficient, eco-friendly cooling effect. The system conserves water and electricity, offering a sustainable way to cool public spaces in the face of rising urban temperatures. This approach has proven effective in other global projects such as the Singapore Pavilion at Expo 2020 Dubai (Raintime, 2024b;).

Cooling Freetown with low-cost and scalable urban heat solutions

Source: Getty Images/Abenaa

Freetown, the capital of Sierra Leone, faces extreme urban heat due to its tropical climate and the widespread use of heat-trapping building materials such as corrugated metal. With 99 percent of the city's structures made from low-reflectivity surfaces, average summer temperatures are about 29°C. To respond, the city has begun adopting innovative technologies. Under the leadership of Africa's first Chief Heat Officer Eugenia Kargbo in 2021, Freetown introduced heat-reflective shade structures across three major open-air markets. Made from plexiglass designed to reflect solar radiation, these structures also integrate solar panels that power nearby streetlights and extend working hours for vendors. Another key initiative is the deployment of cool-roof technologies. In the informal settlement of Kroo Bay, a pilot program is applying reflective coatings to 55 metal rooftops. This simple solution reduces indoor temperatures by reflecting sunlight, providing immediate relief to residents. These low-cost innovations highlight how targeted technology can reduce heat exposure in vulnerable communities (UNDRR, 2025b).

Proven technology solutions

Worker heat-stress prevention: wearable heat-stress monitor

Evalan

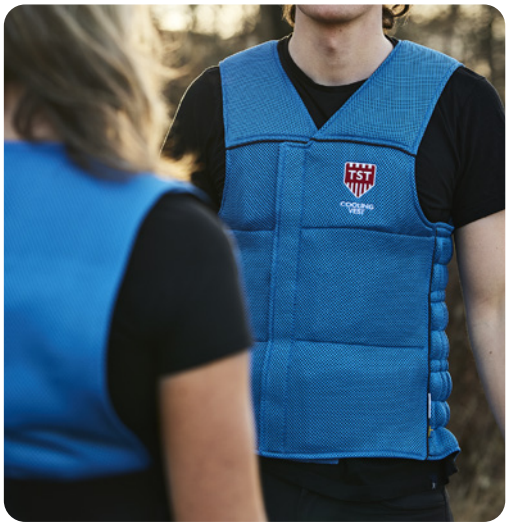
Source: Getty Images/martin-dm

ARMOR is a non-invasive heat-stress monitoring solution to protect individuals in physically demanding roles such as military personnel, athletes, firefighters and industrial or agricultural workers. It measures heart rate and estimates core body temperature and physiological strain index (PSI) using the patented ECTemp algorithm developed by the US Army. The system consists of an optical heart-rate sensor, a compact transmitter device and a mobile app that gives supervisors real-time insights into each user's heat exposure levels. The app displays estimated core temperature and PSI using a customizable color-coded risk scale and issues alerts when heat strain reaches dangerous levels. Designed for group use, ARMOR comes in sets of up to 25 devices with a centralized charging case.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Kingdom of the Netherlands
- Availability: Kingdom of the Netherlands
- Contact: WIPO GREEN Database

Worker heat-stress prevention: cooling vest

TST Sweden



Source: TST Sweden

The Cooling Vest is designed to reduce the risk of heat stress and dehydration – a growing challenge in industrial, emergency, and outdoor work under high-heat conditions. Unlike traditional ice vests that expose the body to extreme cold, the Cooling Vest provides gentle, safe, and consistent cooling. As body or surrounding temperatures rise, the cooling elements absorb excess heat, helping the wearer remain within their optimal performance zone without feeling cold. The vest provides up to 90 minutes of effective cooling at 60 °C / 140 °F or up to 4 hours at 45 °C / 113 °F. The technology behind the cooling elements is a phase-change material that activates at 28 °C / 82 °F. The elements recharge without any external energy source – in a room at 22 °C / 72 °F they recharge within 2–3 hours, and in a freezer within just 5–10 minutes.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Sweden
- Availability: Worldwide
- Contact: WIPO GREEN Database

Air cooling systems: evaporative cooler

Symphony

Source: Getty Images/kckate16

Symphony's evaporative air coolers (also called bio coolers or wet air coolers) cool hot, dry or humid environments by adding moisture to the air. This moisture absorbs heat as it evaporates, reducing the air temperature naturally. An internal fan then circulates the cooler, more comfortable air throughout the space. These energy-efficient coolers are ideal for hot climates and offer a cost-effective alternative to traditional AC.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: India
- Availability: Worldwide
- Contact: WIPO GREEN Database

Emergency cooling: portable air conditioners

DENSO Corporation

Source: Getty Images/onurdongel

MovinCool portable AC units offer fast, effective cooling on wheeled mounts, ideal for emergency or backup use in healthcare, government, education, retail and manufacturing settings. They reduce heat stress for people and equipment, supporting critical operations during heatwaves, power outages, floods and disasters. Easily deployed in mobile clinics, tents or server room failures, they run on generators and outperform fans or dehumidifiers for drying. The Climate Pro K Series suits offices, healthcare and telecom spaces, while the Pro X Series is built for industrial and outdoor use.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Japan
- Availability: Worldwide
- Contact: WIPO GREEN Database

Personal cooling solutions: electrolyte powder

Liquid I.V.

Source: Getty Images/Anastastasiya Larionova

Liquid I.V. offers electrolyte drink mixes designed to boost hydration using their patented Cellular Transport Technology (CTT®), which helps the body absorb water faster than with water alone. Their product line includes standard and sugar-free options, as well as formulas for energy, immune support, children and gut health. Available in over 80,000 US stores, Liquid I.V. also leads a 1:1 Giveback Mission, having donated over 55 million servings of hydration aid globally, with a goal of reaching 150 million by 2032.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO GREEN Database

Personal cooling solutions: cooling pillow

Simba Sleep

Source: Getty Images/Fugacar

The Simba Hybrid™ Pillow features an adjustable design using Nanocube® foam filling, allowing users to modify height and firmness by adding or removing small cubes. This makes it suitable for various sleep positions, particularly effective for side sleepers seeking neck alignment and support. One side of the pillow incorporates Stratos® cool-touch technology, which delivers a lasting cooling sensation and helps regulate temperature during sleep. The construction includes a breathable cotton surface and a mesh border to enhance airflow. The pillow also comes with a zip-off, machine-washable cover and a storage bag for excess Nanocubes®. Its down-like cushioning provides support without the density of traditional memory foam, which can improve comfort.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United Kingdom
- Availability: Worldwide
- Contact: WIPO GREEN Database

Personal cooling solutions: cooling towel

Mission

Source: Getty Images/LittleBee80

The MISSION Cooling Towel regulates body temperature during physical activities. Utilizing proprietary cooling technology, the towel provides immediate cooling upon activation and maintains a cool sensation for up to two hours. This sustained cooling effect helps to lower core body temperature, reduce heart rate and enhance endurance during exercise. It is chemical-free. Studies conducted at the MISSION Heat Lab at UConn's Korey Stringer Institute have demonstrated that the MISSION Cooling Towel can increase endurance by 12 percent, lower core body temperature by 0.56°C, reduce heart rate by 18 beats per minute and boost performance by 3.6 percent.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO GREEN Database

Climate monitoring: WBGT index measurement

Senseca

Source: Senseca

The HD32.2 is a portable thermal microclimate data logger designed to ensure safety, efficiency and comfort in hot working environments by measuring the WBGT index. It supports up to three SICRAM-enabled probes, which store their calibration data internally and are automatically recognized by the device. The HD32.2 can log data in up to 64 sections with customizable sampling intervals and auto-start scheduling. Measurements include globe temperature (combined effect of radiant heat and ambient air temperature), natural ventilated wet bulb temperature and ambient temperature. Using these inputs, it calculates WBGT indexes for both shaded and sun-exposed conditions. Data transfer is done via an RS232 connection. The device is commonly mounted on a small tripod, but for long-term monitoring, a stable tripod version (HD32.3A) is recommended.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Italy
- Availability: Worldwide
- Contact: WIPO GREEN Database

Heat-reducing construction materials: cooling paint

Nippon Paint Singapore

Source: Nippon Paint Singapore

Nippon's SolarCool is a premium 100 percent acrylic exterior cool coating featuring COOL-TEC Technology. It reflects a significant amount of solar energy, reducing surface temperatures by up to 5°C, which helps lower heat build-up and decreases AC energy consumption. SolarCool is weather-resistant and provides protection from the growth of algae with a low-sheen finish. It's ideal for eco-sensitive commercial and residential areas with high human traffic, including hospitals, schools, residential buildings and hotels. Temperature reduction may vary depending on the color used.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Singapore
- Availability: Singapore
- Contact: WIPO GREEN Database

Frontier technology solutions

Worker heat-stress prevention: sweat sensor for hydration

Epicore

Source: Getty Images/Albina Gavrilovic

Epicore Biosystems tap into the power of sweat to monitor hydration, nutrition, stress and key health biomarkers through advanced devices worn on the skin. Sweat is rich in hormones and metabolites and provides a non-invasive window into health – ideal for managing pregnancy, athletic performance and workplace safety. The connected hydration device provides real-time fluid and electrolyte guidance for workers, while the Gx sweat patch helps athletes personalize rehydration and recovery. The biowearables are certified for industrial safety and data security. They transform sweat into actionable insights to improve wellness, performance and preventive care.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO GREEN Database

Worker heat-stress prevention: wearable cooling device

Sony

Source: Sony

The Reon Pocket Pro is a wearable device that cools or warms the body by directly targeting the contact area. It features dual thermo modules that alternate intensity for sustained cooling, with up to 34 hours of use on cool level 1. Advanced sensors and algorithms detect the user's activity and environmental conditions to automatically adjust temperature in Smart Cool or Smart Warm modes. New sensors improve the Auto Start/Stop function by detecting when the device is worn. The device can be paired with the REON POCKET TAG, which measures ambient temperature and humidity to provide even smarter control of the REON POCKET.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Japan
- Availability: Worldwide
- Contact: WIPO GREEN Database

Air cooling systems: smart evaporative digital air cooler

Igenix

Source: Getty Images/venusphoto

The Igenix Smart Digital Air Cooler features a 10 liter removable water tank. When filled, the water absorbs heat from the air, and the integrated fan circulates this cooled air throughout the room. It includes ice packs that can be placed in the water tank to further lower the air temperature, providing an extra cooling effect. By activating the humidification mode, the cooler adds moisture to the air, which can be beneficial in dry environments. It can be controlled remotely using the Tuya Smart Life app or with voice commands via Amazon Alexa and Google Assistant. The cooler offers 120° horizontal oscillation for wider airflow, a timer with two-, four- or eight-hour settings, and three fan speeds plus three wind modes for customizable comfort. A water level window helps easily monitor the tank.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United Kingdom
- Availability: Worldwide
- Contact: WIPO GREEN Database

Air cooling systems: dedicated outdoor AC system for humid environments

Blue Frontier

Source: Blue Frontier

Blue Frontier's BF-DOAS™ is a dedicated outdoor air system that efficiently controls humidity and temperature. Using a patented two-stage core, it employs a non-toxic liquid desiccant to extract moisture from 100 percent fresh ventilation air, while a cooler brings the air to room-neutral temperature. This approach eliminates the need for reheat or refrigerants, improving energy efficiency, comfort and indoor air quality. BF-DOAS™ features energy storage, digital twin reliability and adaptive setpoint control, ensuring precise, independent management of humidity and temperature. It prevents condensation and delivers highly efficient ventilation in a single packaged system.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: United States
- Availability: United States
- Contact: WIPO GREEN Database

Personal cooling solutions: handheld, neck, table, stroller and clip fans

JisuLife

Source: Getty Images/Tatiana

JisuLife specializes in innovative and sustainable personal cooling solutions. A range of portable fans – including handheld, neck, table, stroller and clip fans – are available to enhance air circulation both indoors and outdoors. Many use high-capacity rechargeable batteries offering extended run times, fast charging and improved energy efficiency, which provides for all-day use without frequent recharging. The fans provide powerful airflow with minimal noise for use in offices, bedrooms or public spaces. Wearable neck fans enable hands-free use, while clip-on fans are designed for strollers or desks. Most fans also have multiple speed settings, including eco and turbo modes, which allow users to customize airflow to match their comfort level and conserve battery life.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: China
- Availability: Worldwide
- Contact: WIPO GREEN Database

Personal cooling solutions: cooling chair/cooling pad

ecto

Source: Getty Images/SimonSkafar

Arctica cooling technology circulates ice water through 15 m of micro-cooling lines, cooling to as low as 7°C in under a minute. The Ecto Cooling chair and Chill TOPR can be set up in less than 2 minutes and pack down quickly for easy transport. The technology works with any cooler – the trunk hose is simply dipped into at least 2.5 cm of ice-cold water. There is no need to buy a dedicated cooler; an existing one can be used. Ecto operates with most USB Type-A power banks under 30,000 milliampere-hours (mAh). An optional 5,000 mAh battery is available, providing over 10 hours of operation on high setting and also serving as a backup power source for other devices. Cooling can be controlled with a single button, choosing between 18°C, 13°C, or 7°C, plus a super chill mode that cools in just 90 seconds for quick relief.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO GREEN Database

Air cooling solutions: high-pressure misting system

Cool-Off

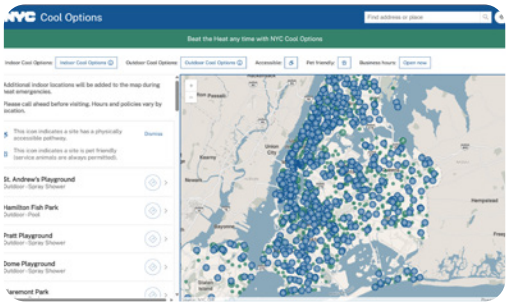
Source: Getty Images/Artem Zakharov

Cool-Off's high-pressure misting systems utilize the principle of evaporative cooling to significantly reduce ambient temperatures. Water is pressurized up to 1,500 pounds per square inch (10,342 kPa) and forced through specialized nozzles with micro-orifices, producing ultra-fine mist droplets around 5 µm in size. These minuscule droplets rapidly evaporate upon contact with the air without wetting surfaces, absorbing heat and lowering the surrounding temperature by up to 14°C in seconds. This creates a comfortable cooling effect for outdoor patios, restaurants and large events. The system includes 30 misting nozzles that work in unison. This misting technology has been operational for years at theme parks, resorts and restaurants, and now it is available to homeowners. The residential misting systems connect to any standard water line.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United States
- Availability: United States
- Contact: WIPO GREEN Database

Public heat response: Cooling center finder online platform

Cool Options NYC



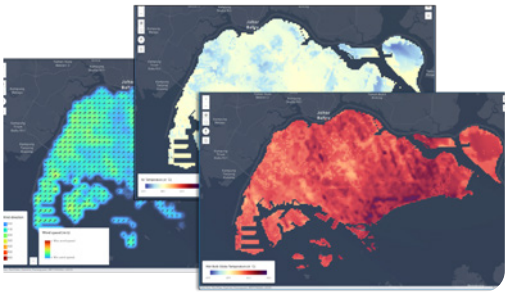
Source: Cool Options NYC

New York City's Cool Options Finder is a GIS-powered online tool available year-round that maps air-conditioned public facilities (including libraries, community and senior centers, and cultural institutions), as well as outdoor cooling features like public pools and spray showers. The platform is maintained by NYC Emergency Management's GIS Division and uses data from city agencies and community partners. During heat emergencies—defined as when the heat index reaches 35 °C for two consecutive days or 38 °C on a single day—the tool is updated in real time to reflect changes in site availability (i.e., when an AC breaks). Users can view current locations, hours of operation, and filter for features such as accessibility and pet-friendliness through the interactive map or by calling the 311 hotline. It's part of a broader "Beat the Heat" strategy that integrates "Notify NYC" alerts, a heat vulnerability index, and community outreach to ensure equitable access during extreme heat events.

- Technological maturity: Frontier
- Contracting type: N/A (proprietary)
- Technology level: Medium
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO GREEN Database

Heat scenario modeling: digital twin

Cooling Singapore (Singapore – ETH Centre)



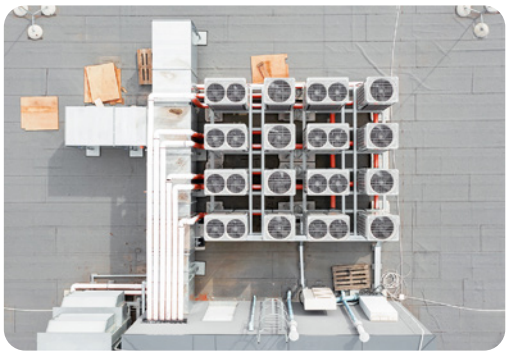
Source: Singapore-ETH Centre

Cooling Singapore is a multi-disciplinary research initiative tackling urban heat in Singapore. In its current phase, the project is developing a digital urban climate twin (DUCT) – a city-wide digital model integrating environmental, land use, industrial, transport and climate data at regional and micro scales. The DUCT includes an interactive interface to run simulations and explore "what-if" urban planning scenarios, helping policymakers and planners assess the heat impacts of buildings, transport and industry. Led by the Singapore-ETH Centre, the project involves partners including Singapore Management University, the Singapore–MIT Alliance for Research and Technology, multidisciplinary research platform TUMCREATE, the National University of Singapore and the Cambridge Centre for Advanced Research and Education, and is supported by the National Research Foundation Singapore under its CREATE program. The team is working closely with government agencies to ensure the DUCT and the DUCT Explorer app meet real-world planning needs.

- Technological maturity: Frontier
- Contracting type: For collaboration
- Technology level: High
- Place of origin: Singapore
- Availability: Worldwide
- Contact: WIPO GREEN Database

Public heat response: AI-powered HVAC systems for buildings and infrastructure

Sener



Source: Getty Images/Vladyslav Horoshevych

RESPIRA® is an AI-powered HVAC management system designed to optimize energy efficiency, thermal comfort and air quality in complex infrastructures such as subways, airports, hospitals and malls. It analyzes and balances factors such as temperature, humidity, energy use and air quality to predict and improve environmental conditions, enhancing user well-being and lowering operational costs. RESPIRA® centrally controls ventilation systems, adjusting fan speeds individually to ensure efficient air renewal, better hygiene and reduced spread of pathogens. Currently being deployed in the Barcelona metro, RESPIRA® manages 187 station fans and 142 tunnel fans, processing over 500 million data points annually. The system is expected to cut winter energy use by 30–40 percent, leading to average annual savings of 25 percent, while also lowering tunnel temperatures and improving air quality for the metro's 400 million annual passengers.

- Technological maturity: Frontier
- Contracting type: For licensing
- Technology level: High
- Place of origin: Spain
- Availability: Worldwide
- Contact: WIPO GREEN Database

Horizon technology solutions

Heat-reducing construction materials: fungi tiles

Nanyang Technological University / bioSEA

Source: Nanyang Technological University

Scientists at NTU Singapore, in partnership with biomimicry design firm bioSEA, have created energy-free cooling tiles made from mycelium, the root network of fungi, and bamboo shavings. These "fungi tiles" offer insulation properties superior to conventional materials such as expanded vermiculite and lightweight clay aggregates. Inspired by elephant skin, the tiles feature a wrinkled, bumpy surface that enhances heat regulation. Just as elephants rely on the crevices in their skin to dissipate heat (since they lack sweat glands), the tile's textured surface mimics this natural cooling mechanism. Lab tests have confirmed the tile's effectiveness in regulating temperature. With the concept validated, researchers are now moving toward scaling production and testing the tiles on actual building facades.

- Technological maturity: Horizon
- Contracting type: Under development
- Technology level: High
- Place of origin: Singapore
- Availability: N/A
- Contact: WIPO GREEN Database

Air cooling systems: efficient AC for humid climates

Transaera

Source: Getty Images/Ake Ngiamsanguan

Transaera is redefining AC to combat humidity-driven energy waste. Their technology uses advanced materials to extract moisture before cooling, while repurposing system heat to power the cycle, dramatically reducing electricity consumption, costs and emissions. Compatible with standard AC equipment, their proprietary coating and devices enable efficiency without major redesigns. This solution targets humid tropical regions, where 2.5 billion people lack cooling access, offering manufacturers a scalable way to deliver affordable comfort.

- Technological maturity: Horizon
- Contracting type: Under development
- Technology level: High
- Place of origin: United States
- Availability: N/A
- Contact: WIPO GREEN Database

Air cooling systems: plug-and-play air conditioner with thermal energy storage

Social Cooling

Source: Social Cooling

TerraBreeze is a plug-and-play air conditioning system designed for rooms of up to 50 m². It uses a patented thermal energy storage system that captures heat inside the device instead of venting it outdoors, eliminating the need for external ducting and installation. The stored heat is absorbed by a phase-change material and later released during low-usage periods, requiring two to four hours to fully discharge. The heat is typically released at night, which is why TerraBreeze is primarily intended for offices and public spaces with night-time off-hours. The system is being trialed in lab conditions in 2025 and will in 2026 be piloted with actors including the Austrian energy utility E-Steiermark AG, the City of Vienna, and two municipalities and a coworking space in Luxembourg. Market launch is planned for the summer of 2026.

- Technological maturity: Horizon
- Contracting type: Available for pre-order
- Technology level: High
- Place of origin: Austria
- Availability: Austria
- Contact: WIPO GREEN Database

Heat-reducing construction materials: sub-ambient cooling coating

Umi Coating New Material Technology

Source: Getty Images/tumsasedgae

UmiCool is a sub-ambient cooling coating developed by a Hong Kong PolyU startup co-founded by Prof. Dai Jianguo. Using patented fluorescent radiative cooling technology, the coating absorbs ultraviolet radiation from sunlight and converts it into infrared radiation for re-emission, achieving up to 97% solar reflectance and reducing indoor temperatures by up to 4 °C. UmiCool can be applied to exterior walls of buildings to lower heat gain and reduce reliance on air conditioning, contributing to energy savings and sustainable urban development. The coating has been proven effective in pilot projects implemented in Beijing, Hong Kong, Qingyuan and Zhuhai. The startup is planning to establish a sales and production base in Guangdong to expand its business in the Greater Bay Area.

- Technological maturity: Horizon
- Contracting type: Under development
- Technology level: Medium
- Place of origin: Hong Kong, China
- Availability: China
- Contact: WIPO GREEN Database

Extreme cold

Emerging technologies are transforming how we respond to extreme cold events. Precision frost protection systems shield crops using targeted sprinklers and wind machines. Buildings deploy ultra-insulated materials and self-regulating roof heaters. Arctic-ready EVs feature cold-optimized batteries, while communities use GPS-guided snow clearing systems and low-temperature district heating networks to maintain critical infrastructure during deep freezes. Winterized energy infrastructure includes heat-traced oil/gas pipelines and freeze-proof instrumentation, while ice-resistant coatings for wind turbines defend against cold extremes.

Technological developments and trends

Extreme cold events can be as deadly as extreme heat but are often overlooked. Arctic warming is causing more record highs than lows globally, yet it can disrupt atmospheric systems, particularly the polar vortex – a ring of strong westerly winds trapping frigid air near the North Pole. When weakened, the vortex distorts, allowing cold Arctic air to spill into mid-latitudes, triggering severe cold snaps (Sherriff, 2025).

Although climate models vary, some research links Arctic warming and the reduced temperature difference between the Arctic and midlatitudes to more frequent vortex disruptions and jet stream "blocking patterns" that prolong cold spells (Dance, 2025). These erratic cold events, combined with increased mixed precipitation such as ice and sleet, pose growing risks as infrastructure and preparedness often lag behind.

Extreme cold threatens health and well-being

Extreme cold preparedness is underprioritized compared to emergency planning for heat. While many cities have cooling centers, fewer have warming centers or plans to transport vulnerable groups there during cold weather.

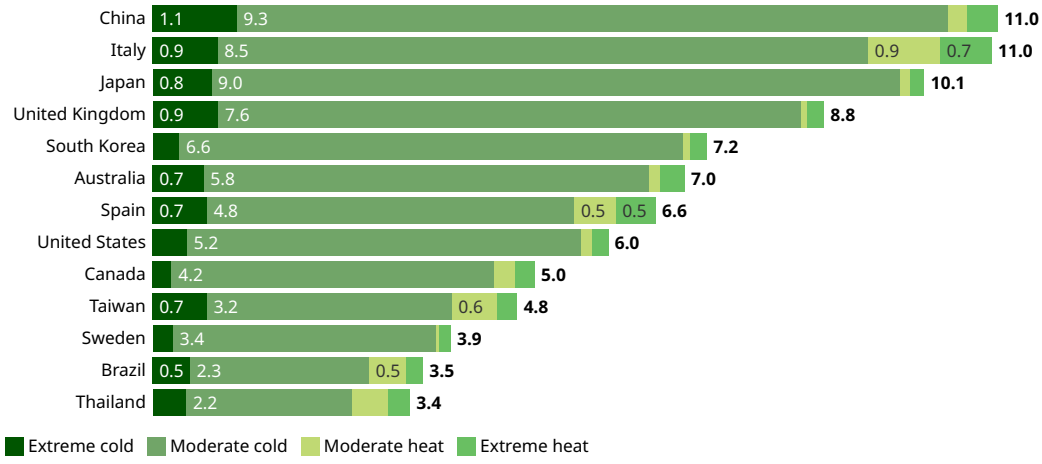
Extreme cold has significant effects on both human health and the environment. Physically, cold temperatures increase the risk of cardiovascular problems, frostbite, hypothermia and respiratory infections by causing inflammation and drying out the mucous membranes. People tend to spend more time indoors during cold weather, which can raise the chances of illnesses such as influenza and pneumonia spreading. Mentally, cold and reduced daylight hours often lead to isolation and contribute to anxiety, depression and seasonal mood disorders. Vulnerable groups such as the elderly, outdoor workers, homeless individuals, infants, those living in poorly heated or insulated homes, disadvantaged populations and people with pre-existing health conditions face heightened risks.

While many cities have cooling centers, fewer have warming centers or plans to transport vulnerable groups there during cold weather

Economic trends can intensify the effects of extreme cold, especially during periods of high inflation. In late 2022, Europe faced inflation rates up to 8.9 percent, largely driven by a 4 percent increase in energy costs, forcing many to choose between heating and other essentials. Recent research revealed that traditional income-based measures of energy poverty underestimate the problem – but using heating use as a metric showed over twice as many households are energy insecure (CDP, 2025). Additionally, extreme cold can lead to a greater reliance on wood stoves and fireplaces, which can deteriorate both indoor and outdoor air quality (Ouranos, 2022).

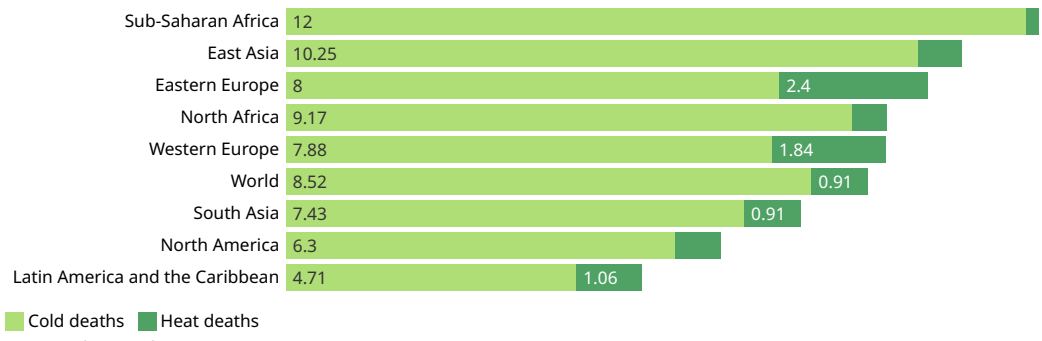
Sub-optimal temperatures cause millions of premature deaths annually, with cold-related deaths occurring four to nine times more often than heat-related ones. Studies estimate that temperature-related deaths account for roughly 7–9 percent of all deaths worldwide, predominantly affecting older populations over 65. Most deaths arise from moderately cold conditions, however, and not extreme cold – and are typically linked to worsening or triggering health issues such as cardiovascular disease, respiratory infections, diabetes or kidney disease. These deaths largely occur among those who would not have died in the next six months otherwise, highlighting a public health challenge posed by unfavorable temperatures, especially as climate change may shift these patterns (Ritchie, 2024a). Figures 8.1 and 8.2 depict the percent share of deaths attributed to suboptimal temperatures.

Figure 8.1 Percent share of deaths from all causes attributed to cold or heat, 2015



Source: Gasparrini et al., 2015

Figure 8.2 Percent share of all deaths attributable to sub-optimal temperatures



Source: Zhao et al., 2021

Fortifying energy assets against freezing conditions

Extreme cold can trigger widespread power outages due to increased heating demand, frozen equipment and damage to power lines, all of which disrupt critical infrastructure such as water and energy systems. Ice and snow add physical strain, weighing down buildings, damaging substations and snapping lines.

Technology plays a key role in both preventing and responding to these outages. Solutions include mini and microgrids, battery storage and smart grid systems that enable faster fault detection and rerouting of electricity. These innovations are featured in the *Green Technology Book* Energy edition and the Asia Pacific EXPO25 editions, while this chapter and the wildfire chapter of this edition discuss technologies that bolster resilience for powerlines and planned outages.

Overload caused by high demand during both heatwaves and cold snaps can exceed capacity and trigger blackouts. Grid modernization is essential, especially in regions with aging infrastructure. This involves upgrading transformers and cables (Montel, 2025b), expanding capacity to handle peak loads, and automating controls through smart meters and demand-response systems. Energy storage can further buffer disruptions, while predictive analytics and weather forecasting improve grid readiness.

> Smart ice sensors and AI algorithms enable real-time detection and prediction of ice accumulation on wind turbines

In 2021, Texas endured a major winter power crisis due to extreme cold temperatures. This catastrophe left 13 million people without electricity and/or water, an estimated $100 billion in economic damages, and killed almost 250 people (Castellanos *et al.*, 2023). Failures included frozen natural gas infrastructure (which made up 80 percent of grid capacity), limited fuel storage, and frozen wind turbines, coal and nuclear plants (Douglas, 2021). Avoiding similar disasters requires upgrading natural gas wells, insulating pipelines, winterizing power plants and enhancing fuel supply resilience.

To support these efforts, emerging technologies now provide critical new capabilities. They combine advanced remote sensing, intelligent monitoring and active thermal management. Smart ice sensors and AI algorithms enable real-time detection and prediction of ice accumulation on wind turbines. Solid-state wind sensors with built-in heating ensure reliable data collection in icy environments without the maintenance issues of moving parts.

In the oil and gas sector, self-regulating heat-trace cables and steam-tracing systems maintain critical pipeline and equipment temperatures, preventing freezing and flow interruptions. Diagnostic tools such as Honeywell's Transmitter Freeze Detector provide early warning of frozen instrument signals, preventing shutdowns in turbomachinery. Cold-adapted battery systems with insulation and hydronic heating (which circulates heated liquid to maintain temperature) keep energy storage functional in subzero temperatures. And for homes and businesses, uninterruptible power supplies, surge protectors, portable generators and solar batteries provide crucial backup.

Home resilience for extreme cold: insulation, snow and ice removal

Building materials resist heat flow to varying degrees measured by their R-value per inch of thickness. The optimal approach to thermal insulation involves insulating the six sides of the building envelope (four walls, ceilings and floors/foundation), while tailoring R-values to local climate zones. To maximize efficiency, thermal bridging and air leaks should be addressed from the design stage.

Optimizing insulation thickness and R-value is key to retaining warmth and improving home energy efficiency (ZEP, 2025). Wall insulation ranges from R-19 in mild climates to R-60 in very cold ones; ceilings range from R-30 to R-80, and floors from R-19 to R-60 (ibid.). Adding thick rigid insulation to exterior walls boosts R-value and reduces thermal bridging. For cold climates, double stud walls (two walls staggered with studs to create thick insulation cavities (R-30 to R-50+) and double plate walls, which increase wall thickness, are effective high-performance options.

For ceilings and roof insulation, dense pack fiberglass or cellulose blown onto flat ceilings or into cathedral ceilings can achieve very high R-values (R-60+), while raised heel truss design allows for extra insulation thickness at the eaves. Adding rigid insulation layers on the roof deck, combined with ventilation channels and insulation between rafters, further improves thermal performance.

Insulated masonry solutions, which combine aircrete blocks with external insulation, provide superior thermal, fire and structural performance, often faster and cheaper than timber frames. Quadruple-glazed and arctic windows with ultra-high R-values (R-15) and airtight seals are ideal for extreme cold climates. Heat and energy recovery ventilators help maintain indoor air quality while recovering heat from exhaust air.

> Automated systems are emerging to reduce maintenance demands and react faster when snow and ice start to build up

Heated roof systems, or roof de-icing systems, use electric heating cables or hydronic tubing to melt snow and ice, preventing ice dams and potential damage. These systems are installed along roof edges, in valleys, around dormers and in gutters/downspouts, ensuring melted snow drains properly and avoids dangerous ice build-up. Ice dams form when melted snow refreezes on roof edges or around drains, trapping water that can leak into buildings and cause damage. Self-regulating heating cables prevent pipe freezing by adjusting heat output efficiently, and electric snow-melting mats can be installed on driveways, walkways and stairs to reduce shoveling and salt use.

As smart technology becomes more integrated into cold-climate resilience, automated systems are emerging to reduce maintenance demands and react faster when snow and ice start to build up. Floe (see frontier technology solutions) is an automated, eco-friendly roof protection system that uses smart sensors and algorithms to detect snow and ice build-up. It then dispenses safe, biodegradable de-icer through discreet tubing, providing a low-maintenance alternative to traditional melting methods. Roof snow load monitoring tools are now able to use AI-powered sensors that detect snow accumulation and provide real-time risk alerts.

Extreme cold at scale: community infrastructure, heating, and emergency technologies

Innovations in snow management infrastructure, heating technologies, and cold-weather equipment are essential for enhancing safety and efficiency in extreme cold environments. Global positioning system (GPS)-guided snow clearing systems optimize routes, reducing labor costs and preventing damage from hidden obstacles. Semi-automated snowplows and salters use real-time salt measurement with cloud connectivity and automated controls to improve efficiency and reduce waste. Advanced spreaders and liquid de-icers further optimize chemical application while minimizing environmental impact.

Heating solutions for extreme cold range from electric mats, foils, and cables to water-based radiant floor heating using polyethylene tubing, ideally paired with heat pumps for low carbon footprints. Ultra-low-temperature district heating adapts community heating systems to

operate at lower temperatures and integrates renewable sources such as solar. Portable fuel-powered air heaters such as the Euroheater 2D/4D (see frontier technology solutions) provide reliable emergency heat in extreme cold (down to –45°C) for extended periods.

Operating in extreme cold requires lightweight and durable gear designed to prevent hypothermia and support self-rescue. Essential equipment includes heated vests and blankets to maintain core temperature, ice awls and traction spikes for stability, waterproof insulated gloves, and signaling tools such as strobe lights and whistles. Specialized drones equipped with self-heating batteries (functioning down to –20°C) and real-time kinematic (RTK) precision can map icy terrain and operate in blizzards, reducing survey time. Winterized lifeboats and rescue vessels, used in Arctic shipping, offshore rigs and polar missions, feature anti-icing shells, cold-rated materials, integrated heating and systems for engine pre-heating and moisture control.

Avalanche triggering systems – managing snow hazards in extreme cold

Avalanches – which are primarily snow- and ice-driven phenomena that occur in mountainous regions – pose a significant risk to communities, infrastructure, and transportation routes. Landslides, on the other hand, are often triggered by heavy rainfall, flooding, or saturated soils, and are addressed in the landslides chapter. Many technologies used to monitor or prevent avalanches such as slope stability sensors, ground-based radar, and remote early warning systems overlap with those used for landslides. Techniques such as LiDAR, drone surveillance and geotechnical instrumentation (e.g., inclinometers, GPS) are applicable to both snow and earth movement. Readers interested in these technologies can refer to the landslides chapter for a more detailed overview.

Avalanche prevention. Avalanche triggering systems are specialized technologies that reduce the risk of dangerous snow build-up by safely inducing controlled releases. These systems work by destabilizing the snowpack in a targeted way, typically using explosive charges to trigger small avalanches before they become hazardous. Explosives may be deployed manually, by helicopter or artillery, or through permanently installed remote systems. These methods create pressure waves that fracture weak snow layers and initiate controlled slides (WSL, 2022). In recent years, remote and automated systems such as Gazex® (see proven technology solutions), which use gas explosions, have become more common due to their precision, safety and ability to operate in all weather conditions. These technologies are often integrated with monitoring tools, such as snow depth sensors.

