

Green Technology Book 2022

Solutions for
climate change
adaptation



In cooperation with our partners





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climate change
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Foreword by WIPO



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Daren Tang, Director General,
World Intellectual Property
Organization (WIPO)

Welcome to the inaugural edition of the *Green Technology Book*, a new Flagship publication from WIPO.

As the UN agency for innovation, creativity and intellectual property (IP), WIPO is committed to supporting the development of green technologies and new innovative solutions in the fight against climate change. The global IP system plays a critical role in ensuring that such solutions create impact. It helps translate basic research into tangible climate change solutions, incentivizes public and private R&D investment into environmentally-friendly technologies and generates a vast treasure trove of information that is open and accessible to all.

This is important. Innovation and technology are critical to tackling the many different facets of the climate crisis. This includes climate change adaptation – the theme of this year’s publication.

Adaptation will increasingly become a necessity for fast-growing parts of the world’s population, as well as for natural ecosystems in every region of the globe. As there is no “one-size-fits-all” approach to adaptation, the solutions take a variety of forms according to local contexts and needs. But investment in climate adaptation has long lagged behind climate mitigation.

This is despite the fact that for many countries – developing countries in particular – it is adaptation responses that have the immediate impact.

With this in mind, the inaugural edition focuses on three areas that can benefit from new technological advances: Agriculture and forestry – Water and coastal regions – and Cities. Our aim is to provide a practical guide for those at the frontline of climate change – coastal communities, farmers, vulnerable urban populations and others – as well as innovators, industry, researchers and agencies, which raises awareness of solutions. By offering this guide we hope to encourage their adoption for the benefit of all.

The book builds upon the work of our tech-matching platform WIPO GREEN, whose growing database of nearly 130,000 entries from around the world connects green technology providers with those seeking environmentally-friendly solutions.

One of the key findings of this inaugural edition of the *Green Technology Book* is that, while there remains scope for speeding up new technology deployment, we should take encouragement – and inspiration – from the sheer range of transformational tools at every stage of development.

We know that the window of opportunity for climate action is narrowing. As the most recent IPCC report states with high confidence, rising temperatures are a serious and mounting threat to human life, biodiversity and infrastructure.

Access to a balanced and neutral guide on the global state of green innovation and technology is therefore critical. By focusing attention on current and emerging technology trends we hope the *Green Technology Book* can be that resource and add momentum to those areas that are driving much-needed change.

I would like to thank our partners the UN Climate Technology Centre & Network (CTCN) and Egypt's Academy of Scientific Research and Technology (ASRT) for their support in this new initiative, as well as everyone at WIPO who has helped make the *Green Technology Book* a reality.

I hope you will find it a store of useful information and valuable insights into how innovation can help us address climate change and its impacts.

Acknowledgments

The *Green Technology Book 2022* is the product of many dedicated contributors – from technology providers to experts in the field. The book was prepared under the general auspices of Director General Daren Tang and WIPO's Global Challenges and Partnerships Sector led by Assistant Director General Edward Kwakwa, as well as the Global Challenges Division led by Director Amy Dietterich.

Special thanks go to our partners at the Climate Technology Centre and Network (CTCN), represented by Dr Rose Mwebaza (Director) and the Egyptian Academy of Scientific Research and Technology (ASRT) represented by Professor Mahmoud M. Sakr (President) for their partnership, vision and contribution.

The *Green Technology Book* is an initiative under WIPO GREEN. It was conceived and led by Peter Oksen, Green Technology and Research Manager, who also acted as editor and writer. However, acknowledgement for the majority of the writing goes to Shanar Tabrizi, Climate Technology Expert and Lead-writer. Jeremy Rutman (CEO) RutmanIP.com helped in the search for technologies. Other WIPO GREEN staff contributed important elements, namely: Anja von der Ropp, Senior Program Coordinator, as well as Dmitry Kalinin, Nivedita Saksena Raj, Didier Georges, Minna Guigon-Sell and Cherise Trotman.

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A group of colleagues from across WIPO and beyond volunteered their experience and valuable advice for which we are deeply grateful. The group includes Amy Dietterich (Director, Global Challenges Division), Andrew Czajkowski (Director, Technology and Innovation Support Division); Carsten Fink (Chief Economist, Department for Economics and Data Analytics), Kevin Fitzgerald (Director, Information and Digital Outreach Division); Walid Abdelnasser (Director, Division for Arab Countries); Aurea Plana (Assoc. Legal Officer, Madrid Legal Division); Edward Harris (Senior Media Officer, News and Media Division), Charlotte Beauchamp (Head, Publications and Design Section), Victor Owade (External Relations and Partnerships Officer, External Relations Division), Rajiv Garg (Regional Manager, CTCN) and Heather Jacobs (Knowledge and Research Specialist, CTCN).

A distinguished group of experts kindly agreed to review various sections of the publication and in doing so significantly improved quality. They include:

UN Climate Technology Centre and Network (CTCN):

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- Rajiv Garg, Regional Manager

International Fund for Agricultural Development (IFAD): Fanny Minjauw, Environment and Climate Monitoring and Results Specialist

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We sincerely thank all the organizations and technology providers making their solutions available to the world. Without them there would be no book.

Foreword by partners



This year at COP27 in Egypt all eyes will be on the continent of Africa where climate change adaptation is a top priority. Technology is a recognized enabler of climate action for adaptation. But we have yet to fully maximize its potential. Technology and innovation are needed to address the myriad considerations that go into planning for more sustainable cities, improving agricultural production and transforming food systems, building resilience in coastal communities, and protecting and conserving our dwindling water resources. Though adaptation remains underfunded, great advances for example in digital technologies should give us hope.

The Climate Technology Centre and Network (CTCN) supports all facets of technology innovation through technical assistance, capacity building and knowledge sharing. Over the past few years, we at the CTCN have observed a rising demand for technical assistance on adaptation and cross-sectoral technologies. Among other initiatives, the CTCN has collaborated with the Adaptation Fund to foster innovation in developing countries through the Adaptation Fund Climate Innovation Accelerator. And the CTCN remains well positioned to support adaptation technology deployment and transfer in developing countries as we embark upon our third programme of work for 2023–2027.

Technology can help us tackle some of the worst impacts of climate change. And innovation is the key to unlocking technology's power to advance adaptation action. Innovation is critical to developed and developing countries alike. It is fundamental to sectors demanding creativity, ingenuity and "thinking outside the box" to address the increasingly complex issues caused and exacerbated by climate change. Each year that passes shows us that no country will escape the impacts of climate change – with each needing to develop, implement and scale up innovative technologies as effectively and efficiently as possible.

The CTCN has partnered with WIPO on this inaugural edition of the *Green Technology Book* in an effort to raise awareness about the breadth of technologies – some of which are truly remarkable – available to us all. They include some that are "proven" and those at an earlier stage of development ("frontier" and "horizon") – which is exciting for the future. Importantly, the *Green Technology Book* affirms what the IPCC has already made clear – many of the technologies and tools we need are already available to us today. It also affirms the imperative to continue our engagement in critical components of technology transfer such as research and development.

We at the CTCN look forward to this collaboration with WIPO in continuing to highlight novel technologies supporting climate solutions across the world. We hope you will be as inspired as we are in presenting them to you.

Dr Rose Mwebaza
Director of the CTCN



All current national policy documents in Egypt consider science and technology to be vital for the prosperous future of the country, particularly in view of its high level of vulnerability to climate change impacts. Egypt's Science, Technology and Innovation Strategy (Egypt STI 2030) revolves around nurturing an enabling environment for STI and improving its ability to produce knowledge efficiently and effectively. This is intended to increase the growth rate of the national economy, develop society sustainably and elevate the quality of life for people.

Egypt's Ministry of Higher Education and Scientific Research has set out strategic objectives and policies aimed at directing research, development and innovation (RDI) projects toward supporting the country's efforts to achieve sustainable development under the climate change crisis. The plan dates back to early 2017 and focuses much attention on allocating the public funds needed to boost green innovation, as well as RDI in renewable energy, water desalination, recycling research, saline and dryland agriculture, biodiversity, more crops per drop of water, the blue economy and the environment.

The Academy of Scientific Research and Technology (ASRT) – Egypt's think tank – has always been capable of providing the vision, roadmaps and policies to pave the way for policymakers to implement Egypt STI 2030. ASRT has always been committed to bringing forward national plans and navigating through the United Nations Sustainable Development Goals to achieve real solutions, not only for national challenges, but global ones too.

As a result of these efforts, the Egypt STI community now runs the biggest RDI and the ASRT pilots renewable energy facilities. These include the MATS concentrated solar power station, a water desalination plant in Borg El Arab city and the China–Egypt Joint PV (photovoltaic) Lab in Sohag. Furthermore, ASRT has supported the implementation of national projects for the conservation of plant genetic resources, the reintegration of mangrove forest and coral reef rehabilitation in the Red Sea.

The *Green Technology Book* is a perfect guide for individuals, organizations and policymakers. It highlights the technological solutions available to meet today's climate challenges, as well as analyzing important current and future innovation trends. This will have a direct impact, in particular on the implementation of adaptation solutions to climate change.

ASRT is proud of its partnership with WIPO and the United Nations in launching this annual Flagship publication promoting green technologies. Our hope is that this can be a vehicle for boosting Egypt's innovation system, at the same time as creating a global awareness of Egypt's role in innovation.

Professor Mahmoud M. Sakr
ASRT President

Acronyms

AfSIS	Africa Soil Information Service
AI	artificial Intelligence
AWD	Alternate Wetting and Drying
CCRO	Closed circuit reverse osmosis
DEVap	desiccant-enhanced evaporative air conditioner
EPO	European Patent Office
ESTs	environmentally-sound technologies
EWS	early warning system
FAO	Food and Agricultural Organization of the United Nations
FDI	foreign direct investment
FI	finance institution
GCF	Green Climate Fund
GDP	gross domestic product
GII	Global Innovation Index
GIS	geographic information system
ICT	information and communications technology
IEA	International Energy Agency
IoT	internet of things
IP	intellectual property
IPC	International Patent Classification
IPCC	Intergovernmental Panel on Climate Change
IPO	intellectual property office
IPR	intellectual property right
LDC	least developed country
MABR	membrane-aerated biofilm reactor
MAR	managed aquifer recharge
MHEWS	multi-hazard early warning systems
MSF	multi-stage flash (desalination)
NAP	National Adaptation Plan
NAPA	National Adaptation Programme of Action
NDC	Nationally Determined Contributions
NRW	non-revenue water
NTFP	non-timber forest product
PCT	Patent Corporation Treaty
ppm	parts per million
R&D	research and development
RO	reverse osmosis
SME	small and medium-sized enterprises
TAP	technology action plan
TNA	technology needs assessment
UTFI	underground transfer of floods for irrigation
UV	ultraviolet
WIPO	World Intellectual Property Organization

Executive summary

Climate change impacts are here. And they are here in force. In 2022 alone, several tragic records were broken and the trend toward more frequent, extreme weather events becomes increasingly apparent with every year that passes. Adaptation is a necessity. Despite decades-long warnings and increasingly desperate calls for action, the world has not yet been able to mitigate climate change. At the current pace of action, it is unrealistic to keep global warming below the 1.5°C that the 2015 Paris Agreement is aiming at under best circumstances.

The role of technology in climate change adaptation

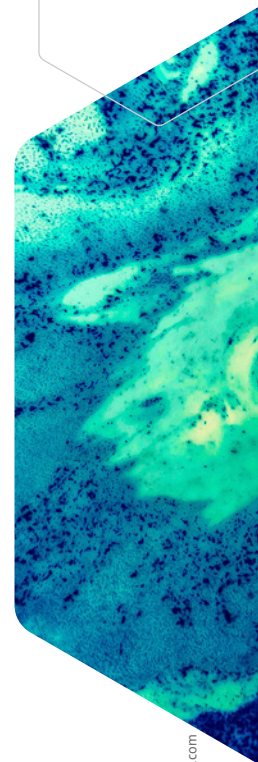
Climate change adaptation aims to increase resilience to climate impacts and reduce vulnerability. Climate change impacts can be difficult to predict and their effects take many forms. It is not only a question of protecting ourselves against extreme events. It is also a matter of adapting to the gradual incremental changes likely to change life from how it is for the majority of us. Climate impacts affect how we grow crops, rear livestock, use water, live with the sea, plan our cities and much more. Also, because many natural ecosystems are under threat, they will need our active support if they are to avoid collapse and widespread species extinction averted. While every country is facing climate change impacts, many developing countries are particularly vulnerable. This could be because like the least developed countries they have only limited means with which to respond. Or it could be because of their geographical setting, which is the case for some small island states. Moreover, as many developing countries were never and are not major CO₂ emitters, actions to mitigate climate impacts may be far less relevant in their case than adaptation measures.

Green innovation and technology have solutions to offer. However, it is not a matter of relying on quick fixes and scaling up of a few major breakthrough solutions. It is instead a matter of developing and deploying thousands of solutions at all levels of sophistication. But it would also be wrong to believe that innovation and technology can solve everything. They cannot. Technology is no substitute for a broad range of fundamental and necessary changes to the way we produce and consume.

In this first edition of the *Green Technology Book* – a new WIPO Flagship publication – we aim to demonstrate that a wealth of innovation and technologies aimed at adaptation is not only being developed but currently available. We look specifically at the major sectors of agriculture and forestry, water and coastal areas, and cities. By showing tangible examples of technologies, we hope that this may inspire others to discover and develop solutions to their own challenges. We have chosen to showcase more than 200 technologies but many more exist which to our knowledge are not inferior to the ones included here. Many more solutions can be found in the WIPO GREEN Database of needs and technologies. Solution providers can freely upload to the database, making it a continually expanding source of innovation, technology and solutions.

Adaptation technologies are available but not always accessible

Although there are many technology-based solutions available, they are not being deployed fast enough to meet the multiple climate change challenges. Adaptation technologies are generally behind mitigation technologies in terms of policy support and funding. However, adaptation is gaining traction. Several funding and support institutions specifically target adaptation. The private sector is also coming onboard, as more ways of assessing the returns to and impact from adaptation investment are developed. One sector seeing a remarkable investment growth is



AgTech. Many countries have also prepared and are now implementing specific adaptation plans. An increasing portion of climate funds is being allocated to adaptation, although still outweighed by mitigation funding. It should also be noted that many of the technologies classified as adaptation technologies also have mitigation aspects, bridging the well-established dichotomy between adaptation and mitigation. Nature-based solutions, where natural processes are utilized or reinforced in order to, for example, protect against floodwaters are gaining ground. Many of those fit under the term “no-regret” solutions providing benefits independent of whether the climate change impacts for which they were designed actually happened as predicted.

A small number of developed countries dominate the innovation space for adaptation technologies, at least when analyzed through patents. Transfer of adaptation technologies to developing countries is happening but at a level well below that of mitigation. This is not so surprising given the often highly advanced technologies being developed for greenhouse gas emissions reduction compared to the very diverse and often less sophisticated solutions needed in adaptation. However, this is not in itself an expression of unwillingness. And what is more, innovation in adaptation technology is growing.

Solutions are created within an innovation ecosystem dependent on many underlying factors. These factors span education, market size and sophistication, and the rule of law. The innovation ecosystem provides the conditions under which an inventor can develop, finance, publicize, market, protect and benefit from an innovation. Intellectual property right is a cornerstone of the innovation ecosystem. And it is through the patenting system that a huge amount of innovation information is made accessible. Technology knowledge can be searched for in several public patent databases. This enables the authorized use of an invention in countries where a patent has been granted, free use in countries where a patent has not been granted, and further development into new patentable inventions.

Thematic areas of the *Green Technology Book*

In this publication, we have focused on three main areas where climate change impacts will be highly significant, namely agriculture and forestry, water and coastal areas, and cities. We have searched for examples of innovation that can provide solutions. They are presented here in order to show what is possible and what can be done.

Technologies are divided into three groups

- Proven technologies which have been around for some time and are well tested;
- Frontier technologies which are new, less well-tested but available; and
- Horizon technologies which are near-future solutions expected on the market within the foreseeable future.

Climate-smart agriculture and forestry

Agriculture and forestry are already heavily influenced by climate change. This manifests itself in changes to cropping season length, higher temperatures and less water, as well as floods, soil salinity and the creation of conditions conducive to pest spread.

In response to these risks, significant developments are taking place in relation to optimized and sophisticated practices. They include using remote and in-field sensing data to provide a detailed understanding of the condition and needs of plants and animals. This information can then direct

The *Green Technology Book* is meant to inspire everyone who needs a solution to a climate change challenge

various machinery to for example dispense an exact dosage of herbicide or water. This reduces the potentially harmful use of such products, saves resources and helps optimize production in a changing environment. Many of these technologies are best suited to larger operations able to access capital for investment in equipment. However, other advanced technologies may not need such large investments. For example, using almost omnipresent mobile devices, advanced data and control technologies can be made relevant in far smaller and poorer contexts. Moreover, simple improvements in techniques can have a significant effect. For example, by saving on water farmers can reduce their vulnerability to climate change impacts. Many of the practices and technologies that come under the broad term *climate-smart agriculture* benefit both mitigation and adaptation alike. Modifying plants and animals to better cope with a changing climate is another active innovation area. But one which, depending on the methods applied, may carry with it the controversy associated with genetic modification.

Water preservation and coastal protection

Water is fundamental to life. Climate change causes too much or too little. For coastal communities, rising sea levels, violent storms and floods, as well as salt water intrusion, are an increasingly common risk. But so is more acidic and warmer oceans, and this calls for strengthened and innovative approaches to marine ecosystem conservation.

Many important innovations can help save water, as well as monitor quality and the state of water reserves. Remote and in-field sensors play an important role in directing other technologies, for example to regulate water use. Improved rainwater harvesting systems and water storage tanks can maintain supply during dry spells. In some countries, an increasing demand for massive water desalination plants is driving innovation toward higher efficiency and lower costs. Water treatment and advanced control of distribution networks combines several innovative technologies to realize impressive water savings. The need for protection against too much water arriving all at once has prompted significant innovation in flood barriers, nature-based stormwater storage and early warning systems. Coastal zones are particularly vulnerable to climate change. As they are often densely populated and important economic zones, the impacts can be far reaching. Advanced modelling of water and sediment movements helps determine what is the most appropriate protection measure, be it beach nourishment, dikes or other hard and soft protection structures. Here also nature-based solutions such as restoring mangrove forests and coral and other reef types can be no-regret solutions with widespread benefits for people and marine ecosystems.

Climate-adapted cities and urban planning

Extreme weather events in recent years have made it abundantly clear that cities and their populations are highly vulnerable to climate change. New thinking – not least new innovation – is required. Heatwaves, heavy rainfall, floods, storms and rising sea levels have already exacted a toll on populations and impacted city budgets.

Advances in urban planning may provide some solutions. For example, incorporating green infrastructure like stormwater drainage and temporarily transforming underground parking and road networks into reservoirs can reduce a city's vulnerability toward heavy rainfall. New materials and green building design can help mitigate heatwave impacts and reduce the heat island effect found in most cities. Many options exist for greening the cityscape. These can help increase surface water infiltration, reduce heat, provide shade and even produce food.

The global progress of adaptation technologies

Searching for solutions from a variety of sources has taught us some important lessons and it is these that inform the following recommendations.

It is clear that the need for adaptation is not confined to developing countries. Climate change adaptation is needed the world over. But the urgency and the diverse solutions required in developing countries is pronounced. A lot of adaptation is directed there already. But often solutions originating in developing countries are less visible when searching through public and globally available channels. This does not mean that innovation is not taking place. Rather, greater visibility is necessary for adaptation solutions originating in developing countries, not least with the aim of transferring solutions between developing countries and the rest of the world.

Supporting the innovation ecosystem is important. It is important not only for innovation creation, but also for receiving, adopting, adapting and developing it further. Supporting the innovation ecosystem pretty much comes down to nurturing all the many factors that enable people's imagination and creativity to flourish and supporting them in developing their ideas into workable and possibly marketable solutions.

Planning for adaptation is complex. Adaptation has highly diverse needs with many unknowns or uncertainties. Therefore a thorough analysis of the risks, costs and benefits before an initiative is undertaken is crucial in order to avoid maladaptation. Using and improving already mainstreamed safeguarding tools such as Environmental and Social Impact Assessments may be a way forward.

Solutions whether simple or sophisticated are required. In many settings, cheap and simple techniques may at first appear the most suitable and feasible. But highly advanced technologies such as satellite imagery and advanced sensor data can through mobile devices make the difference between being prepared or losing everything. They can also help track the development and impacts of climate events in close to real-time.

The *Green Technology Book* is meant to inspire everyone who needs a solution to a climate change challenge. It may also be a valuable source of inspiration for other related needs. We hope it will. We plan this to be an expanding publication with a new edition added every year. We also want to make the WIPO GREEN Database of needs and green technologies an innovation anchor point. One which will grow alongside the publication every time a user uploads a new solution. This will help make even more innovative solutions known to the general public, experts and lay people alike.

Introduction

The *Green Technology Book 2022* is for anyone who has ever wondered about climate adaptation technologies. It is for those seeking concrete solutions with which to adapt their crops, protect their homes and prepare for the adverse impacts of climate change. It is for those curious to know what adaptation technologies are available today and what in the near future – and importantly how to access them. It is for those seeking to invest. It is also for those who design our cities and buildings, and for those who lead our communities, cities and countries along a more resilient path.

By drawing out examples of solutions, we aim to inspire action. The *Green Technology Book* is not a comprehensive collection of all adaptation technologies. Nor does it cover all the areas where adaptation technologies could be relevant. We have chosen instead to focus on three broad areas where we believe climate change adaptation is and will be particularly critical. They are Agriculture and forestry, Water and coastal regions, and Cities.

We welcome greater visibility for local innovation, especially from those countries most affected by climate change. Often the best technology may not be the one on the market but the one available locally but not widely known about, maybe reviving ancient skills and insights. The *Green Technology Book* is more than a catalogue meant for inspiration but a living project where everyone can contribute. The publication links to the free public [WIPO GREEN Database of needs and green technologies](#), where users can create a profile and share their climate solutions and needs.

How we wrote the book

For the purposes of the publication, we considered a broad set of scientific articles, gray literature as well as technology databases developed by private, public and civil society entities and organizations. Search strings included broad terms related to climate adaptation paired with key terms for the three thematic areas, and key terms related to specific technologies (“desalination,” “seawall,” “fertilizer” and so on). Delimiting technology areas was greatly helped by adaptation taxonomies developed by the United Nations Climate Technology Centre and Network (CTCN) (CTCN, 2017), UNEP Copenhagen Climate Centre, and the Korean Green Technology Center (UNEP-DTU, 2021). 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 were uploaded to the [WIPO GREEN Database of needs and green technologies](#), either by the technology owner or by us at WIPO.