Snow barriers are modular, high-strength steel or chain nets installed on slopes to prevent avalanches. These barriers secure the snowpack by stabilizing it and withstanding static pressure, lowering the risk of avalanche release. Usually installed in multiple cascading rows, the barriers are customized to fit local snow depths and landscape conditions.

Avalanche response. Avalanche rescue relies on immediate action by those at the scene, as professional rescuers often arrive too late. The core rescue gear includes a transceiver (beacon), shovel and probe, all of which must be carried by everyone in the group to maximize survival chances. Avalanche shovels are essential for quickly digging out buried victims once their location is found. Probes are collapsible poles used to precisely locate buried victims by probing the snow after the general area is identified by the transceiver. Modern transceivers feature digital technology, multiple antennas and advanced functions such as multiple burial indication and interference management. Avalanche airbag backpacks help keep victims near the surface, reducing burial risk. For airbags, factors such as inflation power, trigger mechanism and airbag volume are crucial, with dual airbags offering added safety (Arva, 2025).

Reliable vehicle solutions for harsh winter conditions

In extremely cold environments, specialized technologies are essential for maintaining vehicle and machinery reliability, safety and comfort. Engine block and fuel line heaters prevent cold-related starting issues by warming the engine and fuel, while battery heaters help maintain optimal performance and faster recharge times in sub-zero temperatures. Passenger car parking heaters pre-warm both the cabin and engine, reducing icy windows and cold starts, and interior heaters keep cabins warm while preventing window fogging. Smart timers allow users to schedule pre-heating in advance for added convenience.

For EVs, cold-resistant charging cables remain flexible and durable in freezing conditions. Advanced winter tires, made with specialized materials and grip technologies, maximize traction and comfort on ice and snow while minimizing environmental impact. Together, these solutions offer a comprehensive approach to navigating harsh winter conditions.

Agriculture and extreme cold: cold injury in plants and their adaptations

As climate disruptions intensify, building cold resilience in agriculture is essential, as plants and animals face distinct challenges from frost, freezing and erratic temperatures. Cold weather can significantly limit crop development, damaging plant buds and roots depending on factors such as the intensity, duration and timing of cold spells. The effects can vary by crop species, growth stage and weather conditions. Cold injury includes chilling injury (above 0°C) and freeze injury (below 0°C). Tropical crops often suffer chilling injury at temperatures below ~12.5°C. Mitigation measures such as pesticide use, nutrient adjustments, replanting and timing can help reduce damage.

Frost poses a major threat to crops globally and may worsen with climate change. It affects annuals, perennials and fruit trees, causing yield loss or reduced quality. Damage depends on frost type and crop sensitivity. Frost occurs just below freezing and is intensified by moisture and ice nucleators, which promote ice formation and cause cellular damage.

There are two main frost types: radiation frost, which forms on clear nights when the ground rapidly loses heat, and black frost, caused by thermal inversions that trap cold air near the ground. Severity varies by species and local adaptations. Sensitivity is highest during flowering and fruit development (Snyder and Melo-Abreu, 2005). In fruit trees, frost can damage buds, blossoms, and woody tissue, with signs such as darkened petals and russet on fruits.

Frost poses a major threat to crops globally and may worsen with climate change. It affects annuals, perennials and fruit trees, causing yield loss or reduced quality

Extreme cold can also affect livestock. Animals tolerate a wide temperature range if well cared for, but wind, moisture, and mud increase cold stress. Cattle thrive around 5–10°C but need shelter, bedding and increased feed to maintain body heat in colder weather. Dairy productivity decreases under thermal stress, with both cold and heat reducing milk yield. Best practices focus on nutrition, shelter, health care and minimizing stress to maintain productivity (Ontario Ministry of Agriculture, 2007).

Surviving the freeze – how plants fight back against cold damage

Plants cope with low temperatures through two main strategies: avoidance and tolerance. Avoidance means preventing freezing damage by physical or environmental means, including through snow cover, dense canopies to reduce radiative heat loss, bulky organs such as trunks and mature fruits, and artificial protection such as foam sprays, row covers or fogging systems to alter the microclimate around plants (Snyder and Melo-Abreu, 2005). Tolerance involves physiological adaptations that help plants survive internal freezing or dehydration (ibid.). These include increasing solutes to lower the freezing point and delay ice formation, shrinking cell contents to resist drying out, and adjusting membrane permeability to slow water movement and prevent ice crystal damage (ibid.).

Avoidance and tolerance can often be enhanced by the process of hardening (where exposure to cold induces physiological changes), helping plants survive freezing conditions. Plants build resistance by accumulating solutes and reducing ice-nucleating bacteria. They naturally combat

cold by accumulating sugars (acting as antifreeze) and producing protective proteins to stabilize cells. Recent research focuses on eco-friendly strategies that enhance these natural defenses. Companies such as Rovensa Next conduct research on plant biostimulation and nutrition that enable plants to thrive under extreme conditions, developing biostimulants from seaweed, amino acids and microbes to improve crop resilience to cold and other stresses.

Warding off winter – frost protection for resilient farming

When water freezes, it releases latent heat and warms the surrounding area. Frost protection methods capitalize on this natural heating effect, with sprinkler irrigation being the most efficient approach. By applying water that freezes around plants, sprinkler irrigation forms a protective ice layer that helps keep crops just above freezing and prevents frost damage. Compared to burning fuel, using water for frost protection provides roughly 120 times more energy per liter of diesel used (Sasoni, 2025). Sprinkler frost protection methods include overhead full cover (uses more water and risks branch damage from ice); under-tree sprinklers (protects soil heat under trees); targeted sprinklers (water applied directly to plants); and strip irrigation (focusing water on plant rows; commonly used in vineyards and orchards) (ibid.).

Frost fans combat frost by mixing warmer air from above with the colder air near the ground, raising temperatures around the plants to prevent frost formation. Additionally, fabric row covers, plastic tunnels or low tunnels trap heat and protect plants from frost and cold winds and extend the growing season. Mulching and cover crops are also used for protection from the cold. Applying organic or plastic mulch insulates soil, reducing heat loss and protecting roots from freezing. Certain cover crops can help retain soil warmth and moisture and offer protection, including winter rye, winter wheat, hairy vetch, crimson clovers, oats, field peas and mustards (brassica species). Planting varieties genetically bred or selected for cold tolerance also reduces damage risk during unexpected frosts or cold spells.

Heated greenhouses and indoor vertical farms provide a controlled environment where temperature, humidity, and light can be regulated to protect crops year-round, regardless of outdoor extreme cold. For livestock, insulated barns and shelters, heat lamps, heated floors and heated waterers prevent freezing and ensure animals have access to water during extreme cold. Additionally, windbreaks and shelterbelts such as planted trees or fences help reduce chilling effects by blocking cold winds, benefiting both crops and animals.

Innovation examples

Forecasting slush flows: tackling Norway's hidden snow hazard with hydrometeorological modeling technology

Source: Getty Images/Radila Radilova

A recurring hazard in Norway, slush flows are masses of water-saturated snow that can travel long distances rapidly. Unlike avalanches that require steep slopes of 30–45°, slush flows start on gentler slopes. Unique Arctic conditions (midnight sun which prevents nighttime freezing and thin soil layers that limit drainage) make slush flows more frequent in Norway than in places such as the Alps. Road closures caused by slush flows in Norway's Finnmark region create significant detours. Although models for avalanche forecasting are well advanced, predicting slush flows is in early stages because the underlying processes are not well understood.

Researchers at the University of Tromsø are developing a digital tool to forecast slush flow risks by combining extreme weather data with advanced simulations adapted from avalanche models. The tool aims to predict hazardous zones, while also creating a comprehensive national hazard map. Field assessments are being conducted through collaboration between Finnmark road authorities and researchers from the Arctic University of Norway, who document slush flow paths and measure snowpack water content using simple tests. This is important, as winters in the Arctic are getting warmer and wetter, increasing wet snow hazards such as avalanches and slush flows. The project promises safer roads and communities in Norway and possibly other snow-prone areas (Impetus, 2025).

Hybrid power systems designed for extreme cold in Canada's Arctic

Source: Getty Images/PhonlamaiPhoto

In the remote Canadian community of Colville Lake, 50 km north of the Arctic Circle, a hybrid power system now combines solar panels, new diesel generators and a Saft lithium-ion battery energy storage system (ESS) designed for extreme cold. This off-grid community of about 160 residents is only accessible by air or ice roads during a six-week window in February and March, and previously relied on expensive diesel fuel transported over these limited routes. However, since 2015, Colville Lake's 136 kW solar array has generated about half the community's annual electricity, working alongside diesel generators and a containerized ESS equipped with advanced insulation and a hydronic heating coil that keeps the batteries within an optimal temperature range of –50°C to +35°C. The battery system stores surplus solar energy and stabilizes the grid by managing voltage and frequency, enabling extended shutdowns of the diesel generators in summer and reducing generator runtime by up to 50 percent. This reduces fuel consumption by over 80,000 liters annually and lowers maintenance costs by preventing wear and tear from constant generator ramping. This innovative setup not only cuts emissions and improves power reliability but also enhances residents' quality of life. Colville Lake's success exemplifies the Northwest Territories Power Corporation's mission to transform remote northern communities' power supplies through renewable energy and tailored energy storage solutions designed for Arctic challenges (Saft, 2016).

Ensuring winter safety at school with advanced snow melting technology

Source: Getty Images/ollo

Kronaskolan, a modern F-6 school overlooking Älvängen and the Göta Älv, Sweden, features a sizeable schoolyard with many activity areas, where an investment was made in Ebeco's Smarta

Tak snow melting system to ensure children can play safely in winter. This system uses over 800 m of heating cables installed on the roof's gutters and downpipes to prevent dangerous ice and snow build-up, protecting students, staff and the property from hazards and moisture damage during winter. The smart system, controlled by the energy-efficient EB-Therm 800, keeps drainage paths clear by melting snow and ice before it can freeze. Installation was streamlined using Ebeco's Smartclip cable clamps and Smartlock junction boxes, which saved time and enhanced safety while working several meters above ground. The Garantera app ensured the entire system was properly documented and tested throughout the installation process. By combining safety measures with solar panels and energy-efficient solutions, Kronaskolan offers a secure environment that supports year-round outdoor activities and reduces maintenance challenges in harsh winter conditions (Ebeco, 2025).

Forecasting technology powers Kazakhstan's early action against severe cold

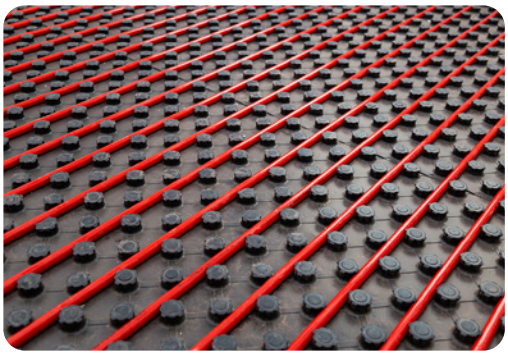
Source: Getty Images/@jansmartino

In Kazakhstan, where winter temperatures can plunge below –50°C, the Red Crescent Society has turned to technology to stay ahead of deadly coldwaves. With support from the IFRC's Disaster Response Emergency Fund, Kazakhstan activated a Simplified Early Action Protocol – a forecast-based funding mechanism designed to trigger rapid, pre-planned humanitarian action. The system relies on real-time weather forecasts from Kazhydromet, Kazakhstan's national meteorological service. A coldwave trigger is met when forecasts predict at least two consecutive days of sub –40°C temperatures combined with wind and precipitation. Once that threshold is crossed, funding is instantly released and early actions begin with no need for further approvals. In December 2024 and February 2025, this system was activated when extreme cold hit the North Kazakhstan, East Kazakhstan, Abay and Karaganda regions. The Red Crescent, which was already stocked with heaters, blankets, hot meals and clothing, quickly mobilized aid to unhoused people, the isolated elderly, and stranded drivers. The Red Crescent's advance contracts with food providers and prior mapping of vulnerable areas enabled a swift and well-coordinated response. Life-saving assistance reached over 1,200 people in just days. One key lesson emerged: the forecast trigger may be set too low, as severe impacts were observed even when conditions were just shy of the –40°C threshold (IFRC, 2024).

Proven technology solutions

Residential heating: water-based floor heating

Florad



Source: Getty Images/bymandesigns

Florad's water-based underfloor heating system utilizes polyethylene pipes arranged in a precise layout beneath the floor to circulate warm water. The system operates on low-temperature water, making it compatible with renewable energy sources such as heat pumps, which can reduce carbon emissions and running costs by up to 66 percent compared to electric heating systems. Alternative heat sources such as wood/pellet, gas, electric boilers and solar can also be used to heat the water. Florad offers various installation options to suit different building structures, including between foundation and topping layers or in surface beds. The system is complemented by individual room thermostats for precise temperature control.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: South Africa
- Availability: South Africa
- Contact: WIPO GREEN Database

Transport: engine block heaters

SESCO B.V.

Source: Getty Images/MarianVejcik

Engine block heaters are essential for ensuring reliable starts and optimal performance of diesel engines in cold climates. They preheat the engine block and its fluids, reducing oil viscosity and preventing fuel gelling, which can impede engine function. Typically, it's recommended to use a block heater when temperatures drop below –6°C for diesel engines, and below 0°C for gasoline engines. Heaters can raise the engine temperature by 11–33°C, facilitating smoother starts and reducing strain on the battery and starter. Additionally, they help improve fuel efficiency and reduce emissions by promoting better combustion. For optimal performance, it's advisable to use a timer to limit heater operation to the critical pre-startup period.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Kingdom of the Netherlands
- Availability: Worldwide
- Contact: WIPO GREEN Database

Transport: fuel line heater

Thermex Engineered Systems

Source: Thermex Engineered Systems

Fuel line heaters are installed between the engine and the fuel tank, utilizing waste heat from the engine's cooling system or an auxiliary heater to preheat the fuel before it reaches the injection pump. This process improves fuel combustion, enhances power output, reduces smoke emissions and facilitates easier cold starts. The stainless-steel construction of the heaters ensures durability and resistance to various fuels, including B100 biodiesel. By maintaining the fuel at an optimal temperature, fuel line heaters prevent issues associated with fuel thickening, especially in vegetable oil conversions, where fuel can become extremely viscous even in mild temperatures. This technology is widely used in heavy-duty trucks, off-road vehicles and industrial machinery operating in cold climates.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Canada
- Availability: North America
- Contact: WIPO GREEN Database

Transport: car battery heater

Arctic Fox

Source: Getty Images/joebelanger

Arctic Fox's BH-3100 Series Battery Heater is a coolant-powered tray that warms Group 31 (and similar) batteries using heat from the engine's cooling system or a diesel-fired coolant heater. Installed beneath the battery, the aluminum plate and stainless-steel tubes transfer warm coolant to increase cold cranking amps, improve state-of-charge, shorten recharge times and extend battery life even in extreme cold. Testing shows that at –18°C, warmed batteries can reach 75–80 percent charge in about 2¼ hours – compared to eight hours without heating. Lightweight yet durable, the system features optional thermostatic bypass control and simplified installation. Designed for heavy-duty applications in construction, mining, oil and gas, and off-highway equipment, it ensures reliable engine starts and protects the battery in subzero environments.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Kingdom of the Netherlands
- Availability: Worldwide
- Contact: WIPO GREEN Database

Avalanche control: avalanche radar

GEOPRAEVENT

Source: Getty Images/georgeclerk

AVYX® Avalanche Radar is an advanced radar system designed for real-time avalanche detection and early warning. Mounted to cover slopes up to 10 km², the radar continuously scans terrain within a 5 km radius, detecting movement by measuring changes in reflected radar signals caused by flowing snow. Unlike point-based sensors, AVYX® doesn't need to be placed directly in avalanche paths. It works 24/7 in all conditions, including fog, snowfall or darkness, where over 80 percent of avalanches occur. Once motion is detected, it identifies flow paths, estimates avalanche size, speed and duration, and instantly triggers alarms to close roads or railways. Simultaneously, it activates a camera to capture photo or video evidence. Data are uploaded to the GRAVX online portal for monitoring and analysis. The system installs within hours, integrates with mobile devices, and can be networked with other radars for broader coverage or combined with other hazard detection tools, such as rockfall or debris flow systems.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: High
- Place of origin: Switzerland
- Availability: Worldwide
- Contact: WIPO GREEN Database

Energy infrastructure heating and monitoring: wind sensor

FT Technologies

Source: FT Technologies

FT Technologies wind sensors utilize AcuRes® technology, providing precise wind measurements up to 90 m/s with no moving parts, thereby requiring low maintenance. They are designed to withstand extreme environmental conditions, including temperatures as low as –40°C, and are sealed to IPX6K standards for water and dust resistance. The sensors also incorporate built-in heating systems to prevent ice formation, making them suitable for harsh climates.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United Kingdom
- Availability: Worldwide
- Contact: WIPO GREEN Database

Cold weather and rescue: winterized lifeboats and rescue boats

VIKING Life-Saving Equipment A/S

Source: VIKING Life-Saving Equipment A/S

VIKING Life-Saving Equipment manufactures lifeboats and rescue boats designed for passenger, cargo, offshore and defense sectors, meeting stringent standards such as DNVGL-OS-A201, NORSOK N-003, MODU code and the Polar Code. VIKING offers various winterization upgrades, including soft and hard shell enclosures, space heating, heat tracing and drainage systems. Special measures encompass suitable material grades, appropriate fluids and lubricants, and enhancements for long-term habitation inside lifeboats. The VIKING Norsafe Lifeboat Enclosure ensures compliance with NORSOK design parameters and DNVGL-ST-E406 equivalency, featuring full maintenance access, illumination, material handling jib and noise reduction during drills. These solutions are tailored for extreme temperatures.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Denmark
- Availability: Worldwide
- Contact: WIPO GREEN Database

Agricultural frost protection: agricultural frost fan

Gener

Source: Getty Images/David Ziegler

Gener agricultural frost fans, also known as wind machines, are designed to protect crops from frost damage. These machines operate by circulating warmer air from higher altitudes down to the ground, preventing the formation of frost pockets that can harm plants. They are particularly effective in orchards and vineyards during cold nights or early mornings. Gener offers both stationary and mobile models, powered by diesel or liquefied propane gas engines, featuring double-wing solid fiber propellers for high efficiency and durability. The machines are equipped with smart domain control unit systems for automated control and optional remote operation. Their compact, weather-resistant cabins include integrated fuel tanks for easy transport and setup. Optional sensors and thermostats can be added for enhanced performance.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Türkiye
- Availability: Europe
- Contact: WIPO GREEN Database

Agricultural frost protection: sprinkler irrigation for frost

Rivulis

Source: Getty Images/A-Basler

Rivulis provides a comprehensive range of sprinkler solutions, including jets, foggers, misters and micro-sprinklers, tailored for various agricultural applications. Their systems are designed for overhead and under-canopy irrigation, protected agriculture, and open field irrigation, adaptable to diverse farming scenarios. Additionally, Rivulis provides frost protection systems that double as climate control solutions, cooling orchards in summer and protecting them from frost in spring. These systems ensure even water distribution across the irrigated area, promoting uniform crop development, and meeting the highest standards for post-harvest, industrial and market requirements.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Israel
- Availability: Worldwide
- Contact: WIPO GREEN Database

Residential heating: roof de-icing self-regulating cables

Warmup

Source: Getty Images/xphotoz

Warmup's self-regulating heating cables are designed to prevent ice dams and icicles by melting snow and ice on roofs, gutters and downspouts. These cables adjust their heat output based on ambient temperatures. Ideal for both residential and commercial applications, they help maintain clear drainage paths, protecting structures from water damage. The system includes a range of controllers, sensors and accessories to optimize performance.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United Kingdom
- Availability: Worldwide
- Contact: WIPO GREEN Database

Avalanche control: remote-controlled avalanche blasting system

Wyssen Avalanche Control

Source: Getty Images/Boris Panasyuk

The Wyssen Avalanche Tower is a permanently installed, remote-controlled system designed to safely trigger avalanches before dangerous snow build-up occurs. Installed directly in avalanche start zones, the tower holds up to six solid explosive charges (4–5 kg each) that are manually loaded and remotely deployed. Charges are dropped from the tower and detonate suspended above the snow surface, producing a powerful airblast with a radius of up to 260 m. Powered by solar-charged batteries, the system operates via the Wyssen Avalanche Control Center (WAC.3®), allowing triggering without exposing personnel to danger.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Switzerland
- Availability: Chile, Europe, North America
- Contact: WIPO GREEN Database

Frontier technology solutions

Avalanche response: avalanche beacon

Pieps

Source: Getty Images/Anze Furlan/psgtproductions

The Pieps PRO Interference Protection System (IPS) is a professional-grade avalanche transceiver designed for ski and rescue teams. It features advanced IPS technology to reduce signal interference and dual antenna signal processing for precise locating. It has an 80 m search strip width and a maximum range of 70 m. The device is lightweight (212 g with batteries) and operates in temperatures from –20°C to +45°C. It uses three AAA batteries, providing up to 800 hours of battery life. Bluetooth connectivity allows firmware updates and training via the Pieps app. Its circular receiving range simplifies coarse searches, while the recommended search strip width ensures thorough victim location.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: Austria
- Availability: Worldwide
- Contact: WIPO GREEN Database

Avalanche response: avalanche airbag

Arva

Source: Arva

The ARVA Mini 15+ is a compact avalanche airbag backpack with an adjustable back length down to 36 cm. It integrates the REACTOR 2.0 system, the lightest and most powerful dual-airbag system on the market. Upon activation, two independent air chambers inflate rapidly (via a mechanical trigger and gas cartridge), enhancing body buoyancy and head protection during an avalanche. The 3D-Fit technology ensures ergonomic load distribution, while the Flex System allows users to swap out the main pack body to adjust carrying capacity. With 15 liters of core storage plus 5 liters expandable volume, it provides mounts for skis, snowboards and ice axes. It is made from 100 percent recycled polyester and dyed using dope-dye technology – a water-use efficient alternative to conventional dying processes.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: France
- Availability: Worldwide
- Contact: WIPO GREEN Database

Heaters: portable air heaters for emergencies

Euroheater

Source: Euroheater

The Euroheater 2D and 4D portable air heaters are designed for extreme cold conditions. The Euroheater 2D delivers 2 kW of heat, operating efficiently in temperatures as low as –45°C and altitudes up to 5,400 m. It features a 7.5 liter fuel tank and provides up to 31 hours of continuous operation at its lowest power setting. The Euroheater 4D offers a higher output of 4 kW, also tested down to –45°C, and is suitable for larger areas. Its 7.5 liter fuel tank allows for up to 72 hours of continuous heat at the lowest power setting. They are ideal for military, rescue and outdoor applications where dependable heating is essential.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Norway
- Availability: Europe
- Contact: WIPO GREEN Database

Transport: EV charging cables for extreme conditions

DEFA

Source: Getty Images/Luka Jankovic

eConnect™ EV charging cables are designed for optimal performance in extreme conditions. These cables remain flexible in temperatures as low as –30°C, offer ergonomic connectors, and are built with recyclable materials. Available in various configurations, they support charging capacities up to 22 kW (32 A) and are compatible with all Type 2 inlets. The cable features ergonomic grips, a retractable connector cap to prevent dirt accumulation, and is constructed without resin-filled plugs, enhancing recyclability. Defa has conducted extensive testing, including cold chamber evaluations and run-over tests, to ensure the cable's robustness and longevity. Accessories such as a lockable docking station and premium cable bag are available to facilitate safe storage and transportation.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Norway
- Availability: Worldwide
- Contact: WIPO GREEN Database

Snow and ice management: GPS snow clearing system

Traqnology

Source: Getty Images/ANATOLii SAVITSKii

Traqnology's Winter Warrior GPS Snow Clearing System provides advanced precision and efficiency for snow removal operations. The system utilizes sub-inch RTK GPS accuracy, ensuring precise route tracking without the need for pre-marking. It supports unlimited route recordings, allowing for adaptable snow clearing across varying conditions. The autosteer functionality reduces operator fatigue by automating steering, enhancing comfort during long shifts. Integration with an iPad app streamlines operations, enabling one-touch route initiation and seamless resumption. The system is compatible with a wide range of equipment, from small machines to large fleets, and is designed to withstand harsh winter environments.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Denmark
- Availability: Australia, Europe and North America
- Contact: WIPO GREEN Database

Snow and ice management: roof snow load monitoring

Domely

Source: Domely

DomelyConnect is an autonomous, solar-powered roof monitoring system designed for flat-roofed commercial buildings. Utilizing AI and long-term evolution machine-type (LTE-M) connectivity, it detects real-time snow loads, water accumulation, debris and structural issues. The self-supporting modules require no drilling and are easily deployable. The system provides 360° visual monitoring, weather forecasts and personalized risk alerts. It also offers recommendations to optimize snow removal timing, potentially reducing costs and preventing structural damage. DomelyConnect is recognized by some insurers, possibly leading to insurance savings.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Canada
- Availability: North America
- Contact: WIPO GREEN Database

Snow and ice management: accumulation management for pitched and flat roofs

Floe

Source: Getty Images/aoldman

Floe is an intelligent, eco-friendly solution for managing rooftop ice and snow accumulation. Developed by engineers from Massachusetts Institute of Technology and Yale University and validated by the US Army Corps of Engineers, Floe utilizes sensors and real-time weather data to predict and detect ice build-up. When necessary, it automatically dispenses a biodegradable, non-corrosive de-icer that is safe for pets and plants.
The system comprises a weatherproof console, a rooftop irrigation network with UV-rated tubing and a de-icer cartridge. It operates autonomously, requiring minimal maintenance – only an annual de-icer cartridge replacement. Floe is designed to last over 10 years, and is compatible with various roof types, including pitched and flat roofs.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United States
- Availability: United States
- Contact: WIPO GREEN Database

Energy infrastructure heating and monitoring: sensor for wind turbines in cold climates

Instrumentation Icetek

Source: Instrumentation Icetek

The IC-1 Ice Condition Monitoring System is designed for wind turbines in cold climates, where ice formation can reduce annual energy production by up to 20% and impact safety. Unlike turbine performance-based heating activation, the IC-1 provides direct measurements of icing conditions using heated probes that apply a patented heat transfer principle to detect the onset of icing event at the earliest signs. The system also measures wind speed and direction, ambient temperature, pressure, humidity, solar radiation, and cloud coverage. All data is processed locally and transmitted to the wind farm control station via a surge-protected control cabinet, enabling the automated control of blade heating systems. Case studies have demonstrated that the IC-1 remains ice-free and operational down to -40 °C, supporting timely heating activation and reducing production losses.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Canada
- Availability: Canada, France, Norway, Sweden, Switzerland, United States
- Contact: WIPO GREEN Database

Horizon technology solutions

Transportation: LiGas electrolyte for cold-resilient lithium-ion batteries

South 8 Technologies

Source: South 8 Technologies

Based in San Diego, California, South 8 Technologies is pioneering the world's first liquefied gas electrolyte (LiGas®) for lithium-ion batteries. LiGas cells enable high-performance operation across an unprecedented temperature range (-60 to +60 °C), unlocking applications in defense, aerospace, and electrified transportation. South 8 offers both finished cells and electrolyte integration kits for partners seeking to advance their systems with cutting-edge electrochemical performance. With the ability to operate where conventional batteries cannot, South 8 is redefining the standards of lithium-ion technology and opening new frontiers for industries in the most demanding environments.

- Technological maturity: Horizon
- Contracting type: For collaboration
- Technology level: High
- Place of origin: United States
- Availability: N/A
- Contact: WIPO GREEN Database

Agricultural frost protection: nature-inspired frost protection

CryoBio

Source: CryoBio

CryoBio is an agricultural biotech startup developing a nature-inspired spray that protects crops from frost damage by lowering the freezing point of water by up to 8 °C. Leveraging molecules derived from cold-adapted organisms, the technology prevents ice formation on plants, offering near-total protection against severe frost. It can be applied to any crop using standard equipment, costs less than one-tenth of current frost-protection methods, and is environmentally safe. CryoBio aims to protect up to 5% of global crop production, enhancing farmers' resilience and reducing agricultural losses exacerbated by climate change. The technology is in the pre-commercialization stage.

- Technological maturity: Horizon
- Contracting type: For collaboration
- Technology level: Medium
- Place of origin: United states
- Availability: N/A
- Contact: WIPO GREEN Database

Residential heating: shape-stabilized Phase Change Materials (ss-PCMs)

Nanolope

Source: Nanolope

Nanolope has developed innovative shape-stabilized phase change materials (ss-PCMs) that dramatically enhance thermal energy storage in buildings, particularly in cold environments. Unlike conventional water-based or gypsum/concrete thermal storage, Nanolope PCM can store up to 24 times more energy than standard gypsum boards in just a 2 cm panel. Made from renewable resources and containing a very high proportion of PCM (~85% of its weight), it absorbs heat during warmer periods and releases it during cold spells, maintaining comfortable indoor temperatures. The material is mechanically stable, leak-proof, and can be retrofitted into walls, ceilings, or floors, enabling lightweight modern apartments to achieve the thermal comfort of massive historic buildings, with passive heating in winter and passive cooling in summer. This technology remains at the horizon stage, offering transformative potential for energy-efficient buildings in extreme cold climates.

- Technological maturity: Horizon
- Contracting type: N/A
- Technology level: High
- Place of origin: Germany
- Availability: N/A
- Contact: WIPO GREEN Database

Part 4: Disaster response logistics

Photo: Getty Images

The transformative technologies that are reshaping the world more broadly – such as artificial intelligence (AI), machine learning, satellite systems, aerial robotics, mobile communications, blockchain and social media – are also being applied to improve disaster response. The difference in this case is they are being used to save lives, reduce chaos and improve resilience.

Although emerging technologies cannot replace essentials like food, shelter and medical care, they are proving indispensable in organizing and accelerating relief efforts (WEF, 2018). Drones, for example, provide access to disaster areas, map terrain and assist in rescue efforts, while mobile solutions and big data help organizations respond more efficiently by gathering real-time feedback and optimizing aid distribution. Forecast- and impact-based warnings provide critical lead times that enable crucial situational awareness allowing responders to pre-position assets, activate the supply chain and mobilize logistics before disaster impacts. And partnerships with local communities and community-led organizations facilitate the meaningful participation and inclusion of those affected.

Emergency infrastructure and rapid deployment

Climate-driven disasters are displacing millions, overwhelming traditional response systems. Innovations like 3D-printed shelters, rescue drones, and mobile solar grids enable faster, adaptive responses. Resilient shelter designs, amphibious aid vehicles, and decentralized logistics tackle challenges while cutting costs and environmental impact.

Technological developments and trends

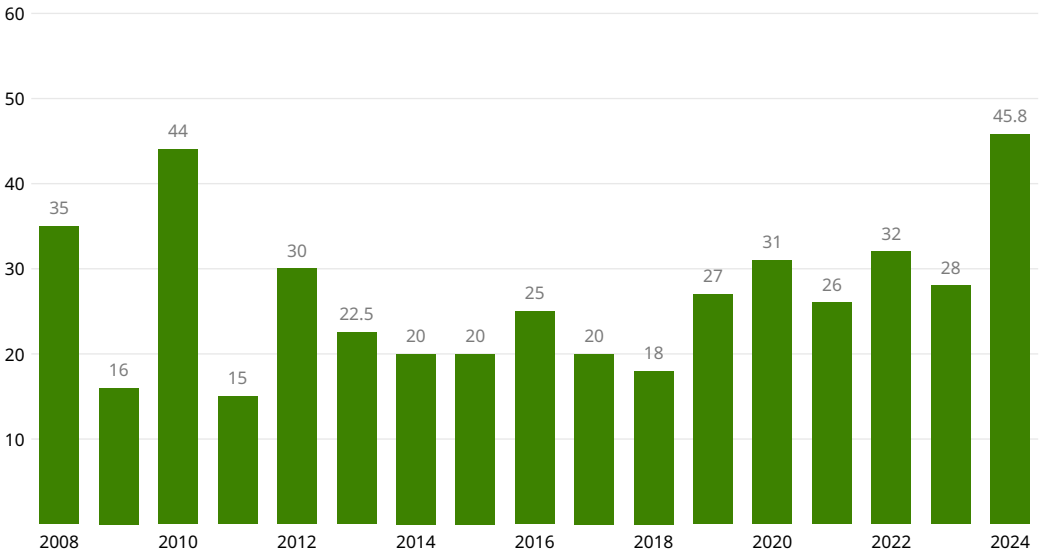
The Internal Displacement Monitoring Centre (IDMC) reports that almost 449 million displacements were triggered by disasters across more than 120 countries between 2008 and 2024 (IDMC, 2025). Floods, storms and earthquakes account for the majority, with floods comprising about 48 percent of the total. Floods and storms are increasingly becoming the main triggers for disaster displacement, underscoring a need for improved disaster risk reduction, preparedness and response, especially in the face of climate change.

Figure 9.1 indicates that the number of disaster displacements in 2024 was nearly double the annual average for the period 2008-2023, reaching 45 million. Strikingly, 2024 broke several records, with 29 countries and territories reporting the highest disaster displacement figures on record. The number of countries reporting displacement caused by both conflict and disasters has tripled since 2009 (IDMC, 2025). The data in Table 9.1, detailing the 448.6 million displacements between 2008 and 2024, show this crisis is overwhelmingly driven by water and weather: floods (213.7 m) and storms (177.2 m) account for a combined 87% of all displacements. Importantly, in 2024, pre-emptive evacuations proved to be an effective life-saving measure in several locations, including in high-income countries, with one-third of all countries reporting their use.

> Almost 449 million displacements were triggered by disasters across more than 120 countries between 2008 and 2024

Displacement due to disasters is not only a humanitarian challenge, but also an operational test of early warning systems. Forecast- and impact-based early warnings can significantly reduce the logistical strain caused by sudden mass movements.

Figure 9.1 Internal displacements in millions, 2008-20024 (448.6 million total in 211 countries)



Source: Aleem *et al.*, 2024

Table 9.1 Internal displacements 2008-2024 (22.1k disaster events reported)

Disaster	Total number disaplaced
Flood	213.7m
Storm	177.2m
Earthquake	41.4m
Drought	5.8m
Wildfire	5m
Volcanic activity	2.6m
Wet mass movement	1.7m
Extreme temperature	1.2m
Dry mass movement	90k
Mixed disasters	19k
Erosion	12k
Wave action	11k

Source: IDMC, 2025

Given the unprecedented scale and frequency of displacement caused by climate-driven disasters, traditional response methods are increasingly stretched thin. Early warning systems play a critical role in ensuring that emergency infrastructure and support services are in place before disaster impacts occur. Accurate hazard forecasts, such as cyclone track projections, flood crest timing or wildfire spread modeling, provide the lead time to logistics activation. Response agencies can synchronize procurement, customs clearance and transport operations with the anticipated onset. However, turning that lead time into effective action depends on having rapid and adaptable response technologies ready to deploy. Emergency infrastructure and rapid deployment capabilities have therefore emerged as critical components in meeting these challenges, enabling swift operational capacity and a more effective disaster response.

Emergency infrastructure and rapid deployment technologies encompass flexible and adaptable, mobile and resilient solutions designed to establish immediate operational capacity in crisis zones. Advanced construction technologies and materials enable fast, low-cost rebuilding and are being used in temporary shelters for displaced people. Mobile medical units and rapidly deployable shelters provide hygiene, health care and safety, while autonomous and robotic systems, such as water and multi-terrain rescue robots and foldable drones, are game changers for search-and-rescue operations. Likewise, logistical supply chain innovations are essential for the delivery of aid to inaccessible areas. Energy and water infrastructure resilience is also crucial for remote and off-grid areas enduring disasters.

Technologies involved in emergency infrastructure prioritize AI and automation, energy independence and localized manufacturing. Many solutions, such as drones and 3D printing, combine hardware with AI. By integrating physical and digital systems, innovative solutions can bring immediate relief alongside long-term recovery. Military-grade technology is often repurposed for use in civilian disaster response efforts. The military's expertise in rapid deployment and robust infrastructure can play a role in enhancing response capabilities. Fortunately, renewable energy and circular design principles are increasingly becoming standard, reducing the environmental impact of these technologies.

From plastic sheeting to 3D printing: evolving shelter technologies

Disasters can cause severe destruction, leaving communities in urgent need of protection – including reliable shelters. In emergency situations, effective shelters prioritize simplicity, safety and the use of locally available, sustainable materials, only resorting to imported materials when necessary. Plastic sheeting is widely used because of its low cost and versatility. However, shelters should offer not only physical protection, but also support the dignity, safety and psychological well-being of displaced people (UNHCR, 2025).

> Improving how shelters are designed and managed is often one of the most practical ways of reducing disaster impact

Temporary shelters can be classified into four types: emergency shelters, which provide immediate and life-saving protection for the very short-term; temporary shelters like tents so that individuals or groups can bridge the gap between emergency and a more stable means of shelter; temporary housing, which is typically more durable and better equipped than shelters; and, lastly, permanent housing, which despite being labeled as "permanent" can sometimes be deployed quickly and cost-effectively in urgent situations. While the choice depends on the nature of the disaster and available resources, emergency and temporary shelters often end up serving as long-term housing for affected people (Subramanya and Kermanshachi, 2022; Parametric Architecture, 2023).

Improving how shelters are designed and managed is often one of the most practical ways of reducing disaster impact. While exact cost–benefit data for humanitarian contexts is limited, evidence from non-humanitarian settings shows that every USD 1 spent on risk mitigation saves between USD 7 and USD 15 in post-disaster damage and recovery costs (Pew, 2018). Reviews of shelter resilience during emergencies highlight many low-cost, high-impact design features. Organizations like the International Federation of Red Cross and Red Crescent Societies (IFRC) and the Global Shelter Cluster (co-led by UNHCR and IFRC) publish widely recognized best practice for effective disaster risk reduction in shelters to enhance resilience (Wilson Center, 2025). Using locally-sourced materials and ensuring local ownership are cornerstones of these efforts, alongside ensuring equitable, gender-responsive, conflict-sensitive and inclusive (human rights-based) approaches.

To reduce disaster impacts on shelters and settlements, practitioners use various techniques tailored to local hazards (Wilson Center, 2025). They include:

- *Strengthening structural connections*: in Indonesia, after earthquakes in 2018 and 2020, the use of light steel framing with diagonal bracing improved shelter resilience against earthquakes, cyclones and high winds.
- *Raising foundations and deep posts*: in Syria, following floods in 2022 and an earthquake in 2023, the Global Shelter Cluster recommended installing plinths at wall bases. Similarly, after 2022 cyclones in Madagascar, posts were sunk at least 75 cm deep, so as to better withstand floods and storms.
- *Creating defensible spaces* (for fire risk): after fires in Palestine in 2018, clearing dry vegetation, waste and debris around shelters in camps helped reduce fire risks.

Additional measures include spacing tents in order to create firebreaks, digging drainage channels to manage water flow, and planting vegetation to prevent erosion. Such strategies vary according to context, but collectively help make shelters more disaster-resilient.

The UNHCR provides minimum standards for floor space in emergency shelters for both warm and cold climates, while also providing a table of the pros and cons associated with different shelter solutions, as shown in table 9.2.

Table 9.2 Pros and cons of shelter solutions

Shelter solution	Pros	Cons
Family tents	Valuable for immediate relief; lightweight, quick to install, winterizable, mass-producible, proven designs	Inflexible, unstable in high winds/snow, hard to heat; repair materials needed for long-term use
Plastic sheeting	UV-resistant, durable, lightweight, flexible; high production capacity; familiar, low cost	Limited wind/rain resistance; environmental impact if not disposed of properly. Using wood for support frames can harm the environment; sustainable material sourcing essential
Materials and tools for construction (shelter kits)	Local materials ideal if available, seasonally appropriate, and culturally familiar	Requires time and training
Prefabricated shelter and containers	Permanent or semi-permanent structures, durable when adapted to local climate	Higher unit cost than local solutions; may not suit cultural preferences; limited insulation
Refugee housing units	Durable, weather-resistant, lightweight, portable and modular	Higher cost than local solutions; may not align with cultural preferences; limited insulation
Rental subsidies/cash-based interventions	Increased competitive market may cause price increases, inflation and speculation; challenges in areas without financial institutions; may require upgrades or repairs, community integration and income for host community	
Shelter rehabilitation/upgrade	Designed for durability, suited to or developed for cold climates	Costly, time-consuming; requires adherence to local codes

Source: UNHCR, 2025

Efforts to promote disaster-resilient shelter solutions often encounter policy limitations, as some host countries prioritize temporary shelter approaches for displaced populations, reflecting the prevailing view of displacement as a short-term situation. This can entail restrictions on the use of durable materials, permanent foundations or long-term infrastructure, which may limit the building of shelters resilient to climate-related hazards. Many mitigation measures, such as framing or installing drainage systems and strengthening walls, are seen as permanent and banned in camps. Innovative and contextually appropriate approaches are needed – for instance, Catholic Relief Services and Caritas International label their durable shelter upgrades for Rohingya refugees in Bangladesh as "mid-term shelters" to comply with government restrictions, despite the work being essentially permanent (Wilson Center, 2025). See Box 9.1 for a description of Sphere, a global initiative that sets standards for quality and accountability in humanitarian response.

Box 9.1 The Sphere Handbook: Humanitarian Charter and Minimum Standards in Humanitarian Response

The *Sphere Handbook* (Sphere Association, 2018) is Sphere's flagship publication and one of the most widely recognized tools for ensuring quality and accountability in the humanitarian response to disasters. It comprises the Humanitarian Charter, Protection Principles, the Core Humanitarian Standard, and minimum standards within four key sectors: water supply, sanitation and hygiene promotion (WASH); food security and nutrition; shelter and settlement; and health. These standards are used by non-governmental organizations, United Nations agencies and governments worldwide to plan, deliver and evaluate humanitarian operations. While not prescribing the use of specific tools, the *Handbook* provides clear guidance on the use of technologies in disaster response. They should be people-centered, uphold the safety, dignity and rights of affected populations, and contribute to meeting sector-specific standards. Technologies must also do no harm, protecting privacy and avoiding risks such as exclusion, exploitation or surveillance. Sphere advises that new technologies be introduced only if they have been tested in or adapted to similar contexts, and always with community consultation, inclusive access, culturally sensitive design, training and long-term planning for support, accessibility and commercial viability.

3D printing enabling rapid, on-demand construction using local materials

Traditional construction methods are often slow, expensive and logistically complex. In contrast, 3D printing presents a promising alternative by enabling faster, more adaptable and cost-efficient solutions for disaster recovery and rebuilding. Historically, societies have responded to disasters with rapid, adaptive architecture – for example, Otto Bartning's modular churches built from wartime rubble in post-World War II Germany or China's prefabricated Fangcang hospitals during the COVID-19 pandemic – each aiming to provide shelter quickly during an emergency (Subramanya and Kermanshachi, 2022).

3D-printed housing employs large robotic arms guided by digital blueprints (CAD files) to lay down layers of material – like concrete or clay – directly onto a building site. The printer follows a programmed path, creating walls and structural elements layer by layer, leaving gaps for doors and windows.

One of the key advantages of 3D printing is its ability to deploy quickly. Mobile 3D printers can be transported directly to disaster-affected areas, where they can produce essential supplies and structures on-site, operating both night and day to maximize output. This approach eliminates long supply chains and reduces delays. Because 3D printing allows for customization, it can address the specific needs of each disaster scenario, and its scalability ensures it can be adapted to varying levels of impact and the available resources.

Cost effectiveness is another benefit. 3D printing minimizes material waste by building objects layer by layer to conserve resources. Homes can be printed in 24 hours for under USD 4,000 by companies like Icon, compared to 40× the cost using conventional methods (Subramanya and Kermanshachi, 2022). It also reduces labor costs by automating much of the construction

process, and can cut down on transportation expenses through localized production. Additionally, the use of recyclable and sustainable materials contributes to environmentally-friendly recovery efforts.

> 3D printing within disaster settings offers quick, customized production in small batches, but is not suitable for mass manufacturing

Beyond constructing immediate shelter, 3D printing can be used to repair infrastructure, such as roads, bridges and utility systems, by rapidly producing replacement parts and structural components. In health care, it supports the production of urgent medical supplies, including prosthetics, surgical tools and personal protective equipment, as well as spare parts for medical machines. It also helps restore the supply of basic needs by printing components for water filtration systems and food production setups. 3D printing may also support education and skills development when used to produce educational materials and training models, and to set up local workshops that teach additive manufacturing skills.

3D printing within disaster settings offers quick, customized production in small batches, but is not suitable for mass manufacturing owing to its current limited speed. In addition, not all components (e.g., doors, windows, roofs) are currently printable. While most high-tech 3D printed construction projects are built in high-income countries, there are emerging pilot projects in low-income, fragile and post-disaster contexts. However, several key challenges continue to limit broader adoption. They include technical skill requirements, regulatory hurdles, equipment fragility, sensitivity to weather, possible high costs, and the need for reliable power – all of which can be difficult to guarantee within disaster-affected settings (Parametric Architecture, 2023; SQ4D, 2024).

Rapid-deploy and mobile units provide shelter, health care, power and logistics

Inflatable emergency response shelters are quick-deploying self-erecting structures used for protection, as well as triage stations, field hospitals, command centers and temporary housing. Some can be inflated in under 6 minutes. Inflatable air tents are ready for rapid setup in an emergency and can help maintain a stable interior temperature.

Portable cabins are versatile, modular and more durable disaster relief solutions that serve multiple functions beyond providing basic shelter. They provide secure emergency housing, can be converted into mobile health centers or hospitals, act as command and control centers for coordination, serve as warehouses for essential supplies, and function as temporary classrooms.

> Shipping containers can serve as secure storage and mobile command centers in disaster relief

Medical containers are portable, modular units – often modified shipping containers – equipped with medical facilities for either an emergency or remote health care provide clean ventilated spaces and ensure accessibility to health care. Technology providers like Proseven produce adhesive pads that can secure equipment inside these containers, ensuring they remain stable during transportation and easy to reorganize on-site. Shipping containers can serve as secure storage and mobile command centers in disaster relief, and can be modified with the addition of eco-friendly features such as solar panels and rainwater harvesting.

Sesame Solar Nanogrids deliver rapid, off-grid renewable power within 15 minutes to support pop-up shelters, medical centers and emergency operations. Providers like Rubb have developed easily deployable, air-transportable emergency shelters and storage structures that can be assembled quickly. High-durability rescue boats support the response to water-related disasters.

Innovations deliver emergency food and water supplies

In the immediate aftermath of a disaster, access to safe drinking water and food is a critical lifeline for affected communities. Innovative technologies help ensure their timely delivery and safety. From emergency water filters that protect against bacteria, parasites and emerging contaminants like PFAS (per- and polyfluoroalkyl substances that break down very slowly) to durable and hygienic drinking water buckets designed for rapid local deployment, advancements in water and sanitation technology are saving lives. Solutions like smart water ATMs enable controlled, contactless access to clean water. At the cutting edge of food delivery, robotics and drones are transforming the transportation of food to disaster areas through projects like RoboFood, which is pioneering edible robots capable of delivering lifesaving nutrients in disaster zones (they are made in part from edible materials). Logistics drones, such as Aeronext's AirTruck, help to deliver critical supplies in a challenging terrain. Together, these integrated technologies address the complex demands of emergency food and water provision during a disaster. However, the use of drones in active conflict regions or in areas beyond state control might not be possible or advisable.

To cut the costs incurred using helicopters and airplanes, the World Food Programme (WFP) has developed SHERP, an amphibious all-terrain vehicle, in Ukraine. It delivers humanitarian aid to remote locations. By replacing airlifts for food delivery, it has significantly reduced transportation expenses, with some operations achieving up to a 75 percent cost reduction (Fleet Forum, 2019). SHERP is designed to navigate through swamps, flooded roads and over rugged terrain. It can float on water and has a high ground clearance of 1 meter, enabling it to negotiate boulders and fallen trees. With a full tank of fuel, SHERP can cover up to 600 kilometers, while carrying a cargo load of up to 1,200 kg (WFP, 2022). During the response to Cyclone Idai in Mozambique, for example, SHERP vehicles delivered 26 tons of food to the isolated community of Buzi, in the process navigating flooded roads and inaccessible routes that conventional vehicles could not traverse (WFP, 2022).

As described in box 9.2, WFP has developed an extensive disaster logistics framework and operation, complete with coordination and information-sharing platforms, logistics and stockpiling hubs for supplies; its own air service; and an ever-expanding drone coordination model for a wide range of services and operations.

Food delivery is obviously vital. The increasing frequency of climate-related disasters has spurred demand for emergency meal services. For example, Hurricane Ian in 2022 required the feeding of 30,000 displaced residents in Florida in the United States. Similarly, in 2019, Cyclone Idai devastated Mozambique, displacing over 1.85 million people and creating urgent food supply challenges in fragile and hard-to-reach areas. Such impacts are often larger in scale and more profound in fragile or conflict-affected areas due to their greater vulnerability. Some governments are responding by increasing funding for food logistics, for example, the United States USD 3.5 billion allocation to FEMA in 2023, which boosts partnerships with catering providers (PW Market Research, 2025). Urbanization also increases vulnerability, particularly for marginalized populations living within informal or overcrowded settlements. Even when services exist nearby, barriers such as affordability, lack of legal identification (ID) or residency papers and infrastructure gaps can limit access, making agile solutions like drones and mobile kitchens increasingly important. The private sector is also adopting emergency catering into business continuity plans. Technological advancements, such as blockchain and AI, are improving supply chain management and response efficiency. The global emergency catering service market, valued at $3.45 billion in 2024, is projected to have grown to $4.89 billion by 2030, at a 6.0 percent annual growth rate (PW Market Research, 2025).

Box 9.2 WFP's technological edge in disaster preparedness and response

In 2023, the World Food Programme (WFP) supported 58 countries in strengthening their emergency preparedness and response systems, reaching 103 million people with assistance during disasters and crises. WFP's approach integrates advanced technologies and innovative logistics that optimize operational efficiency.

WFP employs data-driven early warning systems and geographic information systems (GIS) for real-time risk assessment and disaster impact mapping. WFP's United Nations Humanitarian Response Depot (UNHRD) network maintains strategic stocks at five global hubs, enabling the dispatch of relief items within 48 hours of notification. This system supports over 100 partners with rapid procurement, storage and transport. The organization's global supply chain managed the delivery of an estimated 3.7 million metric tons (MT) of food in 2023, supported by its Logistics Cluster and the Logistics Cluster Information Exchange (LogIE). LogIE's multi-layered, map-based data integration platform supports coordination and information sharing to ensure that aid reaches its destination efficiently. The UN Humanitarian Air Service (UNHAS) – operated by WFP – transported over 388,000 passengers and 4,800 MT of cargo in 2023 to more than 389 destinations using a fleet of 144 aircraft. The Operations Centre (OPSCEN) facilitates 24/7 crisis communication and inter-agency coordination.

Since 2017, WFP has been advancing the use of drones to enhance its emergency preparedness and response to disasters. Supported by partners like Belgium, the United Kingdom's Foreign, Commonwealth & Development Office (FCDO) and the European Union, WFP has developed a global drone coordination model, pre-positioned equipment in five regions, and conducted over 25 capacity-building activities benefiting 600+ participants in 2022. Drones are used for rapid damage assessment and flood modeling; agricultural crop health monitoring using multispectral imaging; and search and rescue missions using infrared technology. They also support emergency connectivity by delivering mobile and internet coverage and facilitate precise site surveying for communication network setup.

Innovation examples

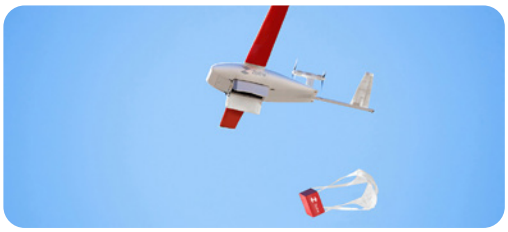
Mobile technology for water and sanitation disaster resilience in the Pacific

Source: Field Ready

Field Ready is a humanitarian organization dedicated to building local capacity and delivering practical solutions for disaster response. In the Pacific region, Field Ready has developed a Mobile Makerspace – a portable workshop equipped with tools and technology – to support rapid repairs, particularly focused on water, sanitation and hygiene (WASH) needs in remote island communities. The Pacific's diverse water sources and climate challenges require innovative approaches to water management. Field Ready emphasizes rainwater harvesting as a sustainable, community-driven solution to water scarcity. Deploying the Mobile Makerspace, teams have supported villages in Fiji in assessing and repairing critical WASH infrastructure, including rainwater systems, sanitation shelters and water tanks. A key piece of equipment, the portable Guttering Machine, enables the on-site production of gutters, allowing communities to maintain and expand their rainwater harvesting systems. The Mobile Makerspace's successful

deployment across islands demonstrates its mobility and adaptability. Field Ready plans to expand this approach throughout the Pacific, including Vanuatu, Samoa and the Solomon Islands, to improve disaster response capabilities regionally (Field Ready, 2023).

Flying lifelines: how Zipline's drones transform medical supply delivery in Rwanda



Source: Zipline

Rwanda's mountainous terrain and poor road infrastructure make transporting medical supplies to rural areas unreliable, causing 25–40 percent of temperature-sensitive products like blood to spoil before reaching a clinic. Zipline – a US-based drone company – addresses these challenges by using drones to deliver blood and emergency medical supplies quickly and efficiently. Operating from two distribution centers, Zipline receives blood collected by the National Centre for Blood Transfusion in Kigali and flies it directly to district hospitals and rural clinics, bypassing difficult terrain and unreliable roads. Health workers order supplies via SMS or phone, and drones fly at speeds up to 160 km/h, delivering packages by parachute within minutes. By early 2020, Zipline was delivering over 75 percent of Rwanda's blood supply outside the capital, reducing delivery times from hours to minutes. Zipline operates through strong partnerships with Rwanda's Ministry of Health, its Civil Aviation Authority and donors like the Global Alliance for Vaccines (GAVI). Zipline's success also highlights the potential of drone delivery to enhance health care access in remote areas through public–private collaboration (Reach Alliance, 2020).

Sustainable, low-cost timber–cardboard shelters for post-disaster relief in Australia

Source: Southern Cross University

After the 2019/20 bushfires and 2022 floods in Northern Rivers, Australia, researchers from Southern Cross University and the University of Queensland developed an innovative, low-cost disaster-resistant housing system using hybrid timber–cardboard materials. The key technology is a "sandwich panel" construction, where recycled cardboard "studs" are bonded between plywood layers made from radiata pine, hoop pine, particleboard and medium-density fiberboard. Structural elements also incorporate low-diameter roundwood and pulpwood residues sourced from local forest thinnings, maximizing use of forestry by-products. This approach significantly reduces material costs and embodied carbon emissions by utilizing waste and residue materials, while creating lightweight panels for framing and cladding. The design simplifies fabrication and assembly and supports easy disassembly for reuse or recycling, which is ideal for rapid deployment in flood or bushfire disasters. Backed by New South Wales' Department of Primary Industries and industry partners, the system aims to provide affordable, sustainable temporary shelters that can be built for around $12,000. This hybrid timber–cardboard technology offers a new class of structural composite material, representing a promising model for scalable post-disaster housing solutions that address urgent shelter shortages in vulnerable communities (Wood Central, 2024; ABC News Australia, 2024).

Proven technology solutions

Shelters: shipping containers for disaster relief

VS&B Containers Group

Source: Getty Images/golfcphoto

Shipping containers, originally designed for global trade, are revolutionizing disaster relief logistics. A sturdy steel construction protects supplies from harsh conditions and theft, while a standardized size allows rapid transport via ships, trucks and trains to ensure aid reaches affected areas quickly. Beyond transportation, containers can be transformed into temporary shelters, mobile clinics, storage units and command centers. They are often reusable and adaptable with eco-friendly technologies like solar panels and rainwater systems. VS&B provides both standard and custom-built containers from a fleet of over 30,000 containers available across Europe and Asia.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Low
- Place of origin: India
- Availability: Asia, Australia, Europe, United States
- Contact: WIPO GREEN Database

Shelters: emergency shelter buildings

Pontarolo Engineering

Source: Getty Images/wabeno

Pontarolo's emergency shelter building solutions enable the rapid construction of durable and energy efficient temporary or permanent housing. Central to this system is the Climablock formwork, an insulated concrete form (ICF) made of expanded polystyrene (EPS) that combines structure and insulation in a single step. The system also includes Kaldo and Spyrogrip panels for floors and ceilings, which provide additional thermal and acoustic insulation. For foundations, IsolCupolex Rialto is a multi-patented system that creates an aerated and insulated slab, and which serves as a stay-in-place forming system for the casting of the pavement slab. This slab can bear heavy loads, while still providing a ventilated crawl space that improves moisture control and structural stability. With no thermal bridges (areas in a building where heat flows more easily due to a break or weakness in the insulation, such as at junctions where walls meet floors or roofs, structural elements, and window/door frames), the constructions support passive or nearly zero-energy building schemes.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Italy
- Availability: Europe, North America, Oceania, South Africa
- Contact: WIPO GREEN Database

Shelters: portable emergency tents for people, supplies and vehicles

Rubb Building Systems

Source: Rubb Building Systems

Rubb's emergency shelter technology offers quickly deployable solutions for disaster relief. Its portable tents can be assembled in just a few hours using basic tools and local labor. Shelters are easily dismantled, stored and redeployed as needed. Larger soft-skin prefabricated structures provide emergency accommodation, secure storage and protection for vehicles, equipment and aircraft from extreme weather. Designed for global field missions, all shelters fit into standard ISO containers and are fully air transportable. The aluminum-framed buildings are especially suited for air freight, enabling rapid deployment worldwide.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Norway
- Availability: Worldwide
- Contact: WIPO GREEN Database

Shelters: inflatable emergency response shelter

Giant Inflatables Industrial

Source: GIant Inflatables Industrial

Inflatable emergency response shelters are essential in disaster situations, humanitarian missions and military operations, serving as field hospitals, command centers and temporary housing. The X-beam Advanced (XBA) shelter is a rapidly deployable, self-erecting inflatable structure that sets up in under 6 minutes using high-strength inflatable beams. It is both lightweight and durable, and provides strong protection against harsh weather. Usable interior space is maximized using vertical walls, and openings on all four sides create a modular system where multiple units connect to create flexible and expandable shelter configurations.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Australia
- Availability: Worldwide
- Contact: WIPO GREEN Database

Robotics and drones: drones for diverse disaster operations

WeRobotics

Source: WeRobotics

WeRobotics is a Swiss-American nonprofit organization founded in 2015 that partners with local experts to deploy drone, data and AI solutions for disaster response in over 40 countries. Its Flying Labs initiative – a global network of locally-led innovation hubs – trains communities to use drone technology for social good. In emergencies, drones provide high-resolution imagery for rapid damage assessment, create detailed maps and 3D models to guide resource deployment, and monitor hazardous areas without endangering responders. They also support search and rescue by covering large areas, detecting heat signatures and delivering real-time data to teams. Beyond response, drones assist in risk reduction by mapping vulnerable zones like floodplains and wildfire-prone regions.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO GREEN Database

Water and sanitation: emergency water filters

LifeStraw

Source: LifeStraw

LifeStraw facilitates access to clean drinking water during emergencies and in homes, addressing contaminants ranging from bacteria and parasites to chemicals like lead and PFAS. Their products utilize an advanced hollow fiber membrane technology, which consists of tiny straw-like fibers with microscopic holes that block bacteria, parasites, dirt and microplastics similar to a super-fine strainer. The company offers product lines tailored to the specific needs of emergencies, outdoor activities, or home use, where the filter is supplemented with additional filtration methods to handle viruses, lead, chemicals, and/or improve taste. LifeStraw is a Climate Neutral Certified B Corp and actively responds to water-related emergencies around the globe.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Switzerland
- Availability: Worldwide
- Contact: WIPO GREEN Database

Water and sanitation: smart water ATM control panel and water vending machine

AALROOT

Source: AALROOT

The AALROOT Smart Water ATM Control Panel is an electronically-operated system designed to facilitate efficient and secure water dispensing in public places. It integrates multiple payment methods, including UPI-QR, eCard and coin, and provides dynamic QR generation based on volume selection. The system uses a flow sensor and solenoid valve (electromechanically operated) to regulate water output based on user selection, providing precise control over dispensed quantities. It is Wi-Fi enabled for remote monitoring and management via a dedicated mobile application. There is an auto-refund feature if water is not dispensed, as well as a low water level switch and emergency stop. Real-time transaction tracking provides information on dispensed water and revenue collection.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: India
- Availability: India
- Contact: WIPO GREEN Database

Water and sanitation: drinking water bucket

Field Ready

Source: Field Ready

Field Ready's "Better Buckets," originally designed by Oxfam, an international development NGO, have been locally manufactured in the Pacific since 2019, improving delivery speed and reducing shipping costs in the wake of disasters. The 14-liter buckets are made from new, high-quality polyethylene and have been drop-tested to withstand a fall from a height of 2 meters without springing a leak. They feature a clip-on cap for easy cleaning and filling, with an optional tap for water dispensing. Designed for hygiene, the buckets have curved interiors to limit bacterial growth, sealable lids to prevent contamination, and a rim-lock system for a tight fit. They are stackable, easy to carry and safe to transport carried on the head. Custom branding options are available, including embossed logos and a choice of color.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO GREEN Database

Frontier technology solutions

Shelters: 3D printers and 3D printed structure with Lavacrete/CarbonX

ICON

Source: ICON

ICON develops robotic and AI-based construction technologies. Their Lavacrete building material is a cementitious mix that prints quickly and produces walls capable of withstanding hurricane-force winds with a two-hour fire rating. The company also offers CarbonX, a low-carbon building material that reduces emissions by 24% compared to the Lavacrete mix. ICON's 3D printers include Vulcan, a gantry-style system capable of printing a 2,000-sqft. single-story house in about seven days with continuous operation. It has to date printed more than 200 structures and homes across social housing, disaster-relief housing, market-rate residential housing and commercial projects. In 2024, ICON also unveiled a new robotic printer enabling multi-story construction. For fine-tuning mixes and ensuring that it maintains the right consistency, curing time and strength, ICON created Magma, a portable mixing system that optimizes their material mixing by automatically adjusting the proportions of additives and water based on construction site temperature and humidity.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: United States
- Availability: Mexico, United States
- Contact: WIPO GREEN Database

Shelters: 3D printing architecture

World's Advanced Saving Project (WASP)

Source: World's Advanced Saving Project (WASP)

WASP's 3D printing technology focuses on sustainable architecture using locally sourced materials. Its Crane WASP system is a large-scale, collaborative 3D printer designed specifically for building houses. It emphasizes the use of on-site materials to minimize costs and environmental impact, thereby embodying the concept of "Km 0" or zero-distance sourcing. Included in its Maker Economy Starter Kit, Crane WASP aims to make affordable, eco-friendly housing accessible by using innovative printing methods and locally available resources, inspired by the "vasaia" wasp as a symbol of efficient construction.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: Italy
- Availability: Worldwide
- Contact: WIPO GREEN Database

Shelters: mobile medical facility

Mobile Medical Container Promotion Council (MMCPC)

Source: Mobile Medical Container Promotion Council (MMCPC)

The MMCPC provides medical containers and prefabricated flat pack units that can be rapidly deployed to create "Micro Hospitals" for emergencies or remote locations. Built in Japan and shipped pre-assembled, they can be installed in less than 30 days and configured as treatment rooms, operating rooms, wards, or laboratories. Equipment such as oxygen concentrators, water units, power generators, and even advanced imaging devices like CT or MRI can be included. Flat pack units offer flexibility, long service life, and can connect to form larger facilities. In Japan, MMCPC containers have been deployed after disasters such as the Noto Peninsula earthquake, where a medical container and portable equipment like oxygen units and monitors were sent to maintain care. The MMCPC oversees the development, transport, and installation of these systems, working with government agencies and offering telemedicine support from specialists in Japan.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Japan
- Availability: Worldwide
- Contact: WIPO GREEN Database

Shelters: nanogrids/rapid deployment pop-up shelters with renewable energy

Sesame Solar

Source: Sesame Solar

Sesame Solar Nanogrids are ready-to-use, rapidly deployable mobile power systems designed for emergency response, medical centers and military operations. They combine pop-up shelters with renewable energy, providing heated and cooled shelter alongside clean water and device charging. Using patented retractable solar arrays, green hydrogen and battery storage, the nanogrids deliver continuous, 100 percent renewable power within 15 minutes. No onsite expertise is needed and they are operable by a single person. Designed for long-term use of up to 20 years, Sesame's Nanogrids can also be clustered to create larger mini-grids, making them versatile solutions for powering temporary or transitional communities during a disaster or disruption.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO GREEN Database

Robotics and drones: search and rescue robot equipped with sonar – river and flood rescue model

Hydronalix

Source: Getty Images/ andrej67

Hydronalix's EMILY is a remote-controlled rescue robot designed to speed up water rescues. Propelled like a jet ski, EMILY can be dropped from the air and remotely driven to collect stranded people at speeds up to 25 mph. It is heat-resistant, durable in water and can carry up to five adults simultaneously. Equipped with speakers, EMILY allows rescuers to communicate calmly with victims during emergencies. The developers are advancing the technology through features like automation, thermal imaging, slowing mechanisms within the proximity of stranded people, and real-time voice translation. Additionally, EMILY incorporates sonar technology for precise underwater navigation and victim detection, thereby enhancing its ability to locate and assist people in distress quickly and safely.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO GREEN Database

Robotics and drones: dedicated logistics drone

Aeronext

Source: Getty Images/ dmark

Aeronext's AirTruck is Japan's first mass-produced logistics drone featuring advanced 4D GRAVITY® technology. Developed in collaboration with ACSL, a licensed user of 4D GRAVITY®, AirTruck has been tested extensively across Japan. The SkyHub® smart logistics system manages drones for delivery networks and integrates flight operations into a unified system. The AirTruck has demonstrated the ability to fly in challenging conditions, including in Mongolia at 1,300 meters altitude and a temperature of –15°Celsius.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: High
- Place of origin: Japan
- Availability: Worldwide
- Contact: WIPO GREEN Database

Robotics and drones: drone operations and emergency response platform

DroneControl

Source: DroneControl

The DroneControl Ecosystem streamlines public safety drone operations through a centralized dashboard with role-based customization, real-time access to flight logs, equipment status, and key organizational and local airspace updates for ensuring informed decision-making. It enables teams to manage pilots, equipment, workflows, and mission data in one secure space. The DroneControl FirstResponder application is purpose-built for emergency deployment, replacing native drone software with an independent interface for secure, ultra-low latency (<200ms) peer-to-peer video streaming and remote drone control. Live feeds can be viewed simultaneously from multiple drones alongside map overlays showing flight tracks, camera orientation, and precise geolocation. Integrated two-way audio enables direct communication between remote operators viewing the same mission feed. Operators can remotely switch cameras, zoom, adjust camera angles, and share views instantly. Upcoming features include tools for simplified flight planning, automated risk assessments and pre-flight checklists, and geofence alerts.

- Technological maturity: Frontier
- Contracting type: For license
- Technology level: High
- Place of origin: Switzerland
- Availability: Europe
- Contact: WIPO GREEN Database

Horizon technology solutions

Robotics and drones: drone equipped with microphone arrays

Fraunhofer

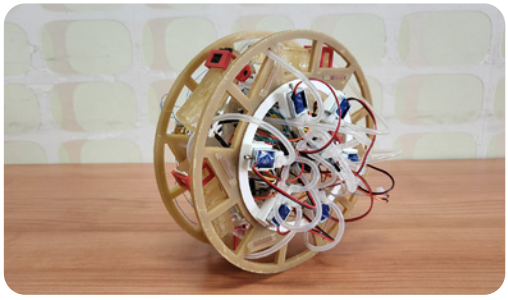
Source: Getty Images/ Cristian Martin

LUCY is an advanced acoustic detection system that mimics human hearing using an array of 48 microphones (soon expanding to 256) to precisely locate sound sources. It works like ears and a brain: microphones pick up sounds, and a signal processing unit analyzes in which direction they came from. Using AI and adaptive filters, LUCY filters out background noise – from wind, rescue equipment, birds and drone rotors – and detects specific sound patterns such as the shouting, banging or clapping that people use to call for help. The system processes signals in real time, providing accurate location data to rescue teams via tablets for efficient victim identification. Its compact, lightweight design allows deployment on various drones and vehicles or on the ground. Researchers continue improving LUCY, so as to enhance its capabilities for emergency response.

- Technological maturity: Horizon
- Contracting type: Under development
- Technology level: High
- Place of origin: Germany
- Availability: N/A
- Contact: WIPO GREEN Database

Robotics and drones: edible robots

RoboFood



Source: RoboFood/Bokeon Kwak

The RoboFood project aims to create edible robots and robotic foods by merging food science with robotics to open new possibilities beyond food delivery drones. These edible robots could provide lifesaving nutrition in emergencies, deliver vaccines to endangered animals, and even monitor their own freshness and safety. By using soft robotics and advanced food processing, RoboFood seeks to develop smart, edible materials and components like sensors, actuators and energy sources. The project focuses on five goals: building a library of smart edible materials; developing manufacturing and preservation techniques; creating complete edible robotic parts; integrating systems and packaging; and demonstrating proof-of-concept models. One of the key applications is edible rescue drones for disaster aid.

- Technological maturity: Horizon
- Contracting type: Under development
- Technology level: High
- Place of origin: Switzerland
- Availability: N/A
- Contact: WIPO GREEN Database

Robotics and drones: emergency medical rescue and transport robot

CSSC Haishen Company and DEEP Robotics

Source: Getty Images/ mikkelwilliam

China has introduced its first emergency rescue and transport robot, developed by CSSC Haishen and DEEP Robotics, designed for extreme temperatures (from –20°C to 55°C) and complex environments like disasters. The robot features three mobility modes – quadrupedal, wheeled and tracked – allowing it to walk, run, climb stairs, avoid obstacles and navigate difficult terrain. During demonstrations, it performed medical functions such as monitoring, infusion, defibrillation, CPR and oxygen supply, while evacuating injured people with real-time treatment. The robot uses advanced smart navigation with two modes: map-based for open areas and video-based for confined spaces, enabling autonomous path planning and obstacle avoidance. Future upgrades aim to incorporate cutting-edge technologies like 6G, quantum tech and embodied intelligence.

- Technological maturity: Horizon
- Contracting type: Under development
- Technology level: High
- Place of origin: China
- Availability: N/A
- Contact: WIPO GREEN Database

Supply chain logistics: early warnings of stockouts of emergency supplies

Arribada

Source: Arribada/Greg McKinney

Arribada partnered with the UK Foreign, Commonwealth & Development Office and the Frontier Tech Hub to develop GeoSeals, a low-cost, open-source supply tracking tool designed to meet the low-connectivity and scaling challenges of humanitarian logistics. The system has two main components: GeoHubs and GeoSeals. GeoHubs are solar-powered IoT devices installed at building entrances at each point in a humanitarian supply chain, while GeoSeals are low-cost, adhesive, passive Radio Frequency Identification (RFID) tags affixed to individual aid items such as boxes of ready-to-use therapeutic food. As GeoSeals-tagged items travel through the network, their arrival at each supply chain point is automatically detected by the GeoHubs. To minimize power consumption, the hubs use infrared sensors to activate only when triggered by movement, prompting the RFID reader to scan. When items are detected, the hub records the unique ID of each one and generates time-stamped geolocation data showing where and when it was scanned. This data is transmitted to the cloud, providing insights into supply levels, stockout risks, and potential bottlenecks.

- Technological maturity: Horizon
- Contracting type: Under development
- Technology level: Medium
- Place of origin: United Kingdom
- Availability: Ethiopia
- Contact: WIPO GREEN Database

Communications and digital coordination

Digital connectivity is now a lifeline in disaster response. When traditional networks fail, satellite systems, mesh networks, and emergency radios keep responders connected. Mobile apps, AI-driven chatbots, and community feedback tools enable real-time alerts and coordination. Meanwhile, blockchain and IoT are streamlining aid supply chains, while drones bridge last-mile delivery gaps.

Technological developments and trends

Over the past decade, there has been a growing recognition that "information is aid," while its absence can have deadly consequences (Access Now, 2024). In today's interconnected world, digital connectivity and real-time communication are essential lifelines during a disaster, enabling responders and affected communities to share vital information, coordinate relief efforts, and maintain situational awareness. As digital tools become central to disaster response, concerns around data privacy and digital protection – especially for displaced and vulnerable populations – are also gaining urgency. Despite significant global progress with over two-thirds of the world's population now online, persistent digital divides and infrastructure challenges remain, especially in vulnerable and remote regions. Innovative technologies, networks and digital tools are helping overcome these barriers, facilitating effective communication during disasters. Advances in broadband, mobile networks, satellite systems and digital platforms are transforming disaster response and community resilience globally.