How we found the technologies

Throughout the publication, we operate with three concepts: innovation, solution, and technology. While sometimes used almost interchangeably, they do have different meanings. We here utilize the term innovation to cover all intellectual creativity that can result in a solution. Solution broadly means to deploy the output of this innovation to solve a specific challenge. Technology is a broad term, but we apply it more narrowly to any physical entity or technique, with or without additional equipment, that is deployed to resolve a specific challenge. We are primarily interested in a technology’s potential for responding to impacts from climate change. We therefore cover technologies broadly, ranging from the very simple to the highly complex. Often the scope of climate technologies is expanded to include enabling mechanisms such as ownership and institutional arrangements that pertain to the technology (e.g., water user



associations or pricing schemes). While recognizing the importance of such mechanisms, we focus mainly 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 in the *Green Technology Book* is therefore not a recommendation of a particular technology. Technologies presented here should be seen as examples of a technology area, of which there may be many similar offerings which to our knowledge are in no way inferior. Photos illustrating the technologies are used with permission from the technology owners. When a permission could not be obtained, we use relevant stock-photos. Photos of technologies may therefore not represent the actual technology.

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 are suitable have been provided. Such an assessment should always be made with the involvement of local experts and stakeholders. Technology owners can freely upload their technology to the WIPO GREEN Database and thereby become part of the project.

The following criteria were used when selecting technologies for the *Green Technology Book 2022*:

- relevance for climate change adaptation;
- relevance for the three thematic areas: 1) agriculture and forestry, 2) water and coastal regions, and 3) cities;
- pertain 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).

In addition, the following factors were 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, start-ups, research teams, non-governmental organizations and so on);
- no harm principle.

We have divided technologies into three broad groups in order to indicate their maturity and availability. *Proven technologies* have been on the market for some time and therefore rely on a tried and tested concept. *Frontier technologies* are available, but still relatively new, and as such possibly less validated in a real-world setting. *Horizon technologies* are those new concepts being developed and expected to become available within a few years' time; that is to say, technologies that are realistic and likely to become available soon.

When presenting technologies, we have included a few classifiers as an easy guidance to relevance for a reader. We have aimed for a broad representation of technologies at various stages of complexity and readiness. We classify technologies as either a low, medium or high level of complexity. This serves as an indication only and does not follow a strict definition of complexity. It reflects the level of human, material and monetary resources required to implement the solution. Meanwhile, technology maturity was broadly assessed according to

the standard Technology Readiness Level (TRL) definition. According to this measure, horizon technologies have the lowest readiness level but are still close to full development (TRL 3–6), whereas proven and frontier technologies are validated and ready for to be scaled-up if not already done (TLR 7–9).

We hope that you will be inspired by the creativity, ingenuity and diversity of the technologies that we have chosen to present. We welcome feedback and suggestions, which can be sent to us through the WIPO GREEN website.

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Climate change adaptation and technology

Climate change adaptation

In preparation for this inaugural edition of the *Green Technology Book*, WIPO launched a short and simple online survey to gather testament from people around the world on how they are experiencing climate change impacts and what they themselves are doing to adapt. The survey revealed that for many people climate change is already a bitter reality – and that it has been necessary to take action in response. In India, farmers are having to stop farming certain areas due to protracted periods of seasonal flooding. In Ethiopia, Antigua & Barbuda and Switzerland, farmers are finding alternative and innovative new ways of efficiently managing irrigation water in order to make it last longer. In the Philippines and Suriname, cultivators are both switching to crop varieties able to thrive at higher temperatures and introducing agroforestry. In Indonesia, efforts are being made to re-grow large sections of coral reefs severely damaged by coral bleaching.

The testament people gave, although anecdotal, served to underline the seriousness of climate change risks. Furthermore, that the impacts are already upon us and being felt. A first step toward fighting climate change is to recognize and understand the threat. Only then can adaptation be devised and implemented. Actions need to be implemented at all scales, from the personal to the global, utilizing a wide variety of means. The *Green Technology Book 2022* aims to inspire action by showing what solutions are available and for which impacts.

Adapting to climate change

At its core, adaptation aims to increase resilience to climate impacts and reduce vulnerability. It is about finding ways to cope with the immediate threats – higher temperatures, rising sea levels, more frequent and intense abnormal weather events and more. But adaptation is also about making communities more robust and resourceful. About providing them with sufficient capacity and surplus to be able to implement both immediate and longer-term changes. A focus on future climate risks is of particular importance in this respect. This is due to the long-term nature of adaptation as climate impacts unfold over time. It may for example include assisting natural ecosystems in adapting not only to current but also expected future climate effects.

Weather systems are highly complex and imperfectly understood. It is therefore difficult to predict how and when climate change will affect individual regions, localities and resources. One of the likely first signs of climate change disruption is highly volatile food and vital commodity prices. And it is also probable that we are already experiencing them. Disruption will be a key characteristic of climate change impacts. Disruption has many consequences hard to predict, or if predictable, hard to avoid. Therefore preparing a community, a village, a city or a whole country for climate change impacts to a large extent comes down to empowering them to be sufficiently flexible and responsive. Generally speaking, this is much easier to achieve for a wealthy and well-managed society. Therefore a lot of the climate change adaptation efforts in many ways resemble the activities and strategies deployed in international development work for decades. Ensuring that local communities are healthy; that they have an adequate, sustainable, well-maintained and well-managed resource base; produce enough to generate a reliable surplus; and have the power, institutions, capability and knowledge to use that surplus to act, develop and adapt is at the core of both development and adaptation.

Adaptation is already happening

“Human-induced climate change, including more frequent and intense extreme events, has caused widespread adverse impacts and related losses and damages to nature and people, beyond natural

New annual records are set for temperature, flooding, storm, drought, forest fire and other unwanted impacts with a frequency never seen before

climate variability". This is how the current situation was summarized in the latest scientific assessment report by the Intergovernmental Panel on Climate Change (IPCC, 2022 p.7).

Since climate change started to become commonly recognized as a reality that required action, probably in the late 1990s, mitigation of greenhouse gas emissions has been dominating both the debate and the search for solutions. This is hardly surprising. Surely it is better to avoid or mitigate impending impacts than have to live with them. However, global atmospheric CO₂ concentrations have hit a new high of 420 ppm and continue to climb (NOAA, 2022a). Efforts to mitigate climate change have not proven enough of a success – so far. Although it is known with a high degree of certainty what is needed to avoid even moderate impacts, actions and commitments still fall short.

Adaptation is therefore a present and growing necessity. It is particularly critical in those developing countries expected to be hit hardest by climate change, and which lack a strong foundation for adapting. Many never have been and are not major CO₂ emitters, meaning mitigation actions may be much less relevant for these countries than adaptation.

Action is also happening

Adapting to a variable climate is not new. And as mentioned, adaptation has strong linkages to national and international development work and cooperation more generally. But immediate climate change adaptation actions are becoming increasingly urgent, as new annual records are set for temperature, flooding, storm, drought, forest fire and other unwanted impacts with a frequency never seen before. In 2022 for example, extremely intense monsoon rains affected most of Pakistan, displacing millions of people and causing over 1,600 deaths (Reliefweb, 2022b). Somalia is facing a fifth consecutive failed rainy season, making it the worst drought in 40 years against a background of conflict and insecurity (Reliefweb, 2022a). In Europe, heatwave and forest fires have reached unprecedented levels (WMO, 2022a; ScienceDaily, 2022; Kirk et al., 2022). Climate-related extreme events already cost the European Union on average over 12 billion Euro every year (European Commission, 2021), while for China the cost is estimated at USD 44 billion annually (PRC, 2022).

Several countries and regions have already made plans for adaptation. For example, China published its "National Strategy for Climate Change Adaptation" in 2013 (PRC, 2013), replaced this year in 2022 by the 2035 strategy (LSE, 2022; PRC, 2022). In 2015, African heads of state launched the Africa Adaptation Initiative which seeks to unite the continent's countries around support for adaptation action and financing (AAI, 2022). This year the African Union published a climate resilience development strategy laying out guiding principles for policy and governance, means of implementation and for regional cooperation in implementing adaptation in Africa (African Union, 2022). In 2018 the Global Commission on Adaptation was launched by a diverse group of national and international organizations, businesses and scientific leaders. The Commission is mandated to accelerate adaptation by promoting political visibility for adaptation and focusing on concrete solutions (GCA, 2022).

The European Union (EU) published in 2009 a White Paper on adaptation listing several initiatives that were largely implemented. In 2013, this was followed up by an actual Adaptation Strategy (European Commission, 2013), renewed in 2021 (European Commission, 2021). Every EU member state now has a national adaptation plan and adaptation has been mainstreamed into EU policies and long-term budgets (European Commission, 2021).

For developing countries, the United Nations Framework Convention on Climate Change (UNFCCC) National Adaptation Plan (NAP) is a process that helps countries identify medium- and

As of 2021, around 79 percent of all countries had at least one adaptation policy, plan, strategy or law in place

long-term adaptation needs and formulate strategies and programs to address climate change adaptation. By mid-2022, 38 developing countries had produced an NAP (UNFCCC, 2022a). Similarly, for least developed countries (LDCs), national adaptation programmes of action (NAPAs) support the formulation of shorter-term adaptation action plans, mostly lists of prioritized adaptation activities and projects. By 2017, 51 countries had submitted NAPAs (UNFCCC, 2022b). As of 2021, around 79 percent of all countries had at

least one adaptation policy, plan, strategy or law in place (UNEP, 2021a). This indicates a strong and growing global concern over climate change impacts.

In order to determine what are their climate technology priorities, many countries undertake a technology needs assessment (TNA). A TNA analyzes various sectors' technology needs in advance of implementing prioritized climate technologies. A key outcome of the TNA process is a technology action plan (TAP). This is a concise national plan for the uptake and diffusion of prioritized technologies in support of social, environmental and economic development, and climate change mitigation and adaptation (TT:Clear, 2022). Such prioritizations can feed into the National Determined Contributions (NDCs), which are the commitments nations made as signatories to the 2015 Paris Agreement. Of the 148 countries that updated their commitments in 2021, 106 included more, and more detailed, adaptation information, despite this being optional (O'Connor et al., 2022).

Technology and innovation as part of the solution

Climate change impacts are disruptive and to some extent unpredictable, diverse and context-dependent. It is therefore not surprising that climate change adaptation activities and initiatives are so many and varied. They range from simple techniques and practices to highly sophisticated technologies. In adaptation, there is not one or a few central technologies which can be scaled-up to solve most of the challenges. Rather, thousands of solutions of every level of sophistication are required – all pulling in the same direction. But technology and innovation alone cannot solve it all. They are no substitute for a broad range of fundamental and necessary changes to the way we produce and consume. In short, it is not a question of one or the other, but a matter of doing both.

In the *Green Technology Book 2022* we embrace the simple and the complex. Both have a role to play in addressing climate change impacts. Every country's innovation ecosystem has the capacity to devise novel technologies able to provide solutions.

Vulnerable smallholder farmers

Global food production is under threat and this threat will increase. Agriculture occupies 40 percent of the Earth's land surface and consumes 70 percent of the freshwater extracted (Altieri and Koohafkan, 2008). Three-quarters of the world's food is derived from only 12 plant and five animal species (FAO, 2012a). And almost all agriculture is highly weather dependent. These factors make food production particularly vulnerable to climate change impacts, which is why agricultural adaptation technologies feature so strongly in the *Green Technology Book*. When it comes to developing countries in particular, the agriculture sector is dominated by smallholders (i.e., household-based farms with less than 10 hectares of land). Five out of six farms worldwide (83 percent) occupy less than two hectares of land, and 70 percent less than one. Also in China, 80 percent of food supply comes from smallholders (FAO, 2022b). Many smallholders produce primarily for their own consumption. Simple tools are used and yields low, with little surplus to provide against failed harvests. This big group, especially its high percentage of female-headed households, is highly vulnerable to any unpredictable change. But it is also an example of how cheap and simple technologies and techniques, often based on local, traditional and Indigenous knowledge, are required on a massive scale to help them adapt to climate change and develop. For example, simple improvements to reduce post-harvest waste can make a significant

difference. At the same time, sophisticated technologies can also aid smallholder farmers. For example, communication technologies and satellite-based early warning systems can to some degree prepare farmers for extreme weather events and facilitate safety nets such as weather-indexed crop insurance.

Trends in adaptation innovation

This publication provides in its various sections a short summary of major trends in innovation and technology for a particular technology area. Overall, innovation in technologies for adapting to climate change lags far behind that for climate mitigation. This is not surprising, given the often highly technical nature of emissions-reducing technologies. Moreover, the technologies needed for adaptation are necessarily diverse and often less technologically sophisticated. It is also noteworthy that innovation in adaptation, as measured through patents, showed a 6.7 percent average annual growth in the period 1995 to 2015, although this is still well below the 10.9 percent growth in mitigation innovation (Dechezlepretre et al., 2020). The origin of innovation is dominated by high-income countries, likely reflecting the importance of a healthy innovation ecosystem as discussed in Chapter 2. The transfer of adaptation technology is also lower than for mitigation technologies, and lower even than for technologies in general, at least as measured by patents filed in more than one country. Agriculture and coastal protection technologies appear to be the least transferred groups (Dechezlepretre et al., 2020).

Many different kinds of innovation are becoming available in the three main sectors looked at in this publication. The agriculture sector is seeing significant developments in relation to optimized and sophisticated practices. This includes remote and in-field sensing data to acquire a detailed understanding of the condition of plants and animals and their needs. This information can guide a variety of machinery, for example to apply an exact dose of herbicide or water. This reduces the potentially harmful use of such products and saves resources. Many of these technologies best suit larger operations that have access to capital for investment in equipment. However, other advanced technologies may not need such large investment. For example, that mobile devices are used almost everywhere means advanced data and control technologies can be relevant in smaller and poorer contexts. Also, simple improvements to techniques can play a significant role. For example, saving water can reduce a farmer's vulnerability to climate change impacts. Moreover, many of the practices and technologies that come under the term *climate-smart agriculture* defy the dichotomy between mitigation and adaptation by being beneficial for both. Modifying plants and animals to better cope with a changing climate is also an active innovation area. But it is one which, depending on the methods applied, may carry with it some of the controversy around genetic modification.

In water conservation and management, there are many important innovations that help save water, as well as monitor its quality and how much is held in reserve. Here also remote and in-field sensors play an important role, for example in directing other technologies to regulate water use. Rainwater harvesting systems and water storage tanks can maintain supply during a dry spell. And in some countries a growing need for massive water desalination plants is driving innovation toward greater efficiency and lower costs. Water treatment and the advanced control of distribution networks combines several innovative technologies to realize impressive water savings. The need to protect against being inundated by too much water has prompted significant innovation in flood barriers, nature-based stormwater storage and early warning

systems. Coastal zones are particularly vulnerable to climate change. Because they are often densely populated and important economic zones impacts here can be far reaching. Advanced modelling of water and sediment movement can help inform implementation of the most appropriate protection measure, be it beach nourishment, dikes or other hard or soft protection structures. But here also nature-based solutions such as the restoration of mangrove forests, coral and other types of reefs can be no-regret solutions with widespread benefits for people and marine ecosystems alike.

Innovation in adaptation, as measured through patents, showed a 6.7 percent average annual growth in the period 1995 to 2015

No-regret solutions provide benefits regardless of whether the actual climate change impacts will be as detrimental as feared

Cities are highly vulnerable to water, storm and heat stresses. Here innovation may also have solutions. Urban planning incorporating green infrastructure such as stormwater drainage and temporarily transforming underground parking and road networks into reservoirs can reduce a city's vulnerability to heavy rainfall. New materials and green building design can help mitigate the impact of heatwaves and reduce the heat island effect found in most cities. Many options exist for greening the cityscape that can also increase surface water infiltration, reduce heat, provide shade and even produce food.

Risk of maladaptation

Admittedly, we who made this publication are slightly techno-optimistic. However, that is not to say all technology is good in every context. There are risks and potential negative implications associated with new technology.

Planning for adaptation is a difficult process with many uncertainties. Implementing adaptation initiatives can therefore lead to unintended consequences or heightened vulnerabilities (Schipper, 2020). This is what is often referred to as maladaptation. For example, technologies like drip irrigation are efficient and conserve water in comparison to other irrigation systems. However, this very efficiency may also lead to an increase in the amount of land used to cultivate water-intensive crops, resulting in an overall increase in freshwater extraction (IPCC, 2022). In Fiji, seawall construction designed to protect against rising sea levels has put certain population groups at risk. This is because these same seawalls prevent stormwater drainage, alter sediment deposits along the coast and damage the marine ecosystem (Rose, 2020). When implementing new measures and technologies, it is therefore imperative to consider thoroughly any potential negative impacts, not only within but outside the targeted area, and to engage communities on the ground. For larger projects, environmental and social impact assessments (ESIAs) are a legal requirement in most countries.

Do it with nature – not against it

Nature-based solutions and so-called blue-green infrastructure solutions built on natural processes are both multipurpose solutions. That is to say, they seek to realize environmental, socioeconomic and climate resilience benefits simultaneously. They are often a part of no-regret solutions as they provide benefits irrespective of whether the actual climate change impacts will prove to be as detrimental as feared. Nature-based solutions include the restoration of wetlands, mangroves and peatlands; the protection of coastal and marine ecosystems; the sustainable management of soils, farmland and forests; water efficiency; and capacity building. Other examples are urban green spaces, green roofs and walls, and water retention areas (European Commission, 2021; GCA, 2020b; UNEP, 2021a). Nature-based solutions have gained traction in recent years, exemplified by the United Nations Environment Assembly (UNEA-5) 2022 resolution adopting a formal definition (UNEA, 2022). Whenever feasible, solutions should be designed in a such a way as to utilize and reinforce beneficial natural processes rather than work against them.

Fragile complexity

The more advanced, complex, automated and connected technologies become, the greater the risk of fragility entering the system. Complex technologies may require special expertise to maintain and repair, and spare parts can be costly and time-consuming to access. Also greater digitalization and technologies like the smart meters installed in people's homes to manage water consumption raise privacy issues. The increasing interconnectedness of technologies is not evident solely in digitally-connected systems, but also within the very nature of global supply chains. A recent example is the Russian Federation-Ukraine Conflict, which has caused global

prices for chemical fertilizers to rise sharply. This disruption has however re-focused interest on locally-made organic fertilizers and organic agriculture.

Unequal access

Access to adaptation technologies is not equal. This is important because marginalized population groups may be hardest hit by climate change. Marginalization can be the result of many factors including ethnicity, poverty, recent arrival, power relations, social segregation and gender. During a heatwave in India, factors such as caste and gender may impact who gets to stay cool (Poonam, 2022). For high-cost technologies such as solar irrigation pumps it is often rich men farmers who benefit most (IPCC, 2022). Indeed, many adaptation solutions require capital, training and labor which may be a barrier to households whose access to credit is limited, often female-headed ones. Gender may also determine who gets access to weather

and climate information. An FAO-study in India found that only one-fifth (21 percent) of women had access to weather information versus 47 percent of men (FAO, 2015). Gender inequalities are also apparent within the innovation ecosystem. In Kenya, Uganda and Rwanda, fewer than 30 percent of AgTech firm owners are women. In Tanzania, South Sudan and Burundi, none are women. Women's lack of access to digital services such as mobile phones may also create barrier toward many farming technologies (Krishnan, 2022; FAO, 2018). Because of this any investment or project targeting increased community access to adaptation technologies must consider factors such as gender, ethnicity, class, poverty and local power dynamics in order to ensure a broad and equal uptake.

Any investment or project targeting increased community access to adaptation technologies must consider factors such as gender, ethnicity, class, poverty and local power dynamics in order to ensure a broad and equal uptake

Adaptation funding

Adaptation is costly

Adapting to climate change is and will continue to be a major expense. USD 140–300 billion a year by 2030 is the current global indicative cost estimate (UNEP, 2021a), although other recent studies indicate it could be higher. The agriculture, infrastructure and water sectors are likely to be most in need of funds, with demands for supporting ecosystems and the health sector growing. Unfortunately, the gap between available funding and what is needed is widening (UNEP, 2021a). The climate finance goal agreed at COP15 in Copenhagen for USD 100 billion to be provided each year by developed to developing countries by 2020 has yet to be met. And even this includes mitigation finance for the main part (58 percent), although the share for adaptation finance is increasing (OECD, 2022a). The COVID-19 pandemic has also negatively affected climate finance, as governments have had to set aside resources to finance urgent domestic priorities (UNEP, 2021a).

Multiple climate finance sources

Finance for climate change comes in many forms and lacks a uniform definition. Largest funders are the development finance institutions (FIs) followed by corporations and commercial FIs. Developed countries contribute a comparatively small share of their budgets as direct financial support to developing countries. But nonetheless they do provide the bulk of the climate-relevant funding flowing through development FIs and multilateral funds. Together, these cover around 73 percent of climate finance. More than half (61 percent) of climate finance was raised as debt (CPI, 2021). Many developing countries already spend significant resources on adaptation measures, and funding also comes from affected sectors such as real estate, infrastructure and agri-businesses, as climate adaptation is being factored into decisions and investments.

The gap between available funding and what is needed is widening

Under the framework of the UNFCCC, a financial mechanism has been established by which several multilateral climate finance funds channel climate finance to developing countries. The Global Environment Facility (GEF) and the Green Climate Fund (GCF) are the two major operating entities under the climate regime both in scale and focus. Also included are the Special Climate Change Fund (SCCF), the Least Developed Countries Fund (LDCF) and the Adaptation Fund (AF) (UNFCCC, 2022d). The latter fund has a dedicated facility for innovation funding where

innovation projects can apply for small or large grants through their national implementing entities (Adaptation Fund, 2022). The Adaptation Fund Climate Innovation Accelerator (AFCIA) provides small grants to innovators in developing countries. The Accelerator is administered by the Climate Technology Centre and Network (CTCN) and the United Nations Development Programme (UNDP) (CTCN, 2022).

The majority of climate funding goes toward mitigation activities. Of the total USD 632 billion climate finance mobilized globally in 2019–2020, only USD 46 billion – or 7 percent – was spent on adaptation (CPI, 2021). This latter amount was provided almost exclusively by the public sector, as data on private sector adaptation spending is largely unavailable. For developing countries, the adaptation finance share is higher. Of the various funding sources, multilateral climate funds under the UNFCCC provide the highest ratio of adaptation finance and the most adaptation grant financing. Several exclusively fund adaptation, whereas the GCF is committed to a balanced allocation between adaptation and mitigation. Multilateral development banks (MDBs) also have a high ratio of adaptation as opposed to mitigation finance at 35 percent, although they do provide the majority of their adaptation finance as loans, not grants. Of these, the African Development Bank (AfDB) has an adaptation share exceeding 50 percent. Among other multilateral development finance institutions, the Islamic Development Bank (IsDB) went so far as to increase its adaptation share from 40 percent in 2019 to 66 percent in 2020. Overall, adaptation finance is growing. In 2019/20, it was nearly double what it was two years earlier (CPI, 2021).

Bankable adaptation

Adaptation is a long-term process sometimes requiring years to achieve results. Although frequently having a high societal value and providing public goods, adaptation projects may be less attractive financially due to a lower income-generating potential and higher project risks

(CPI, 2021). Compared to mitigation projects where impact can be quantified through emissions reductions, it may be more difficult to measure impacts from diverse adaptation projects requiring different sets of indicators. However, part of the deficit in investments into adaptation relates to a lack of bankable adaptation projects. Therefore there is a need to intensify the transformation of adaptation needs into bankable adaptation projects. Adaptation projects that adopt innovative business models and new technologies and have a clear metric of success are more likely to attract private and impact investment, as

well as climate funds. While this may not always coincide with an urgent or relevant need on the ground, which may continue to rely on financial support from the public sector, the private sector does have an important role to play. Public banks and multilateral funds may offer support by building up developing countries' capacity to formulate what is required for adaptation in terms of finance and technology, as well as define indicators and metrics, develop a business case and de-risk technology applications so as to overcome barriers to investment.