Mapping and tracking of mobile connectivity show global gains and regional gaps

The International Telecommunications Union (ITU) estimates that 97.9 percent of the world population is covered by a mobile network (ITU Data Hub, 2025). However, figure 10.1 reveals stark disparities in mobile phone ownership growth between 2019 and 2024. While global ownership rose from 4.6 to 5.4 billion, the growth was highly uneven. Low-income countries saw the most dramatic relative increase, nearly doubling their number of users from 197 to 302 million. In contrast, high-income countries, already with a high baseline, experienced minimal growth. Furthermore, the absolute number of users in vulnerable groups like Land Locked Developing Countries (LLDCs) and Small Island Developing States (SIDS) remains a tiny fraction of the global total (ITU, 2024). Consequently, a substantial digital divide remains, with 2.6 billion people still offline—a population roughly equivalent to the combined populations of Africa and Latin America (ITU, 2024). This gap in usage is mirrored by a gap in technology; while regions like North America and Europe have near-universal 3 G coverage, parts of Sub-Saharan Africa and South Asia still lag behind.

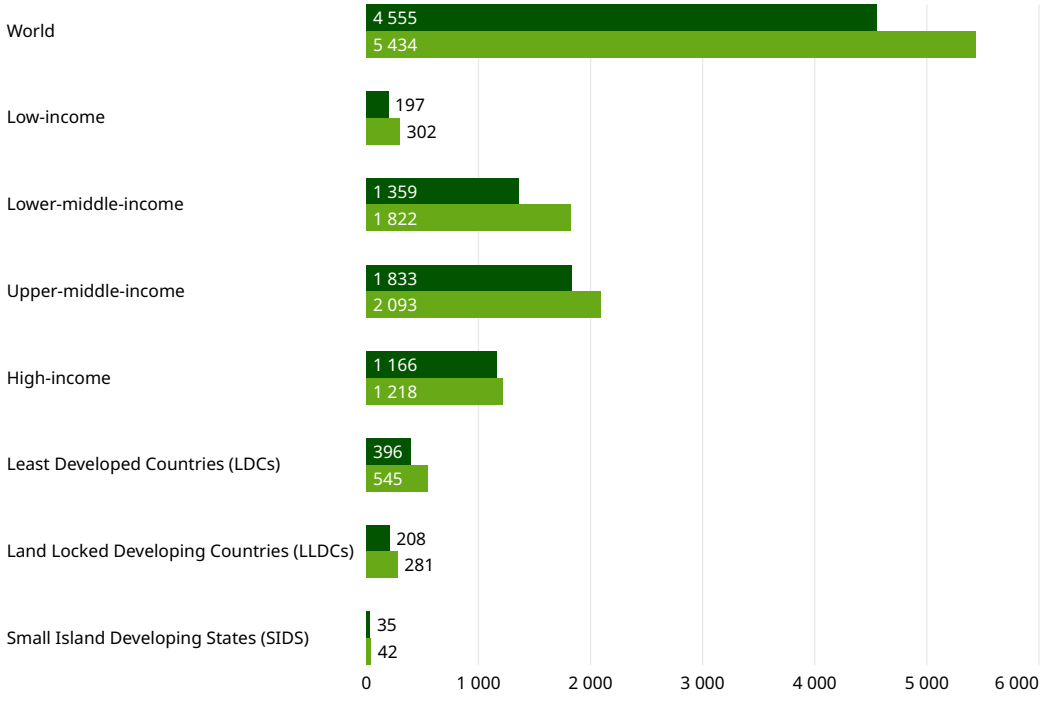
Figure 10.2 shows the rise in active mobile-broadband subscriptions, highlighting a growing reliance on mobile devices as the primary means of internet access (ITU, 2024). This is especially critical in developing countries, where fixed broadband infrastructure may be limited, making mobile broadband essential for economic development, education and social inclusion. Mobile-broadband subscriptions have more than doubled globally since 2015, surging from 3.3

billion to 7.7 billion. This growth has been fastest in the developing world, with subscriptions in low-income countries growing more than fourfold. Despite this rapid adoption, a substantial absolute gap remains, as the total number of subscriptions in the poorest nations is still a small fraction of the total in wealthier ones.

Figure 10.3 depicts the population covered by at least a 3G mobile network in 2015, 2020 and 2024. Global mobile network coverage has expanded significantly, reaching near-universal levels by 2024. This growth has successfully closed the coverage gap for most of the world's population, including those in low-income countries and vulnerable groups like LDCs. However, the final few percentage points of the global population, often in the most remote and challenging environments, remain the hardest to connect.

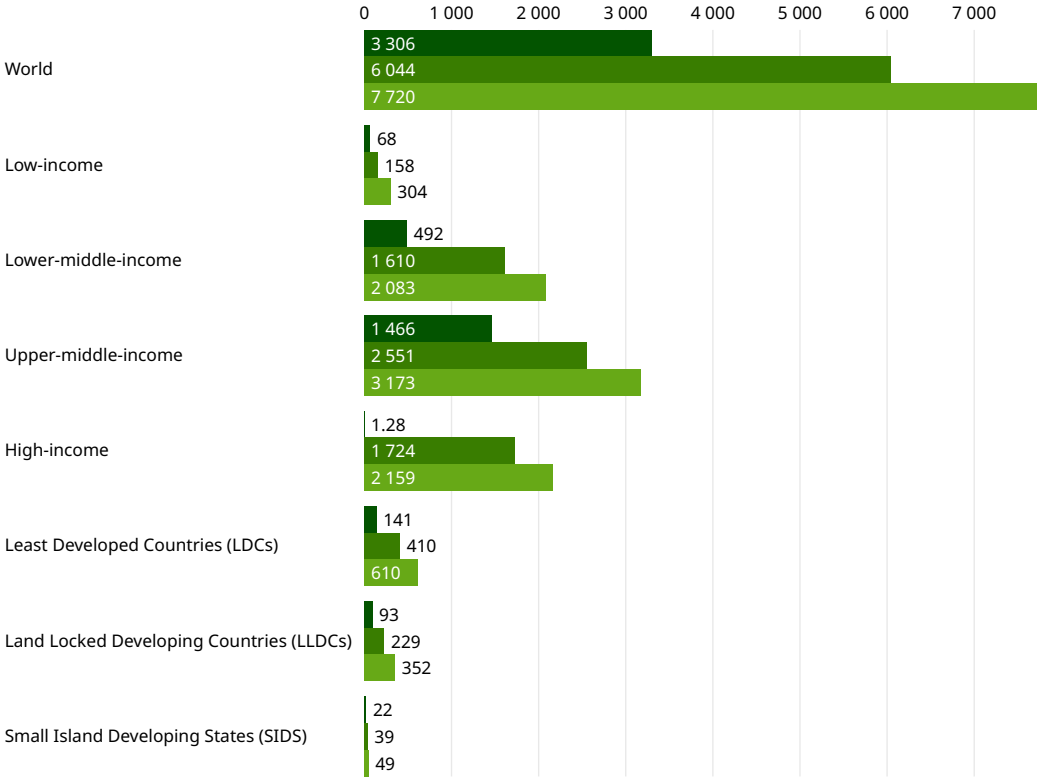
Importantly, even basic mobile phones without internet access remain vital communication tools during a disaster (ITU, 2024). Cell broadcast, SMS, voice calls and unstructured supplementary service data (USSD) services work over standard cellular networks without requiring internet connectivity, enabling responders and affected populations to exchange crucial information and alerts when broadband or internet services are either unavailable or disrupted.

Figure 10.1 Individuals owning a mobile phone, 2019 and 2024 (millions)



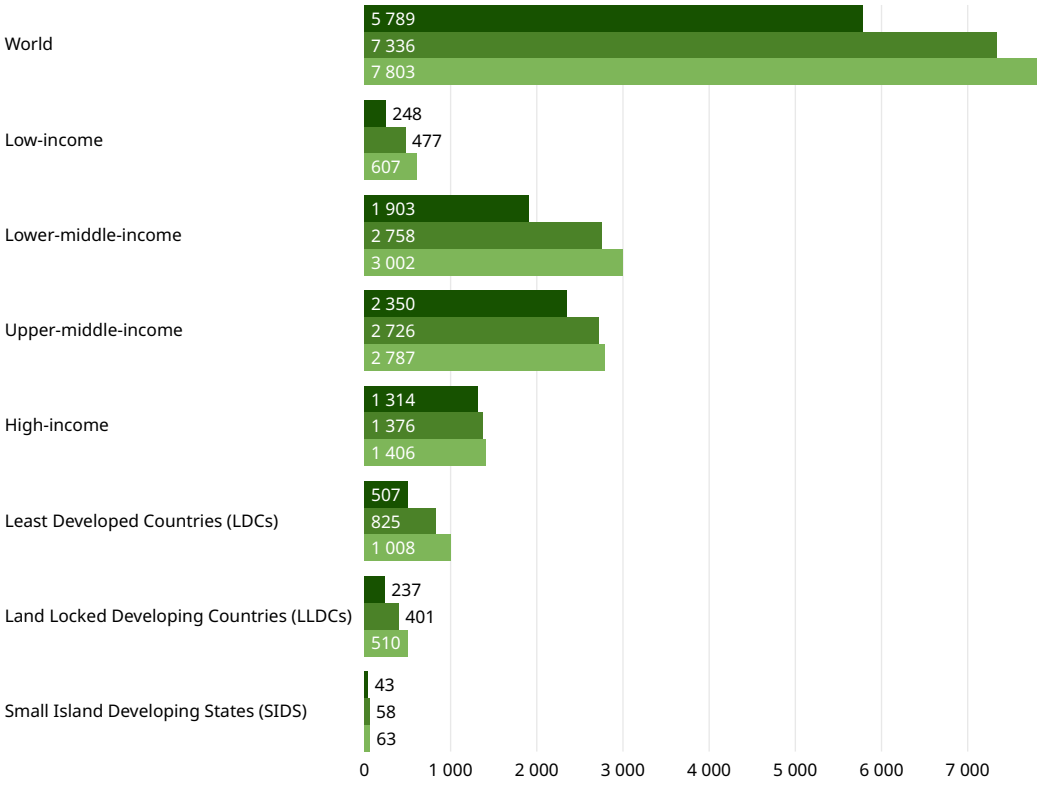
Source: (ITU, 2024)

Figure 10.2 Active mobile-broadband subscriptions, 2015, 2020 and 2024 (millions)



Source: (ITU, 2024)

Figure 10.3 Population covered by at least a 3G mobile network, 2015, 2020 and 2024 (millions)



Source: (ITU Data Hub, 2025)

Staying connected – core technologies enabling communications during disasters

Broadband and next-generation networks provide the backbone for disaster communications, enabling real-time data sharing, remote monitoring and prioritized emergency services.

> Broadband remains crucial for effective disaster response, providing reliable communication in urban areas … and bridging gaps in remote regions

Broadband internet, a high-speed, always-on internet connection that transmits data using a wide bandwidth, plays a vital role in disaster preparedness and response by enabling emergency services, first responders and authorities to share real-time updates, assess situations and make informed decisions. Broadband also supports remote monitoring, the use of devices, like surveillance cameras, environmental sensors and early warning systems, to observe and track conditions in disaster-prone areas without needing people on site.

However, using broadband in disaster situations presents challenges. Limited infrastructure in rural or remote areas can hinder connectivity, while network congestion from increased communication demand may cause delays. Power outages often disrupt broadband services, and accessibility issues can prevent some from using communication tools effectively. Despite these obstacles, broadband remains crucial for effective disaster response, providing reliable communication in urban areas through fiber optics and bridging gaps in remote regions through satellite and wireless technologies.

Next-generation networks (NGNs) are packet-based systems that break information – including voice, video or data – into small packets for efficient routing across shared infrastructure. Unlike older circuit-switched networks, NGNs separate the service layer (what users interact with) from the transport layer (the physical and routing infrastructure). This decoupling allows a wide range of services to run over the same network, regardless of the underlying access technology – whether it be fiber, mobile, satellite or Wi-Fi.

This flexibility is especially valuable in disaster response. If part of the infrastructure is damaged, services can continue using alternative connections. NGNs support dynamic rerouting and quality of service (QoS) mechanisms, meaning critical communications like emergency calls, real-time video or sensor data can be prioritized over less urgent traffic.

Because NGNs are based on internet protocol (IP) standards (the set of rules that governs how data packets are addressed, routed and delivered from one device to another over a network), they also enable better interoperability between agencies and systems. Using IP is crucial, because it allows the seamless integration of different devices, services and technologies across the same network, allowing emergency responders to communicate and access information regardless of the hardware or underlying technology in use.

Global system for mobile communications (originally groupe spécial mobile) (GSM) was first developed in the 1980s as a 2G (second-generation) mobile technology. The standard specifies protocols for the digital cellular networks used by mobile phones for voice calls, SMS and basic data services (Wray Castle, 2024). Over the years, GSM has evolved into a widely used standard for mobile communications, and though 3G, 4G and 5G networks have since emerged, GSM remains essential within mobile networks, especially for basic voice communication and SMS messaging.

In disaster situations, GSM provides reliable communication when infrastructure remains intact and can be quickly restored using mobile base stations or satellite backhaul. GSM supports SMS-based emergency alerts and voice communication, ensuring affordable access for responders

and affected populations. Although challenges like network congestion and damaged infrastructure can arise, GSM remains a critical tool.

When infrastructure fails – alternative and rapid deployment networks

When traditional communication infrastructure fails, resilient disaster communication relies on layering multiple delivery methods to maintain connectivity and coordination. Even for displacement shelters under disaster conditions, alternative and rapid deployment could mean using solar-powered radio transmitters as a fallback when mobile coverage drops, or hand-held loudhailers for rapid perimeter alerts. These layered methods – spanning satellite systems, radio communications and mesh networks – provide redundancy and adaptability for responders and affected communities in unpredictable environments.

> The ability to set up a satellite-based network rapidly is a game-changer for first responders

Satellite communication technology plays a crucial role in disaster response. Satellite phones and devices ensure that emergency responders, leaders and organizations can maintain communication even when landlines, mobile towers or fiber optics are down. While these systems are not designed for everyday citizens in the immediate aftermath of a disaster, satellite-enabled devices allow emergency coordination, rapid deployment of resources, and real-time information sharing. The ability to set up a satellite-based network rapidly is a game-changer for first responders.

Galileo's emergency warning satellite service (EWSS), launching in 2025, adds a satellite-based layer to disaster communications by broadcasting predefined alerts directly to compatible receivers, including smartphones, handhelds and public displays. Operating independently of terrestrial networks, EWSS uses the common alerting protocol (CAP) (a standard format for sending emergency alerts so they can be automatically received and displayed across different devices and systems) to encode messages, which are then decoded locally on the device. Integrated into the Galileo GNSS under EU Regulation 2021/696, the service provides national civil protection authorities with rapid, reliable alert dissemination (ITU, 2023b).

Radio communications. Very high frequency (VHF)/ultra high frequency (UHF) and high frequency (HF) radios are different types of radio networks that provide local and long-range communication and can function independently of broadband or mobile infrastructure. These technologies are used for short-range coordination among emergency responders. Public safety networks (like TETRA, P25 or LTE for Public Safety) are more advanced forms of radio networks designed for secure, prioritized communication between first responders during an emergency.

Box 10.1 Based on technology, the Crisis Connectivity Charter and the Emergency Telecommunications Cluster connect agencies during disasters

The Crisis Connectivity Charter (CCC) is a global partnership between technology companies, satellite operators, telecom providers and humanitarian organizations aimed at rapidly restoring internet and communications during a disaster. By pooling resources and deploying advanced technologies like satellite terminals and portable cell towers, the CCC ensures affected communities and responders stay connected when traditional networks fail. The Emergency Telecommunications Cluster (ETC), hosted operationally by WFP, coordinates these efforts on the ground, managing telecom infrastructure and activating CCC partners during emergencies. This collaboration facilitates disaster response for coordination, aid delivery and communication with vulnerable populations. Recently, the CCC was activated during the 2023 earthquake in Türkiye and Syria, where satellite connectivity was rapidly deployed to support rescue teams, and in the 2024 floods in Mozambique.

More specifically, the ETC is led by the United Nations Office for the Coordination of Humanitarian Affairs (OCHA), which brings together humanitarian organizations, UN agencies, governments and private sector partners to provide telecommunications services during disasters. The ETC sets up emergency communication infrastructure, such as satellite networks, mobile networks and telephony systems (technologies for voice communication, including traditional phone lines, mobile phones and internet-based services like Zoom or WhatsApp). It also restores local FM radio stations, a vital information source for many communities, especially where internet is limited. The ETC runs common feedback mechanisms (CFMs) – two-way systems that let people share concerns or feedback with aid providers – and supports user services like Wi-Fi access points, charging stations and IT help desks. For secure communication, it deploys security communications systems (SCS), which may include satellite phones, radio networks (VHF/UHF) or mobile phones. The ETC also coordinates the safe use of drones for tasks like delivering supplies, capturing aerial imagery or extending connectivity.

Mesh networks. A mesh network is a decentralized wireless network where devices (nodes) connect directly and dynamically to each other, allowing data to be routed through multiple paths for improved reliability and coverage. Nodes then act as both routers and hosts (ScienceDirect, n.d.). Mesh networks provide significant benefits in disaster relief situations owing to their resilience and self-healing capabilities. If one node fails or disconnects, the network can reroute data through other nodes, maintaining connectivity even in harsh environments like during floods or fires when traditional networks often fail. Their decentralized nature eliminates a single point of failure and they can extend network coverage to remote or isolated areas by using intermediate nodes as relays. Mesh networks can be rapidly deployed with minimal setup time and are cost-effective in that they can use off-the-shelf hardware and open-source software. They have been successfully used in disasters such as Typhoon Haiyan and Hurricane Maria.

However, challenges include ensuring data security and privacy in an open, decentralized system and managing network scalability and performance as more nodes join. Setting up a mesh network typically involves wireless devices like smartphones or routers and specialized software with the proper configuration of network parameters.

Digital tools and coordination systems enable effective response across communities

Mobile apps, alert systems and feedback mechanisms play a vital role in disaster response by keeping communities informed and connected. Together with secure communication networks, such tools enable timely updates, two-way engagement, and reliable coordination between affected populations and responders.

> Disaster response apps and websites have significantly improved our ability to stay connected during crises

Mobile-based warning dissemination: cell-broadcast and location-based SMS. Cell broadcast (CB) is a mobile network service that sends text-based warnings to all mobile devices within a defined geographical area, almost simultaneously. Unlike conventional short message service (SMS), which delivers messages one-to-one and can be delayed or blocked during high-traffic periods, CB leverages the cellular network's broadcast capability to transmit a message to all phones connected to a cell tower within the target zone – in near real time. The message appears as a high-priority notification on the mobile screen, accompanied by a unique, loud alert tone and vibration – often overriding silent mode – to ensure it gets immediate attention. Crucially, CB does not require users to either subscribe, download apps or have internet access. Any compatible phone that is powered on within a given area will automatically receive an alert. This makes CB a highly inclusive and effective tool for reaching not only residents, but also visitors, travelers and individuals without a local mobile subscription (GSMA, 2023; ITU, 2023a).

Location-based SMS (LB-SMS), by contrast, uses the standard SMS channel, but targets only those devices currently connected to a cell tower within a defined geographical area. Once an area is selected, the mobile network filters active subscribers within that footprint and sends each one a conventional text message. While LB-SMS can be delivered to most mobile phones without requiring special handset compatibility, delivery is sequential rather than instantaneous, and can be subject to delays under high network load. Nonetheless, it remains a valuable alerting option in contexts where CB is unavailable, as it works on virtually all mobile devices and allows for longer, more detailed messages. LB-SMS is also useful for follow-up information after an initial CB alert, or for sending hazard-specific instructions to targeted locations (GSMA, 2023; ITU, 2023a).

Mobile apps and alert systems. Disaster response apps and websites have significantly improved our ability to stay connected during crises. For example, Facebook's "Safety Check" feature, which allows users to mark themselves as safe during a local disaster, is an effective alert system that helps friends and family quickly confirm each other's well-being. With real-time updates, these platforms help affected individuals access vital information quickly and securely, ensuring that people stay informed even amid the chaos of a disaster. ITU recommends that apps (which users need to download, register and learn how to use) be used mainly in a complementary fashion to the mobile alerting system (CB/LB-SMS), which requires no registration.

A *chatbot* is a computer program that understands text, voice or image inputs, and interacts with users. Its functions range from answering common questions without AI to using AI and machine learning to learn from conversations and better understand user intent. Chatbots can deliver vital information, support health and education, connect communities with responders, combat misinformation, and facilitate monitoring and evaluation. Their accessibility, multilingual support and simple interfaces make them poised to transform human–computer interaction (OCHA, 2021).

Common feedback mechanisms. The common feedback mechanism (CFM) is designed to establish effective two-way communication systems between local communities and humanitarian assistance providers. The purpose is to ensure that affected populations can directly engage with and provide feedback on assistance programs. This feedback loop enhances accountability by enabling humanitarian organizations to make more informed decisions and ensuring that the voices of affected populations are heard. CFMs are a key part of accountability to affected populations (AAP), which is a core component of humanitarian response plans (HRPs). By improving collective accountability, CFMs help organizations coordinate and consolidate resources, avoiding duplication of efforts. CFM setup can vary depending on available technology, but often includes a short code (a four-digit number for easy access), customer relationship management (CRM) software (like WFP's "SugarCRM" for managing interactions) and, potentially, a call center for direct communication.

Security communications systems (SCS) are a central part of the Emergency Telecommunications Cluster (ETC, see box 10.1) and provide secure, reliable communication for humanitarian responders and local authorities during an emergency, following United Nations Department of Safety and Security (UNDSS) guidelines. Its deployment varies according to three scenarios:

- Scenario A: Uses public mobile networks when reliable, with satellite/radio backups.
- Scenario B: Supports mobile networks with fallback VHF/UHF radios or satellite for emergencies.
- Scenario C: Sets up primary VHF/UHF radio networks where mobile coverage is poor, backed by satellite communications.

ETC also establishes security operations centers (SOCs), provides equipment setup and training for staff, and offers technical support to authorities in deploying communication infrastructure. Additionally, the ETC supports the Telecommunications Emergency Support Services (TESS+) initiative, a United Nations (UN)-led service focused on setting telecommunications security standards for both UN and NGO staff safety in disaster zones.

Early warnings connect and protect communities – starting with everyday technologies

Early warning systems (EWS) – discussed in the storms and flooding chapter – are a critical communication tool for disaster response. They rely heavily on robust connectivity and communication to effectively disseminate timely warnings of an impending disaster. Effective EWS also depend on clear, consistent messaging across all channels and involve strategic communication tailored to specific communities. AI can support EWS in transmitting warnings and guiding responses, but careful planning is needed. Information and communication technologies (ICTs) are essential in single-hazard and multi-hazard early warning systems (MHEWS) for message management and delivery. A multi-channel approach that uses both traditional and modern technologies is crucial for reaching diverse populations. This includes using radio, television, social media, mobile phones and satellite communications. Messages should be clear, trusted and relevant, and can benefit from input from the target audience.

> Effective EWS depend on clear, consistent messaging across all channels and involve strategic communication tailored to specific communities

Mobile networks are a powerful tool for issuing public warnings. Cell-broadcast or location-based SMS warnings can be sent to specific populations in at-risk areas. ITU has encouraged countries to consider implementing regulatory approaches that make the use of mobile networks mandatory for issuing public warnings. ITU underscores the point that aligning incentives with funding programs can speed up the rollout of mobile networks and bolster public safety (ITU, 2023a).

Supply chain resilience for aid delivery – another critical component

Global humanitarian aid demand is rising sharply. Over 308 million people were estimated to have been in need in 2024, putting a strain on traditional supply chains (Frontier Tech Hub, 2024). Humanitarian supply chains are complex and difficult to manage due to many agencies using different systems, data and processes. This fragmentation results in poor end-to-end visibility, causing inefficiencies, waste and an increased risk of corruption. Currently, over 60 percent of aid budgets are spent on logistics (Frontier Tech Hub, 2019).

To make matters worse, disasters can severely disrupt supply chains. Ports, warehouses and transportation infrastructure such as roads, railways and airports are all prone to damage from storm surges and flooding. Such disruptions can halt deliveries, delay goods movement and create significant operational challenges, as seen during Hurricane Harvey in the United States when major logistics networks in Houston and Louisiana were forced to suspend services.

To mitigate these risks, companies increasingly rely on technology such as Big Data analytics, which combines historical disaster data with supply chain information from enterprise resource planning (ERP) and warehouse management systems (WMS) to forecast potential disruption and model demand under various scenarios. Inventory management is more strategic with the use of WMS tools that provide visibility across all storage locations – enabling organizations to pre-position essential supplies near high-risk areas. Additionally, by linking hazard-specific forecasts, companies can bolster supply chain resilience. For example, cyclone forecasts issued 72 to 120 hours in advance can trigger phased deployment to secure international procurement orders within the first 24 hours, while flood forecasts predicting crest arrival 48 hours ahead can initiate relocation of stockpiles to higher ground and activation of amphibious transport for last-mile delivery.

Equally important is the ability to maintain constant communication in the field. Rugged mobile devices equipped with GPS, cameras and connectivity features empower responders

to coordinate logistics more efficiently. Developing standardized supplier data and integrating information across systems allows organizations to identify vulnerabilities and plan contingencies ahead of time.

Technologies like blockchain, IoT and drones are beginning to improve aid delivery by making supply chains more transparent and efficient, and by empowering communities to manage their own supply chains. However, challenges, such as infrastructure gaps, local capacity and regulations, must be addressed (Frontier Tech Hub, 2024). Ultimately, success depends on effectively integrating these technologies into existing systems, so as to build adaptable and scalable solutions, while also improving collaboration among development actors.

Transparency continues to be a major challenge within humanitarian supply chains, and blockchain can provide tamper-proof, real-time tracking that improves visibility and accountability, as shown in pilots like the Pakistan-to-Dubai shipment pilot, which tested blockchain technology by tracking a shipment of 304 tents from Lahore, Pakistan, to Dubai. The shipment demonstrated successful real-time tracking and coordination among three separate organizations – DFID, the tent supplier, and the shipping company – using a single blockchain platform (UK Aid, 2019). The pilot established that a private permissioned blockchain can work well in humanitarian aid by enhancing the accountability of shipments and building trust.

However, blockchain is not a universal solution. It can shift trust onto the technology itself, adding complexity and cost, so it must be carefully applied where it can genuinely add value to avoid creating new problems. Broad adoption of blockchain would require clear governance structures and system-wide rules (Frontier Tech Hub, 2019). Complementing blockchain, IoT technology shows great promise in enhancing supply chain visibility. But it is important to note that its success depends on strong integration into existing local and global systems, infrastructure investment, and support for local decision-making.

> Transparency continues to be a major challenge within humanitarian supply chains, and blockchain can provide tamper-proof, real-time tracking

Poor infrastructure can present challenges in delivering aid to remote areas. But drones are overcoming these barriers by enabling faster, more reliable last-mile delivery. Drones used for communication can also act as temporary signal boosters or network relays, often supplementing existing mobile or broadband networks. They fall under the broader category of communication infrastructure, but with the added capability of mobility and on-demand deployment.

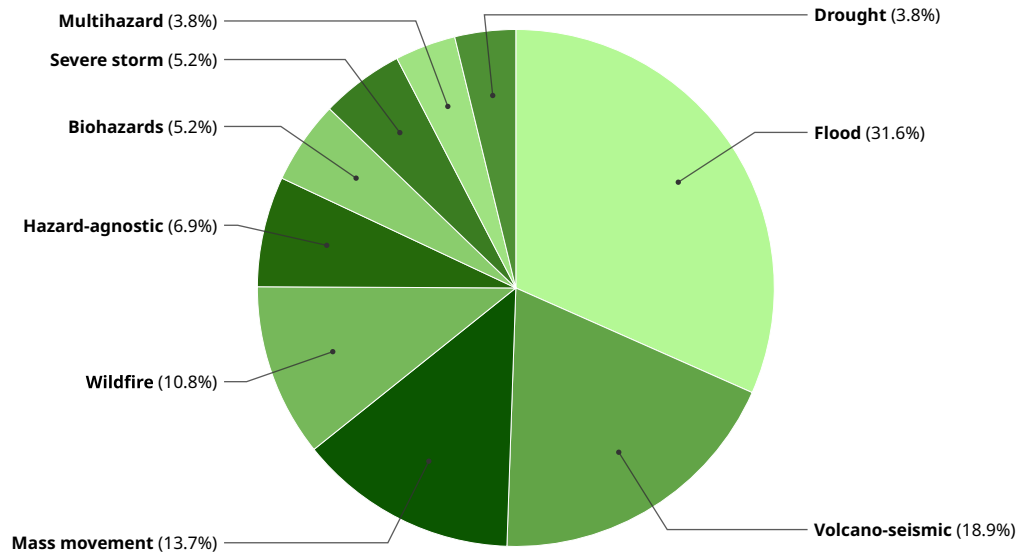
AI may improve disaster communications, but data and ethical challenges remain

In the humanitarian field, AI can accelerate anticipatory action for disasters by quickly analyzing complex data to identify needs, provide early warnings, plan responses and evaluate outcomes. Predictive analytics – a key AI tool – helps forecast sudden disasters, as well as long-term challenges. Integrated with technologies like mobile apps, drones and IoT, AI improves decision-making, supports health care insights, aids education and training, and streamlines administrative tasks, which frees up human resources for critical work (OCHA, 2021).

> Predictive analytics helps forecast sudden disasters, as well as long-term challenges.

A technical report undertaken by the ITU/WMO/UNEP Focus Group on Artificial Intelligence for Natural Disaster Management for communication reviewed literature on recent research and applications in AI-based communications tools. The review revealed an active field of research and development on AI for communications during disasters (ITU, 2023c). Figure 10.4 depicts findings in the literature published between 2018 and 2021 on the hazard types targeted in AI applications for disaster management with a focus on communication elements. Among natural hazards, floods were the most frequently studied, followed by volcano-seismic hazards, wildfires, landslides and drought; biohazards such as insect pests and vector-borne diseases; severe storms; tsunamis and volcanic eruptions (also under volcano-seismic hazards); avalanches (within mass movement); and multiple hazards combined ("multihazard").

Figure 10.4 Hazard types targeted in an application of AI for natural disaster management with a focus on communication elements (from literature published between 2018 and 2021)



Source: ITU, 2023c

However, challenges regarding AI remain a hurdle. AI and predictive analytics require large amounts of open, accurate and timely data, which can be hard to obtain due to limited connectivity, security issues and volatile conditions. Data quality, interoperability and standards are critical because errors or incomplete data can lead to flawed results. Data protection is a major concern, as AI may unintentionally reveal personal information or enable misuse by malicious actors. Bias in AI is a serious issue, often stemming from incomplete data and lack of diversity among developers, which can exacerbate inequalities. AI systems may also lack transparency, making decisions hard to explain or trust, and leading to accountability gaps (OCHA, 2021).

Innovation examples

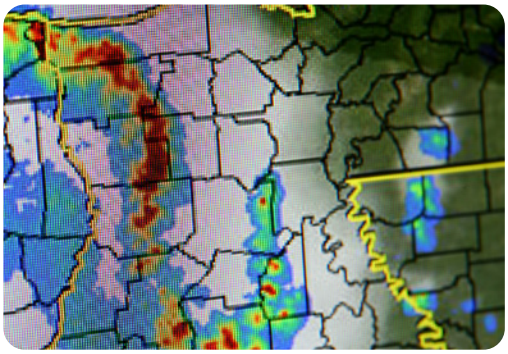
SKAI: AI-powered eyes-in-the-sky for disaster response

Source: World Food Programme

When disaster strikes, reliable ground information is often unavailable. Enter SKAI – the Satellite-based Kinesthetic Assessment and Intelligence tool – developed by WFP and Google

Research – that aims to transform emergency response. Using advanced AI and satellite imagery, SKAI delivers near real-time damage assessments, pinpointing destruction across vast, hard-to-reach areas. It automatically maps building damage and supports situational awareness to enable smarter and faster decisions. In Pakistan, SKAI was deployed after severe floods devastated large swaths of the country. With roads submerged and communications cut off, SKAI's AI algorithms scanned satellite images to identify damaged infrastructure and isolated communities. Within hours, WFP teams received information that helped them prioritize emergency food assistance and coordinate with local authorities. This context-agnostic analysis helped streamline logistics and target aid where it was most needed without waiting for ground reports. As an open-source, collaborative tool that combines machine learning with Earth observation data, SKAI supports governments, NGOs and first responders worldwide (WFP, 2024b).

NOAA expands multilingual weather alerts with AI technology



Source: Getty Images/ spxChrome

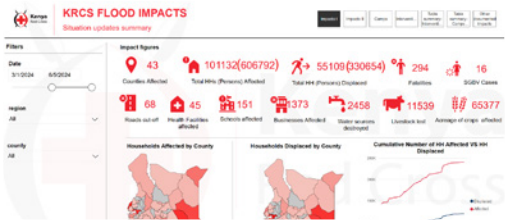
For 30 years, the National Oceanic and Atmospheric Administration (NOAA), a US governmental agency, had its National Weather Service (NWS) forecasts manually translated into Spanish, but is now using AI to improve accuracy, efficiency and inclusivity. Through pilot projects, the NWS has trained AI software with weather terminology in Spanish and simplified Chinese – two of the most common US languages after English – and plans to add Samoan, Vietnamese and more. Partnering with machine learning company Lilt, NWS has developed a specialized language model that drastically reduces translation time – from an hour to under 10 minutes for some products. Features include navigation, hazard maps, geo-location for local forecasts and alert banners. In the future, translations will be integrated into data transmission services (APIs), social media and alert systems, so as to expand reach. The project is improving community readiness and inclusion amid extreme weather caused by climate change (NOAA, 2023).

Coping with recurring disasters in Cox's Bazar, Bangladesh, through communications platforms and EWS

Source: Getty Images/ Joel Carillet

The humanitarian response in Bangladesh's Cox's Bazar – home to the world's largest refugee camp – has increasingly employed technological advancements to enhance disaster preparedness and resilience for over 900,000 Rohingya refugees. Although Bangladesh is one of the most disaster-prone countries globally, it is recognized for its leadership in early warning and anticipatory action. Several forecast dissemination and coordination tools have been implemented. A key innovation has been the integration of technology-driven early warning systems across the 33 camps. This includes the expansion of the Cyclone Preparedness Programme (CPP) to include refugee populations, training over 3,300 Rohingya volunteers who disseminate localized warnings. Technological tools, such as automated SMS alert systems, simple weather gauges, and the INSTANT platform – a custom forecast portal developed by the United Nations Development Programme (UNDP) and the Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES) – deliver 5-day forecasts, seasonal projections and hazard alerts directly to aid agencies. These efforts have embedded anticipatory actions across sectors using real-time forecasts and pre-alert protocols. They trigger coordinated responses including reinforcing shelters, pre-positioning food and medical supplies, and moving vulnerable individuals in advance of extreme weather. Additionally, integration with systems like the United Nations Food and Agriculture Organization's Landslide Early Warning System (LEWS) and national flood forecasting services allows for rapid, data-informed response, thereby improving safety and readiness for vulnerable refugee populations (IFRC Climate Centre, 2022).

KoboToolbox empowers the Kenya Red Cross with data-driven flood relief coordination



Source: Kenya Red Cross Society

When Kenya faced severe flooding in 2024, impacting over 220,000 people, the Kenya Red Cross Society (KRCS) employed technology to enhance the disaster response. Using KoboToolbox, KRCS developed a customized Flood Situation Report (SitRep) Tool that collects data even from remote areas through offline capabilities. The tool gathers detailed information on affected populations and damage to critical infrastructure, helping coordinate aid delivery and aid emergency services like search and rescue. By centralizing and standardizing data collection with a smart survey design using features like cascading selects and skip logic, the tool improves accuracy and reduces survey fatigue. It also integrates with Power BI for dynamic data visualization, enabling daily updates to stakeholders. Since its initial deployment during the 2023 El Niño floods, the Flood SitRep Tool has transformed fragmented data collection into a unified, data-driven process, supporting efficient resource allocation across food distribution, health care, shelter and water sanitation efforts. With over 800 submissions from 43 communities, this technology-driven approach is critical in managing Kenya's ongoing climate challenges, helping KRCS build community resilience (Kenya Red Cross Society and KoboToolbox, 2024).