Adaptation funding is often oriented to the longer term, targeting complex and interrelated issues harder to quantify and monitor. But the cost of this should be weighed against the costs

Adaptation costs should be held up against the costs that would otherwise be caused by climate impacts

that would otherwise be incurred by climate impacts. Such costs could be very large indeed and entail losses that are not purely economic such as a reduction in wellbeing, a loss of cultural practices and sites, and a loss of biodiversity. For the latter, the ecosystem-based services approach serves to reveal the socioeconomic value of biodiversity and a healthy ecosystem. The potential costs of climate impacts may be far-reaching and threaten political and social stability, cause displacement, set in motion mass migrations and lead to widespread impoverishment and unrest. The accelerated funding for adaptation initiatives underway needs to match the speed and intensity of the climate impacts already upon us.

2 Innovation and transfer of solutions

The innovation ecosystem

The innovation ecosystem for climate change adaptation

The primary objective of the *Green Technology Book* is to illustrate that innovation and technology has solutions to climate change impacts. These solutions come from inventors working within specific environmental and socioeconomic contexts. When looking broadly on innovation and what brings about high levels of innovation within a society, a surprisingly large number of factors play a part. Some of the countries that consistently score highest in the annual WIPO Global Innovation Index (GII) are Finland, Germany, Netherlands, Republic of Korea, Singapore, Sweden, Switzerland, United Kingdom and United States (WIPO, 2022a). What characterizes these and other countries with high innovation scores is a socioeconomic environment conducive for an inventor who wants to develop, finance, publicize, market, protect and benefit from an innovation.

The innovation ecosystem's many drivers

No single factor determines what makes an innovation-conducive environment. The GII produces global innovation rankings according to 81 indicators. Most concern the factors conducive for innovation (input indicators). For example, local institutions need to provide political and operational stability, high-quality public services and policies, and ensure the rule of law, including a well-functioning intellectual property (IP) rights system. Human capital is a fundamental resource for innovation. Here factors such as education spending, school attendance and performance, tertiary education opportunities, as well as the number of researchers and research spending, are important. Infrastructure must function well. This includes factors such as information and telecommunication technologies (ICTs), electricity and logistics, and environmental performance. Bringing an innovation to market also depends on a number of factors. Internal and external financial resources to fund investments must be available. Markets must be well-functioning, with economies open to international commerce and highly diversified. But also the business community in general must be able to develop, absorb and market innovation. This requires highly qualified employees with opportunities for continued training, R&D funding and linkages to universities and other innovation nuclei.

A large number of factors determine a healthy innovation ecosystem

All these factors combined may create a healthy innovation ecosystem able to provide the adaptation technologies that will be increasingly required. However, the level of adaptation innovation as measured through inventions remains low, as compared both to mitigation and to general invention levels (Hötte and Jee, 2022; Dechezlepretre et al., 2020). Most innovation is concentrated within a few high-income countries. With the exception of some of this select few, countries in general do not seem to generate more adaptation innovation, even when more exposed to climate risks (Dechezlepretre et al., 2020).

This may relate to the low-key role played by adaptation compared to mitigation. Since less attention and fewer supporting policies have been directed toward adaptation solutions, this leaves demand the main driver. Earthquakes and extreme weather events, such as droughts and floods, have been shown to increase innovation in technologies to control such risks

The level of adaptation innovation as measured through inventions remains low

(e.g., quake-proof buildings, drought-resistant crops, flood control and so on) (Hu, Lei et al., 2018). However, because impacts from climate change are diverse, characterized by extreme events and subtle long-term changes, and clearly manifested in some regions and not others, the call for adaptation solutions is not so loud as it is for mitigation technologies. Adaptation technologies show a consistently stronger reliance on public support compared to other technologies, suggesting market demand is weaker (Hötte and Jee, 2022). But as impacts become increasingly persistent and consequential, the need for solutions is likely to grow. And what is more, grow rapidly.

Boosting the innovation ecosystem

Governments wanting to support innovation in adaptation need to have at the front of their mind the drivers behind a well-functioning innovation ecosystem. The difficulty in selecting the best policy instruments is that adaptation concerns a variety of sectors (agriculture, health, infrastructure, water and so on). Also that the sectors present different challenges and involve different actors from the public and private sector.

Environmental policies and regulatory pressure can be an important driver for environmental innovation. Environmental regulation could contain market-based instruments such as subsidies and environmental taxes, as well as non-market instruments such as technology and performance standards. For example, CO₂ emission taxes have been shown to impact innovation in mitigation technologies (Popp, 2019; Bergh and Savin, 2021). And air and water pollution control legislation in the United States during the 1970s was followed by increased innovation in pollution control and treatment technologies (Hötte and Jee, 2022). Government regulations to ensure that new urban developments and infrastructure are fit to resist more extreme weather events are likely to encourage innovation in the same way (Popp, 2019; Hötte and Jee, 2022).

Supporting the market is another option. Market conditions are determined among other things by credit availability and the level of investment. Clean energy research indicates that government support for small and medium-sized enterprises (SMEs) could stimulate commercialization, and that equity and credit availability promotes clean energy production (Popp, 2019). The same could be true for adaptation technology. Moreover, increased funding in the form of subsidies can also increase demand for adaptation technologies.

Another innovation ecosystem driver is the ability to absorb, modify and utilize new technologies under local conditions. Some authors attribute the low level of innovation and technology transfer in part to a lack of such absorptive capacity. Investing to strengthen this capacity could lead to increased development and adoption (Hötte and Jee, 2022). Here education is likely to play a role and further raise consumer awareness and demand.

Fundamental to the innovation ecosystem is a strong research community. Much innovation originates in universities and research agencies, with an important spill-over of innovation and researchers into the private sector. Therefore funding and other support for such innovation nuclei is likely to be an effective driver. Again, in the case of adaptation innovation, such support must be allocated to a wide variety of technical fields, reflecting the diversity of adaptation needs.

Well-managed intellectual property rights (IPRs) are a cornerstone of protection for the rights of the inventor and as such enable continued innovation and development. Local IP offices (IPOs) which grant patents and other IP assets can for example support the deployment of adaptation technologies by fast-tracking patenting processes; assisting inventors in connecting with investors and the market; facilitating access to patent information; and by cooperating with

foreign IPOs and international patenting processes. A collection of initiatives that IPOs can implement in order to support adaptation and green technologies can be found through the WIPO IPO Green initiative (WIPO, 2022c).

Intellectual property in green technology transfer

Transfer of adaptation technologies

Once a new solution has been created, it must next be deployed in the field. This can be a complex and long process. It is one thing to make a new solution work in the controlled environment of a test-field, laboratory or workshop. It is quite another to make it work in diverse and variable environments inhabited by actual users and make it economically attractive at the same time. Financing, legislation, permits, taxes, know-how, spare-parts and IPRs are some of the other factors determining whether a new solution will be successful. This process is commonly referred to as technology transfer. The term covers both the process of transferring technology from the inventor to the market, as well as from one stakeholder to another. Also international technology transfer is not only about transferring technologies from developed to developing countries, but also in the opposite direction, or between high-income countries as well as between lower-income countries.

Often, a new technology will need adapting to local conditions and complex systems may have to be in place for a solution to work properly. This requires the receiving country or region to be capable of creating the right conditions for a solution to work. This can entail having adequate education or training, a stable electricity supply, a communication and internet connection, reliable transport and delivery systems, a functioning legal system, efficient financial services, an openness to trade, a well-functioning and sizeable market, and peace and stability. In other words, many of the same factors determining a well-functioning innovation ecosystem identified in the previous section.

Technology transfer can take different channels, including foreign direct investment (FDI), international trade, joint research, patents and licensing, as well as certain people moving from one place to another.

IPR is an important factor in technology transfer. This is because it clarifies ownership, strengthens an inventor's negotiating position and helps attract partners and financing

IPR is an important factor in technology transfer. This is because it clarifies ownership, strengthens an inventor's negotiating position and helps attract partners and financing. The importance of IPR depends on the technology. If additional inputs are required and infrastructure a major factor in its implementation, such as for instance construction skills for coastal adaptation technology, IP may be less important than for example for health- and agriculture-related adaptation technologies, which often rely on a stronger science base (Hötte and Jee, 2022).

Monitoring international technology transfer can provide an indication of how knowledge and innovation arises and spreads. However, in view of the diverse channels through which innovation travels, assessing international technology transfer levels can be difficult. One indicator using the IPR system is the rate of diffusion, as measured by how many patents are filed in at least two different patent offices. Recent research suggests that the diffusion rate for adaptation technologies is only 17 percent. That is significantly lower than for technologies generally (24 percent), and only around half the rate for mitigation technologies (31 percent) (Dechezlepretre et al., 2020).

Adaptation innovation is concentrated within a few countries, including China, Germany, Japan, the Republic of Korea and the United States. Diffusion from these to other countries is also low and even shrank by half between 2008 and 2015 (Dechezlepretre et al., 2020). Patent data and FDI analyses do not indicate any significant international transfer to low-income countries (Dechezlepretre et al., 2020). That is not to say such transfer does not happen through other channels, for example between universities or companies, which is more difficult to capture.

Since adaptation technologies are highly diverse, it is difficult to draw general conclusions about the apparently limited international technology transfer. The barriers hampering adaptation technology transfer appear to be similar to those hampering other technologies (Dechezlepretre et al., 2020). Among them are the receiving country's technical capabilities, tariffs, weak financial markets making it difficult to obtain loans, and weak legal systems and IPR enforcement. With the need for adaptation technologies expected to rise dramatically in the near future, it will become increasingly important that these barriers are removed to enable a free flow of innovation, knowledge and technology.

Technological knowledge within the patent system

The international IPR system generates technological knowledge

An inventor of a new solution is best served by securing the intellectual property right (IPR) on their invention. The legal protection conferred by an IPR is an important measure against unauthorized use of an invention. It is also in effect a market tool that allows an inventor to recoup investment in R&D through a government-sanctioned competitive advantage for a fixed period of time. Although usually commercially oriented, an IPR may also be relevant for any inventor who wishes to control their invention's release into the public domain but without benefitting commercially. For example, securing an IPR for an invention destined for free public access can ensure that it stays within the public domain, and that no third party can seek to capture the IPR or market the invention commercially. Protection against competing patenting can also be obtained through a defensive publication of the invention, adding it to the state of the art and thereby effectively rendering it un-patentable.



Granting of a patent is a decision by the designated national authority based on national law

The most common way of obtaining an IPR for a new technology is to apply for a patent in those countries where the invention is expected to be marketed and deployed. Granting of a patent is a decision made by the designated national authority based on national law. However, a few regional patent systems do exist and have different degrees of convergence (e.g., African Intellectual Property Organization (OAPI), African Regional Intellectual Property Organization (ARIPO), Eurasian Patent Organization (EAPO), European Patent Office (EPO), Patent Office of the Cooperation Council for the Arab States of the Gulf (GCC Patent Office)).

The Patent Cooperation Treaty (PCT) administered by WIPO (WIPO, 2022e) is an international arrangement that can greatly facilitate obtaining patent protection in various jurisdictions. It also provides for publication of patent applications according to internationally agreed standards.

Once a patent has been granted, the patent holder has exclusive rights to exploit the invention in the country or countries where the patent was granted for a fixed period of time. This is typically 20 years from the filing date. In return for this exclusive right, the inventor has to disclose detailed information on the invention to the extent that it can potentially be carried out by a skilled person. This information is made publicly available from large patent databases. In this way, the international patent system makes an immense body of technological information

The international patent system makes an immense body of technological information and knowledge available to the general public

and knowledge available to the general public. The information enables authorized (licensed) use of an invention in countries where a patent has been granted, free use in countries where a patent has not been granted, and further development into new patentable inventions.

Technology information availability

Several patent databases are available. Two of the biggest are WIPO's Patentscope (WIPO, 2022d) and the European Patent Office's Espacenet (EPO, 2022a). Data collections and search functions vary depending on the nature and purpose of the database concerned. Several

national patent offices have databases of national patents and patents having effect within their territories. Commercial patent databases also exist. Patents can also be explored through dedicated search engines such as Google Patents (Google, 2022) and Lens (Lens, 2022).

Patent databases often contain millions of patent documents. Navigation can therefore be complex. Intricate and highly detailed classification systems are used to organize the many patents. Within these classifications are classes dedicated specifically to green technologies. For example, the IPC Green classification (WIPO, 2022b) is a collection of already existing classes that relate to Environmentally Sound Technologies (ESTs). And EPO has created a so-called Y02 classification for patents that relate to climate change mitigation and adaptation (EPO, 2022b).

A thorough understanding of patent classification systems allows databases to be used to analyze trends in innovation and technological development. Such an analysis uses patents as a proxy for innovation and for identifying where innovation hotspots are located. This can produce complex insights that would otherwise be difficult and costly to obtain. WIPO publishes a number of such technology trends reports based on patent analyses (WIPO, 2022f).

Another reason why patent databases can be difficult to navigate is their sheer size. Dedicated green technology databases may be a more accessible alternative for anyone interested in this particular field. Several exist. Some are dedicated to specific topics, areas or countries, or are commercial enterprises. The WIPO GREEN Database of needs and green technologies is UN-based, freely available and a public database (WIPO GREEN, 2022). It contains a large collection of user-uploaded needs and technologies, as well as relevant patents, knowledge material and expert profiles. The WIPO GREEN Database also serves as a repository for the adaptation technologies collected for this publication. Collected technologies not included in this publication can also be found there. The database provides an always-on auto-matching of needs and green technologies using artificial intelligence (AI) algorithms.

Patent as a solution

A patent is an IPR granted for innovative technological solutions. There is no easy way of knowing whether a patented invention has gone on to be developed into a solution available on the market for licensing, buying or otherwise accessing. Furthermore, a patent contains a detailed description of the invention for which it was granted. But this information can be highly technical and not always written in a way that is readily accessible to the general public. The WIPO GREEN Database of needs and green technologies has a search function dedicated to searching for commercial applications of patents found in the database. AI-supported analyses of a patent's technology description are analyzed and form the basis of a customized internet search for solutions. This "Patent2Solution" search function is available as a helpful option when patents are displayed in the database.

The international system of IPRs – notably the patent system – creates and publishes a huge body of technological information which can be the basis for licensing, deployment and further innovation. It is also a sound basis for knowledge upon which the innovation ecosystem can function and develop.

3 Agriculture and forestry



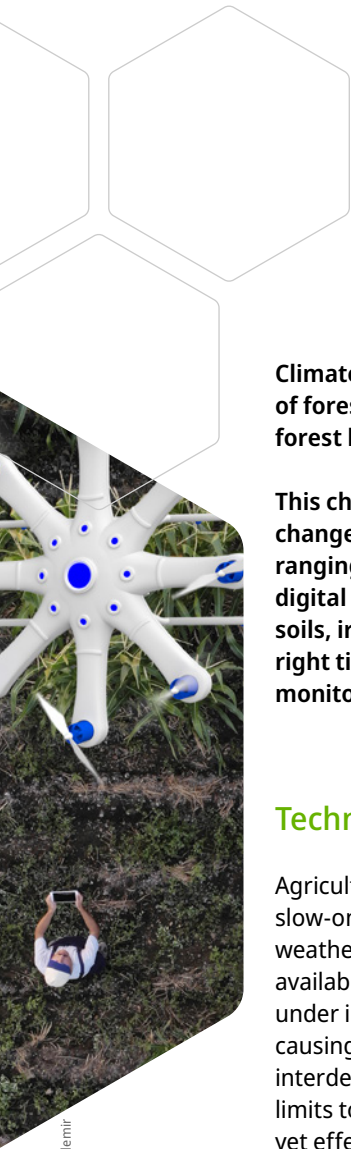


Photo: Getty Images / © baranozdemir

Climate change is leading to multi-billion dollar losses in crop yield and affecting the health of forest ecosystems. Technology can help farmers and forest managers monitor crop and forest health, adapt their practices, use resources more efficiently and manage climate risk.

This chapter presents solutions within agriculture and forestry that respond to climate change impact on food security. It explores proven, frontier and horizon technologies ranging from local and indigenous techniques to urban farming, hydroponics and high-tech digital solutions. Sections take a look at technologies for climate-resilient plants, healthy soils, irrigation, livestock and forest protection. Because the right information at the right time can be vital, the chapter also looks at early warning systems and solutions for monitoring and forecasting climate change impact.

Technological developments and trends

Agriculture and forestry are highly vulnerable to climate change impacts. They are subject to slow-onset stressors like drought, soil salinization and biodiversity loss and exposed to extreme weather events such as forest fires (FAO, 2021c). Moreover, climate change is threatening the availability of resources such as fertile land and irrigation water, putting the agriculture sector under increasing pressure to deliver more with less. Meanwhile, hotter and drier weather is causing tree mortality and forest die-off (Allen et al., 2015). Forest complexity and the major interdependencies and interactions between species and ecosystems at every level is putting limits to the solutions that technology alone can provide. However, solutions can be simple yet effective. Afforestation, agroforestry systems, water harvesting, no-till farming or simply adapting the timing of growing seasons are some answers. But new trends in innovation investments point to a growing interest in technologies that can further accelerate adaptation in the agriculture and forestry sectors.

Precision agriculture and optimization of inputs

With the pressures of climate change on key resources, crop yields need to be optimized per unit area, but also per each food production input. Although cultivated land globally continues to be mainly rain fed, many farmers reliant on irrigation are switching from conventional to water-saving technologies like drip and sprinkler irrigation. Technologies such as sensors and GPS enable precise water and fertilizer application based on a detailed knowledge of things like crop status, livestock health and soil conditions. Other advances include soil spectroscopy and infrared light to analyze soil nutrient and pH levels – data which could help protect the soil and target inputs. Precision agriculture is still mostly confined to relatively high income countries. However, resource efficiency can be achieved without advanced data. Small-scale farms in resource-poor countries are saving substantial amounts of fertilizer by adding fertilizer directly to seeds when sowing, known as microdosing. This saves resources and increases drought resistance (Ibrahim et al., 2016; Sebnie et al., 2020).

An integrated approach to forest resilience

The concept of precision forestry and digital technology use is less established. Many forests are publicly owned or held by small private owners focusing on long-term goals and making conservative or small-scale investments (McKinsey, 2022). Moreover, forest complexity, bound by major interdependencies and interactions between species and ecosystems at every level, limits the solutions that technologies can provide and demand. Often an integrated approach is

needed rather than optimization of a few parameters. A cost-effective approach to resilient forest management has often proven to be strengthening the rights of indigenous peoples to protect and manage their land (FAO and FILAC, 2021; World Bank, 2021a). The planting of climate- and fire-resilient species may also offer some relief, and there have been recent advances in breeding and genetic engineering climate-resilient trees. However, there may be major concerns and risks related to the introduction of new and potentially invasive species regarding any negative effects on ecosystem health. More adaptation efforts are instead placed on developing efficient firefighting technologies, fire forecasting tools and remote sensing of forest health.

A fourth agricultural revolution

A key enabler for technological development in the agriculture and forestry sectors has been the rapid progress in information and monitoring technologies. Many technologies on the market utilize aerial imagery from satellites and drones and data from connected sensors for real-time monitoring and yield predictions. Some farmers are also digitizing crop data. Mobile apps and software allow farmers to keep digital diaries of production cycles, and guide them on when to plant, rotate their crops and harvest. Although adoption has been slow and incremental, there is now talk of a fourth agricultural revolution. One in which the application of technologies such as artificial intelligence (AI), big data analytics, gene editing, internet of things (IoT), robotics and sensors is expected to enable more resource efficiency overall. But some countries lack the underlying technologies and infrastructure – e.g., reliable and fast connectivity – needed to support modern farming technologies. This means that the benefits of this revolution are likely to be spread unevenly across societies and geographies. However, enabling policies are making some technologies more accessible. Examples include patented new gene-editing technologies such as CRISPR becoming available through licensing agreements or disaster forecasting tools becoming subject to “open data” policies making them accessible to global communities.

Urban, indoor and soilless farming on the rise

With urbanization a major trend, interest in urban farming as an adaptation measure is growing. It is estimated that around 15 percent of global food is grown in urban areas (Gerster-Bentaya, 2013). In addition to offering benefits like adding pockets of green to relieve the heat island effect in cities, urban farming enables more local food production systems and reduces transport and complex supply chains. Increasingly irregular and extreme weather patterns are also moving more farming indoors, sometimes as vertical farming when space is scarce. Contrary to earlier expectations, vertical farms may become increasingly relevant beyond cities, with farmers in all areas using it to optimize available land and grow challenging crops (Beacham et al., 2019). This trend is coupled with the increasing popularity of soilless agriculture in the form of hydroponics, aquaponics and aeroponics. These controlled-environment systems protect against unpredictable weather, and to some degree pests, and can be highly water efficient. However, they can have relatively high-energy demands for lighting and pumping systems.

Patents and finance

Biological solutions and off-patent products

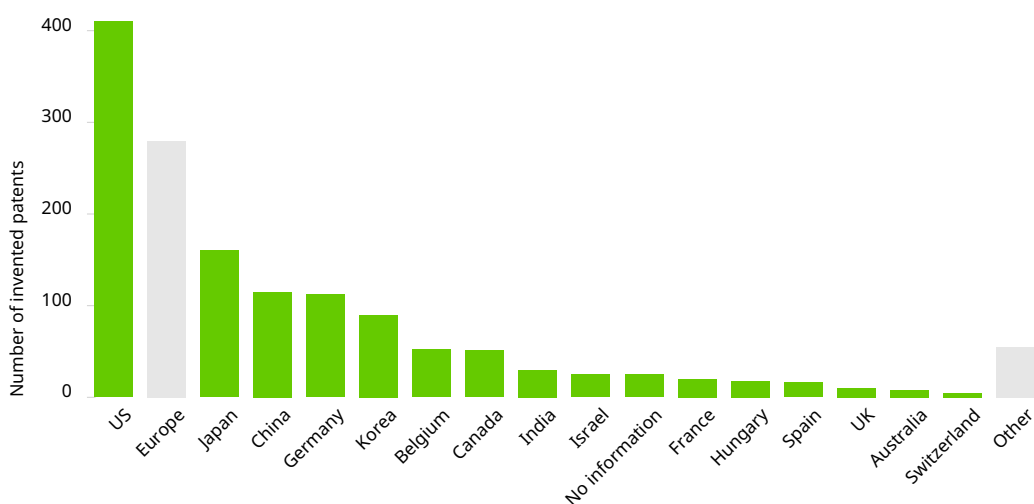
Biotechnology patents have surged since the early 1990s, with sales of genetically-modified seeds reaching similar levels to herbicides (Agrawala et al., 2012; Nishimoto, 2019). For crop

protection, herbicides, insecticides and fungicides have long been a cost-effective way to protect plants and ensure yield stability. However, the negative impact of agrochemicals on soil fertility and the environment has triggered an interest in biological crop protection. Although the market for biological crop protection is still relatively small, sales of new products such as biological control agents (BCAs) and bio-stimulants have been growing faster than conventional crop protection (Shoham, 2020). However, many crop protection products do not have patent protection and many existing patents are due to expire within the next few years. This may present an opportunity for producers to develop products in response to climate change impacts.

Patents point to key trends

Patenting activity in a technology area may be subject to many factors. But it can be a proxy for innovation levels. For instance, patenting activity points to those countries and sectors where innovation ecosystems are thriving. Take composting technologies for an example. More than 60 percent of patents since 2000 were filed in China (Azis et al., 2022). However, a majority of biotechnology patents were filed in the United States (figure 3.1). In general, adaptation-related biotechnology patents are mainly filed in industrialized countries with little cross-border patenting in Asia and South America (Agrawala et al., 2012).

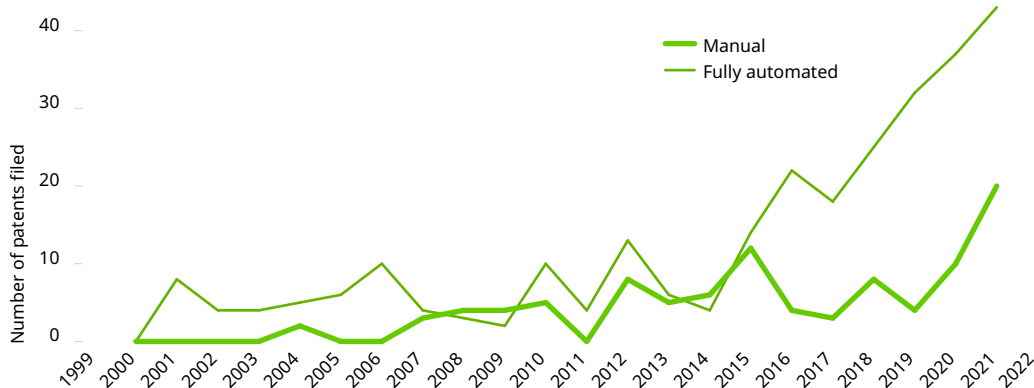
Figure 3.1 Adaptation-related biotechnology patent applications by inventor country, 1990–2007



Note: Based on data extracted from EPO/OECD Worldwide Patent Statistical Database (PatStat).
Source: Recreated from Agrawala et al., 2012.

Patents can also reveal local variations in adaptation technologies and their suitability for various technical, social and economic contexts. Again for composting, the waste type used differs between countries. About 58 percent of patented innovations use general organic waste in electric composters because this suits large, industrial-scale systems. Others rely on food waste (27 percent) followed by animal manure, garden waste or agricultural waste (Azis et al., 2022). Patents in this same sector also reflect wider technological trends, such as increased automation. Partly enabled by lower cost electronics and microprocessors, there has been a move away from labor- and time-intensive manual composting technologies to more automated systems, especially within the last four years (figure 3.2) (Azis et al., 2022).

Figure 3.2 Composting technology trend, 2000–2021



Source: Recreated from Azis et al., 2022.

Investment flows growing, but difficult to assess

For developing countries, agriculture is a key sector in need of adaptation finance (UNEP, 2021a). High material or labor costs can impede uptake and access to climate solutions such as drip irrigation, rainwater storage systems, fertilizers and forecasting technologies. Leasing or direct credit may be available from certain financial institutions. However, the mechanisms behind new technology diffusion on a large-scale are more complex. Global climate finance for adaptation in the agriculture, forestry and other land use (AFOLU) sector was estimated at USD 4 billion in 2020. That same year, an additional USD 2 billion was invested in sector initiatives with adaptation and mitigation objectives (UNEP, 2021a). Multilateral development banks also play a pivotal role, especially in terms of committing funds to low- and middle-income economies. When it comes to forestry, long-term planning and funding can present a challenge, as reforestation or afforestation initiatives may take 20–30 years to evaluate. However, funding in REDD+¹ projects received a large boost in 2020, when USD 309 million was approved by multilateral funds (Heinrich Böll Foundation, 2021). These investments often aim to reduce greenhouse gas emissions. But investments in forest conservation and sustainable forest management also have clear synergies with adaptation.

Diversification of funding sources needed

An important source of funding for adaptation are the three multilateral funds serving the Paris Agreement – the Adaptation Fund (AF), Green Climate Fund (GCF) and the Global Environment Facility (GEF). Around 20 percent of funded projects primarily address the agriculture sector and 20 percent focus on ecosystems, with increased funding for agriculture in the last decade (UNEP, 2021a). Funding often focuses on de-risking adaptation technologies to make them bankable and accessible to local farmers. In Tanzania for example a recent GCF program worth USD 200 million is focused on establishing a lending and de-risking facility for agricultural climate adaptation technologies (GCF, 2022).

The private sector has significant potential as an engine of growth and technology development. Recently there has been a significant increase in venture capitalist investments in agricultural technologies, mainly for start-up and early-stage enterprises. A record year was 2021, with nearly USD 5 billion invested in agtech startups, compared to USD 3.3 billion in 2020. Investments were very diverse and ranged from nitrogen-fixating microbes to vertical farming (Metinko, 2022).

Alternative funding options have existed for some time. They include green bonds and index-based insurance schemes for farmers. One example is the European Bank for Reconstruction and Development “Climate Resilience Bond” dedicated to climate-resilient agriculture and ecological systems. Issued in 2020, to date it represents approximately USD 1.1 billion of funding (GCA, 2021).

1 REDD stands for “Reducing Emissions from Deforestation and forest Degradation”. The “+” represents forest conservation and management.

Climate-resilient plants

Plants must increasingly adapt to salinity, drought, floods and other climate-related impacts. From conventional breeding techniques to CRISPR technology for genetically-modified crops, technology can help increase plant tolerance to such stressors. As a warmer climate helps insects and pests spread, advances in biological pest control and other technologies offer alternatives to pesticides. Meanwhile, integrated farming systems like agroforestry are gaining recognition as a means of strengthening crop resiliency and responding to food security threats.

Plants and food security under threat

Extreme weather events, drought, soil salinization and pests exacerbated by climate change are leading to multi-billion dollar crop yield losses (FAO, 2015; Singh, 2021). This poses significant risks to food security, especially for the most vulnerable countries and populations. At the same time as rising temperatures are extending the growing season and may increase crop yields in Northern altitudes (IPCC, 2022; Nishimoto, 2019), major grain-producing regions are witnessing decreasing productivity. Globally, maize yields are expected to decrease by nearly a quarter by 2050 (Wiebe et al., 2015). But this risk can be reduced. Climate-adapted crops may be one pathway to more resilient food systems. Promoting such crops can have the important added mitigation benefit of improving carbon sequestration and storage in the soil (Climate-ADAPT, 2019c).

Toward climate-resilient plants

All crops are adapted to their particular climate. But the severe consequences of rapid climate change mean some crops must be adapted fast to the new reality. The most basic plant breeding technique is the identification, purposeful selection and propagation of plants that perform better than others. The selection and development of crops with specific properties was once driven by the need to feed a growing population. However, breeding targets are increasingly being defined by a plant's ability to resist climate impacts like drought (González Guzmán et al., 2022). Crop resilience has traditionally been strengthened through techniques that diversify crops and integrate farming systems. These include intercropping, shifting cultivation or agroforestry systems combining crops, trees and even animals on the same land. Other solutions have focused on providing physical protection for crops against external stressors. These include polytunnels (plastic-based crop covers) and insect nets. Meanwhile, the market for crop protection such as agrochemical pesticides has almost doubled in the last 20 years (Nishimoto, 2019). Today, the unprecedented challenges created by growing populations, changing consumer demand and intense climate pressure is accelerating the development of new technologies for climate-resilient species.

The genome era continues

Genetic engineering of crops is not new. However, new gene editing technologies, such as CRISPR/Cas-9, are allowing rapid and more precise modifications. Compared to conventional breeding techniques, these new technologies may enable a faster development of climate-smart crops that improve yields, resist diseases and tolerate stressors like drought, flooding and salinity. While genetically-modified crops (GM crops) combine genes from different sources, gene-editing technologies such as CRISPR can make small changes to a plant's own DNA without introducing foreign genetic material. Although only a few companies own a patent to these key gene-editing tools, they are becoming increasingly accessible through licensing agreements. Users of these innovations are at present mostly found in Europe, Japan and the United States.

Gene editing is increasingly used in combination with other technologies such as indoor farming to optimize yield and reduce costs for relatively expensive farming systems (Cleantech Group, 2021). Technological developments can also be seen in relation to triggering a plant's natural defenses (chemical priming), growth-stimulating bacteria and the study of favorable genetic traits through AI and machine learning. All these technologies are thought to have a huge potential for next-generation agriculture (González Guzmán et al., 2022).



Photo: © Francesco Gallarotti / unsplash.com

From lab to field to fork

Advances in genome editing and other frontier technologies are gaining greater consumer and regulatory acceptance. But they still face legislative barriers and public resistance. Heated debates over the merits and risks of genome editing have closed many markets to GM crops. Short- and longer-term issues need to be carefully considered when modifying plant genomes and cultivating them in the open. They include GM crops becoming invasive, build-up of resistance in target pests, cross pollination to related species, allergens and toxicity (FAO, 2022a). Nonetheless, these innovations may offer part of the solution to feeding a fast-growing world population under uncertain climatic conditions. Simply banning a technology on grounds of principle risks foregoing solutions that could be much needed and even necessary.

Genome editing plants is not simple. It is not necessarily the case that advantages obtained in controlled environments will apply to a crop when used in real-world and less perfect environments. Genome editing has been applied to more than 40 crops across 29 countries. But even though 17 million farmers are planting GM crops (FAO, 2022a), relatively few have been approved for commercialization. Food crops cultivated in some countries using genome-edited varieties are soybean, canola, rice, maize and mushroom. Most have been engineered to tolerate a specific herbicide or be toxic to specific pests (NAS, 2016). When harvested, they cannot be sold on all markets. The major actors in genome-edited varieties are often multinational corporations and large-scale farmers, raising concerns over options and conditions for smallholder farmers (Pixley et al., 2022). With evidence of market concentration, especially in the seeds and biotechnology industries (FAO, 2022a), the success of these technologies must be coupled with efforts to ensure they are safe and beneficial to resource-poor farmers in areas most in need of crops that can withstand climate stresses.



Photo: Getty Images / © SPmemory

Innovation example Seawater rice in China

Rising sea levels lead to salt-water intrusion in groundwater and increased soil salinity. This makes it difficult for crops to survive. Salinity is exacerbated by groundwater depletion driven by droughts and a stronger demand for irrigation. Soils in China are severely affected by this problem (Li et al., 2014). About 100 million hectares of land in China equivalent to the size of Egypt is high in

salinity (FAO, 2017). Farmers traditionally dilute the level of salt in soil by applying large amounts of freshwater. This approach is expensive and wastes water for limited yield improvements. Renowned Chinese agronomist Yuan Longping – dubbed the “father of hybrid rice” – has focused his research on rice since the 1960s. His team eventually made a breakthrough in developing salt-tolerant hybrid rice varieties through advances in traditional breeding techniques; namely, by over-expressing a gene from chosen wild rice more tolerant to salinity. After a series of experiments along coastal areas in China, the hybrids demonstrated high yields of up to 7.5 tons per ha (Qian et al., 2021). In 2020, the Qingdao Saline-Alkali Tolerant Rice Research and Development Center launched an ambitious program of planting the hybrid rice in saline-alkali soils in three cities in Shandong and seven other bases across the country. In 2021, the group was provided with 400,000 hectares of land to expand production of the seawater rice commercially (Bloomberg, 2022).



Photo: Getty Images / © Leila Melhado

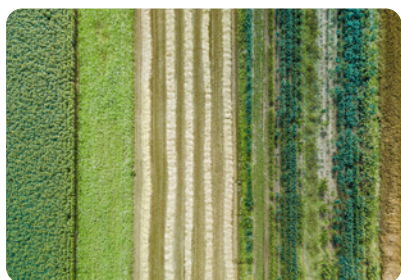
Innovation example Insect-resistant cotton in India

Genetically-modified insect-resistant Bt-cotton was formally released in India in 2002. Genes from the soil bacteria *Bacillus thuringiensis* were inserted into the cotton genome to render it toxic to certain insects. This cotton variety is effective at controlling cotton pests, notably common larvae feeding on the cotton fruiting body. Adoption of the Bt-cotton variety has been hugely

successful. However, the impact of this GM crop has been controversial. There have even been reports of resistance in some pests, leading to massive breakouts (Zafar et al., 2020). However,

within four years of its introduction, insecticide use on cotton halved and average profits approximately doubled. Five years later and 6.8 million farmers planted 9.4 million ha of Bt-cotton hybrids. Bt-cotton has made India a net exporter of cotton for the first time. For five consecutive years after 2005 India produced over 5.1 million tons of cotton, up from 3 million tons annually before its introduction. The seed quality control introduced with the new hybrids was a major factor in their success. There are now some 780 Bt-cotton varieties with several different genetic traits available from more than 30 companies. Competition and regulation has reduced seed prices from an initially very expensive 1,350 Indian Rupee (INR) (USD 17) for a 450 gram packet to nearly half that price. Moreover, increased profitability has enabled investments into other technologies including better pesticides and weeding implements (Zhu et al., 2011).

Photo: Getty Images / © yuelan



Innovation example

Push-pull technology and intercropping in Kenya

Push-pull technology is a novel approach to pest management. The approach entails intercropping plant varieties that repel insects with crops that trap them. It was developed by Kenya's International Centre of Insect Physiology and Ecology (ICIPE) and the United Kingdom's Rothamsted Research in collaboration with partners in Eastern Africa. In this case, the fodder

legume silverleaf desmodium (*Desmodium uncinatum*) was planted together with maize, Napier and Sudan grass. Aromas produced by the desmodium repel (push) pests, for example the maize stemborer, while the scent of the grasses attract (pull) stemborer moths into laying their eggs in the grass instead of the maize. Once hatched, the larvae are trapped in a gummy substance produced by the Napier grass which reduces their survival rate. Furthermore, desmodium roots produce chemicals that stimulate germination of Striga seeds (a major parasite plant also known as Witchweed), but then prevent them from attaching successfully to maize roots. The weed eventually dies and the number of seeds in the soil is reduced. In addition to protecting the maize from pests, silverleaf desmodium and the grasses together provide quality fodder for livestock. Desmodium also gives good ground cover and fixates nitrogen in the soil thereby increasing its fertility. Lastly, biodiversity is improved through the intercropping of multiple species (Khan et al., 2008).

Technology solutions

Proven technologies

Selecting typhoon-resistant crops: Cassava and sweet potato

CGIAR Research Program on Roots, Tubers and Bananas (RTB)

Photo: Getty Images / © jkzsy



Growing cassava and sweet potato in the Philippines was found to substantially increase farmers' climate resilience to extreme weather events such as typhoons. During the super-typhoon Ompong (also known as Mangkhut internationally), which wreaked havoc in the north of the Philippines in 2018, below ground crops such as cassava and sweet potato sustained only limited damage compared to other crops like banana and maize. As a consequence, farmers have started planting root and tuber crops strategically. Cassava has the benefit of

providing long-term food security in the face of variable climatic conditions, by being able to be stored in the ground for up to two to three years. The use of tubers as security against extreme

weather events is a measure that can be taken in any area where such crops can be grown. The Consultative Group on International Agricultural Research (CGIAR) is an umbrella organization for several public agricultural research institutes.

- Contracting type: Locally available materials
- Technology level: Low
- Country of origin: The Philippines
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Marker-assisted breeding of climate-resilient rice

International Rice Research Institute (IRRI)

Photo: © International Rice Research Institute



The International Rice Research Institute (IRRI, a CGIAR member organization) is using a technology known as marker-assisted breeding (molecular breeding) to develop rice varieties that can withstand drought, flooding, heat, cold and soil salinity. The method provides greater accuracy and speed compared to traditional breeding methods, but without the addition of foreign genetic material into organisms. Examples of drought-tolerant rice varieties that have been developed, released and planted by farmers include *Sahbhagi Dhan* in India, *Sahod*

Ulan in the Philippines and *Sukha Dhan* in Nepal. The average yield increase of these varieties is 0.8 to 1.2 tons per ha under drought conditions. Plant breeders have also developed flood-resistant rice through the discovery and isolation of the SUB1 gene that survive being submerged under water for up to 14 days, resulting in a yield increase of 1 to 3 tons for a 10–15 day flood.

- Contracting type: Collaboration
- Technology level: Medium
- Country of origin: The Philippines
- Availability: Asia
- Contact: [WIPO GREEN Database](#)

Polytunnels for extended growing seasons and crop protection

Haygrove

Photo: Getty Images / © Gamet77



Haygrove supplies polytunnels, greenhouses, substrate systems and associated technologies to growers of over 30 crops in more than 50 countries worldwide. The products respond to climate change challenges and protect sensitive crops against weather-related impacts. Polytunnels range from easily constructed, small-scale tunnels for subsistence farmers to multi-base structures with mechanical venting and climate control, measuring up to 5 meters in height. The large air volume in the bigger polytunnels means a slower rate of fluctuation in

temperature. The tunnel fabric diffuses light and provides a thermal heat barrier that creates a more stable, stress-reduced growing environment for plants. Haygrove also provides double-skin tunnels. These can be up to 40 percent more efficient at retaining heat compared to a standard glasshouse without thermal screens.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: United Kingdom
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Agroforestry and integrated farming systems for increased resilience

ICRAF

Photo: Getty Images / © Michele D'Amico supersky77



Agroforestry can increase the resilience of farmlands and landscapes to climatic stress. It does this by integrating trees with crops and/or animals to provide a range of agricultural and forestry products. Agroforestry systems can produce timber and other tree products, as well as food, fodder, fuel and shelter, while protecting ecosystem services provided by the natural environment. Agroforestry can also restore degraded forests and minimize the likelihood of erosion in sloping areas. The Regreening Africa project, led by ICRAF and

supported by the European Union, is restoring over one million hectares of degraded land using agroforestry systems and practices in eight Sub-Saharan countries. ICRAF's "Practitioner's field guide: agroforestry for climate resilience" provides a set of technical instructions and tools for assisting farmers to design, establish and manage climate-resilient agroforestry practices. ICRAF is a CGIAR member organization.

- Contracting type: Locally available materials
- Technology level: Medium
- Country of origin: N/A
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Crop diversification and intercropping

Covers & Co.

Photo: Getty Images / © Michael Edwards



According to the FAO, diversification of crop varieties is a way to hedge against risk of individual crop failure (FAO, 2015). Before modern agriculture's practice of monocropping became widespread, intercropping was a common method offering a sustainable means of growing different crop species together. Under the right conditions, traditional intercropping outperforms modern systems in terms of yield. Legume-cereal intercropping generally outperforms monocrop approaches, as legumes provide additional nitrogen and

phosphorus to the cereal crop. Intercropping is gaining attention once again as a climate-resilient and sustainable farming method (Brown, 2015). Intercropping can be used in mechanized farming, and in the United States strip-cropping is popular where wheat, corn and soybeans are grown alternately, six rows each. Covers & Co. is a cover crop and forage seed supplier specializing in diversified farming practices that improve soil resilience and lower input costs through methods like relay cropping and intercropping.

- Contracting type: Services
- Technology level: Low
- Country of origin: Canada
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Bioinsecticide for pest control in crops

Seipasa



Photo: Getty Images / © Lord Henry Vorton

Sepaisa's bioinsecticides are botanical and microbiological in origin. They offer a natural alternative to conventional synthetic insecticides for use in integrated pest management strategies and organic production systems. Pirecris® is one such bioinsecticide for pest control in crops, particularly for use against aphids, whiteflies and leafhoppers such as the green mosquito. The product has been developed with natural ingredients. When it encounters an insect, it blocks sodium and potassium channels that alter the

transmission of nerve impulses in the insect, provoking hyperactivity and eventual death. More than 80 tests have been carried out on farms all over the world.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: Spain
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Frontier technologies

Improved drought tolerance through seaweed priming

BioAtlantis



Photo: Getty Images / © marjorie anastacio

A plant's natural defense capabilities that can be stimulated to react to pests, diseases or abiotic stress like drought or salinity. Priming technology – a form of pre-conditioning of tissues – can support plants in activating their natural defense systems, so they respond more efficiently to an attack. By applying a chemical agent that stimulates priming, the plant is put on a state of alertness, thereby minimizing any damage caused by a potential stressor (González Guzmán et al., 2022). The biostimulant Super Fifty (SF) produced from the brown

algae *Ascophyllum nodosum* reduces the accumulation of reactive oxygen species (ROS) which typically stifle plant growth during drought. At the same time relative water content remains high in SF-treated plants, while ion leakage – a measure of cell damage – is reduced. BioAtlantis now has a portfolio of six different bioactive priming products for application to crops.

- Contracting type: For sale
- Technology level: High
- Country of origin: Republic of Ireland
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Pest control through release of self-limiting insects

Oxitec



Photo: Getty Images / © kochievrmv

Pest species such as armyworm, which feeds maize, sorghum and millet, have spread due to a warmer climate. It is especially destructive in Sub-Saharan Africa. Armyworm could potentially cost 10 of the continent's major maize producing economies between USD 2.2 and 5.5 billion a year in lost maize harvests (Day et al., 2017). Oxitec is a developer of biological solutions to pest control. They work by releasing genetically-engineered male insects with a self-limiting gene into the environment. When they reproduce with wild

females, their offspring inherit a copy of this gene and do not survive to adulthood, resulting in a reduction in the pest insect population. This method can be used to control many different kinds of insect pests. Oxitec's technology is now being used to combat the autumn armyworm and improve agricultural outcomes.

- Contracting type: For sale
- Technology level: High
- Country of origin: United Kingdom
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Photo-selectivity mesh for crops

Hortomallas



Photo: Getty Images / © mofles

Photo-selectivity meshes on fruit and crop cultivations can provide protection against direct solar radiation, birds and insects. They also help regulate humidity, shade and temperature. This technology consists of plastic nets integrating light-dispersive and reflective elements such as chromophores (scattering of light that favors plant growth). This type of mesh is conducive to floral and vegetable growth as it reduces solar stress while avoiding excess shade. Different colors of mesh can be used to manipulate the radiation reaching

different plants, so as to stimulate plant growth. Blueberries for example produce a higher yield with black netting compared to other colors.

- Contracting type: For sale
- Technology level: Low
- Country of origin: Mexico
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Horizon technologies

Crop gene-editing using CRISPR-based technology

Pairwise



Photo: Getty Images / © wildpixel

Pairwise, an agricultural gene-editing company supported by Monsanto (now Bayer), uses CRISPR proteins to target and edit plant DNA. The goal is to assist farmers by providing new varieties of crops that require less growing resources. The company focuses on CRISPR-Cas9 applied research to improve agriculture, and supports researchers in applying technologies to reduce food waste, limit pesticides and improve drought resistance. The company has also used its gene-editing platform to develop branded leafy greens, seedless berries and pitless cherries.