Proven technology solutions

Communications: ethernet and PoE extenders

Enable-IT

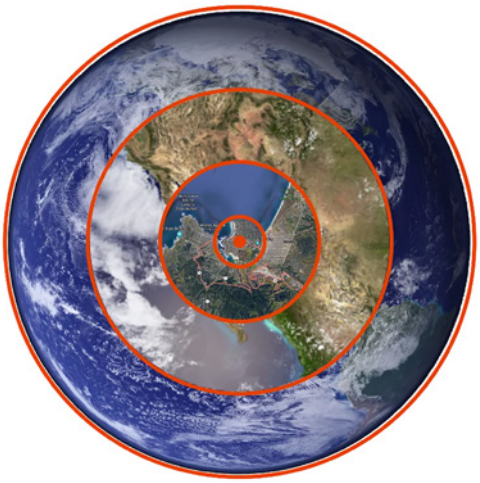
Source: Enable-IT

Ethernet and power over ethernet (PoE) extenders allow the rapid deployment of communication, lighting and security systems in affected disaster areas. By using PoE, they eliminate the need for separate power lines, enabling faster setup of devices like surveillance cameras, LED lights and networking equipment. These extenders support both short- and long-term shelter strategies by providing reliable connectivity across larger distances, even in rugged environments. Ethernet connectivity is used in satellite ground stations, enabling reliable data transmission to end-user devices. Using PoE-powered satellite modems and access points streamlines deployment in disaster zones by removing the need for separate power supplies, allowing faster and more flexible setup in critical situations.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO GREEN Database

AI-enhanced communications: AI-powered disaster intelligence and risk assessment tool

Mayday.ai



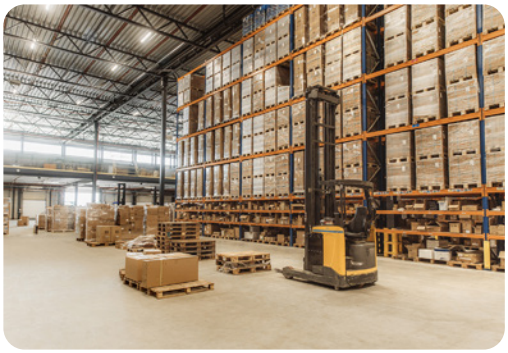
Source: Mayday.ai

Mayday.ai is an AI-powered platform that delivers real-time, full lifecycle (before, during, after) disaster event intelligence by integrating data from satellite and camera imagery, audio, and multilingual social media sentiment analysis. It provides early warning and two-way communication within a unified system, aiming to make critical event information widely accessible through AI automation at the national, regional, municipal, community and household level. The platform's innovations have been recognized and supported by major organizations, including the European Space Agency, German Aerospace Center, NOAA, and various UN offices focused on disaster risk reduction and space affairs.

- Technological maturity: Proven
- Contracting type: For licensing and collaboration
- Technology level: High
- Place of origin: Germany
- Availability: Worldwide
- Contact: WIPO GREEN Database

Logistics: warehouse management system (for supply chain disruption)

Datex



Source: Getty Images/Lorado

The Footprint® Warehouse Management System (WMS) enables organizations to manage inventory across facilities, pre-position supplies, and respond to rapidly changing demands during natural disasters and other disruptions. Coupled with Datex Studio, a low-code visual interface, users can tailor their WMS with ease, configure workflows, and track changes with built-in testing and source control. Handheld mobile computers facilitate efficient communication, damage assessment and coordination, ensuring timely allocation of critical resources.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO GREEN Database

Logistics: mapping platform

OpenStreetMap

Source: OpenStreetMap

Humanitarian OpenStreetMap Team (HOT) is an international volunteer-driven organization that uses open mapping to support humanitarian aid, disaster response and sustainable development. When disasters strike, thousands of HOT volunteers rapidly create detailed, open-source maps of areas where data is limited, using platforms like OpenStreetMap. These maps help responders reach those in need quickly and effectively. HOT also supports communities, NGOs, governments and international organizations by providing training, tools and knowledge to support local mapping and data collection. They develop free, open-source apps and tools for collaborative mapping and geospatial data gathering, widely used by partners such as Red Cross, Médecins Sans Frontières, UN agencies and local groups.

- Technological maturity: Proven
- Contracting type: Open access
- Technology level: Medium
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO GREEN Database

Connectivity: satellite services

Télécoms Sans Frontières

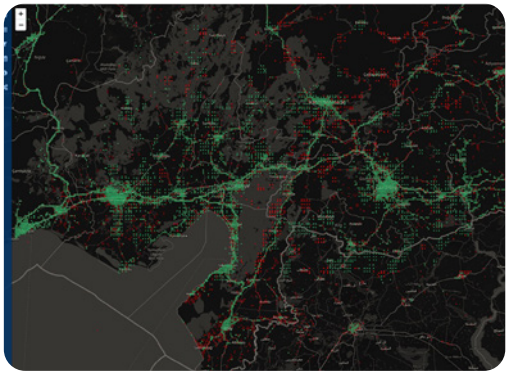
Source : Getty Images/Ali Çobanoğlu

Télécoms Sans Frontières (TSF) integrates cutting-edge satellite and digital technologies to ensure connectivity, education and information flow. The company provides the following solutions for disasters: Oxbird optimizes satellite bandwidth with enhanced quality of service (QoS), improving traffic management and services like VoIP (Voice over Internet Protocol – a technology that enables voice calls using an internet connection). Learning Kit provides portable, battery-powered digital education tools (tablets, server, Wi-Fi) for children. Humanitarian Information Display System uses remotely managed digital screens in refugee camps to share real-time, multilingual info via cloud connectivity. Mobile satellite services (MSS) deploy compact satellite terminals and phones, providing reliable internet and telephony where infrastructure is damaged. Finally, fixed satellite services (FSS) (very small aperture terminals) provide medium to long-term satellite internet access in remote or disaster-affected regions, supporting NGOs, health, coordination and free Wi-Fi within refugee camps.

- Technological maturity: Proven
- Contracting type: For service-based deployments and equipment loan/rental
- Technology level: Medium
- Place of origin: France
- Availability: Worldwide
- Contact: WIPO GREEN Database

Communications: disaster connectivity map

International Telecommunication Union (ITU), World Food Programme Emergency Telecommunications Cluster (ETC), GSMA



Source: International Telecommunication Union (ITU)

The Disaster Connectivity Map (DCM) provides near real-time data on communication network connectivity to governments, telecom operators and first responders, enabling faster, more targeted repairs and restoration after disruptions. It aggregates connectivity measurements from end-user devices, processes them, and displays both historical baselines and current status. Following a disaster, DCM can be activated in affected areas to pinpoint gaps and outages in real time, guiding response decisions. To date, it has been deployed in over 50 disasters worldwide, with a database of more than 200 million data points.

- Technological maturity: Proven
- Contracting type: Technical partnership/ inter-agency coordination
- Technology level: Medium
- Place of origin: Switzerland
- Availability: Worldwide (ITU Member States)
- Contact: WIPO GREEN Database

Communications: ultra-portable GSM network

Vodafone

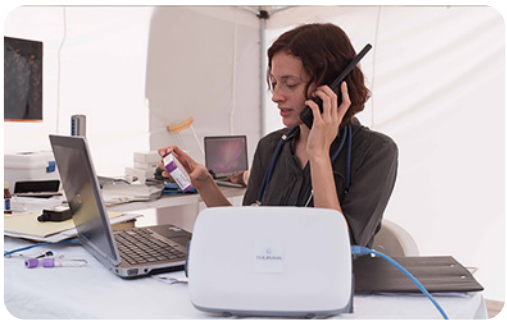
Source: Getty Images/Jupiterimages

Vodafone Instant Network is a highly portable GSM network system designed for rapid deployment in disaster zones. Packaged into four cases weighing under 100 kg, it can be transported aboard commercial flights and set up within 40 minutes to provide secure 2G and 3G connectivity anywhere in the world. Instant Network Mini is an ultra-compact, 11 kg mobile network carried in a backpack and deployable in 10 minutes by non-technical staff. It supports up to five concurrent calls within a 100-meter radius and can send mass SMS alerts. Instant Charge is a modular phone charging station developed to support refugees and disaster survivors with smartphones. It can simultaneously charge up to 66 devices, is designed for outdoor use with minimal supervision, and helps prevent overcrowding in charging areas.

- Technological maturity: Proven
- Contracting type: Provided through partnerships, donations or special agreements
- Technology level: Medium
- Place of origin: United Kingdom
- Availability: Worldwide
- Contact: WIPO GREEN Database

Communications: portable and quickly deployable satellite communication

Thuraya



Source: Thuraya

Thuraya offers quick-deploy satellite communication solutions essential for disaster response and relief operations. The satellite phones and data terminals provide high-speed mobile broadband within seconds, enabling first responders to access critical information like weather updates and mapping services rapidly. These tools support coordination among aid organizations, emergency services, and government or military agencies across different communication platforms. Thuraya's systems also allow for the setup of solar-powered voice, fax, internet and SMS services, helping affected communities stay connected during ongoing relief efforts.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United Arab Emirates
- Availability: Worldwide (except the Americas)
- Contact: WIPO GREEN Database

Logistics: mobile information management platform for humanitarian service delivery

World Vision

Source: Getty Images/Jacob Wackerhausen

World Vision's Last Mile Mobile Solutions (LMMS) is a mobile information management platform designed to streamline humanitarian aid delivery at the critical "last mile" stage. It digitizes beneficiary registration, verification, distribution planning, monitoring and reporting. LMMS integrates software with custom hardware, including mobile devices, servers, printers and ID cards. Used in over 40 countries by more than 20 agencies, LMMS supports cash, food, shelter and health programs, registering over five million beneficiaries annually and facilitating over $100 million in aid distribution. It operates standalone without the need for either the internet or electricity, and is ideal for remote settings. LMMS tracks work, generates payment instructions and provides near real-time distribution reporting. It supports integration with tools like KoboToolbox and Power BI, linking every transaction to individual users for accountability.

- Technological maturity: Proven
- Contracting type: For partnerships, licensing agreements or collaboration
- Technology level: Medium
- Place of origin: United Kingdom
- Availability: Worldwide
- Contact: WIPO GREEN Database

Communications: voice and high-speed data emergency response communications systems

Viasat

Source: Getty Images/Bet_Noire

Viasat offers a range of emergency communication systems providing global voice and high-speed data connectivity on land, sea and air. Quickly deployable terminals – including BGAN, FleetBroadband, and SwiftBroadband – support first responders with seamless communications. The Global Xpress high-speed satellite service provides higher data capacity rates for demanding operations. BGAN PTT delivers push-to-talk voice communications for vehicles, maintaining situational awareness when local networks fail. For beyond line-of-sight radio communication without modifying existing UHF/VHF radios, Viasat's L-TAC service uses satellites as repeaters, reducing reliance on scarce tactical satellite resources. Additionally, the IsatPhone 2 handheld satellite phone offers dependable voice connectivity worldwide.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO GREEN Database

Frontier technology solutions

Communications: mesh network

Meshmerize

Source: Getty Images/bluebay2014

Meshmerize supports disaster response by enabling the rapid deployment of resilient mesh networks and the use of synchronized drone swarms for site inspection, disaster localization, search and rescue, and active team monitoring. This technology enhances information sharing among responders and prioritizes actions in the most affected areas. Meshmerize is also involved in the 6G Life project, advancing 6G communications focused on sustainability, security, resilience and human–machine collaboration.

- Technological maturity: Frontier
- Contracting type: For licensing
- Technology level: Medium
- Place of origin: Germany
- Availability: Worldwide
- Contact: WIPO GREEN Database

Communications: emergency broadband internet

Tekniam

Source: Tekniam

Tekniam's Remote Universal Communication System (RUCS) is a compact, rapidly deployable wireless broadband network designed for emergency responders and rural areas with limited connectivity. It creates a local Wi-Fi internet signal covering a 305+ meter radius and can be extended up to 55 kilometers using daisy-chained units. Weighing just 2.3 kg, RUCS requires minimal power (from a car battery to a small power pack) and connects to any internet source – satellite, fiber or cellular. RUCS is easy to transport and set up in minutes, and provides an affordable, energy-efficient alternative to traditional bulky emergency communication setups.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO GREEN Database

Communications: "pop-up" connectivity (LEO)

Eutelsat Oneweb

Source: Getty Images/Koonsiri Boonnak

Eutelsat OneWeb is a global satellite internet provider using a constellation of low Earth orbit (LEO) satellites to deliver affordable, low-latency broadband worldwide. By combining OneWeb's LEO technology with Eutelsat's geostationary satellite expertise, they provide a comprehensive connectivity solution. Key features include global high-speed internet with low latency via hundreds of LEO satellites, rapidly deployable "pop-up" connectivity; redundant and reliable backup links that ensure continuous operations for businesses during critical events; flexible service plans with cloud-based management; and easy integration via apps and application programming interfaces (APIs).

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: France
- Availability: Worldwide
- Contact: WIPO GREEN Database

Communications: digital self-registration platform for communities in crisis

World Food Programme

Source: © WFP/Theodor Uukongo

WFP is actively overcoming the complex challenge of registering displaced and vulnerable populations during crises by embracing innovative, cost-effective solutions. Traditional in-person registration methods are often slow, costly and resource-intensive – barriers that are especially critical to address as humanitarian funding becomes increasingly scarce. To meet this need, WFP has introduced the People Portal, a self-registration web platform that enables people in crisis to register themselves directly, significantly reducing the need for labor-intensive field operations. Communities may access the platform via WFP partners, field teams, or posters once the WFP initiates operations in the area. The People Portal reduced the cost of registering from US$12 to US$0.50 per person. If scaled to WFP's target of 10 million registrations over the next two years, the People Portal could cut costs from US$120 million to just US$5 million, unlocking an estimated US$115 million in savings and accelerating the delivery of life-saving assistance.

- Technological maturity: Frontier
- Contracting type: Open access via WFP partners, field teams, or posters
- Technology level: Medium
- Place of origin: Italy
- Availability: Worldwide
- Contact: WIPO GREEN Database

Communications: food security modeling platform

World Food Programme

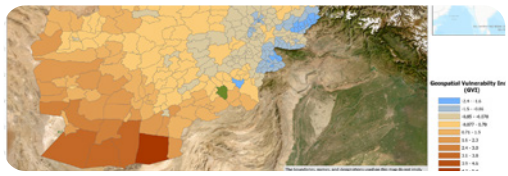
Source: World Food Programme

SHAPES (Shock and Assistance Platform for Economic Simulations) is WFP's advanced modeling platform that uses simulations to evaluate the effects of shocks and assistance on food security. It integrates data from surveys, market prices and satellite sources to predict how households respond to economic, climate, or political crises. By simulating different aid strategies, transfer values, and targeting methods, SHAPES helps optimize humanitarian interventions. The platform has reduced emergency assessment times from six months to three and reduced setup costs for new country operations significantly. It continuously adapts to emerging challenges—such as forecasting displacement trends and evolving crisis dynamics—to enhance response effectiveness. SHAPES aims to expand to all large-scale WFP operations in 120 countries and territories across the world.

- Technological maturity: Frontier
- Contracting type: For collaboration
- Technology level: Medium
- Place of origin: Italy
- Availability: Worldwide
- Contact: WIPO GREEN Database

AI-enhanced communications: user-friendly geospatial vulnerability profiling and targeting tool

World Food Programme



Source: World Food Programme

GeoTar is WFP's AI-powered geospatial tool that enhances emergency and anticipatory decision-making by automating vulnerability assessments. It integrates climate, food security and socio-economic data to deliver granular, real-time insights at the community level. As a backend system, GeoTar complements existing platforms and enables faster, more targeted humanitarian responses. GeoTar boosts geographic targeting accuracy by up to 30 percent and can save countries up to USD 100,000 by cutting the need for extra assessments. In 2024, it helped target six million people in Afghanistan and Chad, saving USD 90,000. GeoTar is now being evaluated for wider use in seven additional WFP country offices.

- Technological maturity: Frontier
- Contracting type: For collaboration
- Technology level: Medium
- Place of origin: Italy
- Availability: Worldwide
- Contact: WIPO GREEN Database

Logistics: disaster logistics platform

Aeronext

Source: Getty Images/mesh cube

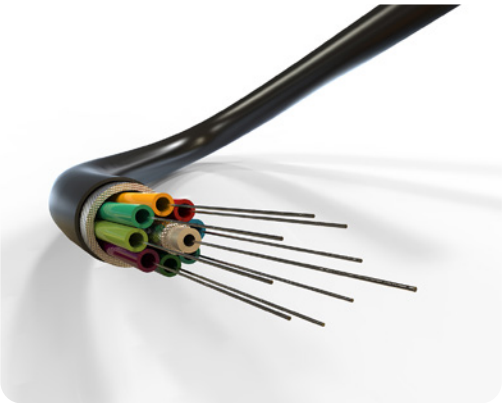
Following the January 2024 Noto Peninsula earthquake in Japan, NEXT DELIVERY, a part of Aeronet, used drones to deliver medical supplies to isolated areas. From this experience, Aeronext developed the SkyHub® Emergency Package, a phase-free (always ready and operational) disaster logistics solution that integrates drone delivery into everyday local logistics. The system creates a smart regional logistics platform, supporting local residents both during normal times and disasters. Challenges that were identified during the 2024 earthquake included disrupted roads, limited knowledge about the status of evacuation sites, and a lack of information on supply stockpiles. By digitizing everyday logistics operations with respect to the location of evacuation centers and prior hazard mapping, the platform enables rapid support during disasters. The everyday logistics services also ensure that residents become accustomed to using these collection points for drone deliveries in daily life, making the transition to emergency drone transport seamless.

- Technological maturity: Frontier
- Contracting type: For license
- Technology level: High
- Place of origin: Japan
- Availability: Japan
- Contact: WIPO GREEN Database

Horizon technology solutions

Communications: optical power supply technology

NTT Group and Kitami Institute of Technology (KIT)



Source: Getty Images/matdesign24

Researchers have developed a way of transmitting 1 watt of electrical power alongside high-speed 10 Gbps bidirectional data through a single multi-core optical fiber (MCF) over distances greater than 10 kilometers. Using separate cores within the same fiber, the system sends power and data independently without interference, enabling disaster-affected areas to maintain communications even during power outages. This technology, demonstrated by NTT and partners, overcomes previous limits on power delivery distance through optical fibers and achieves a world record in optical power-distance product and self-powered data transmission performance. It can integrate with existing optical networks. Future applications will include optical communications in challenging environments – such as rivers, mountainous regions, and areas where electrification is difficult due to strong electric fields or corrosion – as well as the development of sensing networks connected to various IoT devices.

- Technological maturity: Horizon
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Japan
- Availability: Worldwide
- Contact: WIPO GREEN Database

Communications: LEO satellite network

Telesat

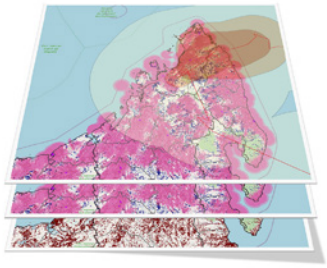
Source: Getty Images/mikdam

Telesat Lightspeed is a low Earth orbit (LEO) satellite network providing ultra-fast connectivity for first responders worldwide. It aims to extend public safety networks during disasters by delivering fiber-like speeds, multiple Gbps bandwidth and continuous global coverage with agile beam technology (the ability of satellite antennas to dynamically steer and shape radio signals or beams in real time, so they can be precisely focused on specific locations – concentrating capacity where demand is highest and adjusting coverage areas based on changing conditions). The first satellite launches are scheduled for mid-2026, with global service expected to commence in 2027.

- Technological maturity: Horizon
- Contracting type: Under development
- Technology level: High
- Place of origin: Canada
- Availability: N/A
- Contact: WIPO GREEN Database

AI-enhanced communications: piloting AI on Early Warning Connectivity Map (EWCM)

International Telecommunication Union (ITU), Microsoft AI for Good Lab, Planet, Institute for Health Metrics and Evaluation (IHME)



Source: International Telecommunication Union (ITU)

The Early Warning Connectivity Map (EWCM) combines AI and satellite imagery to map population density at high resolution and overlay it with mobile network coverage data. EWCM highlights areas where people are vulnerable to natural hazards due to limited access to emergency notifications. It enables authorities to plan alternative alerting methods – such as sirens, radio or community messengers – before disasters strike and make targeted infrastructure investments to enhance resilience. The results will guide data-driven decisions on warning dissemination strategies and mobile infrastructure investment to ensure no one is left behind. As part of the United Nations Early Warnings for All initiative, EWCM supports countries for targeted, inclusive early warning delivery. Pilot deployments are underway with national disaster agencies to refine methodologies, validate data accuracy and integrate results into multi-hazard early warning platforms.

- Technological maturity: Horizon
- Contracting type: Currently pilot projects
- Technology level: High
- Place of origin: Switzerland
- Availability: Pilot countries
- Contact: WIPO GREEN Database

Financial resilience, risk transfer and insurance technologies

Innovative financial technologies are transforming disaster risk response: parametric insurance triggers automatic payouts, while index-based insurance protects smallholder farmers using weather or yield benchmarks. AI-enhanced catastrophe bonds attract private capital, and mobile money platforms deliver anticipatory cash transfers before disasters strike. Biometric systems and blockchain streamline aid distribution while combating fraud.

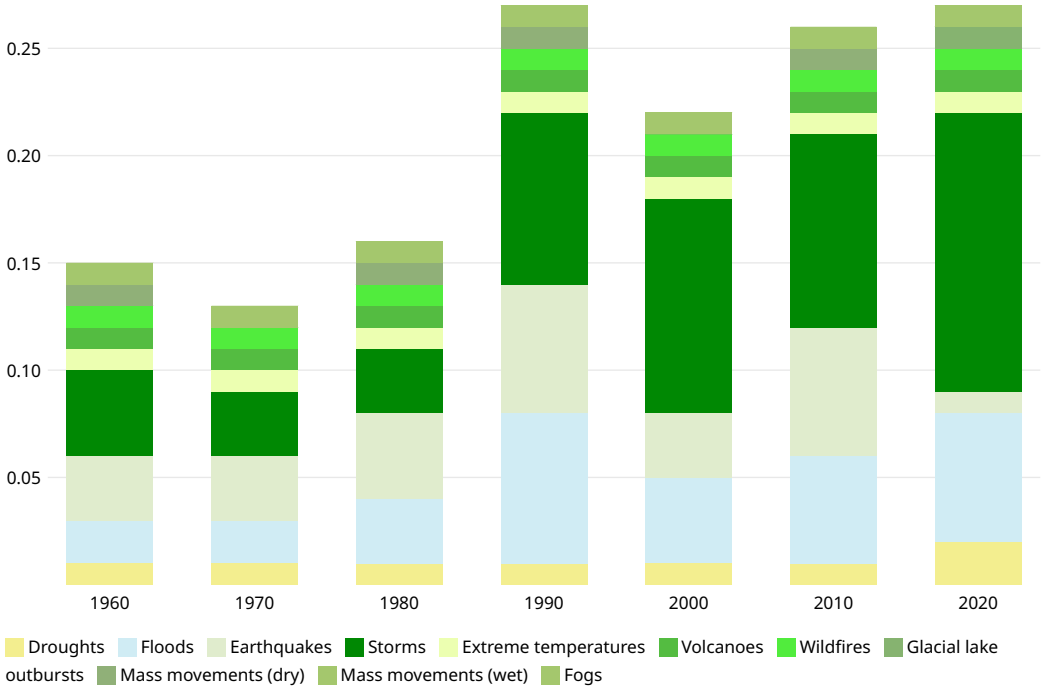
Technological developments and trends

The economic toll of disasters has risen sharply over the past century. Low-income countries have borne the heaviest relative burden, averaging losses exceeding 2 percent of GDP annually in recent decades – over twice the share of GDP compared to wealthy nations. As shown in figure 11.1, high-income countries that face absolute economic losses generally sustain lower relative damages that are typically below 0.5 percent of GDP (Ritchie *et al.*, 2022).

> High-income countries face the highest relative losses due to wildfires, most likely due to suburban sprawl

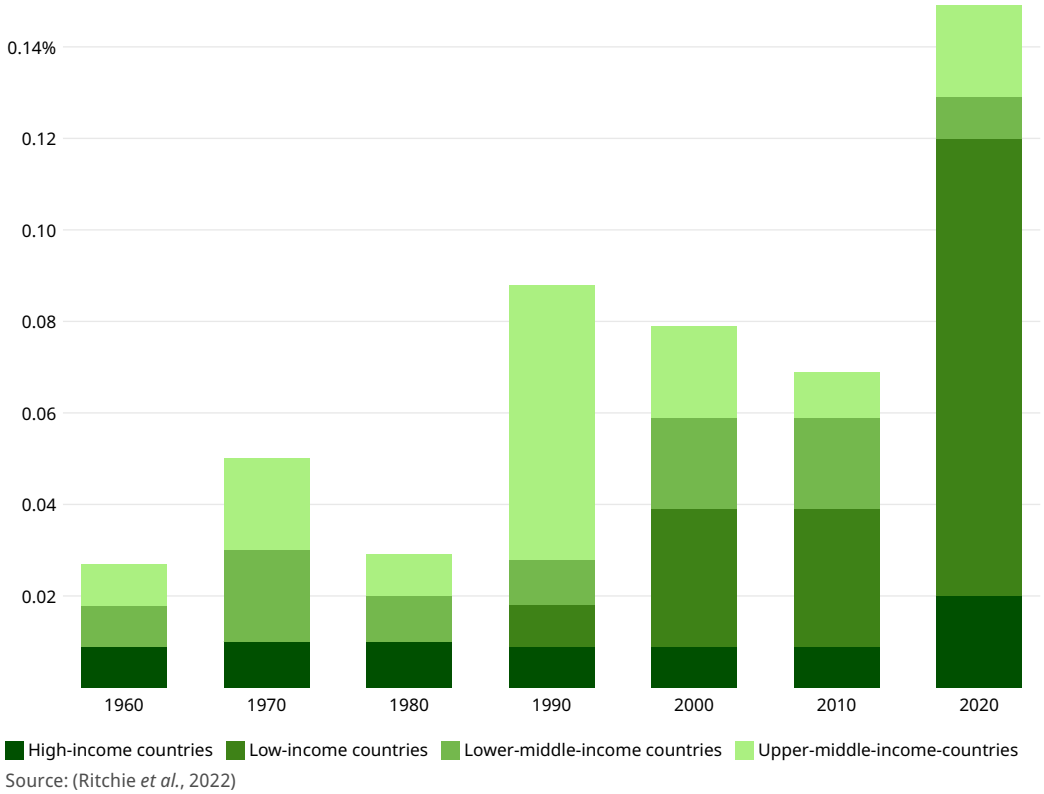
When considering economic damages by disaster type, the differences come into sharper relief. For example, figure 11.2 shows economic damage from drought, depicting low-income countries as impacted the most profoundly. Figure 11.3, on the other hand, shows economic damage from wildfire events (Ritchie *et al.*, 2022). In relative terms, drought is more economically damaging than wildfires, with peaks near 0.14 percent of GDP in low-income countries compared to 0.045 percent of GDP in recent decades in high-income countries. However, while GDP percentages highlight disparities, they understate how smaller absolute losses can devastate low-income economies, whereas wealthy nations are able to absorb larger shocks before GDP reflects impacts. That said, high-income countries face the highest relative losses due to wildfires, most likely due to suburban sprawl, representing an emerging threat for wealthier nations that has increased notably since the 1980s.

Figure 11.1 Annual economic damages from disasters as a share of GDP, 1900-2020 (decadal average)



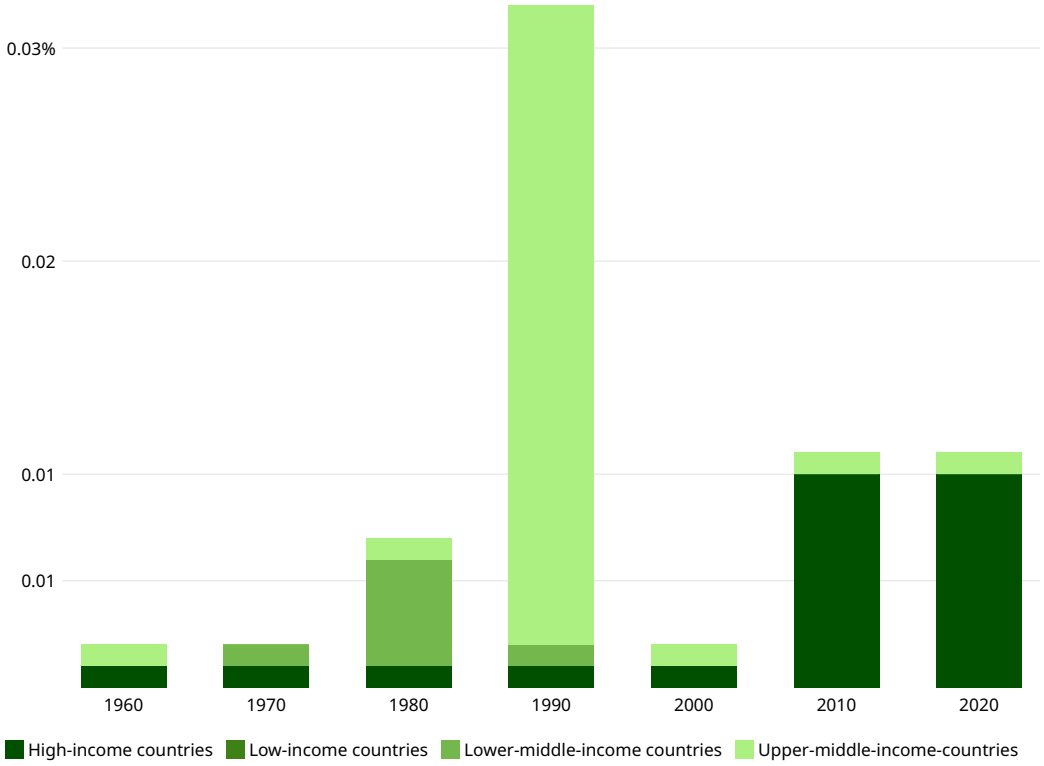
Source: (Ritchie *et al.*, 2022)

Figure 11.2 Annual economic damages from drought as a share of GPD, 1900-2020 (decadal average)



Source: (Ritchie *et al.*, 2022)

Figure 11.3 Annual economic damages from wildfires as a share of GDP, 1900-2020 (decadal average)



Source: (Ritchie *et al.*, 2022)

As climate change intensifies hazards, the need for robust and tailored risk transfer mechanisms becomes critical for the mitigation of financial shocks. This is especially true for low-income countries, since traditional insurance often fails to reach the most vulnerable. Financial and insurance technologies are revolutionizing risk management, while bolstering resilience for both disaster victims and even the insurance companies themselves (WEF, 2024b). From AI-powered anticipatory cash relief to parametric insurance that automatically triggers payouts when floods or droughts strike, innovation is making assistance faster, more transparent, and more equitable.

Mobile money platforms enable direct cash transfers to be made to vulnerable populations, while cryptocurrency donations bypass traditional banking barriers for cross-border aid. Indexed-based insurances using satellite data and catastrophe bonds use big data and AI to protect farmers and governments from climate shocks. Digital cash and voucher assistance (CVA) programs now integrate biometrics and blockchain to reduce fraud. The World Bank and private insurers are adopting AI-powered risk models to streamline catastrophe bond issuance, attracting capital markets to disaster recovery. Yet challenges remain, such as ensuring equitable access, safeguarding data privacy in biometric verification systems, and protecting the three billion people still underserved by microinsurance (UNDP, 2025). This suite of new tools is building financial resilience, while navigating trade-offs between efficiency, accessibility and equity.

Digital cash can make disaster aid smarter, faster and safer

Cash and voucher assistance (CVA) is a humanitarian aid approach whereby those affected by crises receive cash or vouchers instead of direct goods or services. Cash assistance means giving beneficiaries money (physical or digital) that they can spend as needed. Voucher assistance provides beneficiaries with coupons or electronic vouchers that can be exchanged for specific goods or services from approved vendors. As humanitarian aid shifts from in-kind to cash-based assistance, digital cash is replacing traditional cash delivery due to its agility, transparency and cost-effectiveness. It empowers recipients with greater choice, supports local markets, improves speed and flexibility, enhances accountability, promotes financial inclusion, and reduces personal risks associated with carrying physical cash or in-person transactions.

Financial and insurance technologies are revolutionizing risk management, while bolstering resilience for both disaster victims and even insurance companies

Mobile money solutions like M-Pesa (Kenya), bKash (Bangladesh) and GCash (Philippines) are essential tools for disaster relief. This is especially the case in areas with limited banking infrastructure, enabling the direct transfer of funds to individuals via their mobile phones. bKash, for example, operates through SMS and unstructured supplementary service data (USSD) codes, enabling users without smartphones or internet access to perform transactions. With strong security protocols and integration with mobile and agent networks, these platforms ensure reliable access to financial services, especially in emergency situations.

Using predictive analytics, preemptive cash transfers can be issued in advance of disasters, while mobile money systems enable instant aid disbursement, even in low-connectivity areas. Meanwhile, blockchain and biometrics are streamlining CVA to reduce fraud. Blockchain technology can support disaster response by providing secure, transparent and decentralized methods for managing identities and aid distribution. In emergency situations where displaced individuals often lose physical documents, blockchain enables fast and verifiable ID management (Zwitter *et al.*, 2020). Its core features – immutability, transparency and decentralization – address common challenges in disaster relief such as inefficiency, lack of transparency and poor coordination. Blockchain allows for the transparent tracking of donations, decentralized data storage that ensures integrity even in low-connectivity areas, and the use of smart contracts to automate and speed up aid delivery without intermediaries. Blockchain may also to be further integrated with AI, IoT and Big Data to enhance efficiency. However, there is a lack of awareness around blockchain's potential among state and local agencies, NGOs, case managers and survivors (Murahari Sahithi *et al.*, 2025).

Biometric technology (also discussed below), including fingerprints, iris scans and facial recognition, is used alongside mobile and blockchain technologies in CVAs. It is seen as a tool to enhance accountability, prevent fraud and ensure aid reaches the intended individuals. However, the political context of each country and the unequal implementation of biometric-based CVAs can create challenges, hindering efforts to promote independence and dignity, especially when biometric data is either not recognized or restricted (Forced Migration Review, 2024). Although biometric verification in CVA began as early as 2013 with UNHCR and WFP in Kenya, its broader adoption across humanitarian settings remains relatively recent.

Forecast-based/anticipatory cash assistance. Ahead of Cyclone Remal's expected landfall in Bangladesh's southern coastal regions in 2024, the WFP promptly distributed cash assistance of USD 43 (BDT 5,000) to 30,000 vulnerable families across five districts, helping them prepare for and recover from the storm (WFP, 2024a). Facilitated through the mobile financial service bKash, the distributed funds enabled families to purchase essentials like food and medicine, reinforce homes, and arrange safe transportation. This effort is part of WFP's Anticipatory Action program, which supports early interventions based on weather forecasts to reduce the impact of climate shocks on food security and nutrition. These efforts highlight the potential of anticipatory aid in enhancing community resilience. By integrating AI-driven forecasts with digital cash transfers, humanitarian organizations can deliver timely assistance, thereby reducing reliance on traditional aid mechanisms.

Insurance solutions that bridge gaps in climate risk coverage gaining traction

Insurance plays a vital role in mitigating climate risks by transferring financial burdens from vulnerable individuals and communities to broader markets (Kusuma *et al.*, 2019). Emerging index-based models use parametric triggers to enable faster, more affordable payouts that are particularly valuable for low-income farmers and small businesses. These solutions help bridge gaps in traditional coverage, but challenges like basis risk, the lack of legal frameworks and data limitations remain critical hurdles to overcome (Cordella and Yeyati, 2015). See Box 11.1 for further discussion of barriers to disaster insurance adoption.

Box 11.1 Overcoming barriers to disaster insurance adoption

Disaster insurance faces significant adoption challenges, especially in low-income countries. Market failures stem from high risk, limited financial capacity, poor risk data, as well as behavioral factors like "charity hazard" (reliance on post-disaster aid) (Kita, 2025). While developed nations often over-insure risky areas, developing countries suffer from chronic underinsurance due to weak markets and resource constraints. Index-based solutions, though promising, grapple with basis risk (mismatched payouts) and technological gaps in data accuracy (Kita, 2025). Cultural biases and traditional coping mechanisms further hinder uptake. Critics note that these systems often fail to address climate equity principles. As an example, only 2.5 percent of Malawians have insurance, predominantly urban motor/health policies, while rural areas and farmers remain underserved because of access barriers, low trust and financial literacy gaps (The Times Group, 2023).

Collaboration, especially public–private partnerships, is key to improving disaster insurance by addressing market gaps, tailoring products to local needs, and boosting resilience using innovative schemes. Understanding risk impacts on the willingness to pay for insurance alongside specific risk characteristics also helps inform better insurance strategies. In addition, policy and governance are key to disaster insurance uptake, but many developing countries have reactive, weak frameworks. Success requires political will, strong laws, stakeholder coordination and government/donor support in data, legal setup and capacity-building (Kita, 2025).

Insurtech (insurance technology) refers to the use of innovative technologies to improve and transform the insurance industry. In relation to disasters, insurtech involves tools like AI-driven risk modeling, satellite imagery, IoT sensors and digital platforms that help insurers better predict, assess and manage disaster risks. For example, insurtech solutions can provide faster and more accurate damage assessments after a hurricane or wildfire, automate claims processing and enable parametric insurance products that trigger instant payouts based on predefined weather events.

Fintech (financial technology) broadly encompasses technology-driven innovations that improve financial services. When applied to disaster and catastrophe risk management, fintech includes financial instruments and platforms that facilitate the transfer and management of catastrophe risks. Catastrophe bonds, for instance, are fintech innovations that allow insurers to transfer disaster risks to the capital markets, raising funds for disaster recovery. Blockchain technology enhances transparency and automation in disaster risk finance by enabling secure, tamper-proof contracts and faster claims payouts.

Microinsurance (insurance products specifically designed for low-income populations offering low premiums, limited coverage and simple terms) and *inclusive insurance* (which aims to ensure access to affordable insurance for all underserved populations, including informal workers, rural communities, migrants, refugees and other marginalized groups) are an increasingly used tool for building financial resilience into low-income and vulnerable populations, but there is still a significant coverage gap. While coverage has grown by 70 percent in 37 countries over the past three years, only 12 percent of the three billion people who could benefit are currently covered (Merry and Rozo, 2025). Scaling microinsurance therefore remains a

challenge, with a need for simpler, more affordable products and improved claims processes. The market potential is large, valued at around USD 41 billion, but misconceptions about profitability hinder growth. Microinsurance is also a key component of financial inclusion strategies, working alongside mobile money and other financial services, while inclusive insurance is promoted by organizations such as the International Association of Insurance Supervisors (IAIS) and the Access to Insurance Initiative (A2ii). To expand reach, public–private collaboration is essential, along with tailored solutions for gender inclusion and investments in infrastructure (Merry and Rozo, 2025 https://microinsurancenetwork.org/resources/the-landscape-of-microinsurance-2024).

Parametric insurance pays out a predetermined amount based on the occurrence of a specific event or condition, rather than on the actual loss incurred. It is based on a trigger, such as wind speed, and requires no inspections or loss adjustment, thus enabling a fast payout – which is useful for disasters, agriculture, drought, and climate-related risks. Take, for example, a coastal business that purchases parametric insurance paying out USD 100,000 if a Category 4+ hurricane passes within 50 miles. If such an event occurs, the company receives the money, regardless of the actual damage incurred.

Whereas parametric insurance pays out a predetermined amount based on the occurrence of a specific event or condition rather than on the actual loss incurred*, index-based insurance* is a specific type of parametric insurance whose trigger is based on an index, such as rainfall amount, temperature or crop yield average. This index is determined by measured data from a third party, such as weather stations or satellites. For example, a farmer buys rainfall index insurance. If rainfall drops below 50 mm during the growing season (based on satellite data), the farmer will then receive a payout without the need for a time-consuming in-situ assessment. This type of insurance is commonly used in agriculture within developing countries. Importantly, it helps to avoid issues like disputed claims or fraud, and is gaining traction in markets where traditional insurance is too expensive or complex to implement. A further subset of parametric insurance is satellite-indexed insurance. This specifically uses satellite imagery and remote sensing technologies to assess and validate disaster-related claims in areas where ground-based assessments are either difficult or costly, or both. These particular products can trigger payouts based on a predefined threshold, for example, rainfall level, vegetation health measured by the normalized difference vegetation index (NDVI) or soil moisture and drought indicators.

Insurance industry challenges and parametric reinsurance. Reinsurers provide catastrophe policies covering extremely rare events – those that might happen only once every 100, 250 or even 500 years. Consequently, major firms develop models considered adequate for reinsurers to underwrite these catastrophe risks. However, issues emerge when models designed for such rare events are applied to more frequent events occurring every five to 10 years (Wallace, 2024).

The insurance industry is facing an affordability crisis

The insurance industry is facing an affordability crisis, especially with secondary perils like severe convective storms causing rising losses to outpace premiums, thus straining primary insurers. Reinsurers, wary due to past losses and modeling challenges for frequent, less extreme events, are reluctant to increase exposure to such risks. To address this gap, companies such as Demex (see Frontier technologies) are promoting parametric reinsurance to improve protection for insurers. This innovative approach aims to balance risk between insurers and reinsurers, helping stabilize the market without reinsurers withdrawing from secondary peril coverage (Wallace, 2024).

Catastrophe bonds, while fundamentally financial instruments, are intertwined with advanced technology, making them a key innovation in the insurtech and fintech spaces. Their creation and management rely heavily on sophisticated catastrophe modeling that uses AI, satellite data, climate simulations, and other cutting-edge analytics to predict the likelihood and impact of disasters. This modeling informs the design of bond triggers and payout structures by accurately quantifying risk exposure. Additionally, the issuance and trading of “cat” bonds often

occurs on digital platforms that use blockchain technology and smart contracts to automate trigger events and payouts, which can contribute to transparency and security. Cat bonds integrate real-time data feeds and early warning systems to connect insurers, reinsurers and capital markets, ultimately bolstering the broader risk management ecosystem.

AI-enhanced catastrophe modeling. The World Bank is exploring the use of AI to enhance catastrophe risk modeling and streamline catastrophe bond transactions. AI can analyze huge datasets to identify patterns and correlations that traditional methods might miss. This approach allows for the more accurate assessment of vulnerabilities and potential economic losses. By improving modeling reliability, AI could facilitate more transactions being made within the catastrophe bond market, potentially increasing investor confidence and participation (Artemis, 2024).

Broadly speaking, AI is increasingly being used within the insurance industry. It can help insurers improve claims processing and make insurance more affordable by lowering transaction costs. As discussed in other chapters in this year's *Green Technology Book*, it is being applied for weather prediction, damage assessment and improving resilience in disaster-prone regions. However, the effectiveness of AI depends on the quality of data it uses. Additionally, industry-wide collaboration between different stakeholders is necessary to enable it to reach its full potential for insurance and other disaster response technologies (genpact, 2023).

Biometrics technologies support disaster relief and fraud prevention – but data concerns remain

Digital ID systems usually consist of multiple technologies working together to enable identification. Because of such complexity, there is no single agreed-upon definition. A digital ID can be a digital version of an identity document, a collection of personal attributes used in a transaction, or a network of digital identifiers that uniquely identify someone (Access Now, 2024). Biometric ID systems, often in combination with blockchain and mobile technologies, are essential tools in preventing duplicate claims during disaster relief operations. By using technologies like fingerprinting, facial recognition, iris scanning and mobile biometric systems, humanitarian organizations can ensure the fair and efficient distribution of aid, while safeguarding against fraud and abuse. Biometric ID systems are becoming increasingly important in disaster relief, being especially useful when large populations are displaced and aid is distributed on a large scale. Box 11.2 discusses UNHCR's biometric data system. Below are some of the key biometric technologies specifically tailored to disaster response and claims management:

- *Fingerprint recognition*. In disaster-affected areas, fingerprint biometric systems are used by humanitarian organizations to register individuals, ensuring each person can claim relief without the risk of duplicate or multiple claims being made under different identities. It can be deployed in refugee camps, temporary shelters or at remote field offices.
- *Facial recognition for aid distribution*. In high-traffic disaster response areas, facial recognition technology is used to verify identities at aid distribution points by using pre-recorded images (such as those taken at registration centers).
- *Iris scans* are increasingly used in disaster-prone regions for identification, since the iris is a unique, unchangeable feature. Some organizations like the Indian Red Cross have tested iris-scanning technology to ensure that aid reaches the correct individuals, while reducing administrative overheads and delays.
- In regions where infrastructure is damaged, *mobile biometric kits* allow field officers to register people using a smartphone or portable device. The data collected, including fingerprints, facial or iris scans, can be stored and processed in the cloud, allowing for real-time verification of claims.
- *Behavioral biometrics for ongoing claim verification*. After an initial registration, behavioral biometrics – such as typing patterns, walking gait, and even smartphone usage patterns – can be used to track a claimant's identity continuously. While still experimental within disaster settings, this kind of behavioral biometric system can potentially be applied more frequently in the future to track aid recipients via digital platforms or cash transfers.
- *Blockchain with biometric verification*. Blockchain technology combined with biometric systems can be used to securely store identity data for disaster victims. Blockchain ensures that once a person's identity is verified using biometrics, their data cannot be altered. WFP

has tested a blockchain-based system using biometric verification for food assistance in refugee camps.

- *Voice biometrics for remote verification*. In areas with limited access to physical biometric devices, voice biometrics can be used over mobile phones. People register their voice patterns, and during subsequent interactions their identity can be verified through their unique voice features. In some developing countries, microinsurance companies are exploring voice biometric systems for verifying claims via mobile phone (FasterCapital, 2025). In Bangladesh, where mobile money systems like bKash are widespread, voice biometrics are being explored to verify identities before funds are released to individuals who have registered for disaster relief (Bharadwaj *et al.*, 2023).
- *Biometrics for medical assistance*. Disasters often overwhelm health care systems with a surge of patients. In such a situation, biometric technology can play a role in improving medical care by recording the unique physical characteristics of an individual, thereby streamlining patient identification.

Box 11.2 UNHCR employs biometric data

UNHCR employs its Biometric Identity Management System (BIMS), which uses fingerprint scanning, iris images and facial photos to create unique biometric records for refugees. This system ensures accurate identification, prevents fraud and enables the efficient delivery of services like food, shelter and cash assistance. BIMS provides a centralized database that is accessible across locations, supports mobile and offline use, and integrates with other systems to streamline operations. To enhance data sharing and coordination, UNHCR uses the PRIMES Interoperability Gateway (PING), a secure platform that allows the safe exchange of biometric and biographical data with partners including WFP. This collaboration has improved food distribution for refugees in Tanzania by enabling WFP to access verified identity data via PING and synch it with WFP's cloud-based SCOPE platform. SCOPE is used for registering and tracking beneficiaries, deduplicating personal data, managing beneficiary lists, and monitoring assistance delivery (both cash and in-kind). It also supports beneficiary authentication, transfer value management and operational data storage.

The partnership between UNHCR and WFP through their interoperable technologies boosts data transfer speed and adds biometric security to reduce fraud, ensuring aid reaches the correct people efficiently.

Source: (UNHCR, 2023; 2024)

Biometric vending machines are innovative tools used during a disaster response to provide essential supplies like food, water and emergency items quickly and securely. In Japan, disaster-response vending machines have been used since 2007, having first been developed by the Institute of Disaster Mitigation and Coca-Cola West. They automatically dispense resources during emergencies, providing water, electricity and information, while using biometric authentication to control access. In India, the GrainATM (Annapurti) is a biometric-enabled automated grain dispenser that provides subsidized grains 24/7 to beneficiaries under the Public Distribution System. Launched in Odisha and supported by WFP, it allows ration card holders to quickly access up to 50 kg of grains with biometric verification, cutting waiting times by 70 percent (WFP, 2024c).

Significant biometric data technology challenges remain. In camps like Dadaab in Kenya, refugees have faced challenges such as biometric data not being recognized, delays in aid distribution and restrictions on the types of food or services they can purchase. Cash assistance is often restricted to specific vendors, which limits choice. Additionally, some refugees feel trapped by the need for biometric verification to maintain access to assistance, which can limit their mobility and economic freedom (Forced Migration Review, 2024). There are also significant data protection risks, particularly in regions with underdeveloped or unenforced privacy laws. Humanitarian agencies may have little control over how biometric data is used once shared with other entities, which increases the risk of data breaches or misuse (Forced Migration Review, 2024).

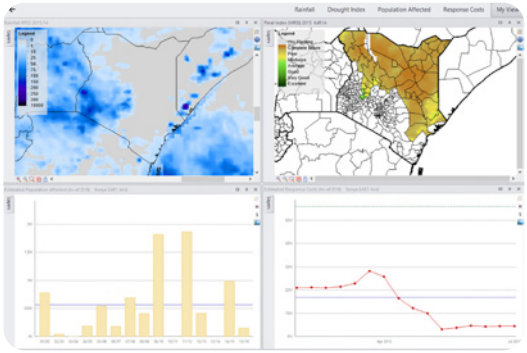
Innovation examples

AI-driven cash relief before and after disasters strike

Source: GiveDirectly (photo from Ujeh, Nigeria)

In response to Hurricanes Helene and Milton, disaster aid delivery has been transformed using AI. The nonprofit organization GiveDirectly is pioneering a direct cash assistance program, having provided $1,000 payments to nearly 1,000 households in North Carolina and Florida. This approach aims to rush relief to those most affected by leveraging Google's machine learning tools to identify high-need households in disaster zones. Using AI to analyze satellite imagery and poverty data, GiveDirectly targets communities with significant damage and economic vulnerability. Eligible recipients are invited to enroll via the Propel app, where funds are deposited directly onto debit cards, reducing delays and documentation burdens typical of traditional aid programs. Direct cash assistance offers recipients flexibility in addressing diverse needs such as food, clothing, childcare and bill payments. While the model has proven effective, limitations include the requirement for smartphone access and internet connectivity, which exclude some vulnerable populations. GiveDirectly plans to expand its reach through hybrid remote and in-person assistance. Additionally, Google is using AI to predict severe floods up to a week in advance, enabling the International Rescue Committee and GiveDirectly to send cash transfers *before* disasters strike. This anticipatory aid, piloted in Nigeria and Mozambique, uses satellite data, government information and mobile money platforms to identify at-risk populations and deliver funds quickly (Fast Company, 2024).

African Risk Capacity (ARC) Group parametric insurance payouts power rapid climate crisis relief in Zimbabwe and Somalia



Source: African Risk Capacity (ARC) Group

The African Risk Capacity (ARC) Group pioneers parametric disaster insurance solutions across Africa, providing rapid financial support to countries facing climate-induced crises. In 2024, Zimbabwe received a historic payout of USD 16.8 million to aid drought-affected populations amid severe food insecurity caused by El Niño. This payout was triggered by ARC's Africa RiskView software, an early warning system that automatically releases funds based on predefined drought severity metrics impacting over 4.7 million people. Through the ARC Replica program, humanitarian organizations can purchase insurance policies that complement governments' insurance coverage, thereby increasing protection for populations against climate risks. Humanitarian partners World Food Programme (WFP) and Start Network have received USD 6.1 million and USD 8.9 million, respectively, enabling humanitarian organizations to deliver timely or early assistance to vulnerable populations following a shock. Premiums are

supported by donors including the Swiss Agency for Development and Cooperation and KfW, a German development bank, ensuring predictable emergency funding. Somalia also secured USD 1.46 million from ARC's sovereign drought insurance pool for the 2024/25 season, with Start Network receiving $728,000 via Replica to provide cash transfers to over 45,000 drought-impacted households. These efforts represent a shift from reactive aid to prearranged risk financing, showcasing how ARC's parametric insurance and Replica program use technology-driven risk monitoring and prearranged financing to strengthen disaster resilience across Africa (ARC, 2025; 2024).

Blockchain-based index insurance protects Southeast Asia's coffee farmers from climate risk

Source: Getty Images/Tanes Ngamsom

Insurtech company Igloo has expanded its blockchain-based parametric Weather Index Insurance to coffee farmers in Southeast Asia, building on the success of its program for rice farmers. Launched in Vietnam's Central Highlands, the program covers five provinces and insures plots as small as 0.1 hectares at a cost starting around USD 42 per hectare, with coverage up to USD 1,700. The insurance uses rainfall data and pre-assigned loss values to automate claims, eliminating the need for on-site damage assessment and ensuring fast, transparent payouts. Smart contracts hosted on a public blockchain guarantee consistency and trust in the payout process. Igloo partners with local insurers, meteorological agencies and international reinsurers to implement the program. This is crucial, as climate change increasingly threatens coffee crops across the region with drought, erratic rainfall and suboptimal temperatures that jeopardize farmer livelihoods, as well as global supply chains. By using big data, real-time risk assessment and automated claims management, Igloo's model counters the high cost, delays and inefficiencies of traditional agricultural insurance and helps small-scale farmers protect their income, while adapting to growing climate volatility (Igloo, 2023).

Proven technology solutions

Insurance and risk transfer: agriculture disaster insurance

ACRE Africa

Source: Getty Images/Wirestock

ACRE Africa is an agricultural and climate risk enterprise offering innovative insurance solutions to smallholder farmers across Africa. Its approach includes providing weather index-based insurance products, such as Bima Pima, which allow farmers to pay premiums in small, affordable installments via mobile money platforms like M-Pesa. These products are designed to trigger automatic payouts based on weather data, eliminating the need for on-site inspection and reducing administrative costs. ACRE Africa collaborates with local partners, including mobile network operators and agro-dealers, to distribute insurance products and build trust within farming communities. Its use of technology, including satellite data and blockchain for smart contract automation, enhances the efficiency and scalability of services. Since its inception, ACRE Africa has expanded its reach to over 3.1 million farmers across multiple African countries.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Kenya
- Availability: Sub-Saharan Africa
- Contact: WIPO Green Database

Insurance and risk transfer: bespoke parametric insurance

Descartes Underwriting

Source: Getty Images/onurdongel

Descartes Underwriting delivers advanced parametric insurance using AI, satellite imagery and real-time data analytics to protect businesses from disasters like hurricanes, earthquakes, floods and extreme weather. Policies trigger automatic payouts when specific conditions – such as wind speeds or seismic activity – are met, so as to enable fast claims-free financial relief. By integrating machine learning and sensor data, Descartes builds precise, dynamic risk models that capture climate trends and local hazards. Focused on large corporate clients, its offers scalable solutions covering extensive geographical areas worldwide. Descartes issues policies on A-rated paper (referring to insurance policies or contracts that are backed by insurers with an "A" (Excellent) rating from independent rating agencies like A.M. Best, Standard & Poor's, and Moody's), and is supported by leading reinsurers.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: France
- Availability: Worldwide
- Contact: WIPO Green Database

Cash transfers and financial inclusion platforms: mobile money platform

bKash

Source: Getty Images/andresr

bKash operates as a mobile-based digital payment platform that leverages USSD and smartphone apps to provide secure, easy-to-use financial services. It enables users to send money, pay bills, recharge mobile phones and access banking services without the need for a traditional bank account. USSD works over the GSM network and allows users to access financial services by dialing codes on basic feature phones. The platform integrates with Bangladesh's banking infrastructure and uses robust encryption and authentication methods to ensure transaction security. Its technology supports real-time transactions, interoperability with other financial institutions, and scalability to serve millions of users, making digital finance accessible even in remote or underserved areas.

- Technological maturity: Proven
- Contracting type: Subscription or usage-based services
- Technology level: Medium
- Place of origin: Bangladesh
- Availability: Bangladesh
- Contact: WIPO Green Database

Cash transfers and financial inclusion platforms: mobile money platform

M-Pesa

Source: Getty Images/Roger Yebuah

M-Pesa is Africa's leading mobile money service and the continent's largest fintech platform. It offers a safe, convenient way for both banked and unbanked people to make payments and access financial services. Launched in 2007 by Safaricom, Vodafone's Kenyan partner, M-Pesa now serves over 60 million customers across eight African countries. M-Pesa uses SMS and USSD technology to enable financial transactions on basic mobile phones without internet. It links mobile numbers to digital wallets for sending money, paying bills and more. The system operates on a secure, centralized platform that processes transactions instantly and integrates with banks and agents for cash services. Robust encryption and authentication ensure user security. In 2020, Vodacom and Safaricom acquired the M-Pesa brand from Vodafone Group through a joint venture, giving them full control over product development and support.

- Technological maturity: Proven
- Contracting type: Subscription or usage-based services
- Technology level: Medium
- Place of origin: Kenya
- Availability: Democratic Republic of Congo, Egypt, Ethiopia, Ghana, Kenya, Lesotho, Mozambique, South Africa and Tanzania
- Contact: WIPO Green Database

Insurance and risk transfer: crop and weather monitor with built-in index viewer

Swiss Re

Source: Swiss Re

Swiss Re, a large Swiss reinsurance company, is expanding its parametric agricultural insurance to help smallholder farmers and public sector clients manage climate risks like droughts, floods and heatwaves. Using predefined triggers such as rainfall, soil moisture, temperature and vegetation indices, payouts are made automatically and faster without the need for traditional claims processing. The company's Opti-Crop platform leverages near real-time satellite and weather data to enhance transparency and reduce delays. Swiss Re supports insurers and governments in product design and data integration, aiming to better align payouts with actual losses. Active in South America, Central Asia, Africa, and Southeast Asia, Swiss Re offers standardized indices that include soil moisture, rainfall, temperature, normalized difference vegetation index (NDVI) (vegetation density) and area yield to track environmental conditions and improve insurance access.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Switzerland
- Availability: Worldwide
- Contact: WIPO Green Database

Insurance and risk transfer solutions: index-based livestock and yield index insurance

Pula

Source: Pula

Pula's insurance products use satellite technology and data analytics to protect farmers and pastoralists. Its Index-Based Livestock Insurance (IBLI) uses satellite-derived NDVI data to monitor pasture health and detect grazing shortages caused by drought or delayed rains. This enables timely payouts to support livestock care during critical periods. For crops, Pula's Yield Index Insurance (YII) divides regions into agro-ecological zones using historical climate and yield data. Satellite and ground data help measure actual yields at season's end, triggering compensation if yields fall below set thresholds. A hybrid insurance combines Weather Index Insurance (WII) and YII, using weather data and yield measurements to deliver fast payouts for weather-related losses and broader coverage for drought, floods, pests and diseases. This enables efficient risk assessment and rapid financial support without the need for individual loss verification.

- Technological maturity: Proven
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Switzerland
- Availability: Ethiopia, Kenya, Nepal and Nigeria
- Contact: WIPO Green Database

Cash transfers and financial inclusion platforms: blockchain-based decentralized donation platform

Giveth

Source: Giveth

Giveth is a blockchain-based donation platform that uses Ethereum smart contracts to ensure transparency and accountability in funding social impact projects, allowing donors to track exactly how and where their contributions are used in real time. Giveth uses decentralized technology to reduce reliance on traditional intermediaries, creating a direct and auditable link between donors and projects. The platform supports recurrent donations, milestone-based funding, and integrates with Web3 wallets – digital wallets that allow users to interact with decentralized applications (dApps) and blockchain networks, especially those built on platforms like Ethereum. Unlike traditional wallets used for storing fiat currency, Web3 wallets manage cryptographic keys – enabling users to store, send and receive cryptocurrencies and digital assets, and to authenticate themselves on decentralized platforms without needing a username or password. Giveth is open source, enabling global participation in supporting charitable causes through cryptocurrency.

- Technological maturity: Proven
- Contracting type: Open source
- Technology level: Medium
- Place of origin: Switzerland
- Availability: Worldwide
- Contact: WIPO Green Database

Cash transfers and financial inclusion platforms: blockchain-based platform for impact projects

Alice SI

Source: Getty Images/CHUYN

Alice SI is a blockchain-based platform designed to bring transparency and accountability to charitable donations. It uses Ethereum smart contracts to ensure that funds are only released when verified outcomes are achieved, helping build trust between donors and organizations. The platform integrates technologies like Etheroscope, which visualizes smart contract data in real time, and Sensor TRX, which uses IoT and APIs to automate impact validation – the platform connects to devices and software systems to automatically track whether specific outcomes have been achieved without requiring manual checking. In areas with limited connectivity, Alice also offers Tappy, a contactless wallet that allows beneficiaries to validate impact and access funds. By combining blockchain with real-time data and verification tools, Alice SI ensures that donations are traceable in order to increase donor confidence and facilitate more effective social impact funding.

- Technological maturity: Proven
- Contracting type: Open source
- Technology level: Medium
- Place of origin: United Kingdom
- Availability: Worldwide
- Contact: WIPO Green Database

Insurance and risk transfer solutions: catastrophe bonds

World Bank

Source: Getty Images/Brina Bunt

The World Bank's Capital at Risk (CAR) Notes program helps transfer disaster-related financial risk from countries to global investors by issuing catastrophe and pandemic bonds. These bonds may risk investors' principal and are issued under the World Bank's Global Debt Issuance Facility, benefiting from tax and securities law exemptions, but often without a credit rating. Unlike traditional catastrophe bonds that use a special purpose vehicle (SPV) to issue bonds and hold collateral, the World Bank issues bonds directly and manages contracts, investments and payments. In this setup, the sponsor (a country or client) enters into an insurance or derivative contract with the World Bank. The bonds pay out when predefined disaster events – for example, when an earthquake or storm meets parametric criteria – occur. For example, in Mexico, payouts triggered by such events are routed through intermediaries like Swiss Re and Agroasemex. If no disaster happens, investors receive their principal back at maturity. This program helps countries manage risks from disasters by tapping global capital markets efficiently.

- Technological maturity: Proven
- Contracting type: Risk transfer agreement/ structured finance product
- Technology level: Medium
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO Green Database

Insurance and risk transfer solutions: climate risk insurance as a part of a comprehensive risk management package

World Food Programme

Source: Getty Images/Tomal Das

Over the past decade, the World Food Programme (WFP) has expanded access to climate risk insurance, reaching over 10.5 million people through a portfolio of products, including weather index, area yield, hybrid index, livestock index and business interruption insurance. These products protect vulnerable groups that include smallholder farmers, pastoralists and micro, small and medium enterprises (MSMEs) from climate-related perils such as drought, excessive rainfall and pests. In 2024 alone, WFP facilitated access to insurance for three million people across 15 countries with over USD 41 million in payouts benefiting more than 1.5 million people. WFP embeds insurance into broader financial services and resilience-building strategies by linking premium subsidies to disaster risk reduction and climate adaptation efforts, integrating insurance with savings, loans and market access, and promoting crop-agnostic coverage to support livelihood diversification. It also develops Forecast Index Insurance to unlock pre-disaster financing for Anticipatory Action. These integrated models enhance risk protection and incentivize adaptive practices and investment.

- Technological maturity: Proven
- Contracting type: For collaboration
- Technology level: Medium
- Place of origin: Ethiopia
- Availability: Bangladesh, Burkina Faso, Côte d'Ivoire, Cuba, Ethiopia, the Gambia, Guatemala, Haiti, Iraq, Kenya, Kyrgyz, Madagascar, Malawi, Mozambique and Senegal
- Contact: WIPO Green Database

Frontier technology solutions

Risk assessment and modeling tools: climate risk models and insurance mapping tool

SkyFi

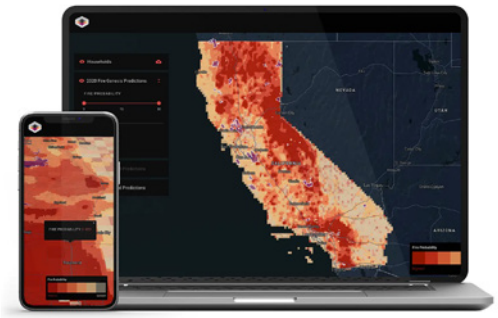
Source: SkyFi

SkyFi delivers advanced geospatial analytics specifically designed for the insurance sector to improve risk assessment, claims management and disaster response. Using high-resolution satellite imagery and remote sensing, SkyFi helps insurers evaluate environmental risks, such as flood likelihood, soil moisture and terrain changes over time, thereby enabling precise underwriting and risk modeling. After disasters, like a flood or fire, insurers can quickly assess structural damage remotely, speeding up claims prioritization and processing. Real-time geospatial data also supports emergency response by mapping impact severity and optimizing service routes. Additionally, SkyFi offers continuous monitoring of insured assets to detect early signs of damage or wear, helping reduce claim frequency by enabling proactive maintenance. This data-driven approach allows insurance companies to improve accuracy, reduce costs and enhance customer service by responding faster and more effectively to risks and claims. Overall, SkyFi empowers insurers with actionable insights through satellite technology to manage risks and optimize operations efficiently.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO Green Database

Risk assessment and modeling tools: parametric wildfire and hurricane insurance

Kettle



Source: Kettle

Kettle uses proprietary machine learning algorithms that analyze billions of data points from sources like NASA, NOAA, and the European Space Agency. This technology processes vast raw data through an ETL (referring to “extract, transform, load,” a data processing method used to collect data from multiple sources (extract), clean and organize it into a usable format (transform), and then load it into a database or system where it can be analyzed or used (load) pipeline to train deep neural networks, generating over two million high-resolution wildfire footprints at 100-meter scale. Kettle’s suite of models – including Ignition, Contagion, Building Vulnerability, Fire Edge Downscaling, and Parcel Risk Assessment – predict wildfire risks by simulating ignition and spread patterns across millions of grid cells. Kettle’s Genesis Model divides areas into micro-grids, analyzing factors driving wildfire ignitions monthly. Using deep long short-term memory convolutional neural networks, Kettle accurately captures the temporal and spatial dynamics of wildfire spread.

- Technological maturity: Frontier
- Contracting type: For partnership and collaboration
- Technology level: Medium
- Place of origin: United States
- Availability: Worldwide
- Contact: WIPO Green Database

Cash transfers and financial inclusion platforms: instant disbursements via digital identity

AID:Tech

Source: Getty Images/Bilanol

AID: Tech's Kare platform is a digital aid distribution system designed to improve disaster relief by using blockchain and digital identity verification. Funds are sent directly to recipients inside digital wallets accessible via mobile apps. Users can spend these funds using virtual Visa debit cards, which work with Apple Pay and Google Pay. The platform allows customizable disbursement controls, such as restricting purchases of alcohol or tobacco. Kare offers real-time tracking of aid distribution and resource usage, ensuring transparency. Additionally, it partners with Amazon to deliver physical goods directly to those in need.

- Technological maturity: Frontier
- Contracting type: For licensing
- Technology level: Medium
- Place of origin: Ireland
- Availability: Worldwide
- Contact: WIPO Green Database

Cash transfers and financial inclusion platforms: blockchain payment solution for digital cash distribution

Stellar

Source: Getty Images/Aleksei Gorovoi

UNHCR, in partnership with the Stellar Development Foundation (SDF), has launched a pioneering blockchain-based payment solution using the Stellar network to deliver cash assistance to internally displaced persons (IDPs) and war-affected people within Ukraine. The pilot distributes funds in USD Coin (USDC), a stablecoin, directly into recipients' digital wallets accessible via smartphones. This allows beneficiaries to use or withdraw money globally at MoneyGram locations. The solution ensures full traceability and accountability. Initially piloted in the cities of Kyiv, Lviv and Vinnytsia, the platform aims to expand globally. This initiative complements UNHCR's long-standing commitment to cash-based interventions, which have delivered nearly USD 5 billion to over 35 million people worldwide.

- Technological maturity: Frontier
- Contracting type: Collaborative humanitarian solution
- Technology level: Medium
- Place of origin: Ukraine
- Availability: Ukraine (with plans to expand)
- Contact: WIPO Green Database

Cash transfers and financial inclusion platforms: rescue card/ Zinli

World Food Programme

Source: WFP/Luc Junior Segur

When emergencies occur, WFP's cash-based assistance can take up to six months to set up without existing payment arrangements. Many unbanked individuals are excluded due to strict Know Your Customer (KYC) requirements (a set of rules financial institutions and organizations follow to verify the identity of their clients. The goal is to prevent fraud, money laundering and terrorist financing). The Rescue Card, a prepaid, reloadable card linked to WFP's digital wallet, offers immediate aid within 72 hours, with flexible KYC to include marginalized groups. As of 2025, it has helped over 88,000 people across eight countries. Rescue Card has cut costs by 70–85 percent and reduced delivery times by up to two years. In 2024, most assistance—56 percent to 68 percent—went directly to women, with 80 percent spent on food. To boost preparedness, 5,000 cards were prepositioned in Barbados ahead of Hurricane Beryl. Nowadays, Rescue Card is prepositioned in eight countries to support emergency operations and anticipatory action.

- Technological maturity: Frontier
- Contracting type: For collaboration
- Technology level: Medium
- Place of origin: Panama
- Availability: Barbados, Bolivia (Plurinational State of), Cuba, Dominican Republic, Guatemala, Haiti , Honduras, Peru
- Contact: WIPO Green Database

Risk assessment and modeling tools: AI solution for assessing damage caused by disasters

Tractable

Source: Getty Images/Sladic

Tractable's AI Property solution uses AI to rapidly assess external building damage due to wind, hail and hurricanes, cutting damage evaluation time from months to a single day. Homeowners simply upload photos via a mobile web app, and AI processes them in order to estimate damage and submit a report to insurers. This technology is currently being used by Japan's MS&AD Insurance Group, as it was during Typhoon Mindulle in 2021, helping expedite claims and recovery. The AI focuses on external damage, such as to fences and walls, and there are plans to include indoor damage such as from water leaks and smoke. Initially, human experts verify AI assessments, but the system is designed to learn and move toward full automation. AI Property is also available in North America, aiming to help insurers respond faster to disasters and improve customer support during crises.

- Technological maturity: Frontier
- Contracting type: For licensing
- Technology level: Medium
- Place of origin: United Kingdom
- Availability: Japan, North America
- Contact: WIPO Green Database

Insurance and risk transfer solutions: bespoke index-based insurance

IBISA

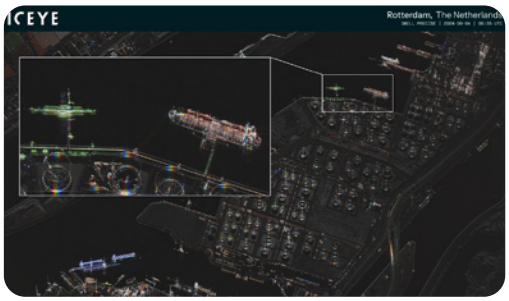
Source: Getty Images/baranozdemir

IBISA is a climate InsurTech specializing in parametric insurance solutions that protect against weather-related risks, mainly within agriculture. Its index-based policies trigger automatic payouts when predefined weather conditions – such as extreme rainfall, cyclones or temperature anomalies – are met, thereby eliminating lengthy claims processes and providing fast financial aid. Recently, IBISA raised EUR 2.8 million from investors, including The Acumen Resilient Agriculture Fund, Equator, and the Asian Development Bank Ventures, to expand into emerging markets in Asia and Africa. IBISA's approach involves analyzing local weather data to define tailored triggers relevant to each region. Once a weather event exceeds these thresholds, satellite data is reviewed and claims processed within 10 days.

- Technological maturity: Frontier
- Contracting type: For sale
- Technology level: Medium
- Place of origin: Luxembourg
- Availability: Africa, Asia
- Contact: WIPO Green Database

Risk assessment and modeling tools: multi-peril data solution for catastrophes related to natural hazards

ICEYE



Source: ICEYE

ICEYE operates the world's largest synthetic aperture radar (SAR) satellite constellation, with 50+ satellites launched to date, to deliver near real-time observation data on natural catastrophes such as floods, hurricanes, earthquakes, and wildfires. Unlike optical sensors, SAR technology functions continuously—day or night, through cloud, smoke, and ash—ensuring reliable information in all conditions. ICEYE's Multi-Peril Data Solution integrates these observations into GIS-ready hazard and damage layers, enabling insurers to obtain comprehensive situational awareness within hours of an event. By replacing model-based projections with observed evidence, the technology accelerates loss assessment, improves claims prioritization, and enhances the precision of underwriting and pricing. Through timely, observation-based catastrophe intelligence, ICEYE strengthens financial resilience and supports climate adaptation within the insurance sector.

- Technological maturity: Frontier
- Contracting type: For licensing
- Technology level: Medium
- Place of origin: Finland
- Availability: Worldwide
- Contact: WIPO Green Database

Horizon technology solutions

Insurance and risk transfer solutions: enhanced parametric insurance pilot

Mercy Corps Ventures and MiCRO

Source: Jorge Barrientos/MiCRO

Mercy Corps Ventures and MiCRO have launched a pilot in Guatemala to reduce basis risk in parametric insurance for smallholder farmers. The initiative establishes a Basis Risk Fund that compensates farmers when qualifying climate-related losses occur but do not trigger payouts under existing parametric policies. To improve accuracy and affordability, the project will test technology-led methods to verify field losses, including the use of drones to assess crop damage, and compare their cost-effectiveness against traditional, in-person verification. Data and insights from the pilot will be used to refine the parametric insurance model, improve event identification and evaluate the long-term sustainability of the fund. Developed in partnership with Guatemala's Ministry of Agriculture, the pilot aims to strengthen farmers' trust in insurance products, enhance climate resilience and identify scalable ways to deliver faster, fairer compensation for farmers affected by extreme weather.