- Contracting type: N/A
- Technology level: High
- Country of origin: United States
- Availability: N/A
- Contact: [WIPO GREEN Database](#)

Robotized identification of crop characteristics

Alphabet

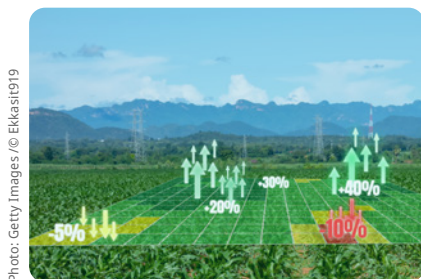


Photo: Getty Images / © Ekkasi919

Google's parent company Alphabet has unveiled prototype robots to gather crop data. These rover robots – collectively nicknamed “Don Rovertro” – measure crop traits by rolling through fields on upright pillars and capturing imagery of each plant. Machine learning is then used to identify traits such as leaf count, leaf area, leaf color, flower count, plant count and pod dimensions. This process of tracking plant characteristics and how they respond to the environment, called phenotyping, is normally slow and manual. The rover

robots reportedly operate at far greater speed, frequency and accuracy than has previously been possible. For example, they have allowed researchers to observe closely the components of bean plant flowering, which are normally too subtle to track. This can aid researchers in better understanding how the bean plant will cope and continue to reproduce in response to different environmental stressors, like hotter temperatures and drought.

- Contracting type: N/A
- Technology level: High
- Country of origin: United States
- Availability: N/A
- Contact: [WIPO GREEN Database](#)

Healthy soils

Adapting soils to the impacts of climate change such as erosion, salinity and reduced moisture content is imperative for a resilient agriculture sector. There is a wealth of knowledge among farmers all over the world on how to maintain healthy soils, from no-till farming and cover crops to the use of fertilizers and composting. This section also presents recent climate change solutions covering nitrogen-fixating microbes, soil analytics and soil conservation in desert environments.

Climate impact on soil health

Soil is frequently discussed in the context of climate mitigation. Specifically the importance of soil carbon sequestration (IPCC, 2019). However, healthy soil is also vital for food security. Soils provide the essential nutrients, water, oxygen and root support needed for plants to thrive. They also ensure good quality, high-yield crops. A strong soil structure, with an abundant and healthy soil fauna, supports key services such as water retention so important for drought resistance. It also reduces runoff which helps hold topsoil in place. Climate extremes of excessive heat, floods, heavy rain and winds cause eroded and saline soils leading to reduced productivity (FAO, 2015). Declining soil moisture is impacting the water cycle and increasing the need for irrigation. Soil improvement, for example soil moisture conservation, is viewed as a climate adaptation measure for both natural and managed ecosystems (IPCC, 2022). Other appropriate adaptation options include those focused on increasing soil organic matter content and reducing soil compaction, erosion and salinization (IPCC, 2019).

Low-tech still going strong

Farmers are rising to the challenge by applying age-old, as well as innovative technologies, to minimize soil disturbance and enhance soil quality. This can mean building shelterbelts, wind breaks or hedgerows to avoid soil erosion. Others practice minimal or no-till farming, or else enrich the soil with nutrients, either with or without the use of agrochemicals. Cover crops grown to protect and enrich the soil rather than for harvesting, such as cereals, grasses and legumes, reduce vulnerability to soil erosion and nutrient loss (IPCC, 2019). Meanwhile, organic fertilizers are experiencing a rapid market growth rate – projected as 6 percent a year up until 2030 (ALM, 2021). Countries like Sri Lanka are on a mission to become the world's first 100 percent organic food producer through their recent nation-wide ban on agrochemicals, such as fertilizers, pesticides and fungicides. This sudden-ban approach and its impacts have been criticized. But it points to a growing awareness of the effects of fertilizers on soil depletion. Alternative fertilizer solutions range from low-tech solutions (including simple mixtures of neem, garlic and urine) and legume planting for nitrogen fixation to advanced technologies for adding nitrogen-fixating bacteria to roots. Another technique becoming increasingly popular in countries where fertilizers might be financially unattainable is microdosing. This is the application of small doses of fertilizer in the planting hole when sowing. This enables quicker root growth while maintaining nutrient and water use efficiency. It can also increase late-season drought resistance (CGIAR, 2021).

Knowledge can be power when it comes to soils

Soil health is increasingly in the spotlight. Farmers are now applying various technologies for monitoring soil conditions such as moisture, temperature and salinity to understand the linkages between soil status and crop productivity. Although access to data does not always influence decision-making, it can help assess risk. Technologies include in situ sensors and probes, or drones and satellite imagery to capture data and alert farmers to changes in soil moisture content at an early stage (FAO, 2015). Such knowledge may also enable real-time adjustments to avoid excessive fertilization and irrigation. It may also help identify the most relevant soil improvement techniques. However, the most advanced technologies are not always the most accessible. Many smallholder farmers cannot afford new soil monitoring and enhancement technologies. And the digital divide among demographic groups and areas further limits access. More start-ups are focusing on bridging such barriers. They include Zenvus Technologies in Nigeria which helps farmers monitor soils, keep electronic farm diaries and access capital and insurance for their crops.

Photo: Getty Images Plus / © Hiramam



Innovation example Microdosing and precision fertilization in Africa

Microdosing is a fertilizer placement technique. It was developed by researchers at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), a CGIAR member organization. By applying small doses of fertilizer in the planting hole together with the seed during sowing, or at the base of plants a few weeks after planting, farmers can use fertilizers more efficiently and

reduce costs. The technique has proven especially appropriate for resource-poor small-scale farmers. The concentration of nutrients at source helps roots grow out quickly while maintaining nutrient and water use efficiency, strengthening the plant in adapting to late-season droughts and other climate variabilities (CGIAR, 2021). A study evaluating the microdosing of fertilizer to sorghum in the Amhara region in Ethiopia pointed to a yield increase of up to 174 percent using only half the recommended amount of fertilizer (Sebnie et al., 2020). Fertilizer microdosing is now becoming the most common technique deployed by smallholder farmers in regions where the high cost of inorganic fertilizer is a constraining factor, particularly across Sub-Saharan West Africa (Ibrahim et al., 2016).

Photo: Getty Images / © AlexRodrigo Brondani



Innovation example Zero and no-tillage farming

These two farming methods disturb the soil as little as possible. Low- or no-till farming increases nutrients in the soil, prevents erosion, water loss and soil compaction, and saves fuel (Bonis-Profumo et al., 2019). Adoption of no-till practices has grown steadily since 1994. No-till, low-till or zero-till farming (also called conservation agriculture in some regions) entails leaving

the soil undisturbed to the extent possible by avoiding tillage before sowing and planting, and leaving plant residues on the soil surface after harvest. It is considered a highly effective soil conservation system. Research shows that sustained no-till practices result in soil, water and biological systems that more closely resemble native soils. No-till systems also provide cover for wildlife if stubble from the previous crop is left to lie on the field (Gellatly and Dennis, 2011). The United States is the country with the largest area under no-tillage, followed by Brazil, Argentina and Canada. The technology is growing rapidly. First adopted on 45 million ha worldwide, no-till farming had grown to cover 111 million ha by 2009. South America has experienced the fastest adoption rates (Derpsch et al., 2010). No-till farming has many benefits, but it relies heavily on herbicides for weed control and termination of cover crops. Innovation is needed, with new research suggesting that integrated weed-management methods could be one solution (Summers et al., 2021).

Technology solutions

Proven technologies

Animal-operated planter-fertilizer

Indústria Mecânica Knapik Ltda Epp

Photo: © Indústria Mecânica Knapik Ltda Epp



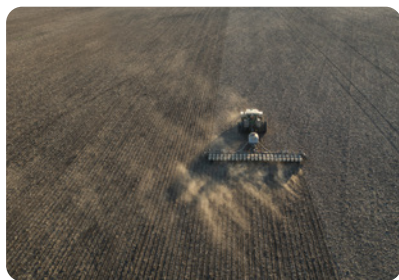
This combined planter and fertilizer eliminates the need for tractors. It is suitable for a no-tillage system because it avoids soil compaction. The device has been developed for animal traction and can be used for direct and conventional planting of beans, corn, soybeans, sorghum and other grains. The product is suitable for small farms and not recommended for areas larger than 15 ha. Internal parts are made of non-corrosive material (plastic, nylon, stainless steel).

- Contracting type: For sale
- Technology level: Low
- Country of origin: Brazil
- Availability: Brazil
- Contact: [WIPO GREEN Database](#)

Simultaneous seed and precision nutrient application

Blacksoil

Photo: Getty Images / © Artist GND photography



Blacksoil provides precision fertilization through a fertilizer formula adapted to the specific agricultural context and seeds in question. The company maps various environments in different regions and develops tailor-made fertilizers to avoid crop damage (phytotoxicity). Liquid fertilizer is applied using a device developed by the company. It enables the simultaneous application of seeds, water and liquid fertilizers to reduce costs and increase efficiency. The machine can be mounted to any seeder. The company currently operates

in Argentina, Australia, Bolivia, Brazil, Paraguay and Uruguay. Expansion through distributors in the different regions is planned.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: Argentina
- Availability: Latin America
- Contact: [WIPO GREEN Database](#)

Fungi-based biofertilizers

BIOPRODUCTS MYCONATIVA LTDA.



MYCONATIVA provides biofertilizer products obtained from fungi. They are designed to improve soils, save water and increase agricultural productivity in the face of climate change. Products can be applied to fruit trees, crops, garden plants, as well as part of various bioremediation and ecosystem conservation efforts. Yegun Nativa® Irrigation (PM) is a bioproduct based on native soil-borne fungi (*arbuscular mycorrhizal*) isolated from the La Araucanía region of Chile. It enables the formation of a symbiotic relationship between fungi and

the roots of plants. The fungus increases water absorption, macro- and micronutrients and plant resistance to disease. This benefits plants that live in environments high in water stress, salinity and contamination. Its formulation allows nutrients to be applied together with irrigation water, without adding harmful elements.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: Chile
- Availability: Chile
- Contact: [WIPO GREEN Database](#)

Liquid biostimulant for soil improvement

Bio-CO₂



This technology consists of a liquid biostimulant for soil improvement. It is in the form of a natural concentrate obtained from *Spirulina cyanobacterium*. The product acts as a humic substance (organic compounds of humus make up an important fraction of soil) in the growth and development of crops. It contains high levels of free amino acids, nutrients, minerals and trace elements with a high cation exchange capacity (a measure of soil fertility). This stimulates microbial activity in soil and provides levels of micronutrients necessary for

plant strengthening and disease resistance. The technology is applied directly on the ground in agricultural and forestry crops in recommended dosages.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: Chile
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Bokashi composting

Bokashi Bran

Photo: Getty Images / © AnSyvanych



Bokashi (Japanese for “fermented organic matter”) is a traditional method of composting commercialized in Japan in the 1980s. Unlike traditional composting, *Bokashi* is an anaerobic process. It requires separating organic materials from oxygen to the greatest extent possible, for example using closed buckets. The technique entails layering organic matter with an inoculant usually consisting of wheat germ, wheat bran or sawdust combined with molasses. A key ingredient is effective microorganisms (EM), such as lactic acid

bacteria or yeast. Although EM Bokashi™ is trademarked, the technology is now available the world over. For example, Bokashi Bran is a company based in South Africa that offers *Bokashi* systems for both home and commercial kitchens. Products include composting ingredients, as well as the vessels required for composting, such as large-scale macerating machines where the food is dewatered before being treated with *Bokashi*.

- Contracting type: For sale
- Technology level: Low
- Country of origin: South Africa
- Availability: South Africa
- Contact: [WIPO GREEN Database](#)

Use of microorganisms to increase soil fertility

Korin Agricultura

Photo: Getty Images / © Sinhyu



Fertibokashi is a commercial biological soil improvement product developed by the Korin Agropecuária Group founded in 1994. It was generated from the trademarked effective microorganisms (EM) bokashi technique.

This involves capturing organisms in nature, especially in inhospitable environments such as volcanoes, the seabed and air currents. Unlike conventional composting, input matter is fermented by bacteria rather than decomposed. The functional groups of microorganisms are selected for their ability to colonize

quickly. The product is currently in its eighth iteration regarding selection of bacteria strains and the fungi and yeasts added to soil to promote mineral absorption by roots.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: Brazil
- Availability: Brazil
- Contact: [WIPO GREEN Database](#)

Frontier technologies

Nitrogen-fixating biofertilizer

Kula Bio



Photo: Getty Images / © Ju Photographer

Kula Bio uses non-genetically-modified organism (GMO) bacteria to fixate nitrogen from the air into soil. It can be applied to both conventional and organic crops and helps farmers improve crop yield and reduce environmental impact. Bacteria in the biofertilizer are fortified before being applied to a field, and provided with a carbon-rich energy source enabling them to build larger reserves of energy and nutrients. By fixing nitrogen on a needs-basis, the risk of nitrogen run-off and waste is reduced compared to industrial fertilizers. When the bacteria run

out of energy, they decompose naturally and in so doing increase organic carbon in the soil.

- Contracting type: N/A
- Technology level: Medium
- Country of origin: United States
- Availability: N/A
- Contact: [WIPO GREEN Database](#)

Nitrogen-fixating microbes

Pivot Bio



Photo: Getty Images / © Tomasz Klejdyś

Pivot Bio Proven is an alternative to conventional fertilizers, in which nitrogen-producing microbes applied during planting form a symbiotic relationship with corn plants. Because it adheres directly to the corn plant root, it does not run off during weather events. Crop nutrition to increase crop yield is provided by the microbes' taking nitrogen from the air to create ammonia, which is then supplied to the plant during critical growth stages. Once the corn begins to grow, bacteria attaches to the plant root and feeds on the sugar in the corn roots. This

startup is scaling up to begin manufacturing, which will happen in a decentralized way nearby farms, in part because the product does not have a long shelf life.

- Contracting type: For sale
- Technology level: High
- Country of origin: United States
- Availability: N/A
- Contact: [WIPO GREEN Database](#)

Soil analytics using genomics and machine learning

Trace Genomics

Photo: Getty Images / © Khanchit Khirisuchalual



Trace Genomics provides advanced chemical and biological analysis of soil using soil DNA diagnostics and metagenomics sequencing. Services support farmers, agronomists and biological product companies in understanding and quantifying the complexity of soil and management practice impact. Improved understanding of soil health and activity can allow for better management decisions such as where crops would benefit from biofertilizers. By understanding the soil microbes responsible for nutrient cycling functions

and soil pathogens, the service may enable better planning in the face of unpredictable growing conditions and crop market prices.

- Contracting type: Service
- Technology level: High
- Country of origin: United States
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Soil conservation in desert environments

Dake Rechsand

Photo: Getty Images / © Sebastian Condrea



In the United Arab Emirates (UAE) and other Middle Eastern countries, a dry environment and high soil salinity pose challenges for agriculture. Dake Rechsand, based in the UAE, provides a “breathable sand” technology named Rechsand, suitable for soil conservation in such environments. This hydrophobic sand enables water to be retained for extended periods by stopping it from percolating down to the groundwater or soils below roots.

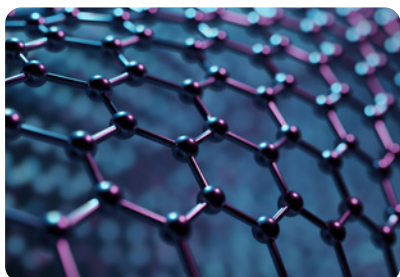
- Contracting type: For sale
- Technology level: Medium
- Country of origin: China, South Africa
- Availability: UAE, United States, India, China, South Africa
- Contact: [WIPO GREEN Database](#)

Horizon technologies

Graphene for improved fertilizer

The University of Adelaide

Photo: Getty Images / © vchal



The material graphene as a fertilizer carrier for improved efficiency has caught researchers' attention, including at Adelaide University. It has been demonstrated that effective slow-release fertilizers can be produced by loading essential trace elements onto graphene oxide sheets. This material enables fertilizer use to be more targeted and increases nutrient absorption of plants (i.e., their ability to bind to more of the nutrient ions plants need). Graphene-based carriers have so far been demonstrated with the micronutrients zinc and copper.

Work is continuing with macronutrients such as nitrogen and phosphate. Current challenges include producing graphene in large quantities at a decent quality (Kabiri et al., 2017).

- Contracting type: N/A
- Technology level: High
- Country of origin: Australia
- Availability: N/A
- Contact: [WIPO GREEN Database](#)

Soil additive for increased water uptake

Carbon Neutral AgSciences

Photo: Getty Images / © JJ Gouin



BountiGel is a soil additive that comes in both powder and granular forms. When added to soil it can absorb up to 150 times its weight in water while retaining its mechanical strength. It does this by holding excess water near a plant's roots as a reserve for dry spells. Researchers at University of California, Davis, found the product caused broccoli crops to grow 30 percent larger despite using 25 percent less water. The product also claims to be eco-friendly and last three years before biodegrading into the soil.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: United States
- Availability: United States
- Contact: [WIPO GREEN Database](#)

Farming technologies

Since the Green Revolution of the 1960s, technological change has played a key role in maintaining agricultural productivity and resilience. Faced by an increasingly complex climate landscape, innovations such as vertical farming and precision farming are attracting interest. The world is now in expectation of what is likened to a fourth agricultural revolution.

Impact of smart farming not yet known

Artificial intelligence, big data analytics, internet of things (IoT), machines and sensors. These are all technologies that could enable a new, more efficient use of resources (USDA, 2022). Major innovative advances are seen in areas such as automation and robotic farming technologies. They are increasing efficiency and yields, for example through targeted application of nutrients and crop-protection inputs. Such “smart farming” can support crop or livestock production cycles through automatic watering, autonomous tractors, drones, robotic harvesters and seeding robots. Smart sensors and automation technology can also provide better awareness of growing conditions. This is important for the optimization of crops to enhance resilience. The availability of advanced technologies is increasing rapidly. But it is yet to be seen which will survive harsh reality tests for ruggedness and reliability and yield tangible results for farmers.

Indoor farming and precision agriculture

Farmers are faced by an increasingly water-scarce agricultural landscape. Soilless farming technologies such as hydroponics, aeroponics and aquaponics² can help address the food security challenge. But start-up and energy costs are often high. Europe is at the forefront, and the global hydroponics market is growing by over 10 percent a year (MarketsandMarkets, 2021). By moving food indoors and avoiding the use of soil, food can be produced irrespective of weather and growing season. At the same time the need for agrochemicals can be reduced. Because this approach to growing food is particularly suited to urban farming, it can be considered a strategy to help build resilient food systems at local and regional levels (Dubbeling and de Zeeuw, 2011). Here, technologies such as indoor and vertical farming in urban areas – and increasingly in rural areas – allow plants to thrive despite limited space, water and soil. Meanwhile, precision agriculture may steer the sector toward a greater reliance on large amounts of data for decision-making. This means applying various sensors, satellites, drones and other technologies to monitor key crop-related variables and direct resources to precisely where they are needed and at the right time. It has been estimated that were 15–25 percent of farms to adopt precision agriculture, global crop yield could be increased by up to 15 percent by 2030 (WEF, 2018). The market for precision agriculture is now expected to be over USD 8 billion by 2027 (Research and Markets, 2022).

Access to technologies still challenging

Technological advances that increase food system resiliency are needed and welcome. But there is a challenge in accessing the technologies. Many farming technology innovations require enabling infrastructure such as fast mobile broadband to access them. Major support is required if these innovations are to reach those regions most in need of climate resilience and adaptation. This needs to be in the form of funding, knowledge on how to use the technologies, supportive policies and local systems of innovation. For innovation and technology to have a real breakthrough in climate-resilient farming, they must be accessible for smallholder farmers and large high-output farms alike, while simultaneously addressing the root causes of climate vulnerability.

2 Hydroponics is using water as a medium instead of soil, whereas aeroponics is growing plants suspended in misted air. Aquaponics combines hydroponics and fish farming in an integrated nutrient recycling system.



Photo: Getty Images / © Ivanmatelyev

Innovation example Floating gardens of Bangladesh

Around a quarter of Bangladesh is flooded for several months of the year. This causes soil salinity and disruption to agriculture. Floating gardens (locally known as *dhap* or *baira*) have been around for hundreds of years in countries like Bangladesh, Cambodia, India and Myanmar. These floating gardens secure a variety of nutrient- and protein-rich foods such as okra, gourds, spinach and eggplant in areas that cannot otherwise be cultivated. They also ensure these foods, survival during periods of increased and erratic rainfall when rivers fill with water. Unlike raised field agriculture on land, floating gardens are raft-like, soilless cultivations. They are made by layering native plants such as water hyacinths about three feet deep. Farmers then plant vegetables inside these floating gardens. As the hyacinths and other host plants decompose, nutrients are released. These feed the crops and vegetables planted within the raft, which in principle resembles a deep-water hydroponic system. Because floating gardens adapt to water movement, they are of particular interest for flood-prone areas with fluctuating river levels. Despite volatilities in yield due to climate impacts, floating gardens provide stability in terms of food production and income, sometimes earning families several times more than traditional rice cultivation. The FAO has declared them a globally important agricultural heritage system. Indigenous floating gardens are undergoing a revival as an effective climate adaptation technology. In 2013, the Government of Bangladesh allocated USD 1.6 million to promote floating farms for climate change adaptation in nearly 50 locations across the country (Tabrizi, 2021).



Photo: Getty Images / © PeopleImages

Innovation example Digital farming technologies in Africa

Farming technologies that rely on robotics, indoor farming systems and biotechnology are yet to reach mass scale in Africa. However, digital technologies are beginning to transform parts of the agriculture sector in many of the continent's countries. One key advance is digital agricultural marketplaces connecting farmers with sellers. Examples include Uganda's AgroMarketDay app which allows farmers to upload pictures of their produce and auction it to the highest bidder, or Kenya's Twiga Foods open-bidding app (Twiga Agent) and its services which now serve 30,000 customers each month (World Bank, 2020a). Among other examples are farming apps that improve access to crop advice and financial offerings to help increase farm productivity. Even blockchain technologies are being used to secure farmers' titles to land or protect against poor quality food products. Only entering the market in early 2000, these types of digital technologies in East Africa attracted investments of over USD 425 million in 2015–2017 (ODI, 2018).

Technology solutions

Proven technologies

Precision planting

Precision Planting



Photo: Getty Images / © Blue Planet Studio

Increased access to agricultural data, such as visualizations of field conditions, can support farmers in optimizing planting and harvesting to maximize yield performance. The company Precision Planting offers a set of digital tools that use historical and real-time data to enable decision-making related to sowing and managing crops. One product is the 20I20 agricultural imaging system. This is software that monitors, controls and diagnoses past and present field conditions (e.g., temperature and humidity of the furrows) to optimize

farming equipment performance. These digital tools can be connected to air seeders and seed drills to provide data for optimal seed distribution and downforce.