- Technological maturity: Horizon
- Contracting type: N/A
- Technology level: Medium
- Place of origin: Guatemala
- Availability: Guatemala
- Contact: WIPO Green Database

Insurance and risk transfer solutions: blockchain-integrated carbon credit-backed insurance

Ryskex/Arx Veritas

Source: Getty Images/Bilanol

The Arx Veritas Parametrics Cell, developed by Ryskex and Arx Veritas, uses blockchain and AI to transform climate risk into investable assets using 10 million emission reduction units (ERUs). The cell, within the Veritas Ex Machina platform, turns carbon credits (10 million emission reduction units valued at $73 each) into investable, auditable assets. The initiative integrates blockchain (via Redbelly Network) and AI-driven underwriting to create a fraud-proof framework for climate-related risk transfer. Launched in April 2025, it uses Token "X" (a blockchain-based token or digital asset that represents a stakeholder's ownership or investment – letting investors share in financial outcomes linked to carbon credit-backed insurance) to enable secure participation by institutional investors. The cell applies parametric principles relying on data-driven triggers similar to disaster risk models to facilitate payouts.

- Technological maturity: Horizon
- Contracting type: Under development
- Technology level: Medium
- Place of origin: United Kingdom
- Availability: N/A
- Contact: WIPO Green Database

Insurance and risk transfer solutions: parametric heat insurance for women workers

Climate Resilience for All

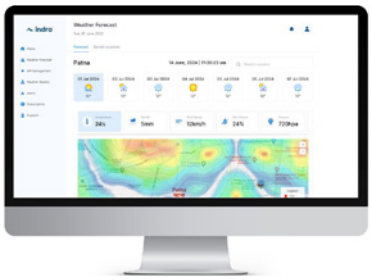
Source: CRA/Rameshwar Bhatt

Starting in April 2024, Climate Resilience for All launched the one year-long Women's Climate Shock Insurance and Livelihood Initiative (WCSI). The program combined parametric microinsurance, direct cash assistance, and early warning systems to support women facing income and health risks from extreme heat while working in the informal sector. Implemented with the Self-Employed Women's Association in India and underwritten by Swiss Re Public Sector Solutions, the pilot covered 50,000 women across 23 districts in Gujarat, Maharashtra, and Rajasthan. Direct cash assistance equivalent to about two day's wages was provided when temperatures reached 40°C for two consecutive days, while the insurance issued larger one-time payouts at higher thresholds between 42–43.5°C. Premiums averaged six dollars annually, shared between participants and philanthropic contributions. The model integrates historical climate data for threshold design and aims to advance toward forecast-based financing. WCSI is planned for expansion to Thailand, Pakistan, and Sierra Leone, and coverage for floods and cyclones is being examined.

- Technological maturity: Horizon
- Contracting type: For collaboration
- Technology level: Medium
- Place of origin: South Africa
- Availability: India
- Contact: WIPO GREEN Database

Insurance and risk transfer solutions: parametric climate derivatives platform

mistEO



Source: mistEO

In 2024, mistEO launched IndraWeather, a weather intelligence platform delivering hyper-local, real-time weather data and forecasting. It utilizes sources including the proprietary "Indra Numerical Weather Prediction Model", satellite imagery, radar systems, and in situ automated weather stations. The processed data feeds into mistEO's suite of Climate Decision Intelligence platforms, providing, for instance, livestock farmers with tools for informed decision-making, including weather-related alerts and actionable insights on topics ranging from heat stress in cattle to preparing farms for inclement weather. IndraWeather data also supports parametric insurance solutions across agriculture, renewable energy, mobility, and marine industries, and mistEO is now developing a weather parametric derivatives platform for broader applications across these verticals. This platform will consist of financial tools enabling businesses to hedge against weather-related risks, such as logistics disruptions from the sudden onset of heavy snow, and will be offered to banking and insurance companies designing bespoke financial products.

- Technological maturity: Horizon
- Contracting type: For collaboration
- Technology level: High
- Place of origin: India
- Availability: N/A
- Contact: WIPO GREEN Database

Bibliography

Aalto University (2022). New AI system predicts how to prevent wildfires. *A! Signs of Change*, Available at: https://www.aalto.fi/en/news/new-ai-system-predicts-how-to-prevent-wildfires [accessed April 24 2025].

ABC News Australia (2024). Sustainable cardboard homes may provide emergency shelter after flood, bushfire disasters. Available at: https://www.abc.net.au/news/2024-12-08/cardboard-homes-provide-emergency-shelter-after-disasters/104692704 [accessed June 13 2025].

Access Now (2024). *Mapping humanitarian tech: exposing protection gaps in digital transformation programmes.* Access Now. Available at: https://www.accessnow.org/wp-content/uploads/2024/02/Mapping-humanitarian-tech-February-2024.pdf.

Adu-Poku, Akwasi, Ebenezer K. Siabi, Nathaniel Oppong Otchere, Francis B. Effah, Edward A. Awafo, Francis Kemausuor and Mashael Yazdanie (2024). Impact of drought on hydropower generation in the Volta River basin and future projections under different climate and development pathways. *Energy and Climate Change,* 5, 100169.

AgEagle (2021). Landslide mapping: assessing geological hazards using drones. Available at: https://ageagle.com/use-cases/landslide-mapping-assessing-geological-hazards-using-drones/ [accessed March 17 2025].

AgriTech Insights (2024). Larger U.S. farms lead precision agriculture adoption, small farms lag behind. Available at: https://agritechinsights.com/index.php/2024/12/13/larger-u-s-farms-lead-precision-agriculture-adoption-small-farms-lag-behind/ [accessed May 2 2025].

Alam, Mohammad Shah, Jiarui Kong, Ruofu Tao, Temoor Ahmed, Md Alamin, Saqer S Alotaibi, Nader R Abdelsalam and Jian-Hong Xu (2022). CRISPR/Cas9 mediated knockout of the OsbHLH024 transcription factor improves salt stress resistance in rice (Oryza sativa L.). *Plants,* 11(9), 1184.

Aleem, Muqadas, Muhammad Khuram Razzaq, Maida Aleem, Wenliang Yan, Iram Sharif, Manzer H. Siddiqui, Saba Aleem, Muhammad Sarmad Iftikhar, Benjamin Karikari, Zulfiqar Ali, Naheeda Begum and Tuanjie Zhao (2024). Genome-wide association study provides new insight into the underlying mechanism of drought tolerance during seed germination stage in soybean. *Scientific Reports,* 14(1), 20765.

Alexeeff, Stacey E, Noelle S Liao, Xi Liu, Stephen K Van Den Eeden and Stephen Sidney (2021). Long-term PM2. 5 exposure and risks of ischemic heart disease and stroke events: review and meta-analysis. *Journal of the American Heart Association,* 10(1), e016890.

Alfieri, Lorenzo, Berny Bisselink, Francesco Dottori, Gustavo Naumann, Ad de Roo, Peter Salamon, Klaus Wyser and Luc Feyen (2017). Global projections of river flood risk in a warmer world. *Earth's Future,* 5(2), 171–82.

Alsop, Neil and Tom Palastanga (2023). The invaluable use of drone imagery as a tool in landslide assessments. *New Zealand Geomechanics News,* (105).

AMC (2019). *Ahmedabad heat action plan: guide to extreme heat planning in Ahmedabad, India.* Amdavad Municipal Corporation (AMC). Available at: https://www.nrdc.org/sites/default/files/ahmedabad-heat-action-plan-2019-update.pdf.

Andela, Niels, Douglas C Morton, Louis Giglio, Yang Chen, Guido R van der Werf, Prasad S Kasibhatla, Rurth S DeFries, GJ Collatz, S Hantson and Silvia Kloster (2017). A human-driven decline in global burned area. *Science,* 356(6345), 1356–62.

Arachchige, Sameera Maha and Biswajeet Pradhan (2025a). AI meets the eye of the storm: machine learning-driven insights for hurricane damage risk assessment in Florida. *Earth Systems and Environment*, 1–21.

Arachchige, Sameera Maha and Biswajeet Pradhan (2025b). AI Meets the Eye of the Storm: Machine Learning-Driven Insights for Hurricane Damage Risk Assessment in Florida. *Earth Systems and Environment*.

Arbaje, Paul (2024). Wildfires and power grid failures continue to fuel each other. *The Equation*, Union of Concerned Scientists. Available at: https://blog.ucs.org/paul-arbaje/wildfires-and-power-grid-failures-continue-to-fuel-each-other/ [accessed April 8 2025].

ARC (2024). *The ARC Group makes a total of US$32 million climate insurance payouts to assist people affected by drought in Zimbabwe.* Harare: African Risk Capacity (ARC) Group. 4 July 2024. Available at: https://www.arc.int/news/arc-group-makes-total-us32-million-climate-insurance-payouts-assist-people-affected-drought.

ARC (2025). *The ARC Group makes climate insurance payouts to the Federal Republic of Somalia and the Start Network to assist people affected by drought.* Nairobi: African Risk Capacity (ARC) Group. 21 March 2025. Available at: https://www.arc.int/news/official-press-release-arc-group-makes-climate-insurance-payouts-federal-republic-somalia-and.

Arnell, Nigel W. and Simon N. Gosling (2016). The impacts of climate change on river flood risk at the global scale. *Climatic Change,* 134(3), 387–401.

ARSET (2025a). *ARSET – Fundamentals of Remote Sensing. NASA Applied Remote Sensing Training Program.* NASA Applied Remote Sensing Training Program (ARSET). Available at: https://appliedsciences.nasa.gov/get-involved/training/english/arset-fundamentals-remote-sensing.

ARSET (2025b). *ARSET – Introduction to NASA Earth Observations and Tools for Wildfire Monitoring and Management.*, NASA Applied Remote Sensing Training Program (ARSET). Available at: https://appliedsciences.nasa.gov/get-involved/training/english/arset-introduction-nasa-earth-observations-and-tools-wildfire.

Artemis (2024). World Bank has now facilitated over US $4.8bn in catastrophe bonds. Artemis. Available at: https://www.artemis.bm/news/world-bank-has-now-facilitated-over-us-4-8bn-in-catastrophe-bonds/

Arva (2025). Rescues: equipment and training. Arva. Available at: https://www.arva-equipment.com/en/content/775-snow-safety-program-rescues-14 [accessed July 23 2025].

Axios Tampa Bay (2025). How recycled oyster shells help filter Tampa Bay's water, combat erosion. Available at: https://www.axios.com/local/tampa-bay/2025/01/07/recycled-oysters-living-shorelines-erosion-water-quality? [accessed March 25 2025].

Ayyad, Mahmoud, Muhammad R Hajj and Reza Marsooli (2022). Artificial intelligence for hurricane storm surge hazard assessment. *Ocean Engineering,* 245, 110435.

AZoCleanTech (2024). How does fog harvesting provide sustainable water solutions? Available at: https://www.azocleantech.com/article.aspx?ArticleID=1782 [accessed May 4 2025].

Bekele, Shambel (2017). Impacts of climate change on livestock production: A review. *Journal of Natural Sciences Research,* 7(8), 53–59.

Bharadwaj, R, T Mitchell, N Karthikeyan, N Raj, S Chaliha, R Abhilashi, K Chinnaswamy, B Raghini, I Deulgaonkar, D and Chakravarti and T McCabe (2023). *Delivering anticipatory social protection: Country readiness assessment.* London: International Institute for Environment and Development (IIED). Available at: https://www.preventionweb.net/media/91089/download?startDownload=20250623.

Byers, Edward A., Gemma Coxon, Jim Freer and Jim W. Hall (2020). Drought and climate change impacts on cooling water shortages and electricity prices in Great Britain. *Nature Communications,* 11(1), 2239.

C2ES (2020). Hurricanes and climate change. Available at: https://www.c2es.org/content/hurricanes-and-climate-change/ [accessed 2025 March 4].

California Public Utilities Commission (2025). Public Safety Power Shutoffs (PSPS). Available at: https://www.cpuc.ca.gov/psps/ [accessed April 8 2025].

Caltech (2024). AI improves monsoon rainfall predictions. Available at: https://www.caltech.edu/about/news/ai-improves-monsoon-rainfall-predictions [accessed March 17 2025].

Camps-Valls, Gustau, Miguel-Ángel Fernández-Torres, Kai-Hendrik Cohrs, Adrian Höhl, Andrea Castelletti, Aytac Pacal, Claire Robin, Francesco Martinuzzi, Ioannis Papoutsis, Ioannis Prapas, Jorge Pérez-Aracil, Katja Weigel, Maria Gonzalez-Calabuig, Markus Reichstein, Martin Rabel, Matteo Giuliani, Miguel D. Mahecha, Oana-Iuliana Popescu, Oscar J. Pellicer-Valero, Said Ouala, Sancho Salcedo-Sanz, Sebastian Sippel, Spyros Kondylatos, Tamara Happé and Tristan Williams (2025). Artificial intelligence for modeling and understanding extreme weather and climate events. *Nature Communications,* 16(1), 1919.

Cardi, Teodoro, Jana Murovec, Allah Bakhsh, Justyna Boniecka, Tobias Bruegmann, Simon E Bull, Tom Eeckhaut, Matthias Fladung, Vladislava Galovic and Anna Linkiewicz (2023). CRISPR/Cas-mediated plant genome editing: outstanding challenges a decade after implementation. *Trends in plant science,* 28(10), 1144–65.

Cardil, Adrián, Santiago Monedero, Gavin Schag, Sergio de-Miguel, Mario Tapia, Cathelijne R. Stoof, Carlos A. Silva, Midhun Mohan, Alba Cardil and Joaquin Ramirez (2021). Fire behavior modeling for operational decision-making. *Current Opinion in Environmental Science & Health,* 23, 100291.

Castellanos, Sergio, Jerry Potts, Helena Tiedmann, Sarah Alverson, Yael R. Glazer, Andrew Robison, Suzanne Russo, Dana Harmon, Bobuchi Ken-Opurum, Margo Weisz, Frances Acuna, Keri K. Stephens, Kasey Faust and Michael E. Webber (2023). A synthesis and review of exacerbated inequities from the February 2021 winter storm (Uri) in Texas and the risks moving forward. *Progress in Energy,* 5(1), 012003.

CBSA (2024). Explore container-based sanitation. Container-based Sanitation Alliance (CBSA). Available at: https://cbsa.global/about-cbs [accessed July 29 2025].

CDP (2025). Ice, Snow and Extreme Cold. Center for Disaster Philanthropy (CDP). Available at: https://disasterphilanthropy.org/resources/extreme-cold/ [accessed July 10 2025].

Center for Disaster Philanthropy (2025). 2024 State of disaster philanthropy. Available at: https://disasterphilanthropy.org/cdp-resource/measuring-the-state-of-disaster-philanthropy-2024/ [accessed September 10 2025].

Chaudhary, Nischay and Rubby Sandhu (2024). A comprehensive review on speed breeding methods and applications. *Euphytica,* 220(3), 42.

Choularton, R and E Montier (2023). *Global mapping of humanitarian disaster risk finance. Report of the USAID Climate Adaptation Support Activity implemented by Tetra Tech and funded by the U.S. Agency for International Development.* Tetra Tech. Available at: https://www.preventionweb.net/media/90385/download?startDownload=20250912.

Clean Technica (2025). Third of China's farms sprayed by drones, marking agricultural revolution. Available at: https://cleantechnica.com/2025/04/25/third-of-chinas-farms-sprayed-by-drones-marking-agricultural-revolution/ [accessed May 1 2025].

Climate Tech Wiki (2024). Flood hazard mapping: why do we need it? Available at: https://climatetechwiki.org/flood-hazard-mapping/ [accessed March 10 2025].

Columbia Southern University (2025). 5 wildfire trends in 2025 and beyond. Available at: https://www.columbiasouthern.edu/blog/blog-articles/2025/april/wildfire-trends/ [accessed April 4 2025].

Cordella, Tito and Eduardo Levy Yeyati (2015). CATalytic insurance: the case of natural disasters. *Oxford Review of Economic Policy,* 31(3/4), 330–49.

CPI (2024). *Global landscape of climate finance 2024: insights for COP29.* Climate Policy Initiative (CPI). Available at: https://www.climatepolicyinitiative.org/wp-content/uploads/2024/10/Global-Landscape-of-Climate-Finance-2024.pdf.

Croitoru, Lelia, Juan José Miranda, Abdellatif Khattabi and Jia Jun Lee (2020). *The cost of coastal zone degradation in Nigeria: cross river, delta and Lagos states,* World Bank Group Washington, DC. Available at: https://openknowledge.worldbank.org/entities/publication/81e75dc2-20a8-5487-9349-7cf9063586ee

CSIRO (2023). *GRDC announces $12.7 M project for long coleoptile wheat.* Commonwealth Scientific and Industrial Research Organisation (CSIRO). February 27, 2023. Available at: https://www.csiro.au/en/news/all/news/2023/february/grdc-announces-project-for-long-coleoptile-wheat.

Curwen, Thomas (2025). Inconvenient truths about the fires burning in Los Angeles from two fire experts. *Los Angeles Times,* January 11, 2025, Available at: https://www.latimes.com/california/story/2025-01-11/fire-experts-asses-los-angeles-blazes-amid-changing-times.

Dance, Scott (2025). Warmth is weakening the polar vortex. Here's what it means for extreme cold. The Washington Post. Available at: https://www.washingtonpost.com/weather/2025/01/30/polar-vortex-disruptions-warming-extreme-cold/ [accessed July 11 2025].

Das Adhikari, Manik, Seunghee Park and Sang-Guk Yum (2025). Coastal vulnerability to extreme weather events: An integrated analysis of erosion, sediment movement, and land subsidence based on multi-temporal optical and SAR satellite data. *Journal of Environmental Management,* 374, 124025.

DOE (2022). Design for extreme heat. U.S. Department of Energy (DOE). [accessed July 10 2025]. Available at: https://basc.pnnl.gov/information/design-extreme-heat#:~:text=Provide%20windows%20and%20glass%20doors,Solar%20Control%20and%20Energy%20Efficiency

Douglas, Erin (2021). Texas largely relies on natural gas for power. It wasn't ready for the extreme cold. The Texas Tribune. Available at: https://www.texastribune.org/2021/02/16/natural-gas-power-storm/ [accessed July 11 2025].

Ebeco (2025). Smarta Tak at Kronaskolan. Ebeco. Available at: https://www.ebeco.com/solutions/snow-melting-roof/smarta-tak-kronaskolan [accessed July 8 2025].

Ebrahim, Kyrillos M. P., Sherif M. M. H. Gomaa, Tarek Zayed and Ghasan Alfalah (2024). Recent phenomenal and investigational subsurface landslide monitoring techniques: a mixed review. *Remote Sensing,* 16(2), 385.

EC-JRC and UNCCD (2024). *World Drought Atlas.* Luxembourg: Publications Office of the European Union. Available at: doi:10.2760/3842670, JRC 139691. Available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC139691

EDO & GDO (2025). *Standardized Precipitation Index (SPI).* EDO and GDO indicator factsheet, Copernicus European Drought Observatory (EDO), Global Drought Observatory (GDO). Available at: https://drought.emergency.copernicus.eu/data/factsheets/factsheet_spi.pdf.

EEA (2024). The impacts of heat on health: surveillance and preparedness in Europe. European Environment Agency (EEA). Available at: https://www.eea.europa.eu/en/analysis/publications/the-impacts-of-heat-on-health?activeTab=babece34-c8a2-478e-b947-4eaedc9fb9e3 [accessed July 14 2025].

Engel, Ruth, Mackres, Eric:, Madeline Palmier and Eillie Anzilotti (2025). Beyond the thermometer: 5 heat metrics that drive better decision-making. World Resources Institute (WRI). Available at: https://www.wri.org/insights/beyond-thermometer-measuring-heat?utm_campaign=wridigest&utm_medium=email&utm_source=wridigest-2025-03-26 [accessed June 30 2025].

European Climate and Health Observatory and Climate ADAPT (2025). Landslides. [accessed March 20 2025]. Available at: https://climate-adapt.eea.europa.eu/en/observatory/evidence/health effects/landslides#:~:text=Projected%20effects,et%20al.%2C%202023

European Commission (2024). Global drought threatens food supplies and energy production. *The Joint Research Centre: EU Science Hub*, Available at: https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/global-drought-threatens-food-supplies-and-energy-production-2024-10-02_en

European Union (2022). EpiSeed Link. Available at: https://episeedlink.eu/ [accessed May 1 2025].

FAO (2002). *Guidelines on fire management in temperate and boreal forests. Forest protection working papers – FPF/1.* Rome: Food and Agriculture Organization of the United Nations (FAO). Available at: https://www.fao.org/4/ag041e/AG041E13.htm.

FAO (2025). Water and One Health. Food and Agriculture Organization of the United Nations (UN). Available at: https://www.fao.org/one-health/areas-of-work/water/en [accessed August 14 2025].

Farmonaut (2025). Climate-smart agriculture in Zimbabwe: how farmers are adapting to drought with innovative crops and techniques. Available at: https://farmonaut.com/africa/climate-smart-agriculture-5-ways-zimbabwe-farmers-beat-drought [accessed April 29 2025].

Fast Company (2024). Google is using AI to predict floods—and sending cash to people before disaster hits. Available at: https://www.fastcompany.com/91144047/google-using-ai-to-predict-floods-and-send-families-cash-before-disaster-hits [accessed June 5 2025].

FasterCapital (2025). Innovations in microfinance. FasterCapital. Available at: https://fastercapital.com/topics/innovations-in-microfinance.html/1 [accessed June 16 2025].

FedScoop (2024). Behind the technologies at the forefront of improving NOAA hurricane data. Available at: https://fedscoop.com/behind-technologies-improving-noaa-hurricane-data/

Ferrario, Filippo, Michael W. Beck, Curt D. Storlazzi, Fiorenza Micheli, Christine C. Shepard and Laura Airoldi (2014). The effectiveness of coral reefs for coastal hazard risk reduction and adaptation. *Nature Communications,* 5(1), 3794.

Field Ready (2023). How a Mobile Makerspace can reach more Pacific Islands. Available at: https://www.fieldready.org/post/how-a-mobile-makerspace-can-reach-more-pacific-islands [accessed June 13 2025].

Fire & Safety Journal Americas (2024). Advancements in fire resistant materials. Available at: https://fireandsafetyjournalamericas.com/advancements-in-fire-resistant-materials/ [accessed April 11 2025].

Fleet Forum (2019). 2019 Best Transport Achievement Award. Available at: https://www.fleetforum.org/post/2019-best-transport-achievement-award [accessed June 6 2025].

Flouris, A., M. Azzi, H. Graczyk, B. Nafradi and N. Scott (2024). *Heat at work: Implications for safety and health – a global review of the science, policy and practice.* International Labour Organization (ILO). Available at: https://www.ilo.org/sites/default/files/2024-07/ILO_OSH_Heatstress-R16.pdf.

Flouris, A., M. Azzi, H. Graczyk, B. Nafradi and N. Scott (2024). *Heat at work: Implications for safety and health – a global review of the science, policy and practice.* International Labour Organization (ILO). Available at: https://www.ilo.org/sites/default/files/2024-07/ILO_OSH_Heatstress-R16.pdf.

Flyability (2024). Investigating a collapsed tunnel after a landslide in the Swiss Alps. Available at: https://www.flyability.com/casestudies/collapsed-tunnel-landslide [accessed March 24 2025].

Forced Migration Review (2024). Challenges and risks associated with biometric-enabled cash assistance. Available at: https://www.fmreview.org/digital-disruption/siad/ [accessed June 6 2025].

Frontier Tech Hub (2019). Blockchain technology for the humanitarian supply chain. Available at: https://www.frontiertechhub.org/pilot-portfolio/blockchain-humanitarian-supplychain [accessed May 28 2025].

Frontier Tech Hub (2024). How three frontier technologies are transforming humanitarian aid supply chains. Available at: https://www.frontiertechhub.org/insights/three-frontier-technologies-transforming-humanitarian-supply-chains [accessed June 11 2025].

G20 DRR Working Group (2025). Addressing the multidimensional risk posed by extreme heat' in *G20 DRR Working Group Side Event*, Cape Town, United Nations Office for Disaster Risk Reduction (UNDRR). Available at: https://g20drrwg.preventionweb.net/media/105940

Garland, Sarah and Helen Anne Curry (2022). Turning promise into practice: Crop biotechnology for increasing genetic diversity and climate resilience. *PLoS Biology,* 20(7), e3001716.

Gasparrini et al. (2015). Mortality risk attributable to high and low ambient temperature: a multicountry observational study. – processed by Our World in Data. Our World in Data. Available at: https://archive.ourworldindata.org/20250903-083611/grapher/deaths-temperature-gasparrini.html [accessed July 14 2025].

genpact (2023). The AI insurance revolution in the era of climate change. Available at: https://www.genpact.com/insight/the-ai-insurance-revolution-in-the-era-of-climate-change [accessed June 16 2025].

Geostock (2022). Interferometric Synthetic Aperture Radar (InSAR) technology. Available at: https://www.geostockgroup.com/en/interferometric-synthetic-aperture-radar-insar-technology/ [accessed March 19 2025].

GFZ Helmholtz Centre for Geosciences (2025). Hyperspectral remote sensing applications. Available at: https://www.gfz.de/en/section/remote-sensing-and-geoinformatics/topics/hyperspectral-remote-sensing-applications [accessed March 21 2025].

GHHIN (2023). Heat Early Warning Systems Roundtable. Global Heat Health Information Network (GHHIN). Available at: https://ghhin.org/wp-content/uploads/Heat-Early-Warning-Systems-Roundtable-4-1.pdf [accessed July 3 2025].

Global Center on Adaptation (2022). 5 reasons why floating development is set to take the world by storm. Available at: https://gca.org/5-reasons-why-floating-development-is-set-to-take-the-world-by-storm/ [accessed February 25 2025].

Global Forest Watch (2025). Fires. Available at: https://www.globalforestwatch.org/dashboards/global/?category=fires&location=WyJnbG9iYWwiXQ%3D%3D [accessed April 7 2025].

Global Market Insights (2024). Drought resistant crops market – by crop type (cereals & grains, oilseeds & pulses, fruits & vegetables), by trait (herbicide tolerance, insect resistance, disease resistance, abiotic stress tolerance), by technology & forecast, 2024-2032. Available at: https://www.gminsights.com/industry-analysis/drought-resistant-crops-market [accessed May 5 2025].

Globe Newswire Research and Markets (2025). Precision Agriculture Market Report 2025: Global precision agriculture market to surge to $22.49 billion by 2034, driven by technological advancements and sustainable farming practices. Available at: https://www.globenewswire.com/news-release/2025/03/03/3035739/0/en/Precision-Agriculture-Market-Report-2025-Global-Precision-Agriculture-Market-to-Surge-to-22-49-Billion-by-2034-Driven-by-Technological-Advancements-and-Sustainable-Farming-Practice.html?

Google (2025). Google Patents. Google. Available at: https://patents.google.com/ [accessed September 14 2025].

GSMA (2023). *Cell broadcast for early warning systems: a review of the technology and how to implement it.* Global System for Mobile Communications Association (GSMA). Available at: https://www.gsma.com/solutions-and-impact/connectivity-for-good/mobile-for-development/wp-content/uploads/2023/11/Cell-Broadcast_R.pdf.

Guha-Sapir, D., R. Below and P. H. Hoyois (2018). *EM-DAT: International Disaster Database.* Brussels. Available at: http://www.emdat.be/.

Hammer, Roger B, Volker C Radeloff, Jeremy S Fried and Susan I Stewart (2007). Wildland–urban interface housing growth during the 1990s in California, Oregon, and Washington. *International Journal of Wildland Fire,* 16(3), 255–65.

Harin Song (2024). HB4 wheat: a new frontier in climate-resilient crops. New Crop Breed and Varieties. Available at: https://mynewbreed.com/2024/10/05/hb4-wheat-a-new-frontier-in-climate-resilient-crops/ [accessed May 2 2025].

Hernández-Delgado, Edwin A. (2024). Coastal restoration challenges and strategies for Small Island Developing States in the face of sea level rise and climate change. *Coasts,* 4(2), 235–86.

Hintz, Marie Josefine, Christopher Luederitz, Daniel J. Lang and Henrik von Wehrden (2018). Facing the heat: A systematic literature review exploring the transferability of solutions to cope with urban heat waves. *Urban Climate,* 24, 714–27.

Hou, Hui, Hao Geng, Yong Huang, Hao Wu, Xixiu Wu and Shiwen Yu (2019). Damage probability assessment of transmission line-tower system under typhoon disaster, based on model-driven and data-driven views. *Energies,* 12(8), 1447.

howstuffworks (n.d.). Top 6 fire-resistant building materials. Available at: https://home.howstuffworks.com/home-improvement/construction/materials/5-fire-resistant-building-materials.htm [accessed April 10 2025].

Hülsen, Sarah, Robert I. McDonald, Rebecca Chaplin-Kramer, David N. Bresch, Richard Sharp, Thomas Worthington and Chahan M. Kropf (2023). Global protection from tropical cyclones by coastal ecosystems—past, present, and under climate change. *Environmental Research Letters,* 18(12), 124023.

ICARDA (2023). *New drought-tolerant crops for resilient dryland livelihoods.* 2025, International Center for Agricultural Research in the Dry Areas (ICARDA). Available at: https://icarda.org/media/blog/new-drought-tolerant-crops-resilient-dryland-livelihoods.

IDMC (2025). Internal displacements (disasters). Internal Displacement Monitoring Centre (IDMC). Available at: https://www.internal-displacement.org/database/displacement-data/

IEA (2018). *The future of cooling: opportunities for energy-efficient air conditioning.* Paris: International Energy Agency (IEA). Available at: https://iea.blob.core.windows.net/assets/0bb45525-277f-4c9c-8d0c-9c0cb5e7d525/The_Future_of_Cooling.pdf.

IFRC (2024). Kazakhstan: 'Early action' helps people stay warm through deadly cold snaps. International Federation of Red Cross and Red Crescent Societies (IFRC). Available at: https://www.ifrc.org/article/kazakhstan-early-action-helps-people-stay-warm-through-deadly-cold-snaps? [accessed July 15 2025].

IFRC Climate Centre (2022). *Anticipatory action in refugee and IDP camps: challenges, opportunities, and considerations.* International Federation of Red Cross and Red Crescent Societies (IFRC). Available at: https://www.climatecentre.org/wp-content/uploads/Anticipatory_Action_in_Refugee_and_IDP_Camps.pdf.

IFRC Climate Centre (2025a). Europe gripped by dangerous heatwave. International Federation of Red Cross and Red Crescent Societies (IFRC). Available at: https://www.climatecentre.org/15660/europe-gripped-by-dangerous-heatwave/ [accessed 2025 July 2].

IFRC Climate Centre (2025b). Heat Action Day 2025: As heatwaves intensify, knowledge saves lives. International Federation of Red Cross and Red Crescent Societies (IFRC). Available at: https://www.climatecentre.org/15443/heat-action-day-2025-as-heatwaves-become-more-extreme-knowledge-can-save-lives/ [accessed July 2 2025].

Igloo (2023). Igloo seeks to protect Southeast Asia's multi-billion dollar coffee industry as it extends weather index insurance to coffee farmers in Vietnam. Igloo. Available at: https://iglooinsure.com/press/igloo-seeks-to-protect-southeast-asias-multi-billion-dollar-coffee-industry-as-it-extends-weather-index-insurance-to-coffee-farmers-in-vietnam/ [accessed May 21 2025].

IGRAC (n.d.). Managed Aquifer Recharge (MAR): How groundwater and managed aquifer recharge are connected. International Groundwater Resource Assessment Centre. Available at: https://un-igrac.org/why-groundwater/topics/managed-aquifer-recharge-mar/#:~:text=About%20Managed%20Aquifer%20Recharge%20(MAR)&text=It%20relies%20on%20both%20built,to%20seep%20into%20the%20aquifer [accessed May 4 2025].

Impetus (2024). Catalonia's innovative approach to combatting coastal erosion: a success story in dune restoration. Available at: https://climate-impetus.eu/catalonias-innovative-approach-to-combatting-coastal-erosion-a-success-story-in-dune-restoration/ [accessed March 20 2025].

Impetus (2025). Understanding slush flows: the arctic hazard threatening lives and infrastructure. Impetus. Available at: https://climate-impetus.eu/slush-flow-forecasting/ [accessed May 9 2025].

IPCC (2019). *IPCC special report on the ocean and cryosphere in a changing climate. Summary for policymakers.* Geneva: Intergovernmental Panel on Climate Change (IPCC). Available at: https://www.ipcc.ch/srocc/download-report/.

IPCC (2021). *FAQ 10.3: Do urban areas warm differently than rural areas? In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.*, Intergovernmental Panel on Climate Change (IPCC). Available at: https://www.ipcc.ch/report/ar6/wg1/downloads/faqs/IPCC_AR6_WGI_FAQ_Chapter_10.pdf.

IPCC (2022). *Working group II sixth assessment report. Impacts, adaptation and vulnerability. Summary for policymakers.* Geneva: Intergovernmental Panel on Climate Change (IPCC). Available at: https://www.ipcc.ch/working-group/wg2/.

ISAAA (2020). Biotech crops drive socio-economic development and sustainable environment in the new frontier. *International Service for the Acquisition of Agri-biotech Applications (ISAAA) Brief,* (55).

ITU (2023a). *Digital transformation and early warning systems for saving lives.* International Telecommunication Union (ITU). Available at: https://www.itu.int/hub/publication/d-gen-digital-transfor-01-2023/.

ITU (2023b). Early warning systems: Saving lives through mobile connection. International Telecommunication Union (ITU). Available at: https://www.itu.int/hub/2023/01/early-warning-systems-mobile-connectivity/ [accessed June 17 2025].

ITU (2023c). *ITU-T Focus Group Technical Report. AI for communications: Towards natural disaster management.* Focus Group on Artificial Intelligence for Natural Disaster Managementt. International. Telecommunication Union (ITU). Available at: https://www.itu.int/dms_pub/itu-t/opb/fg/T-FG-AI4NDM-2023-2-PDF-E.pdf.

ITU (2024). ICT data for the world, by geographic regions, by urban/rural area and by level of development, 2005-2024. International Telecommunication Union (ITU). Available at: https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx

ITU Data Hub (2025). Population coverage, by mobile network technology. International Telecommunications Union (ITU). Available at: https://datahub.itu.int/data/?e=701&c=701&i=100095 [accessed June 24 2025].

Jasechko, Scott, Hansjörg Seybold, Debra Perrone, Ying Fan, Mohammad Shamsudduha, Richard G. Taylor, Othman Fallatah and James W. Kirchner (2024). Rapid groundwater decline and some cases of recovery in aquifers globally. *Nature,* 625(7996), 715–21.

Jay, Ollie, Anthony Capon, Peter Berry, Carolyn Broderick, Richard de Dear, George Havenith, Yasushi Honda, R. Sari Kovats, Wei Ma, Arunima Malik, Nathan B. Morris, Lars Nybo, Sonia I. Seneviratne, Jennifer Vanos and Kristie L. Ebi (2021). Reducing the health effects of hot weather and heat extremes: from personal cooling strategies to green cities. *The lancet,* 398(10301), 709–24.

Jean Lotus (2025). Flame-resistant hemp blocks survive Australian Bushfire. *Hemp Build Magazine*,

JPO (2025). Japan Patent Office patent search. Japan Patent Office (JPO). Available at: https://www.jpo.go.jp/ [accessed September 14 2025].

Kenya Red Cross Society and KoboToolbox (2024). Data-driven climate disaster response: how the Kenya Red Cross Society is using KoboToolbox in the flooding crisis. Available at: https://www.kobotoolbox.org/blog/data-driven-climate-disaster-response-how-the-kenya-red-cross-society-is-using-kobotoolbox-in-the-flooding-crisis? [accessed June 26 2025].

KIPO (2025). Korean Intellectual Property Office patent search. Korean Intellectual Property Office (KIPO). Available at: https://www.kipo.go.kr/ko/MainApp.do [accessed September 14 2025].

Kita, Stern Mwakalimi (2025). Disaster insurance for climate loss and damage: assessing challenges and opportunities to adoption in Malawi. *Risk, Hazards & Crisis in Public Policy*, e70002.

Kjellstrom, T (2025). *Workplace heatstress.* [Email correspondence], October 2,

Kossin, James P, Kenneth R Knapp, Timothy L Olander and Christopher S Velden (2020). Global increase in major tropical cyclone exceedance probability over the past four decades. *Proceedings of the National Academy of Sciences,* 117(22), 11975–80.

Kusuma, Aditya, Cuong Nguyen and Ilan Noy (2019). Insurance for catastrophes: why are natural hazards underinsured, and does it matter? In Okuyama, Yasuhide and Adam Rose, eds., *Advances in Spatial and Economic Modeling of Disaster Impacts*, Cham: Springer International Publishing, 43–70.

Lipper, Leslie, Philip Thornton, Bruce M. Campbell, Tobias Baedeker, Ademola Braimoh, Martin Bwalya, Patrick Caron, Andrea Cattaneo, Dennis Garrity, Kevin Henry, Ryan Hottle, Louise Jackson, Andrew Jarvis, Fred Kossam, Wendy Mann, Nancy McCarthy, Alexandre Meybeck, Henry Neufeldt, Tom Remington, Pham Thi Sen, Reuben Sessa, Reynolds Shula, Austin Tibu and Emmanuel F. Torquebiau (2014). Climate-smart agriculture for food security. *Nature Climate Change,* 4(12), 1068–72.

Luijendijk, Arjen, Gerben Hagenaars, Roshanka Ranasinghe, Fedor Baart, Gennadii Donchyts and Stefan Aarninkhof (2018). The state of the world's beaches. *Scientific Reports,* 8(1), 6641.

Lütjens, Björn, Brandon Leshchinskiy, Océane Boulais, Farrukh Chishtie, Natalia Díaz-Rodríguez, Margaux Masson-Forsythe, Ana Mata-Payerro, Christian Requena-Mesa, Aruna Sankaranarayanan and Aaron Piña (2024). Generating physically-consistent satellite imagery for climate visualizations. *Ieee Transactions on Geoscience and Remote Sensing*.

MarketsandMarkets (2024). Incident and emergency management market. Available at: https://www.marketsandmarkets.com/Market-Reports/incident-emergency-management-market-1280.html? [accessed September 12 2025].

Matteoli, F., J. Schnetzer and H. Jacobs (2021). Climate-Smart Agriculture (CSA): An integrated approach for climate change management in the agriculture sector. In Luetz, Johannes M. and Desalegn Ayal, eds., *Handbook of Climate Change Management: Research, Leadership, Transformation*, Cham: Springer International Publishing, 409–37.

Matthew, Richard A (2014). The Water-Energy-Food Nexus: A New Approach in Support of Food Security and Sustainable Agriculture. Available at: https://openknowledge.fao.org/items/c171bc10-9788-4f3d-878a-a137be150c71

Matzarakis, Andreas (2024). Importance of heat health warnings in heat management. *Atmosphere,* 15(6), 684.

Mentaschi, Lorenzo, Michalis I. Vousdoukas, Jean-Francois Pekel, Evangelos Voukouvalas and Luc Feyen (2018). Global long-term observations of coastal erosion and accretion. *Scientific Reports,* 8(1), 12876.

Merry, A. and J.S. Rozo (2025). *The landscape of microinsurance 2024.* Micro Insurance Network. Available at: https://microinsurancenetwork.org/resources/the-landscape-of-microinsurance-2024.

Michigan State University Extension (2021). Forage alternatives for livestock in drought years. Available at: https://www.canr.msu.edu/news/forage-alternatives-for-livestock-in-drought-years [accessed April 29 2025].

Minas, Ministerio de Energía y (2024). Principales Indicadores al mes de Diciembre 2023 del Sector Eléctrico a nivel Nacional. Available at: https://www.gob.pe/institucion/minem/informes-publicaciones/2992739-principales-indicadores-a-enero-2023-del-sector-electrico-a-nivel-nacional

Montel (2025a). How do droughts affect hydropower generation? Available at: https://montel.energy/resources/blog/how-do-droughts-affect-hydropower-generation [accessed May 5 2025].

Montel (2025b). How to prevent power outages? Montel. Available at: https://montel.energy/resources/blog/how-to-prevent-power-outages [accessed July 8 2025].

Murahari Sahithi, Regati Varsha, Lakkoju Dhanya and Manjusha Nambiar Pv (2025). A blockchain based solution for transparent charity donations. *International Journal Of Engineering Research & Technology (IJERT),* 14(05).

Murray, Christopher JL, Aleksandr Y Aravkin, Peng Zheng, Cristiana Abbafati, Kaja M Abbas, Mohsen Abbasi-Kangevari, Foad Abd-Allah, Ahmed Abdelalim, Mohammad Abdollahi and Ibrahim Abdollahpour (2020). Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *The lancet,* 396(10258), 1223–49.

NASA (2022). A force of nature: hurricanes in a changing climate. National Aeronautics and Space Administration (NASA). Available at:https://science.nasa.gov/earth/climate-change/a-force-of-nature-hurricanes-in-a-changing-climate/#hds-sidebar-nav-3 [accessed March 5 2025].

NASA (2025). NASA supports wildland fire technology demonstration. National Aeronautics and Space Administration (NASA). Available at: https://www.nasa.gov/centers-and-facilities/armstrong/nasa-supports-wildland-fire-technology-demonstration/ [accessed April 17 2025].

National Centre for Atmospheric Science (2024). Hurricane Milton: What are hurricanes and is climate change making them more damaging? Available at: https://ncas.ac.uk/hurricane-milton-what-are-hurricanes-and-is-climate-change-making-them-more-damaging/ [accessed February 20 2025].

National Geographic (2024). Urban heat island. National Geographic. Available at: https://education.nationalgeographic.org/resource/urban-heat-island/ [accessed July 3 2025].

National Hurricane Center – processed by Our World in Data (2023). *0 hours (dataset).* Available at: https://ourworldindata.org/weather-forecasts.

Ndayishimiye, V., G. Bakkabulindi and E. Miyingo (2022). Analysis of the effects of drought conditions on hydroelectric power generation in Uganda' in *2022 IEEE PES/IAS PowerAfrica*, 22–26 Aug. 2022, 1–5.

Neuroject (2024). Ultimate guide to landslide sensors 2024. Available at: https://neuroject.com/landslide-sensors/ [accessed March 20 2025].

NOAA (2023). NOAA uses artificial intelligence to translate forecasts, warnings into Spanish and Chinese. National Oceanic and Atmospheric Administration (NOAA). Available at: https://www.noaa.gov/news-release/noaa-uses-artificial-intelligence-to-translate-forecasts-warnings-into-spanish-and-chinese

NOAA (2024). Historic NOAA – Saildrone mission is helping scientists improve hurricane forecasts. National Oceanic and Atmospheric Administration (NOAA). Available at: https://research.noaa.gov/historic-noaa-saildrone-mission-did-more-than-set-records-its-helping-scientists-improve-hurricane-forecasts/ [accessed February 27 2025].

NOAA National Weather Service (NWS) National Hurricane Center (2024). 2024 Atlantic Hurricane Season. National Oceanic and Atmospheric Administration (NOAA). Available at: https://www.nhc.noaa.gov/data/tcr/index.php?season=2024&basin=atl [accessed March 5 2025].

NSF NCAR Earth Observing Laboratory (2025). How do radars work? Available at: https://www.eol.ucar.edu/content/how-do-radars-work [accessed February 28 2025].

OCHA (2021). *From digital promise to frontline practice: new and emerging technologies in humanitarian action.* United Nations Office for the Coordination of Humanitarian Affairs (OCHA). Available at: https://reliefweb.int/report/world/digital-promise-frontline-practice-new-and-emerging-technologies-humanitarian-action.

OCHA (2023). *Global humanitarian overview 2024.* United Nations Office for the Coordination of Humanitarian Affairs (OCHA). Available at: https://www.unocha.org/attachments/54c06781-48bb-4132-9d42-fc098192378c/GHO-2024-EN_full_contribute.pdf.

OECD (2015). *Disaster risk financing: A global survey of practices and challenges.* Paris: Organization for Economic Cooperation and Development (OECD). Available at: https://www.oecd.org/content/dam/oecd/en/publications/reports/2015/11/disaster-risk-financing_g1g543e4/9789264234246-en.pdf.

OECD and ADB (2020). *Leveraging technology and innovation for disaster risk management and financing.* Paris: OECD Publishing. Available at: https://doi.org/10.1787/cd4ed15b-en.

OEPM and INPI (2022). *Patents and forest fire control.* Oficina Española de Patentes y Marcas (OEPM), Instituto Nacional da Propriedade Industrial (INPI). Available at: https://www.oepm.es/export/sites/oepm/comun/documentos_relacionados/Publicaciones/Estudios-Articulos/Patentes_y_control_de_incendios_forestales_ingles.pdf.

Ohenhen, Leonard O., Manoochehr Shirzaei, Chandrakanta Ojha, Sonam F. Sherpa and Robert J. Nicholls (2024). Disappearing cities on US coasts. *Nature,* 627(8002), 108–15.

Ohio State News (2023). A new tool to better model future wildfire impacts in the United States. Available at: https://news.osu.edu/a-new-tool-to-better-model-future-wildfire-impacts-in-the-united-states/ [accessed April 9 2025].

Ontario Ministry of Agriculture, Food and Rural Affairs (2007). Cold stress in cows. Government of Ontario. Available at: https://www.ontario.ca/page/cold-stress-cows? [accessed July 18 2025].

Opperman, J., E. Oyare, H. Baleta, and S. Fahrbach and R. Camargo (2021). *Waterways to resilience: Nature-based solutions for adaptation in Africa.* Gland: WWF International. Available at: https://wwfint.awsassets.panda.org/downloads/waterways_to_resilience_naturebased_solutions_wwfabinbev.pdf.

Ouranos (2022). Extreme cold. Ouranos. Available at: https://www.ouranos.ca/en/climate-phenomena/extreme-cold-impacts [accessed July 9 2025].

Parametric Architecture (2023). Exploring 3D printed housing as a solution for post-disaster temporary shelters. Available at: https://parametric-architecture.com/exploring-3d-printed-housing-as-a-solution-for-post-disaster-temporary-shelters/?srsltid=AfmBOorCAepZnLYO8pV-29aB6jMj8WLuwZoJQ5wAPZc3uyju18dIuVgn [accessed May 19 2025].

Peters, Adele (2025). Wildfire tracker Watch Duty gives citizens—and governments—the intel they need to stay safe. *Fast Company.* Available at: https://www.fastcompany.com/91271054/watch-duty-most-innovative-companies-2025

Pew (2018). Every $1 invested in disaster mitigation saves $6. Pew Charitable Trusts. Available at: https://www.pew.org/en/research-and-analysis/articles/2018/01/11/every-$1-invested-in-disaster-mitigation-saves-$6 [accessed June 24 2025].

Phys.org (2023). Bangladesh's 'tiny houses' tackle giant flood challenge. Available at: https://phys.org/news/2023-12-bangladesh-tiny-houses-tackle-giant.html [accessed March 4 2025].

PIX4D (2022). Accurately mapping a landslide to make the right decisions. Available at: https://www.pix4d.com/blog/drone-mapping-landslide/ [accessed March 8 2025].

PW Market Research (2025). Emergency Catering Service Market. Available at: https://pmarketresearch.com/it/emergency-catering-service-market/ [accessed June 5 2025].

Qin, Feng, Chengrong Huang and Zhenjie Lin (2024). Big data and artificial intelligence-driven natural disaster prediction and prevention: Technological advances and prospects. *Geographical Research Bulletin,* 3, 381–98.

Qiu, Minghao, Nathan Ratledge, Inés M. L. Azevedo, Noah S. Diffenbaugh and Marshall Burke (2023). Drought impacts on the electricity system, emissions, and air quality in the western United States. *Proceedings of the National Academy of Sciences,* 120(28), e2300395120.

Radeloff, Volker C, Roger B Hammer, Susan I Stewart, Jeremy S Fried, Sherry S Holcomb and Jason F McKeefry (2005). The wildland–urban interface in the United States. *Ecological Applications,* 15(3), 799–805.

Rai, Navreet Kaur, Ravika, Rajesh Yadav, Minakshi Jattan, Karuna, Prashant Singh Rai, Nisha Kumari, Babita Rani, Amit Sharma, Sachin and Sunaina Yadav (2023). Speed breeding: a budding technique to improve crop plants for drought and salinity tolerance. In Kumar, Ashwani, Pooja Dhansu and Anita Mann, eds., *Salinity and Drought Tolerance in Plants: Physiological Perspectives*, Singapore: Springer Nature Singapore, 295–313.

Raintime (2024a). Innovative urban cooling through fog technology. raintime. Available at: https://www.raintime.at/en/innovative-urban-cooling-through-fog-technology/ [accessed July 4 2025].

Raintime (2024b). Summer heat in the city? Misting systems provide relief. raintime. Available at: https://www.raintime.at/en/summer-heat-in-the-city-misting-systems-provide-relief/ [accessed July 4 2025].

Reach Alliance (2020). *From A to O-positive: blood delivery via drones in Rwanda.* Reach Alliance. Available at: https://reachalliance.org/case-study/ziplines-impact-on-health-outcomes-of-the-hardest-to-reach-in-rwanda/#article

Ritchie, Hannah (2024a). How many people die from extreme temperatures, and how this could change in the future: Part one. Our World In Data. Available at: https://ourworldindata.org/part-one-how-many-people-die-from-extreme-temperatures-and-how-could-this-change-in-the-future [accessed July 9 2025].

Ritchie, Hannah (2024b). Weather forecasts have become much more accurate; we now need to make them available to everyone. Our World In Data. Available at: https://ourworldindata.org/weather-forecasts [accessed March 26 2025].

Ritchie, Hannah, Pablo Rosado and Max Roser (2022). Natural disasters. Our World In Data. [accessed June 2025]. Available at: https://ourworldindata.org/natural-disasters#article-citation

RMI (2025). How we can keep cool without frying the grid (or the planet). Rocky Mountain Institute (RMI). Available at: https://rmi.org/how-we-can-keep-cool-without-frying-the-grid-or-the-planet/?utm_term=title-1&utm_source=spark&utm_medium=email&utm_campaign=2025_08_07&utm_content=spark&jobid=63260&c_src=&sfmc_id=94735091 [accessed August 6 2025].

Ronglan, Edvard, Alfonso Parra Rubio, Alexis Oliveira da Silva, Dixia Fan, Jeffrey L Gair, Jr., Patritsia Maria Stathatou, Carolina Bastidas, Erik Strand, Jose del Aguila Ferrandis, Neil Gershenfeld and Michael S Triantafyllou (2024). Architected materials for artificial reefs to increase storm energy dissipation. *PNAS Nexus,* 3(3).

Saft (2016). Saft enables microgrid to harness the midnight sun for Arctic Circle community. Saft. Available at: https://saft.com/en/case-studies/saft-enables-microgrid-harness-midnight-sun-arctic-circle-community-0 [accessed July 10 2025].

Samborska, Veronika and Hannah Ritchie (2024). Wildfires. Our World In Data. Available at: https://ourworldindata.org/wildfires [accessed April 2 2025].

Sarawak Tribune (2020). RM70 mln for reef balls in marine conservation initiative. Sarawak Tribune. Available at: https://www.sarawaktribune.com/rm70-mln-for-reef-balls-in-marine-conservation-initiative [accessed September 15 2025].

Sasoni, Eliad (2025). Innovation in frost protection. European Irrigation Association (EIA). Available at: https://irrigationeurope.eu/en/innovation-in-frost-protection/ [accessed July 10 2025].

Sastry, Minni and Mihir R. Bhatt (2025). *Urgency of urban heat adaptation.* All India Disaster Mitigation Institute (AIDMI). Available at: https://aidmi.org/wp-content/uploads/2025/05/220-Snet-Urgency-of-Urban-Heat-Adaptation.pdf.

Schlader, Zachary J., Thomas Boswell, Heath Prince, Catarina Wesseling, Fabiano A. Amorim, Dinesh Neupane, Esteban Arias, Scarlette Poveda, Erik Hansson, Rebekah A.I. Lucas, Kristina Jakobsson, David H. Wegman and Jason Glaser (2025). A Rest-Shade-Hydration-Hygiene program reduces acute kidney injury and increases production at a sugar mill in Nicaragua, an economic analysis. *medRxiv*, 2025.02.19.25322486.

Sengupta, Dhritiraj, Ruishan Chen, Michael E Meadows and Abhishek Banerjee (2020). Gaining or losing ground? Tracking Asia's hunger for 'new'coastal land in the era of sea level rise. *Science of the Total Environment,* 732, 139290.

Sensorex (2023). Dry spells turn deadly: how droughts wreak havoc on water quality. Available at: https://sensorex.com/droughts-water-quality/?srsltid=AfmBOopbEupJOa4Un4ykYTtXnj2Vi2nKIAG4LLB–pbI-XHdgjIti8Xo [accessed May 6 2025].

Sethi, Narendra (2024). Border Roads Organisation turns to rock-bolt tech to tackle landslips. *The New Indian Express,* Available at: https://www.newindianexpress.com/nation/2024/Dec/07/border-roads-organisation-turns-to-rock-bolt-tech-to-tackle-landslips.

Sherriff, Lucy (2025). How the polar vortex fuels intense winter weather in the US. BBC. Available at: https://www.bbc.com/future/article/20250115-how-the-polar-vortex-brings-arctic-weather-to-the-us [accessed July 10 2025].

Shuai, Hang, Fangxing Li, Jinxiang Zhu, William Jerome Tingen Ii and Srijib Mukherjee (2024). Modeling the impact of extreme summer drought on conventional and renewable generation capacity: Methods and a case study on the Eastern U.S. power system. *Applied Energy,* 363, 122977.

Snyder, Richard L and J Paulo Melo-Abreu (2005). *Frost protection: fundamentals, practice and economics. Volume 1.* Food and Agriculture Organization of the United Nations (FAO). Available at: https://www.fao.org/4/y7223e/y7223e00.pdf

Sphere Association (2018). *The Sphere handbook: Humanitarian charter and minimum standards in humanitarian response.* Geneva: Sphere Association. Available at: https://www.spherestandards.org/handbook-2018/.

SQ4D (2024). The Role Of 3D Printing Technology In Disaster Relief and Emergency Housing. Available at: https://www.sq4d.com/the-role-of-3d-printing-technology-in-disaster-relief-and-emergency-housing/ [accessed 2025

Statista (2024). Number of natural disasters worldwide in 2023, by type. Available at: https://www.statista.com/statistics/269653/natural-disasters-on-the-continents-by-nature-of-the-disaster/ [accessed March 5 2025].

Subramanya, Karthik and Sharareh Kermanshachi (2022). Exploring Utilization of the 3D Printed Housing as Post-Disaster Temporary Shelter for Displaced People' in *Construction Research Congress 2022*, 594–605.

Swartz, Angela (2025). When is it too dangerous to be outside? New wearable tech could tell you. Available at: https://www.nationalgeographic.com/health/article/excessive-heat-wearable-technology [accessed July 3 2025].

The African Exponent (2024). Community efforts in Kenya transform water access with innovative sand dams. Available at: https://www.africanexponent.com/community-efforts-in-kenya-transform-water-access-with-innovative-sand-dams/ [accessed May 7 2025].

The Energy Mix (2025). Seville turns to 1,000-year-old technology to cool public spaces. Available at: https://www.theenergymix.com/seville-turns-to-1000-year-old-technology-to-cool-public-spaces/ [accessed July 4 2025].

The Guardian (2025). 'Cañahua chose me': can an ancient relative of quinoa revive rural Bolivia's economy? Available at: https://www.theguardian.com/global-development/2025/apr/20/canahua-ancient-andean-superfood-rural-bolivia? [accessed April 28 2025].

The Nature Conservancy (2023). New study finds continued loss of coastal ecosystems may jeopardize millions of lives in the face of tropical storms. Available at: https://www.nature.org/en-us/newsroom/new-study-coastal-ecosystems-protection-and-climate-change/ [accessed 2024 March 5].

The Times Group (2023). Insurance penetration stagnates at only 2.5%. Available at: https://times.mw/insurance-penetration-stagnates-at-only-2-5/ [accessed 2025 June 17].

Tufts Now (2020). The consequences of spraying fire retardants on wildfires. Available at: https://now.tufts.edu/2020/09/11/consequences-spraying-fire-retardants-wildfires [accessed Apriluc 2025].

UC San Diego (2023). ALERTCalifornia: Developing technology to stay ahead of natural disasters. University of California, San Diego. Available at: https://alertcalifornia.org/ [accessed April 14 2025].

UK Aid (2019). *Blockchain technology for the humanitarian supply chain.* UK Aid. Available at: https://static1.squarespace.com/static/6160742e58596279bef906ba/t/65254b4699e5c22b5381cd22/1696942922105/Blockchain-Humanitarian-v1.pdf.

UkrAgroConsult (2025). Adoption record: GM crops reached 210 mln ha in 2024. UkrAgroConsult. Available at: https://ukragroconsult.com/en/news/adoption-record-gm-crops-reached-210-mln-ha-in-2024/ [accessed August 11 2025].

UN DESA and UNDRR (2022). *Gaps, challenges and constraints in means of implementing the Sendai Framework for disaster risk reduction in Small Island Developing States.* United Nations Department of Economic and Social Affairs (UN DESA) and United Nations Office for Disaster Risk Reduction (UNDRR). Available at: https://www.un.org/ohrlls/sites/www.un.org.ohrlls/files/sids_drr_gap_assessment_report_on_moi_digital_version_final_november2022_0.pdf.

UNCCD (2024). Drought Toolbox. United Nations Convention to Combat Desertification (UNCCD). Available at: https://www.unccd.int/land-and-life/drought/toolbox [accessed July 31 2025].

UNDP (2024). Agricultural transition using the Internet of Things and artificial intelligence. United Nations Development Program (UNDP). Available at: https://www.undp.org/acceleratorlabs/blog/agricultural-transition-using-internet-things-and-artificial-intelligence [accessed April 29 2025].

UNDP (2025). Microinsurance coverage reaches 344 million people in 2023, 88% protection gap persists. United Nations Development Programme (UNDP). Available at: https://irff.undp.org/press-releases/microinsurance-coverage-reaches-344-million-people-2023-88-protection-gap-persists? [accessed August 12 2025].

UNDRR (2015). *Sendai Framework for Disaster Risk Reduction 2015–2030.* United Nations Office for Disaster Risk Reduction (UNDRR). Available at: https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030.

UNDRR (2017). Definition: Disaster. United National Office for Disaster Risk Reduction (UNDRR). Available at: https://www.undrr.org/terminology/disaster [accessed September 15 2025].

UNDRR (2023). *GAR Special Report: Measuring resilience for the Sustainable Development Goals.* Geneva: United Nations Office for Disaster Risk Reduction (UNDRR). Available at: https://www.undrr.org/media/88718/download.

UNDRR (2024a). *Global status of multi-hazard early warning systems 2023.* United Nations Office for Disaster Risk Reduction (UNDRR). Available at: https://www.undrr.org/reports/global-status-MHEWS-2023

UNDRR (2024b). Landslide. United Nations Office for Disaster Risk Reduction (UNDRR). Available at: https://www.preventionweb.net/knowledge-base/hazards/land-slide [accessed March 18 2025].

UNDRR (2025a). *Global assessment report on disaster risk reduction. Resilience pays: financing and investing for our future.* United Nations Office for Disaster Risk Reduction (UNDRR). Available at: https://www.undrr.org/gar/gar2025.

UNDRR (2025b). *Making cities resilient 2030. Urban heat risk management resource package.*, United Nations Office for Disaster Risk Reduction (UNDRR). Available at: https://mcr2030.undrr.org/publication/urban-heat-risk-management-resource-package.

UNDRR (2025c). Prevention Web: Flood. United Nations Office for Disaster Risk Reduction (UNDRR). Available at: https://www.preventionweb.net/knowledge-base/hazards/flood

UNDRR and WMO (2023). *Global status of Multi-Hazard Early Warning Systems.* Geneva: United Nations Office for Disaster Risk Reduction (UNDRR) and World Meteorological Organization (WMO). Available at: https://www.undrr.org/publication/global-status-multi-hazard-early-warning-systems-2023.

UNDRR GFMC (2025a). Meant to protect the land from wildfires, fire retardant could be doing damage of its own. United Nations Office for Disaster Risk Reduction (UNDRR). Global Platform for Disaster Risk Reduction (GFMC). Available at: https://gfmc.online/2025/02-2025/meant-to-protect-the-land-from-wildfires-fire-retardant-could-be-doing-damage-of-its-own.html [accessed April 11 2025].

UNDRR GFMC (2025b). SUNY Canton researchers say lightweight concrete homes could survive wildfires. United Nations Office for Disaster Risk Reduction (UNDRR). Global Platform for Disaster Risk Reduction (GFMC). Available at: https://gfmc.online/2025/02-2025/suny-canton-researchers-say-lightweight-concrete-homes-could-survive-wildfires.html [accessed April 11 2025].

UNEP (2024a). *Adaptation Gap Report 2024: Come hell and high water – as fires and floods hit the poor hardest, it is time for the world to step up adaptation actions.*, Nairobi: United Nations Environment Programme (UNEP). Available at: https://www.unep.org/adaptation-gap-report-2024.

UNEP (2024b). Sponge City: How San Salvador is using nature to fight floods. United Nations Environment Programme (UNEP). Available at: https://www.unep.org/news-and-stories/story/sponge-city-how-san-salvador-using-nature-fight-floods [accessed March 20 2025].

UNEP (2025). As drought sets in, farmers in Saint Kitts and Nevis turn to technology for help. United Nations Environment Programme (UNEP). Available at: https://www.unep.org/news-and-stories/story/drought-sets-farmers-saint-kitts-and-nevis-turn-technology-help [accessed April 30 2025].

UNESCO (2024). *The United Nations world water development report 2024: water for prosperity and peace.* Paris: United Nations Educational, Scientific and Cultural Organization (UNESCO). Available at: https://unesdoc.unesco.org/ark:/48223/pf0000388948

UNHCR (2023). *UNHCR's biometric tools in 2023.* United Nations High Commissioner for Refugees (UNHCR). Available at: https://www.unhcr.org/blogs/unhcrs-biometric-tools-in-2023/.

UNHCR (2024). *Biometrics innovation: transforming the way we collect fingerprints at UNHCR.* 2025, United Nations High Commissioner for Refugees (UNHCR). Available at: https://www.unhcr.org/blogs/biometrics-innovation-transforming-the-way-we-collect-fingerprints-at-unhcr/.

UNHCR (2025). *Emergency Shelter Solutions and Standards.* United Nations High Commission for Refugees (UNHCR). Available at: https://emergency.unhcr.org/emergency-assistance/shelter-camp-and-settlement/shelter-and-housing/emergency-shelter-solutions-and-standards.

United Kingdom Met Office (2023). Why an 'exact date' weather forecast headline isn't what it seems. Available at: https://www.metoffice.gov.uk/blog/2023/why-an-exact-date-weather-forecast-headline-isnt-what-it-seems#:~:text=Despite%20the%20certainty%20suggested%20in,come%20with%20in%2Dbuilt%20uncertainty [accessed March 26 2025].

United Nations (2024). Secretary-General's call to action on extreme heat. United Nations. Available at: https://www.un.org/en/climatechange/extreme-heat [accessed August 4 2025].

UNU-EHS (2024). 5 ways AI can strengthen early warning systems. Available at: https://unu.edu/ehs/series/5-ways-ai-can-strengthen-early-warning-systems [accessed March 4 2025].

Urban Innovative Actions Initiative (2022). What is Cartuja Qanat? European Union (EU). Available at: https://cartujaqanat.com/ [accessed July 4 2025].

Vitousek, Sean, Patrick L Barnard and Patrick Limber (2017). Can beaches survive climate change? *Journal of Geophysical Research: Earth Surface,* 122(4), 1060–67.

Wallace, Mia (2024). Are parametric reinsurance solutions the key to solving the insurability crisis? ReInsurance Business. Available at: https://www.insurancebusinessmag.com/reinsurance/news/breaking-news/are-parametric-reinsurance-solutions-the-key-to-solving-the-insurability-crisis-499333.aspx [accessed June 17 2025].

Wang, Xiaopeng, Biqiong Wu, Guoliang Zhou, Tao Wang, Fanwei Meng, Li Zhou, Hui Cao and Zhengyang Tang (2025). How a vast digital twin of the Yangtze River could prevent flooding in China. *Nature,* 639(8054), 303–05.

Warnell, K., S. Mason, A. Siegle, M. Merritt and L. Olander (2023). Coastal habitats. 5. Dune restoration. *Nature-based solutions roadmap*, Durham, NC: Nicholas Institute for Energy, Environment & Sustainability, Duke University.

Water Education Foundation (2023). High-tech mapping of Central Valley's underground blazes path to drought resilience. Available at: https://www.watereducation.org/western-water/high-tech-mapping-central-valleys-underground-blazes-path-drought-resilience [accessed May 5 2025].

WEF (2018). 4 ways technology can help us respond to disasters. World Economic Forum (WEF). Available at: https://www.weforum.org/stories/2018/01/4-ways-technology-can-play-a-critical-role-in-disaster-response/ [accessed May 24 2025].

WEF (2024a). The power of AI in wildfire prediction and prevention. World Economic Forum (WEF). Available at: https://www.weforum.org/impact/artificial-intelligence-wildfire-prediction-and-prevention/ [accessed April 17 2025].

WEF (2024b). Why parametric insurance could be a climate disaster aid solution in the Global South. World Economic Forum (WEF). Available at: https://www.weforum.org/stories/2024/02/why-parametric-insurance-could-be-the-solution-to-uncertain-relief-capital/? [accessed August 12 2025].

WFP (2022). Meet SHERP: The all-terrain vehicle helping us save lives in the hardest-to-reach places. World Food Programme (WFP). Available at: https://www.wfpusa.org/articles/sherp-atvs-help-wfp-save-lives/? [accessed June 23 2025].

WFP (2024a). *Ahead of Cyclone Remal, WFP's anticipatory action cash assistance reaches over 30,000 families most at-risk in Khulna and Barishal Division.* World Food Programme (WFP). Available at: https://www.wfp.org/news/ahead-cyclone-remal-wfps-anticipatory-action-cash-assistance-reaches-over-30000-families-most?

WHO (2024a) Drought. World Health Organzation (WHO). Available at: https://www.who.int/health-topics/drought#tab=tab_1[accessed March 19 2025].

WHO (2024b) Landslides. World Health Organzation (WHO). Available at: https://www.who.int/health-topics/landslides#tab=tab_1[accessed March 19 2025].

Wilson Center (2025). Shelter from the storm: building dignified and resilient shelters for refugees. Available at: https://www.wilsoncenter.org/article/shelter-storm-building-dignified-and-resilient-shelters-refugees [accessed 21 May 2025].

WIPO (2025). PATENTSCOPE Search. World Intellectual Property Organization (WIPO). Available at: https://patentscope.wipo.int/search/en/search.jsf [accessed September 14 2025].

Wired (2024). Darpa thinks walls of oysters could protect shores against hurricanes. Available at: https://www.wired.com/story/darpa-thinks-walls-of-oysters-could-protect-shores-against-hurricanes/? [accessed 2025

WMO (2020). Drought. World Meteorological Organization (WMO). Available at: https://wmo.int/about-us/world-meteorological-day/wmd-2020/drought [accessed April 28 2025].

WMO (2021a). *State of the climate in Africa 2021.* World Meterological Organization (WMO). Available at: https://library.wmo.int/viewer/58070/download?file=1300_State_of_the_Climate_in_Africa_2021_en.pdf&type=pdf&navigator=1.

WMO (2021b). Weather-related disasters increase over past 50 years, causing more damage but fewer deaths. World Meteorological Organization (WMO). Available at: https://public.wmo.int/en/media/press-release/weather-related-disasters-increase-over-past-50-years-causing-more-damage-fewer [accessed October 2022].

WMO (2024). Tropical cyclone. World Meteorological Organization (WMO). Available at: https://wmo.int/topics/tropical-cyclone [accessed February 17 2025].

WMO (2025a). Early warnings for all. World Meteorological Organization (WMO). Available at: https://wmo.int/activities/early-warnings-all [accessed March 17 2025].

WMO (2025b). Heatwave. World Meteorological Organization (WMO). Available at: https://wmo.int/topics/heatwave [accessed 2025 June 30].

Wood Central (2024). The $12,000 Disaster-Proof House Built from Timber and Cardboard! Available at: https://woodcentral.com.au/the-12000-disaster-proof-house-built-from-timber-and-cardboard/ [accessed June 13 2025].

World Bank (2017). Chart: Globally, 70% of freshwater is used for agriculture. *World Bank Blogs*, Available at: https://blogs.worldbank.org/en/opendata/chart-globally-70-freshwater-used-agriculture? [accessed May 1 2025].

World Bank (2023). Climate action game changers: adaptation to climate shocks. Available at: https://www.worldbank.org/en/news/immersive-story/2023/11/14/climate-action-game-changers-adaptation-to-climate-shocks [accessed August 13 2025].

World Bank (2024). Climate action game changers: adaptation to climate shocks. Available at: https://www.worldbank.org/en/news/immersive-story/2023/11/14/climate-action-game-changers-adaptation-to-climate-shocks [accessed March 4 2025].

World Weather Attribution (2025). Climate change increased the likelihood of wildfire disaster in highly exposed Los Angeles area. Available at: https://www.worldweatherattribution.org/climate-change-increased-the-likelihood-of-wildfire-disaster-in-highly-exposed-los-angeles-area/ [accessed April 7 2025].

Wray Castle (2024). Understanding GSM: what is GSM and how does it work? Available at: https://wraycastle.com/blogs/knowledge-base/what-is-gsm?srsltid=AfmBOoq053YORhv79OHfxgWcquZmmiBpuBardUiZ1zcjlK1e1qdq-JfM [accessed June 4 2025].

WRI (2024a). Europe's cities should prepare for hotter, more hazardous days ahead. World Resources Institute (WRI). Available at: https://www.wri.org/insights/europe-cities-extreme-heat-climate-change?utm_campaign=wridigest&utm_medium=email&utm_source=wridigest-2025-07-10 [accessed July 8 2025].

WRI (2024b). The latest data confirms: forest fires are getting worse. World Resources Institute (WRI). Available at: https://www.wri.org/insights/global-trends-forest-fires [accessed April 8 2025].

WSL (2022). Artificial avalanche triggering. Swiss Federal Institute for Forest, Snow and Landscape Research (WSL). Institute for Snow and Avalanche Research (SLF). Available at: https://www.slf.ch/en/avalanches/avalanche-protection/artificial-avalanche-triggering/ [accessed July 22 2025].

Yang, Yifan, Chen Xie, Ziwu Fan, Zhonghou Xu, Bruce W. Melville, Guoqing Liu and Lei Hong (2024). Digital twinning of river basins towards full-scale, sustainable and equitable water management and disaster mitigation. *npj Natural Hazards,* 1(1), 43.

Yazdani, Maziar and Milad Haghani (2023). A dynamic emergency planning system for relocating vulnerable people to safe shelters in response to heat waves. *Expert Systems with Applications,* 228, 120224.

Yuyu, Chen, Zhu Aike, Xue Pao, Wen Xiaoxia, Cao Yongrun, Wang Beifang, Zhang Yue, Shah Liaqat, Cheng Shihua and Cao Liyong (2020). Effects of GS3 and GL3. 1 for grain size editing by CRISPR/Cas9 in rice. *Rice Science,* 27(5), 405–13.

ZEP (2025). Super-insulate the building envelope: Step 5. Zero Energy Project (ZEP). Available at: https://zeroenergyproject.com/build/twelve-steps-affordable-zero-energy-home-construction-design/super-insulate-net-zero-building-envelope/ [accessed July 8 2025].

Zhang, Guoqing, Jonathan L Carrivick, Adam Emmer, Dan H Shugar, Georg Veh, Xue Wang, Celeste Labedz, Martin Mergili, Nico Mölg and Matthias Huss (2024). Characteristics and changes of glacial lakes and outburst floods. *Nature Reviews Earth & Environment,* 5(6), 447–62.

Zhao et al. (2021). Global, regional, and national burden of mortality associated with non-optimal ambient temperatures from 2000 to 2019: a three-stage modelling study. – processed by Our World in Data. Our World in Data. Available at: https://ourworldindata.org/grapher/temp-deaths-zhao [accessed July 14 2025].

Zwitter, Andrej J., Oskar J. Gstrein and Evan Yap (2020). Digital identity and the blockchain: universal identity management and the concept of the "self-sovereign" individual. *Frontiers in Blockchain,* Volume 3 – 2020.

The Green Technology Book: Solutions for confronting climate disasters looks at solutions for confronting climate disasters, highlighting how innovation is transforming disaster preparedness, response, and recovery.

As climate-driven crises intensify, emerging technologies, such as AI, IoT, drones, satellites, and nature-based systems, are redefining how we protect lives and livelihoods. From flood forecasting to modular shelters, these adaptive solutions combine digital intelligence with disaster-ready infrastructure in an increasingly volatile climate.

The Green Technology Book also serves as a matchmaking tool. Information about the featured technologies can be accessed through the WIPO GREEN Database of Needs and Green Technologies, where technology owners can be contacted directly and where needs and new technologies can be uploaded.