- Contracting type: For sale
- Technology level: High
- Country of origin: United States
- Availability: North America, Argentina
- Contact: [WIPO GREEN Database](#)

Precision agriculture through IoT technology and sensors

Libelium



Photo: Getty Images / © Ekkasit919

Libelium provides a wireless sensor network platform whose many uses includes precision agriculture. The technology uses internet of things (IoT) networks in a scalable way to reduce maintenance costs. Smart Agriculture models allow monitoring of multiple environmental parameters involving a wide range of applications. They have sensors for air and soil temperature and humidity, solar visible radiation, wind speed and direction, rainfall, atmospheric pressure and so on. Main applications for the Waspmote Plug & Sense!

model are precision agriculture, irrigation systems, greenhouses, weather stations and more.

- Contracting type: Service
- Technology level: High
- Country of origin: Spain
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Robotic farming technologies for precision agriculture

SwarmFarm Robotics



Photo: Getty Images / © Kinwun

Autonomous robotic farming technologies developed by SwarmFarm Robotics enable precision application of nutrient and crop-protection inputs. The product is a robot for crop row farming. By optimizing herbicide and fertilizer application farmers can respond better to precise needs and forecasted environmental and weather conditions while reducing the amount of agrochemicals used. The company claims to have sprayed, weeded and mowed more than 200,000 acres of farmland within the past two years. This startup also

offers the SwarmConnect ecosystem, a software that enables developers, farmers and partner organizations to program its robots to suit their needs.

- Contracting type: For sale
- Technology level: High
- Country of origin: Australia
- Availability: Australia
- Contact: [WIPO GREEN Database](#)

Container-based hydroponic farms

Grow Pod Solutions



Photo: Getty Images / © zorazhuang

Grow Pod Solutions provides a hydroponic system for growing high-quality specialty crops, specifically leaf crops and varieties of herbs. Compared to field growing, yields can be better regulated and monitored to provide all-year-round outputs while using water more efficiently. Crops are grown in containers in which air and water is filtered. Due to the sealed environment, risk of contamination is reduced. LED lights are designed to emit only wavelengths needed for photosynthesis. The container system is modular and stackable to enable a vertical growing environment for space efficiency.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: United States
- Availability: United States
- Contact: [WIPO GREEN Database](#)

Soilless agriculture with alternative medium

Soilless Farm Lab



Photo: © Soilless Farm Lab

Soilless agriculture is gaining popularity among indoor farmers, urban farmers and those facing harsh weather conditions and limited land space. Instead of using soil, a plant's roots are fed by either a nutrient solution or a substrate such as perlite, peat, moss, coconut fiber or rockwool. Fresh water is provided at a balanced pH level, while oxygen is supplied through air mists, pumps or by creating a space between the plant base and a water reservoir. Soilless Farm Labs is a Nigerian agritech and food-tech startup applying technologies such as

machine learning and artificial intelligence to soilless farming systems. Systems implemented could either be substrate or non-substrate based depending on crop and investment capacity. The company has supported the establishment of 400 hectares of farming. It offers training and capacity building covering a variety of hydroponic techniques including nutrient film techniques, ebb and flow methods and deep-water culture.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: Nigeria
- Availability: Nigeria
- Contact: [WIPO GREEN Database](#)

Vertical aquaponic farms

Dachnik Aquaponics



Photo: © Dachnik Aquaponics

Dachnik Aquaponics provide a turn-key aquaponic system in a tower design. This makes efficient use of space, energy and water for growing plants. The system includes a tank configured to hold fish and nutrient-rich water. The smallest units can grow over 190 plants in 1 square meter of space. The largest (3-trough) commercial unit can grow over 313 plants per square meter of space and can scale to any size. The modular design allows individual units to be put on pause for cleaning and maintenance.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: United States
- Availability: United States
- Contact: [WIPO GREEN Database](#)

Frontier technologies

Agrivoltaics for crop resilience

Arizona Board of Regents on behalf of Arizona State University

Photo: Getty Images / © Miroopa



Agrivoltaics combines agriculture and solar photovoltaic (PV) panels. Growing crops under a PV array has been found to significantly impact three factors affecting plant growth and reproduction – air temperature, direct sunlight and atmospheric demand for water. Shade provided by the PV panels results in a cooler daytime and warmer nighttime temperature than a traditional open-sky planting system (The University of Arizona, 2019). Researchers at Arizona State University have developed various PV unit versions that include

an optical element that redirects light toward the PV cell. This solution diffuses light of certain wavelengths and allows it to pass through the PV unit to facilitate the crops underneath the PV unit to grow. The positioning of solar PVs above crops makes more efficient use of land.

- Contracting type: N/A
- Technology level: High
- Country of origin: United States
- Availability: N/A
- Contact: [WIPO GREEN Database](#)

Self-driving tractors

Northstar Robotics Inc.

Photo: Getty Images / © Igor Borisenko



This technology makes more efficient use of farm inputs and labor to improve crop productivity. Northstar Robotics offers autonomous technologies for a wide range of applications. Through its open hardware and software platform, Northstar Robotics turns existing farm equipment into customized, autonomous field solutions through retrofit kits. These kits can be retrofitted to most equipment since many tractor models use the same steering, acceleration and control systems. An intelligent control system is connected to a

cloud robotics platform. This allows farmers to dictate assignments such as feeding, harvesting, seeding and weeding from a mobile phone app. GPS technology is used to ensure accuracy.

- Contracting type: For sale
- Technology level: High
- Country of origin: Canada
- Availability: Canada
- Contact: [WIPO GREEN Database](#)

Horizon technologies

Agricultural drone for automated fertilizer and pesticide application Kray Technologies



Photo: Getty Images /© baranozdemir

Kray Technologies provides an unmanned drone crop sprayer. This flies over fields to deliver on-demand fertilizer and pesticides. Droplets are charged electrostatically to attach better to crop surfaces, spreading products more evenly as they are released from a low-altitude 1 meter above the crop. The drone can spray approximately 5 km² of crop a day. It is programmed to visualize the field in 3D. This allows it to estimate the required amount of product. The drone uses cameras and LiDAR technology to reconstruct terrain 100 meters ahead with 10 cm precision so as to detect potential obstacles.

- Contracting type: For sale/Service
- Technology level: High
- Country of origin: United States
- Availability: United States
- Contact: [WIPO GREEN Database](#)

Automated harvesting AppHarvest

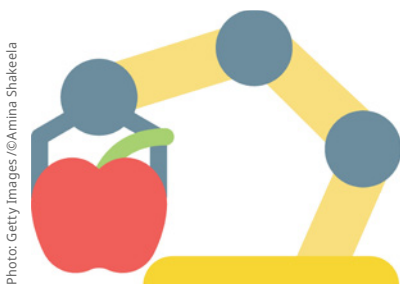


Photo: Getty Images /©Amina Shakeela

Fresh and delicate produce is often handpicked to avoid bruising. Climate change is likely to impact the yields and profitability of farms. Therefore increased automation and labor productivity is becoming an area of interest for high-segment farming markets. Root AI, recently acquired by company AppHarvest, has developed an automated robot named Virgo for picking tomatoes and potentially other types of foods. In addition, the robot is able to evaluate crop health and predict yields. Robots are currently being developed for the network of indoor

farms managed by AppHarvest. Future developments in robotic harvesting may increase the accessibility of such technologies.

- Contracting type: N/A
- Technology level: High
- Country of origin: United States
- Availability: N/A
- Contact: [WIPO GREEN Database](#)

Irrigation

Crop irrigation has been around for millennia. But faced with global water scarcity, a major area of technological development relates to water use efficiency in agriculture. To combat a predicted increase in global irrigation demand, we showcase innovative examples ranging from drip irrigation to water recycling and remote sensing technologies for precise water application.

Demand for irrigation expected to increase

Several studies have tried to understand climate change impacts on water use and irrigation demand. But large uncertainties in prediction remain and regional variations are huge. A recent study projected a two-thirds increase in global irrigation demand by 2080 due to global warming and changing precipitation patterns (Fischer et al., 2007). Another predicts irrigation demand in Brazil will increase by up to a fifth by mid-century due to changes in rainfall (Gondim et al., 2012). Although decreased evapotranspiration in some regions could reduce irrigation demand, global demand overall is expected to grow (Woznicki et al., 2015). Lowered ground and surface water levels and increased evapotranspiration are some of the other key drivers of irrigation demand. Traditionally, surface irrigation technologies such as furrow irrigation (laying water in rows of parallel channels) and basin irrigation (surrounding cropland with embankments and flooding it with water) have been popular methods for watering crops and extending growing seasons, particularly on level land. However, technological developments and improved irrigation management mean potentially more efficient water use. For this reason, the FAO estimates that irrigated land in developing countries will increase by 34 percent by 2030. Yet, agricultural water use will increase by only 14 percent (FAO, 2022c).

Moving toward water-saving irrigation

More contemporary approaches such as drip and sprinkler irrigation are becoming popular worldwide. Here, North America has the biggest market share due to a well-established range of ICT service providers and large consumer base. Asia and the Pacific is expected to have the biggest growth rate over the next decade (CMI, 2022). In Africa, on the other hand, food production is almost entirely rainfed despite the potential of irrigation to boost agricultural productivity by at least 50 percent. In 2010, the area equipped for irrigation made up just 6 percent of all cultivated area in the region (IFPRI, 2010). Many technological developments relate to improved irrigation system efficiency and water loss measures. GPS-based technologies, micro-irrigation systems, self-propelled sprinklers and wireless sensor networks can all enable farmers to apply water and agrochemicals more precisely, corresponding to soil and plants' specific needs (Evans and Sadler, 2008). However, the most effective means of conserving water appears to be through carefully managed deficit irrigation strategies (Evans and Sadler, 2008). This means withholding irrigation during specific crop and plant growth stages. In one example, withholding as much as 87 percent of the irrigation needed by peach trees decreased vegetative growth by 75 percent but without reducing fruit yields (Kozlowski and Pallardy, 1997).

Recycled water to counter water scarcity

Irrigation faces many challenges. Agriculture already accounts for 72 percent of all freshwater withdrawals, mainly for irrigation (FAO, 2021d). Other potential challenges acknowledged by the Intergovernmental Panel on Climate Change (IPCC) include groundwater depletion and increasing soil salinity created by mineral residues from evaporated water (IPCC, 2022). More than half the world's population faces severe water scarcity for at least one month every year, driven in part by irrigated land expansion (Mekonnen and Hoekstra, 2016). This places an uneven burden on the poorest communities, because most irrigated land expansion is likely in low-income countries (FAO, 2021d). As temperatures rise, limited water availability challenges the potential effectiveness of irrigation technologies. In a worst case scenario, the dissemination of high-cost irrigation technologies in areas projected to have more intense drought conditions may lead to maladaptation and increased vulnerability and inequalities, especially in view of weak governance structures (IPCC, 2022). Water scarcity is also driving some farmers to use non-renewable groundwater (FAO, 2021d). In response to water scarcity issues, irrigation technologies using alternative water sources are quickly emerging. Such alternatives, including recycled wastewater, desalinated brackish water or desalinated sea water, could represent new water



Photo: Getty Images / © David McNew / Staff

sources for irrigation. However, unless based on renewable energy sources, their energy demand could lead to a threefold increase in greenhouse gas emissions compared to conventional water use (Qin and Horvath, 2020). Rainwater harvesting for irrigation may offer a more simple, low-cost and sustainable alternative, particularly as supplementary irrigation in arid and semi-arid regions (Velasco-Muñoz et al., 2019).

Photo: Getty Images / © Jurij Savenko



Innovation example The drip irrigation revolution

Modern drip irrigation began in Germany in 1860. Researchers experimented with subsurface irrigation using clay pipes to create combined irrigation and drainage systems. The technology was further developed into a practical surface drip irrigation system by the company Netafim in Israel (Goyal, 2012). Uptake was slow at first. Introduced to California in the late 1960s,

by 1988 a modest 5 percent of land was irrigated using this system. However, by 2010, 40 percent of irrigated land in California was using drip irrigation (Taylor and Zilberman, 2015). Contrary to conventional irrigation methods that range from flooding entire fields or laying water in furrows, drip irrigation systems pump water through long thin plastic tubes stretched across fields. The technology allows for a more precise application of water which travels along the length of the tube and trickles down to the base of plants through hundreds of drippers. This direct application of water also reduces water loss from evaporation. The enormous water-saving potential of drip irrigation technology can be regarded as an important breakthrough in the face of increased drought and water scarcity. It allows farmers to better control timing and the amount of watering. They can reduce water consumption by as much as 60 percent and significantly increase crop yields compared with conventional irrigation methods. New solutions and business models are continuously being developed suitable for off-grid markets, low-income communities and small-scale farmers in Africa, Asia and South America (MIT, 2017; Taylor and Zilberman, 2015).

Photo: Getty Images / © xefstock



Innovation example Off-grid irrigation systems

The cost of large-scale water-saving irrigation systems can often be a significant barrier for low-income countries. For this reason, some of the technologies associated with the Green Revolution have had a relatively low impact in regions such as Sub-Saharan Africa. Low-cost solar-powered irrigation systems could be one solution to a lack of electric grid connectivity in

many countries. It could also protect farmers from fluctuating prices of fossil fuels. Researchers at Stanford University have analyzed solar-powered drip irrigation as a strategy for enhancing food security in the rural Sudano-Sahel region of West Africa. They used household surveys and field data in a matched-pair comparison of villages in northern Benin to study the effect on adoptees of a solar photovoltaic (PV) drip irrigation system. Through the first year of harvest in these villages, they found that solar-powered drip irrigation significantly increased both household income and nutritional intake, particularly during the dry season, and was cost effective compared to alternative technologies (Burney et al., 2010). Several companies and start-ups on the continent are now offering solar-powered irrigation systems to bring water to the fields through business models such as pay-as-you-go or leasing.

Technology solutions

Proven technologies

Low-pressure irrigation system

Netafim



Photo: Getty Images / © DiyanaDimitrova

Netafim is a leading provider of irrigation solutions offering their technologies worldwide. Products include a patented low-pressure drip irrigation system. It includes special low-pressure dripper units and a system of connectors allowing for easy assembly. Drip irrigation saves water as it delivers water – and possibly also nutrients – frequently and in small doses across a field, directly to each plant’s root zone.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: Israel
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Lining irrigation canals

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)



Photo: Getty Images / © ImagineGolf

Lining canals can save substantial amounts of water by minimizing leaks and seepage from irrigation. Because canals enable better distribution of irrigation water, they reduce pumping needs. Therefore they are mainly used to improve efficiency of existing irrigation systems. Various methods exist. An example of good practice is lining the main earthen irrigation canals with concrete and their sides with solid cement blocks. Concrete support posts are then set at intervals and also capped in concrete. Where water is diverted from

the main canal into the secondary canals, the turnouts are built in cement and equipped with gates that open and close as required. Canal lining has been practiced for thousands of years. A number of organizations, including GIZ, have developed manuals and guidelines describing their implementation and benefits.

- Contracting type: Free/Locally available materials
- Technology level: Medium
- Country of origin: N/A
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Alternate wetting and drying (AWD)

International Rice Research Institute (IRRI)



Photo: Getty Images / © wiratgasem

AWD is a water-saving technology that allows farmers to reduce irrigation water consumption in rice fields by 30 percent without yield losses. AWD also reduces the frequency of flooding in rice farms. This improves soil structure quality. Importantly, AWD has been proven to effectively mitigate greenhouse gas emission – specifically methane – from rice production by between 30–70 percent. AWD entails periodic draining of a field to a certain threshold followed by re-flooding. Simple plastic tubes can be used to monitor water depth on the

field. After irrigation, water depth will gradually decrease. When the water level has dropped to about 15 cm below the soil surface, the field should be re-flooded to a depth of about 5 cm. From one week before flowering to a week after, the field should be kept flooded and topped up to a depth of 5 cm as needed. After flowering, during grain filling and ripening, the water level can be allowed to drop again to 15 cm below the soil surface before re-irrigation. AWD does not require advanced equipment other than a well-functioning irrigation management system.

- Contracting type: Free/Locally available materials
- Technology level: Medium
- Country of origin: N/A
- Availability: Lowland rice-growing areas
- Contact: [WIPO GREEN Database](#)

Smartphone control of alternative energy powered irrigation system

TECH-INNOV NIGER



Photo: © Tech-innov Niger

The founder of the TECH-INNOV company, Abdou Maman, has developed a remote-controlled irrigation system adapted to the semi-arid conditions of Niger in West Africa. It introduces the concepts of digital farms and tele-irrigation in support of agricultural development in the country. The company provides farmers with tools enabling them to move away from manual watering and reduce water waste. The system uses mobile devices so farmers can manage irrigation remotely and efficiently. It also integrates hydraulic and meteorological data so farmers can optimize water usage.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: Niger
- Availability: Niger
- Contact: [WIPO GREEN Database](#)

Irrigation control system

Agua Control



Photo: Getty Images / © Simon Skafar

Agua Control provides automatic irrigation control systems. These help farmers decide when to water their crops and by how much. They also help do this more accurately. With local or remote access via mobile phone or internet, this technology can be installed in an orchard connected to a network of sensors, pumps and control valves that allow remote monitoring and water control. The technology is suitable for large-scale applications and can measure and control water flow, as well as save water by detecting pump failures or leakages.

This service also includes the control and monitoring of ground and surface water supplies and assesses soil moisture using sensors. Measurement of soil moisture, along with variables such as evapotranspiration in leaves and climate forecasts, contribute to determining irrigation needs.

- Contracting type: For sale/Service
- Technology level: Medium
- Country of origin: Chile
- Availability: Chile
- Contact: [WIPO GREEN Database](#)

Combined rainwater harvesting and irrigation

Naireeta Services



Photo: © Naireeta Services

Bhungroo is a simple rainwater infiltration and storage technology developed in India. It helps save crops from becoming waterlogged during monsoons and ensures adequate irrigation during dry seasons. The technology contains an underground unit that filters, injects and stores excess farm or storm water. The unit top consists of a cemented pit 1–2.5 meters in diameter and 0.5–1 meters deep. Units are normally installed on land that has a slight tilt or gradient. Connected to the cemented pit is a pipe descending to a depth of up to 100

meters that allows water to be stored in coarse sand soil layers. Water stored in this way during rainy seasons can then be pumped for irrigation during a dry season. Bhungroo technology is handmade from locally available materials and only requires a one-time low capital investment. End users are personally involved in erection, maintenance and self-propagation. The technology is open source to enable scalability.

- Contracting type: Service/Open source
- Technology level: Low
- Country of origin: India
- Availability: Asia
- Contact: [WIPO GREEN Database](#)

Solar irrigation

SunCulture



Photo: Getty Images / © Billy Hustace

Off-grid solar irrigation can enable farmers in remote locations to adapt to a warmer climate and increase farm output. The company SunCulture provides off-grid solar technology. This includes products that combine solar water pumping technology with high-efficiency drip irrigation. Solar irrigation systems are suitable for farms of up to nearly one hectare and include a submersible pump, 50 meter electric cable, solar panels plus fittings. The submersible pump can pump water from a depth of 70 meters and has a flow rate of 50 L/min. Batteries

support up to four lights, two phones and a water pump. Through their Pay-as-you-Grow option farmers can pay for the technology in small monthly installments.

- Contracting type: For sale
- Technology level: High
- Country of origin: Kenya
- Availability: Kenya
- Contact: [WIPO GREEN Database](#)

Frontier technologies

Fertigation and irrigation with treated municipal wastewater

Yamagata University



Photo: Getty Images / © Dinesh Ahir

Water recycling can result in more reliable irrigation water sources. Continuous irrigation systems with treated wastewater could offer a cost-effective way to recycle water and plant nutrients while eliminating mineral fertilizer use. Researchers at Yamagata University have proposed a wastewater reuse practice that provides rice cultivation fertilization and irrigation by supplying continuous treated municipal wastewater throughout the crop season. Water is applied to the soil surface of paddy fields or via an underground pipe

system eliminating mineral fertilizers and saving freshwater. The system has produced rice yields with a higher protein content compared to conventional rice fields using mineral fertilizers and channel water irrigation (Ouoba et al., 2022).

- Contracting type: Research collaboration
- Technology level: Medium
- Country of origin: Japan
- Availability: N/A
- Contact: [WIPO GREEN Database](#)

Precision irrigation intelligence system using remote sensing

Manna



Photo: Getty Images / © Balonci

Manna offers multi-spectral high-resolution satellite imagery of fields the world over. This solution enables precision agriculture. In particular, systems and methods designed for precision irrigation based, among other factors, upon the actual and forecasted water needs of a specified crop. There is a pay-as-you-go pricing model for the remote sensing of fields. The company also provides targeted irrigation recommendations based on a combination of remote sensing data, pin-point weather information and crop-specific models. Soil characteristics

are factored into local growing practices to develop irrigation recommendations for better planning and water stress strategies.

- Contracting type: For sale
- Technology level: High
- Country of origin: Israel
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Horizon technologies

Super moisture absorbent gel (SMAG)

University of Texas



Photo: Getty Images / © LuFeeTheBear

Engineers at the University of Texas have developed an atmospheric water irrigation system based on a new type of soil – super moisture absorbent gel (SMAG). This gel added to soil harvests water from cooler, more humid night-time air. During day-time, solar heating of the soil activates the gels. These then release water into the soil, providing water for plants even in drought-ridden areas. Some of the water distributed through the gels into the soil evaporates, increasing humidity. This could liberate farming systems in underdeveloped and dry

areas from relying on long-distance water and power supplies for irrigation. Depending on crop, approximately 0.1–1 kg of the soil can provide enough water to irrigate about 1 km² of farmland (Zhou et al., 2020).

- Contracting type: N/A
- Technology level: Medium
- Country of origin: United States
- Availability: N/A
- Contact: [WIPO GREEN Database](#)

Robotic irrigation systems

University of California, Merced



Photo: Getty Images / © Edwin Tan

Artificial intelligence (AI)-based and automated solutions could increase water efficiency in the irrigation sector. In one example, researchers at the University of California have explored robotic irrigation solutions for precision application of water grape vines. As infrared sensing and drones for remote monitoring of plant status are already available, researchers looked at ways to exploit that information. This included attaching small, cheap plastic emitters to individual irrigation lines. These were then controlled by devices operated by field workers

or mounted on mobile robots. The devices signalled to the emitters when to adjust the amount of water received by each vine. The robots travel along rows of crops adjusting irrigation flows according to data provided by sensors, thus watering each vine according to need.

- Contracting type: Research collaboration
- Technology level: High
- Country of origin: United States
- Availability: N/A
- Contact: [WIPO GREEN Database](#)

Livestock

Despite demand expected to double by 2050 (Rojas-Downing et al., 2017), livestock is expected to decline globally (Boone et al., 2018). Technologies and climate adaptation solutions often relate to developing resilient feed crop and livestock breeds, pasture rehabilitation and optimizing feed and production systems. This section also presents advances in heat stress detection and management, and digital technologies for livestock monitoring and precision ranching.

Livestock under pressure

Livestock represents approximately 40 percent of global agricultural gross domestic product (GDP) (FAO, 2015). It is often a major savings asset in rural communities. It can also provide an important buffer against climate change and other shocks that impact crop cultivation (FAO, 2015). In addition to being a major greenhouse gas emitter, the livestock sector is a heavy consumer of land used for grazing and food production (FAO, 2012b). What is more, it demands large volumes of increasingly scarce water (Heinke et al., 2020). However, animal dependency on natural resources, together with their increasing exposure to heat stress, makes them vulnerable to climate change. This is due in part to the threatened availability and quality of grazing land, as higher levels of atmospheric CO₂ allow woody plants to expand into grasslands and savannas (IPCC, 2022). The climate impact on rangelands affects different parts of the world differently. For example, the expected increase in production in the United States and Canada contrasts starkly with the projected decrease of nearly 46 percent for West Africa by 2050 (Boone et al., 2018).

To make matters worse, rising temperatures are increasing survival rates for disease vectors and pathogens. Diseases such as West Nile virus, schistosomiasis, bluetongue and Lyme are projected to expand into new areas (FAO, 2015). Most diseases are prevalent in areas that are hot, wet and poor (CIAT, 2014). This points to the importance of recognizing the need for different adaptation approaches and strategies depending on region. In addition, different livestock systems have different functions and meanings for different people, which must also be taken account of in adaptation strategies (Rivera-Ferre et al., 2016).

Improved feeding technologies and animal health

Improved feeding practices could include changing diets, feeding times and frequencies of feedings (Rivera-Ferre et al., 2016). Fodder banks, that is the planting of high-quality fodder species, can supplement feeds during drought. One of the most promising adaptation measures for hedging against drought intolerance, heatwaves, disease and pest outbreaks is diversification of crop varieties and animal breeds or species (Rojas-Downing et al., 2017). New technologies that manage sustainable grazing patterns include drone mustering (i.e., the gathering or directing of livestock) and virtual fencing technologies which help confine animals within a fixed area by emitting shocks from a collar, such as a loud sound, when livestock stray beyond the virtual fence limit (USDA, 2022). Other solutions include community mapping of natural resources and pastures through 3D maps to better manage the collective use of scarce resources.

Similar to precision agriculture, a growing trend is seen in precision livestock farming technologies. High-value data may guide better management of grasslands. And these technologies can offer tools for understanding the relationship between nutrient availability and animal performance. Examples of next-generation technologies in this field include on-animal sensors (e.g., smart tags) and products based on remote-sensing technologies such as satellite imagery (Williams et al., 2021). By using such technologies more knowledge can be gathered about the health of animals. However, consequent changes in livestock management may also make farmers more distant from their animals. Acknowledging and addressing potential threats and opportunities related to animal welfare should therefore be integrated into adaptation planning.

Increasing animals' climate-tolerance

The climate tolerance of livestock could be increased by identifying and strengthening those local breeds that are already resilient. Alternatively, local genetics can be improved through cross-breeding with heat and disease-tolerant breeds (IFAD, 2009). Meanwhile, advances in breeding technologies are now enabling genome modification in livestock by using gene editing



Photo: Getty Images / © Alaa Abo Elmagd / 500px

tools to unlock specific traits. For example, gene editing can limit milk yield reduction during hot weather. Other horizon technologies relate to the genomic evaluation of a young animal's performance, based on tissue samples to determine whether offspring are likely to have certain characteristics such as heat tolerance. This enables farmers to determine breeding values and strengthen climate-resilient traits among their herds. Many livestock breeds are already well adapted to harsh climatic conditions. But there are challenges in widening their diffusion due to trade constraints and limits on their development in structured breeding programs (FAO, 2015). Another key challenge for breeding technologies is how to increase productivity while maintaining animals' climate-tolerance (Rojas-Downing et al., 2017).

Photo: © Hindou Oumarou Ibrahim



Innovation example Participatory 3D mapping for natural resource management in Chad

In Chad, climate change has exacerbated conflicts over natural resources such as grazing land. Indigenous Mbororo communities have worked with meteorologists to map natural resources and ecosystems through 3D participatory mapping to facilitate climate adaptation planning. The 3D participatory mapping workshops help

create pathways and calendars for seasonal grazing patterns to fertilize farmlands. This involves a long process of consultation and consensus-building within the communities. After first identifying a geographical area, inventories are drawn up in which key ecosystem elements are identified. These can include rivers, lakes, mountains, trees, grass and even birds and other fauna which are then located on the 3D maps. Elements are added to the maps using for example pins to represent specific locations, yarns to draw up roads and paint to mark out territories. Once completed, the maps can be digitized and georeferenced through a geographical information system (GIS). By contributing to the communities' understanding of their land, resource-based conflicts are mitigated, even as climate change affects their access to useful resources such as pastures. The maps also support communities in monitoring changes in the most vulnerable ecosystems to strengthen preservation and conservation efforts. With this information, appropriate adaptation plans and restoration activities can be developed in support of local and governmental decision-making (Tabrizi, 2021).

Photo: Getty Images / © Ashley Cooper



Innovation example Improved forage through Chinese Juncao technology

Juncao technology was developed in 1986 by the National Engineering Research Center for Juncao Technology of the Fujian Agriculture and Forestry University (FAFU) in China. This technology uses Juncao grass as a medium or raw material through decomposition and symbiosis with fungi to produce outputs such as mushroom, fertilizer

and livestock feed (IFAD, 2022). The grass itself has several positive climate adaptation aspects: 1) trees are conserved, because mushroom farmers no longer require wood logs as a fungi cultivation medium; 2) Giant Juncao grass is drought tolerant and particularly suitable as livestock fodder; 3) the grass as a feed additive has shown a slight improvement in dairy milk production (Zhou et al., 2021); and 4) the grass can function as a green barrier to control soil erosion and stop desertification (Yuan, 2019). China, with the support of the United Nations Peace and Development Fund and other organizations, is now aiding other countries through the transfer of Juncao technology. It has successfully supported countries, including Fiji, Lesotho, Papua New Guinea and Rwanda, in developing national and scaled-up Juncao farms (UNPDF, 2017). Other forages with similar benefits include Napier and Brachiaria grasses, which have seen a good uptake in countries like Kenya. Meanwhile, in Jordan, adding cactus to livestock feed has been shown to improve milk yields during periods of feed scarcity (SEBI Livestock, 2022).

Technology solutions

Proven technologies

Conservation of climate-resilient indigenous breeds

AgTech Inc.



Photo: Getty Images / © 1001slide

Indigenous livestock breeds (ILBs) are often well-adapted both to their natural environment and abiotic stress. These specific genetic traits enable them to make good use of scarce resources. However, cross-breeding and inbreeding is weakening ILBs. Conservation programs can help halt further dilution of breeds and preserve desirable traits for the future. In situ conservation through live animal breeding farms can be costly. An alternative for small populations is conservation through cryogenic methods where semen and embryos are

frozen to preserve their genetics. Cryoconservation has successfully helped restore threatened species such as the Gaur (Indian bison), an animal that can sweat and tolerates heat well. AgTech Inc. is one company offering cryogenic storage and shipping.

- Contracting type: For sale
- Technology level: High
- Country of origin: United States
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Infrared thermography for heat stress detection

Teledyne FLIR

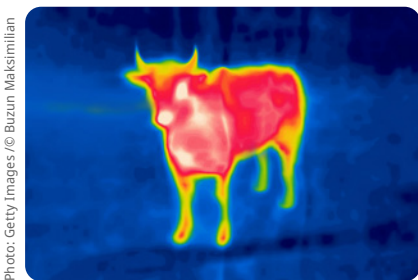


Photo: Getty Images / © Buzun Maksimilian

Teledyne FLIR provides a thermal imaging camera and automatic analysis software. The software uses advanced algorithms to detect infections such as mastitis in livestock before they fully develop. Thermal imaging, or infrared thermography (IRT), is a tool for measuring the surface temperature of livestock by gauging its infrared radiation. It can be used diagnostically to detect infections and heat stress, for example by measuring eye temperature. Thermal imaging presents a less time-consuming and labor-intensive means of measuring animal-based indicators of heat stress compared to other tools such as standard thermometers.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: United States
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Feed additive and monitoring app for heat stress management

Thermo



Photo: Getty Images / © locknloadlabrador

Thermo, part of the CCPA Group, provides feed additives for ruminants, pigs and poultry so they can better manage hot and humid weather. Active ingredients include spices such as chili and turmeric, electrolytes (Na+, K+), green tea and a buffer (bicarbonate). These are added to animal feed to support heat dissipation through the skin, correct electrolyte imbalance and stimulate ingestion. Products are added to animal feed 15 days before expected high temperatures, and then continuously during hot periods. The company also

provides an app that helps estimate the impact of heat stress on the farm and any potential performance loss by using indicators such as the temperature humidity index (THI) and wind speed. Sensors can be connected to the app to get more accurate measurements from the livestock environment.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: France
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Livestock misting and fogging systems

Truemist

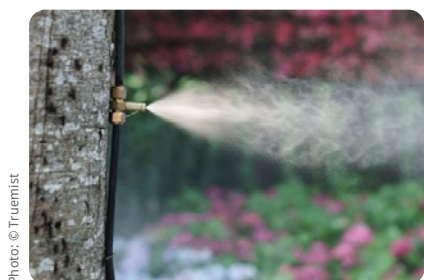


Photo: © Truemist

Misting and fogging systems can help animals in industrial livestock production systems stay cool. Fine droplets of pressurized water from a nozzle evaporate and mix with the air to create a curtain of mist that can reduce temperatures within the immediate vicinity by several degrees. The smaller the water droplets, the better the cooling. Truemist is a company based in India that provides misting and fogging systems for various types of applications including indoor and outdoor misting, ultrasonic misting and aeroponic misting.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: India
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Hydrogreen vertical greenhouse livestock feed farming

CubicFarm® Systems



Photo: Getty Images / © AzmanL

HydroGreen, a division of CubicFarm Systems, has developed automated vertical pastures. The technology consists of an indoor hydroponic growing system that produces livestock feed such as barley and wheat in a controlled environment, minimizing land, water and fertilizer need. The company claims that these vertical pastures reduce greenhouse gas emissions and use 90 percent less water than traditional growing methods. The system is fully automated, including functions such as seeding, watering, harvesting and re-seeding. The technology was developed for drought-prone areas.

- Contracting type: For sale
- Technology level: High
- Country of origin: United States
- Availability: United States and Canada
- Contact: [WIPO GREEN Database](#)

Livestock watering practices

Croc Trough Pumps



Photo: Getty Images / © PaulGrecaud

Livestock watering practice management and improvement is becoming increasingly important as water becomes scarce. The solar-powered Croc trough pump system is designed to aerate, filter and soften water to slow the growth of bacteria, including E. Coli and blue-green algae. The system has been designed to be retrofitted onto existing troughs, including concrete, steel, rectangle or round troughs. The company is continuously performing trials with livestock owners to understand how their pump impacts livestock water consumption, weight gain and walking and

drinking habits.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: Australia
- Availability: Australia
- Contact: [WIPO GREEN Database](#)

Smart tags for livestock monitoring

Ceres Tags



Ceres Tags has developed so-called “smart tags.” Attached to the ears of animals, these tags continuously monitor all aspects of animal behavior, health and welfare, including ambient temperature. For example, they detect and monitor signs of heat stress in cattle. A tag can run 10 years or more without a change of battery and all data is transmitted directly via a constellation of low earth orbit (LEO) satellites. Data can be collected without the need for any other infrastructure. Once received via satellite, all data is transferred and stored

securely in the company’s cloud-based data platform. This enables users to share data with third parties. Tags can be linked to existing herd or farm management software so that the data can be combined, analyzed and visualized.

- Contracting type: For sale
- Technology level: High
- Country of origin: United States
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Livestock control with virtual fencing

Vence



Control of a herd and where it grazes may be important when adapting to climate change and extreme weather. Vence’s digital fencing platform and app enable ranchers to isolate specific areas for grazing, such as protected areas and waterways. Instead of physical fences or corrals, the Vence app uses GPS collars worn by the cattle to rotate a herd through pasture. Collars emit a radio frequency (RF) signal to put a virtual fence around the cattle. The Vence app keeps track of a herd’s location. If any cattle breach the virtual fence an alert is sent

and the animal in question located and collected with the help of GPS tracking. Vence’s virtual fencing technology also enables cattle producers to gather real-time data on their herd. The app monitors animal well-being, collecting data from sensors built into the livestock-worn devices.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: New Zealand
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Frontier technologies

Precision ranching

Pasture.io



Photo: Getty Images / © BALLS

Pasture.io provides a precision livestock farming tool that enables ranchers to continually monitor data remotely. Remote measurements gathered from weather stations, daily satellite flyovers from over 200 satellites and machine learning are used to measure and monitor crucial production information. Data on variables such as pasture cover and pasture growth rate allow farmers to estimate and plan for example the pasture intake per animal and milk production per cow. By forecasting pasture growth, feed shortages can be prevented and

the nutritional value of feeds optimized. By mapping out the farms remotely, sustainable grazing management practices such as break fencing can be applied. This entails setting up temporary fences to protect recently grazed pasture and guide livestock toward nutritious pasture through a more even grazing pattern.

- Contracting type: For sale
- Technology level: High
- Country of origin: Australia
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Genomic evaluation service

Livestock Improvement Corp.



Photo: Getty Images / © bestdesigns

When a calf is born breeding, values such as heat tolerance are determined by the parental average. However, the reliability of this method will remain low (around 30 percent) until herd test data can be incorporated. Genomic evaluation enables early evaluation and a more accurate prediction of a young animal's performance. The Livestock Improvement Corporation (LIC) patented method is based on using a tissue sample to determine whether an animal and/or its offspring are likely to have certain characteristics,

including heat tolerance. By including an animal's DNA information in an evaluation, breeding value reliability is improved by around 60 percent.

- Contracting type: Service
- Technology level: High
- Country of origin: New Zealand
- Availability: New Zealand
- Contact: [WIPO GREEN Database](#)

Horizon technologies

Genetically-modified animals having increased heat tolerance

Recombinetics

Photo: Getty Images / © Kurt Sauer / 500px



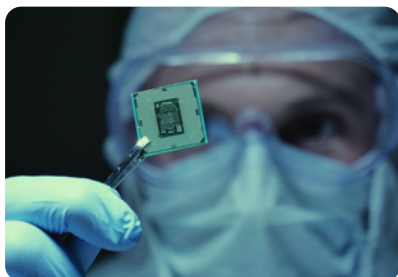
Recombinetics, through its subsidiary Acceligen, works with animal breeders globally to provide precision breeding technologies that address animal health and well-being challenges. The company's aim is to modify the genome in livestock to have superior thermoregulatory abilities and lessen the milk yield reduction during hot summer periods. By making precise changes to animal DNA using a multitude of gene-editing tools including TALENs and CRISPRs specific traits can be unlocked. The company also leverages the animal cell's ability to repair its own DNA during the editing process.

- Contracting type: Service
- Technology level: High
- Country of origin: United States
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Biochips for disease detection

Radox Food Diagnostics

Photo: Getty Images / © HQQualityVideo



Conventional methods for viral detection in livestock can be costly, labor intensive and time consuming. New methods are being developed more suitable for field environments and quick results. Among them biosensors as analytical devices can offer fast and efficient disease diagnostics and even have potential for real-time analysis. For example, Radox Food has developed a test based on biochip array technology that can simultaneously detect six commonly found pathogens in cows. A milk sample is screened for biomarkers

related to common diseases and results provided within two and a half hours of the test being conducted. The technology can also be used to ensure milk quality, for example by detecting antibiotic residue.

- Contracting type: For sale
- Technology level: High
- Country of origin: United Kingdom
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Forest and ecosystem management

Forest and trees are critical to our survival. But climate change is an emerging major threat to forest ecosystems. Pests are on the rise, wildfires raging and thousands of hectares are left with dead or dying trees. Adapting to such brutal and yet complex processes is a great challenge that technology can support by helping monitor health, fight fires and restore forest cover.

Forest loss

Forests provide crucial ecosystem services like oxygenizing and cleaning our air, filtering our water and offering shade and windbreaks. They also protect against erosion and landslides while offering important habitat for a wide range of species. An estimated 1.6 billion people fully or partly depend on these services for their livelihood and resilience (FAO, 2015). Many forest ecosystems have a natural ability to adapt to disturbances. But climate change may pose challenges too big to overcome. Periodic droughts in parts of the Amazon since the 1990s, partly attributable to climate change, have impacted forest productivity to such an extent that the Amazon momentarily turned from a carbon sink into a net carbon emitter (IPCC, 2022). Forest ecosystems, including coastal ecosystems such as mangrove forests, are also subject to wind and water erosion, storm damage and landslides. Along with the millions of hectares of forest lost within the last decade (IPBES, 2019), these impacts are exacerbating land degradation and biodiversity loss (FAO, 2015). In 2015, around 98 million ha of forest was affected by fire and 40 million ha damaged by insects, disease and severe weather events (FAO, 2020).

No-regret solutions a safer choice

The best way to strengthen forests against climate stress is by maintaining healthy ecosystems. However, implementing effective adaptation measures can be challenging. Forest resources require a long-term, holistic management approach. This limits any benefits from adopting technologies or solutions quickly. Recommended measures are often those that generate social or economic benefits irrespective of the climate impact they attempt to address. These so-called no-regret solutions include solutions that help protect against wildfires and pest outbreaks (FAO, 2015). Among these are resilient species, mixed forests and remote sensing-based observations of forest health. As global warming increases wildfire and forest fire risk, forecasting systems are becoming more important than ever (IPCC, 2022). Such modelling systems can be highly complex. But artificial intelligence (AI)-based methods such as artificial neural networks and support vector machines can produce forest fire predictions based on fewer parameters. As this lowers cost, it may enable widespread deployment also in developing countries (Sakr et al., 2011). Remote sensing technologies for monitoring forest and ecosystem impacts are also increasingly becoming subject to “open data” policies, making data accessible for the global community (FAO, 2020). Several new inventions relate to AI and drone use in controlling and fighting forest fires. Meanwhile, some governments are working with local communities to implement indigenous fire management techniques. Horizon technologies include biological control agents, drones for reforestation and afforestation or even biotechnology to mitigate threats through genetic manipulation of desirable traits in forest species (Six, 2019).

Adaptation solutions vary according to ecosystem

Depending on region, different climate adaptation measures may be more suitable and prioritized. Regionally, Africa experienced the highest net forest loss annually in the last decade, followed by South America (FAO, 2020). However, the picture is varied. In the same period some 36 countries, including China and India, saw a net increase in forest cover. Fire prevention measures will be particularly important in the tropical domain, where around 4 percent of forested area was affected by fire in 2015. Over two-thirds of the total forest area affected globally was in Africa and South America (Reytar et al., 2022). This picture may change. Regions such as Europe are also witnessing extended forest fire seasons, with more forest fires than average (JRC, 2022). Meanwhile, the majority of forest damaged by insects, disease and severe weather events is in temperate and boreal domains. In many parts of the world, protecting and strengthening indigenous peoples’ ability to protect and manage their land can



Photo: Getty Images / © RICARDO STUCKERT

be a cost-effective approach to resilient forest management. Compared to areas managed by public and private entities, territories held by indigenous peoples often show better resiliency, emissions reduction and biodiversity protection. In Latin America for example deforestation rates in territories held by indigenous peoples are 50 percent lower (World Bank, 2021a; FAO and FILAC, 2021).



Photo: Getty Images / © Gideon Mendel

Innovation example Indigenous peoples' fire management in Australia

Indigenous communities are often good forest protectors. Relying on non-timber forest products (NTFPs), these communities have successfully opposed mining and logging in support of lower deforestation rates compared to non-indigenous-owned land. Their forest management techniques often include

knowledge of how to manage, benefit from or mitigate forest and bush fires. Peoples such as the D'harawal communities in Australia traditionally practice indigenous fire-management techniques, sometimes known as cultural burns. These techniques involve initiating small controlled fires or cool-burning. This mitigates large natural bushfires by clearing kindling and dead organic material. Cultural burnings may also enhance biodiversity by maintaining and protecting the habitat for mammals, reptiles, insects and birds. These small fires are usually ignited in selected areas between March and July during the early dry season in Australia. As the fires burn gradually, they remove the potential fuel for bigger fires later in the dry and hot season, while the ashes fertilize the ground (Tabrizi, 2021). Australia is now developing programs and working with indigenous fire experts to plan controlled burns to strengthen forest resiliency. Similar initiatives are seen in Brazil. In other places, including Canada, indigenous forest management techniques are under threat from legislation and cumbersome approval processes. This happens when governments fail to acknowledge indigenous peoples' practices and fire management policies are more focused on fire suppression. California for example has banned indigenous use of fire completely (Gershon, 2020), although that might be set to change.



Photo: Getty Images / © UniversalImagesGroup / Contributor

Innovation example Remote sensing forest health

The Forest Condition Monitor (FCM) is an open access interactive online platform that uses satellite imagery to determine the greenness of European forests. This tool, developed by scientists at the Technical University of Munich (TUM), uses color-coded visualizations to determine tree greenness based on long-term rankings and deviations from long-term norms. By monitoring

tree greenness over time, interesting conclusions can be drawn about the state of European forests faced by climate change. For example, forests have been shown capable of regeneration after extreme drought conditions, but with some exceptions. Pine and spruce forests in certain regions for example did not recover after particularly hot periods in 2018 and 2020, indicating substantial long-term heat damage. Data is now available covering individual countries and time periods. This allows identification of hotspots for climate-induced forest stress and decline throughout the continent.³ To fully grasp the causes of observed effects – including climate change – researchers recommend combining data with additional sources of environmental information. These include climate station data, phenological observations and additional high-resolution satellite imagery. When combined, these observations can support decision-making and planning actions to increase forest resilience in the face of climate change (Buras et al., 2021).

3 For data download see interaktiv.waldzustandsmonitor.de.

Photo: Getty Images / © Tomasz Klejczysz



Innovation example Biological control agents

Research institutions are exploring biocontrol measures. This is the use of one living species to control another as a means of protecting forest trees against pests and diseases, often as part of an integrated pest management strategy. Much of the research focuses on the behavior of the biocontrol agents, how they interact with the environment and their genetic and

environmental impacts. For example, the parasitic beetle *Dastarcus helophoroides* has been artificially mass-reared as a natural enemy insect and released into woodlands to control the damaging longhorn beetle species (for which suitable regions are expected to grow because of climate change). Many studies, particularly focused on China, have established this parasitic beetle as a successful biological control agent (Gao et al., 2019; Zhou et al., 2021).

Technology solutions

Proven technologies

Planting flame-retardant trees and plants as natural firebreaks

Conservation International

Photo: Getty Images / © Jia Xin Kwok / EyeEm



Plants with specific flame-retardant properties have been identified in several countries for use in inhibiting forest and bushfires. The Archipelago of New Caledonia, home to around 2,500 native species, has up to 2 percent of land affected by bush fires every year, a situation aggravated by climate change. For generations the indigenous Kanak peoples have recognized the ability of a unique local plant known as the Bourao tree to help halt bushfires. Due to its thick and large leaves, the plant withers but seldom burns. This property means it

can help limit fire spread. Conservation International is piloting a program to plant Bourao as a green firebreak in fire-prone areas. Other suitable trees, depending on location, could include the Mediterranean cypress (BBC, 2015), crepe myrtle, the hybrid flame tree, Persian ironwood, some fruit trees and even some native eucalyptus which is otherwise known to be relatively flammable due to its oil content (GCA, 2020a).

- Contracting type: Collaboration/Locally available materials
- Technology level: Low
- Country/territory of origin: New Caledonia
- Availability: New Caledonia
- Contact: [WIPO GREEN Database](#)

Reforestation and afforestation using climate-resilient species

IUCN

Photo: Getty Images /© Nora Carol Photography



The International Union for Conservation of Nature (IUCN) has recommended selected climate-resilient tree species for reforestation in Indonesia. Species chosen are native to Indonesia's Kutai National Park. Trait analysis of around 250 species of tree and other plants identified species resilient to increasing fires and drought conditions. Two fire-resilient species identified are the native palm *Borassodendron borneense* and the hardwood tree *Eusideroxylon zwageri* known locally as Bendang and Ulin. They are described as

strongly resistant to fire. Other climate-resilient species identified included *Croton argyratus*, *Endospermum peltatum* and *Macaranga gigantea*. It is recommended they are planted in buffer zones around fire-prone areas.

- Contracting type: Collaboration/Locally available materials
- Technology level: Low
- Country of origin: Indonesia
- Availability: Indonesia
- Contact: [WIPO GREEN Database](#)

Pest management through satellite observation

Spacegen

Photo: Getty Images /© jantechros



The most efficient way of monitoring large forests is through satellite observation. This helps in detecting early warning signs that trees are suffering water or heat stress and therefore more susceptible to pest attack. Satellite observations also allow forest managers to spot early signs of infestation, such as dryness, foliage loss or dieback. Spacegen provides forest growth surveys based on remote sensing data from satellites or drone-based LiDAR. Data covers the species composition, average height, canopy density and crown width of individual

trees. Remote sensing data combined with various ground-collected geographical and field survey data are used by Spacegen to detect forest insect and pest risks over a large area in a timely manner (even in real time). This enables an evidence-based allocation of resources for early reporting and prevention to minimize economic damage to the forest.

- Contracting type: Service
- Technology level: High
- Country of origin: Hong Kong, Malaysia
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Wildlife crossings and underpasses

Veidekke



Photo: Getty Images / © Jacek Pacholczyk

Studies on wildlife adaptation to climate change highlight the importance of wildlife corridors and crossings in preventing extinction and helping preserve biodiversity (Thompson and Fronhofer, 2019). Veidekke is one of Scandinavia's largest construction groups. They have built a wildlife overpass above a highway in southern Sweden, connecting wildlife and plants on either side of the road. By providing animals safe passage, the overpass is expected to reduce wildlife accidents on the road. This particular overpass is 76 meters long and

32 meters wide and contains two road tunnels, as well as passages for smaller animals. Similar structures are to be seen in many countries including Canada, France, India, the Netherlands and Switzerland.

- Contracting type: Service
- Technology level: Medium
- Country of origin: Sweden
- Availability: Sweden
- Contact: [WIPO GREEN Database](#)

Aerial firefighters

Canadair, De Havilland Aircraft



Photo: Getty Images / © WanderingNomad

Originally built by Canadair, the Canadair CL-415 is one of a series of amphibious aircraft designed to fight wildfires from above. The CL-415 is no longer in production. But De Havilland Aircraft of Canada is presently manufacturing similar aircraft under the name DHC-515, with expected delivery to several European Union countries by 2025. The aircraft is designed to deliver drops at a rapid rate, suppressing fires more quickly. This allows it to deliver a higher daily amount of water into a fire-zone compared to similar technologies. Tanks can be refilled in 12 seconds using water from nearby rivers, small lakes and oceans.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: Canada
- Availability: European Union
- Contact: [WIPO GREEN Database](#)

Frontier technologies

Open source fire forecasting systems

Pyregence

Photo: Getty Images / © FrankRamsrott



Pyregence is a company that offers various wildfire forecasting products for utility companies, fire-risk managers, policymakers and the general public through an open-source approach. The company is conducting research to understand climate and fuel conditions driving a new era of severe wildfires, using the results to build the next generation of wildfire risk models.

In 2020, Pyregence released a beta version of its fire forecasting tool on pyrecast.org where users can view active fires burning in California in the United States to

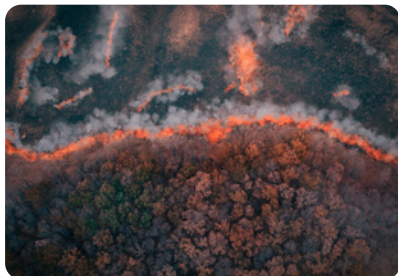
see where they are likely to spread over the course of 48 hours. The company also offers climate change projections.

- Contracting type: Free/Service
- Technology level: High
- Country of origin: United States
- Availability: United States
- Contact: [WIPO GREEN Database](#)

Wildfire monitoring using artificial intelligence

ChoochAI

Photo: Getty Images / © Andrii Chagovets



ChoochAI is a company using artificial intelligence (AI) and image analyses to detect fire based on data from satellites, drones and land cameras. Satellite imagery is analyzed every 10 minutes to identify where new wildfires have started. The company has trained AI models to identify wildfires using aerial imagery with a high accuracy. Special cameras installed on satellites or aircraft capture videos that are then analyzed by the AI model to detect fire activity. Based on this information, alerts are then sent to decision-makers for them to take appropriate action.

- Contracting type: Services
- Technology level: High
- Country of origin: United States
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Horizon technologies

Forest and mangrove reforestation using drones

Distant Imagery

Photo: Getty Images / © Akarawut Lohacharoenvanich



Distant Imagery is a company that among its other projects is using drones that can drop 2,000 germinated seeds in 10 minutes to replant mangrove forests. To increase survival rate, seeds are coated with solid nutrients to make them heavier and able to penetrate mud and soil. According to a project spokesperson, the survival rate is between 35 and 43 percent (Begum, 2022) with room for improvement.

- Contracting type: Collaboration
- Technology level: Medium
- Country of origin: United Arab Emirates
- Availability: United Arab Emirates
- Contact: [WIPO GREEN Database](#)

Genetic engineering of forest species

FuturaGene


Photo: Getty Images / © metamorworks



A lack of desirable natural genetic variations within a species can hamper climate-resilient tree breeding. Genetic engineering has emerged as an alternative means of developing trees that are pest and disease-resistant or are more drought tolerant. Although this has been successfully demonstrated in greenhouse or field environments, regulatory barriers and high costs can slow down commercial applications (Chang et al., 2018). However, there are a few companies offering genetically-engineered tree species for use as biomass,

such as FuturaGene with their yield-enhanced Eucalyptus trees. Despite heavy national protest, Brazil became the first country to approve genetically-modified eucalyptus. The company is now in the process of developing insect resistant tree species, which may represent progress toward reducing climate vulnerability of trees.

- Contracting type: Research collaboration
- Technology level: High
- Country of origin: Brazil
- Availability: N/A
- Contact: [WIPO GREEN Database](#)



Early warning systems, modelling and monitoring

Knowing what weather conditions are coming can mean the difference between having a full harvest or no harvest at all. Advances in early warning and forecasting systems can make the difference. From satellites and drones to crowdsourced data from people on the ground, technology can enable climate information to reach those who need it when they need it.

Early warning systems a key adaptation tool

It is estimated that early warning systems provide a more than tenfold return on investment, making it a key adaptation measure (UNFCCC, 2022c). Remote sensing data, such as satellite imagery, and other types of information are now helping us analyze climate events and understand how we should respond. Over half the essential climate variables used by the Intergovernmental Panel on Climate Change (IPCC) to measure and monitor climate change are recorded using satellites. Technological advances have made it possible to gain more long-term understanding and make better predictions about climate-related changes. These include growing season length, precipitation and flooding patterns, and vegetation regrowth after drought and wildfires. Meanwhile, crowdsourced data, real-time monitoring technologies and software can help trigger an early and rapid response to threats such as locust swarms. Advanced forecasts are yet unavailable to many smallholder farmers in regions most vulnerable to climate change. But context-specific and participatory approaches such as resource allocation maps and seasonal calendars backed by historical weather data and short-term and seasonal forecasts may support farmers in managing risks (Ky-Dembélé et al., 2020). Strong community engagement at local level is also a key factor for success in response to hazards. The use of low-tech monitoring tools such as river and rainfall gauges combined with activities, such as community risk assessments, locally-made evacuation signs and the use of color-coded flags, drums, megaphones and runners to get warning messages out, help enable more people-centered early warning systems (Cowan et al., 2014).

Satellites, drones and sensors see it all

Land degradation and risks to food security, especially in vulnerable regions, have spurred the development of agricultural monitoring technologies. The earliest examples of remote sensing include aerial photography, first widely used during the First World War. Today, satellites, airplanes, balloons, unmanned aerial vehicles (UAVs or drones), ground-based platforms and in situ sensors can be applied to understand crop health, vegetation cover, pest attacks and weather impact patterns. Satellite imagery in particular has undergone rapid development. Commercially and publicly-available imagery offers high-resolution, multi-band recording and high re-visit frequencies. Data from these technologies tell us which agricultural areas need irrigation or fertilizer, as well as livestock roaming patterns. Pest epidemics during crop growth are closely linked to climate change. Insect monitoring, which was automated as early as 1973, can now be performed using drones equipped with LiDAR radar able to distinguish between species over a large area by observing wingbeat frequency (Rydhmer et al., 2022). This could be key to supporting food security. According to the FAO, up to 40 percent of global crop yields are lost annually due to pests and disease (FAO, 2021a).

Access to information enables climate insurance

Farmers with access to weather and climate information are more likely to adapt their practices. Data can guide them in timing plantings, choice of crops, agroforestry practices or soil and water conservation measures (Friedman et al., 2022). Advanced data access has enabled the development of weather-indexed insurance products. Combining historical and real-time data into such geospatial analytics helps support climate risk assessment. This may create opportunities also for smallholder farmers in low-income countries to obtain crop insurance. Insurances based on real-time remote observations and near future predictions mean much faster payout mechanisms can be put in place. However, crop insurance may be a new and complex concept for many which also requires trust in the insurance system. Adoption may therefore not be straightforward. But crop insurance may gain importance as a potentially effective measure against food insecurity. It is actively promoted by humanitarian relief

organizations such as the World Food Programme (WFP) through its R4 Rural Resilience Initiative. However, for many countries, basic technology infrastructure and adoption capability is a limiting factor for technology and knowledge transfer, especially related to remote sensing (IPCC, 2022).



Photo: Getty Images / © Jennifer Watson

Innovation example Early warning system for locust swarms

Above average rainy seasons create favorable conditions for locust swarms to breed. A small swarm of 1 km² can in just one day consume crops and vegetation that could feed 35,000 people (World Bank, 2020b). Their invasion presents a huge threat to food security in Africa and the Middle East. In 2020, it was estimated that the desert locust outbreak in Ethiopia put over 1 million Ethiopians

in need of food assistance (World Bank, 2020b). The FAO, which is leading global work on desert locust control, was instrumental in reducing the negative impact on lives and livelihoods. The Organization quickly delivered desert locust surveillance and control to the three most affected countries of Ethiopia, Kenya and Somalia. The FAO Desert Locust Information Service (DLIS) early warning system applies a range of different technologies to the daily monitoring of conditions that favor locust invasions (CERF, 2020). The system draws on locust data shared by 20 countries and field teams via the eLocust3 tablet for data collection. The information is analyzed together with satellite imagery and weather and habitat data. This enables forecast-based alerts to be issued up to six weeks in advance of a possible invasion. To make data collection more accessible in the field, the FAO and University of Pennsylvania have developed a mobile smartphone app. Together with global GPS supplier Garmin, they also modified a satellite data communicator to enable farmers without connectivity to collect data. Locust data is sent to the FAO and then shared with teams on the ground and in the air who can quickly target and eradicate swarms using chemical pesticides and biopesticides (FAO, 2021b).

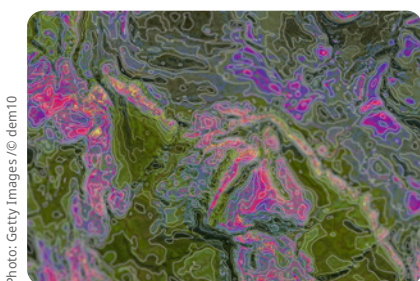


Photo: Getty Images / © dem10

Innovation example Mapping soils to maximize food production

In Sub-Saharan Africa, 30 percent of people are facing food insecurity, partly as a consequence of an underperforming agriculture sector (Bjornlund et al., 2020). Lack of knowledge about soil conditions has long been one of the limiting factors for managing soil fertility and achieving higher yields. In 2009, the International Soil Reference and Information Centre (ISRIC) began

the first digital soil mapping of Africa, covering 42 Sub-Saharan countries (Gilbert, 2009). The initiative, named the Africa Soil Information Service (AfsIS), combined satellite data with soil measurements taken on the ground to provide updated information on soil texture and moisture and nutrient levels in support of farmers and policymakers across the continent. Maps were made publicly available for any farmer to use when taking decisions on what type and amount of fertilizer to apply to their land to maximize food production. Advances in satellite imagery are now enabling more high-resolution and accurate assessments and predictions. While the most current information can often be obtained via a country's national soil services, organizations such as the FAO have compiled and harmonized such information in regional datasets, or used the data to develop digital soil maps. Consistent sets of indicators and field protocols to assess soil and land health such as the Land Degradation Surveillance Framework (LDSF) can also become part of monitoring frameworks (ICRAF, 2020).

Technology solutions

Proven technologies

Crop monitoring and irrigation control using satellite information Satellogic



Satellogic specializes in satellites that monitor the status of particular geographical areas in real time. The company has its own satellites and is capable of providing services that optimize production processes through the analysis of satellite imagery. Services available are crop monitoring, irrigation control, tree counting, estimation of biophysical variables, production control and classification of land use, among others.

- Contracting type: Service
- Technology level: High
- Country of origin: United States
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Crop monitoring using artificial intelligence, machine learning and machine vision Austral Falcon Sensing Solutions



Austral Falcon Sensing Solutions is a precision agriculture company that provides monitoring and prediction of agricultural variables. The platform uses vehicle-based machine vision, artificial intelligence and machine learning technology to capture data and digitize processes normally carried out manually in the agricultural industry. This enables faster decision-making based on quantitative information about factors such as yield, irrigation and fertilization. Data can be entered into an app which then processes the relevant data to provide crop maps, harvest estimations and so on.

- Contracting type: Service
- Technology level: High
- Country of origin: Chile
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Wireless sensor networks for management of agricultural resources

Envira IOTE



Photo: © Envira IOTE

Nanoenvi® AG is a device designed for remote data capture and transmission in precision agricultural applications. The device allows the creation of wireless sensor networks to monitor, predict and optimize the management of agricultural resources in real time due to their cloud connection. These networks give greater control to farms, enabling them to manage disease, regulate the application of plant protection products, make efficient use of water in irrigation and optimize resource use in general. Nanoenvi® AG is compatible

with various types of sensors, such as meteorological (temperature, humidity, pressure, rain, solar radiation), gas (H_2S , CO , CO_2 , SO_2) or agricultural (leaf moisture, soil pH, dendrometers and so on). Through solar-powered wireless sensors connected to the cloud, the farm knows the real-time status of a wide range of variables involved in agriculture. By connecting to the service through computer, mobile phone or tablet, a farmer can take immediate crop productivity decisions.

- Contracting type: For sale
- Technology level: High
- Country of origin: Chile
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Crop yield prediction using satellite and geospatial data

S4Risk



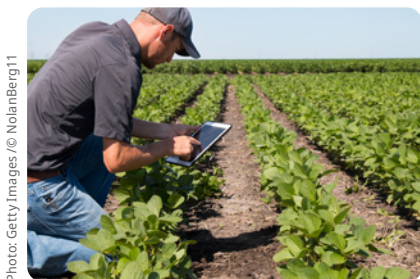
Photo: Getty Images / © Igor Borisenko

S4Risk is a platform that generates insights into agricultural production through geospatial databases and satellite imagery. The technology enables farmers to take better investment decisions by calculating climate change-related risks to crops, for example from drought and floods, based on historical yields and guide them in buying appropriate insurance.

- Contracting type: Service
- Technology level: High
- Country of origin: Argentina
- Availability: Argentina, Uruguay, Brazil
- Contact: [WIPO GREEN Database](#)

Crop monitoring and planning using sensors, drones and satellite imagery

Sentera



Sentera provides digital agronomic tools that give farmers access to real-time data about crop performance in the field. The software (FieldAgent) integrates weather data with data collected from the field. Data is collected through various channels, including satellite imagery, sensors and drones which fly over fields and provide an acre-by-acre crop overview. Data can then be analyzed to forecast yields and to plan and understand the impact of various fertilization and irrigation choices in maximizing yields.

- Contracting type: For sale
- Technology level: High
- Country of origin: United States
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Meteorological monitoring for the fisheries sector

Clima Pesca



Clima Pesca is an initiative of the Central American Organization of the Fisheries and Aquaculture Sector (OSPESCA) highlighting the impact of climate change on the fisheries sector. The app forecasts cyclones up to two days in advance, as well as sea surface temperature, atmospheric pressure, wind waves, marine currents and so on. Due to its user-centric design and an application that integrates relevant weather information in an easy and simple way, Clima Pesca is able to help 120,000 subsistence fishing-dependent households annually. Platform users include local and national governments, academia and civil society.

- Contracting type: Free
- Technology level: High
- Country of origin: United States
- Availability: Latin America
- Contact: [WIPO GREEN Database](#)

Frontier technologies

Automated insect monitoring EFOS/Trapview



Photo: © Trapview

The digital tools provided by Trapview help monitor more than 60 insect species in over 40 countries around the world. The product consists of a “smart” insect trap with cameras. It is fully automated and solar powered. It provides a clear view of the various pest populations and daily sends automatic farm updates. This enables farmers to plan more accurate pest control measures and save time by not having to patrol fields and manually monitor pests.

- Contracting type: Service
- Technology level: High
- Country of origin: United States
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Blockchain climate-risk crop insurance Sprout



Photo: Getty Images / © TU IS

Sprout is a startup that is leading the development of a blockchain-based climate-risk crop insurance. The company uses satellite data and machine learning to assess climate risk. They then send mobile messages directly to farmers to advise them on unexpected weather patterns and give useful advice on how to navigate the changes on their farms. Insurance companies can then offer climate insurance to farmers using Sprout’s online web portal, where insurance and program data can be monitored. Sprout insurance

contracts are made using Blockchain technology. This means the contracts are automated and protected from unauthorized changes throughout the season. Sprout was developed in Kenya but is active in multiple supply chains and crops around the world.

- Contracting type: Service
- Technology level: High
- Country of origin: United States
- Availability: Kenya (pilot)
- Contact: [WIPO GREEN Database](#)

“Smartdust” for detailed crop and environmental monitoring

Analog Devices Inc.

Photo: Getty Images / © Shutterstock2U



Micromechanical systems (MEMS), or “smartdust,” are a network of wireless devices, or “motest,” with sensors that can collect, process, store and transmit data (Forbes, 2018). These swarms of microscopic computers can range from 1 mm in size down to 0.02 mm and are best classified as a part of the industrial internet of things (IIoT). Each small device contains a microprocessors and sensor to monitor variables like pressure, humidity and crop status, and signal them back to users such as farmers. The devices are connected and

communicate through a so-called mesh network. This consists of many of these small devices, with communication either by optical or radio frequency. Use cases include monitoring vast areas of crops to determine irrigation, fertilization and pest management needs. Analog Devices in collaboration with scientists from the University of California in Berkeley have also used the technology to measure snow depth, solar radiation, humidity and soil moisture on the snow pack in the Sierra Nevada Mountains. Such information can be used to anticipate droughts and floods, as well as support water resources planning.

Note: Mainstream adoption is at least a decade away, high costs (due to need for satellite tech etc.) and there are potential privacy and security concerns (potential for surveillance and military use).

- Contracting type: Service
- Technology level: High
- Country of origin: United States
- Availability: N/A
- Contact: [WIPO GREEN Database](#)

4 Water and coastal regions

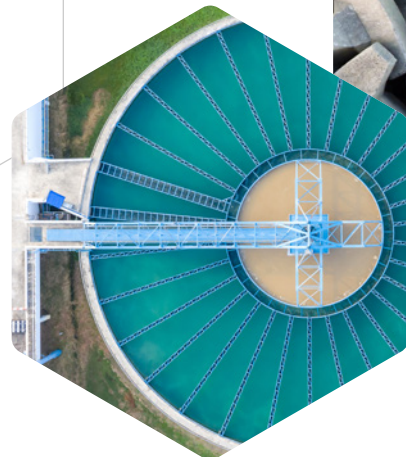




Photo: Getty Images / © Malakpet Ps / 500px

Technological developments and trends

Climate adaptation in relation to water can take many shapes and forms. Often, it is a matter of adapting to having either too much or too little water.

As coastal communities face rising sea-levels, technologies can help keep water at bay. For those confronting water pollution and scarcity, there have been huge advances in capturing and treating water from all kinds of sources. However, climate impacts are felt beyond the human population. Increasingly acidic and warm oceans call for strengthened and innovative approaches to marine ecosystem conservation.

Too much water

Stacked sandbags and houses on stilts are many people's idea of flood-related technologies. In many ways, innovation is following the same path but using new types of materials, improving ease of use and being guided by forecasting and mapping tools. Depending on where you are in the world, sandbags and stilts might still be the best option. However, more recent developments include quickly installed and removed mobile flood barriers, or tubes and bags containing super-absorbent powder placed around houses and other assets that swell on contact with water. Meanwhile, nature-based solutions include flow-through dams, reconnecting floodplains and wetland conservation to help reduce flood volumes and delay downstream water flow. However, all of these alternatives may have limited effectiveness in the face of high-impact floods and disasters. When adapting to floods and protecting coastal communities and assets from hazards, relocation and retreat from hazard-prone zones may in some cases be the only viable long-term solution.

Too little water

Parts of the world are facing the dual challenge of not only increased floods but drought. Technologies such as managed aquifer recharge (MAR) can turn floodwater into a resource by directing it into underground aquifers for use during dry periods. Increasing water scarcity has spurred the development and adoption of technologies that recycle and make use of alternative water sources. While there are advances in the treatment and reuse of water from agriculture, households and industry, they often come with large energy footprints. For instance, water-stressed countries such as Saudi Arabia and Kuwait depend on seawater desalination for their drinking water. Moreover, many other countries increasingly regard desalination as necessary. As global freshwater demand is expected to far outstrip water supply in the future (Boretti and Rosa, 2019), development of water conservation technologies is becoming a growing trend. Significant potential lies in switching to water-efficient irrigation systems such as drip and sprinkler irrigation. However, advances in remote sensing and internet of things (IoT) technologies can provide further water savings by enabling precision agriculture and remote detection of leaks in irrigation and urban water infrastructure.

Protecting marine ecosystems

Life below water faces unprecedented challenges from climate change. Impacts include warming oceans and acidification, as well as other major human-induced threats (IPCC, 2018). The consequences are unclear. But there are technologies being developed related to marine ecosystem conservation and the strengthening of species' climate resilience. From artificial reefs to coral gardening, much innovation seems focused on specific ecosystems such as coral. Trends

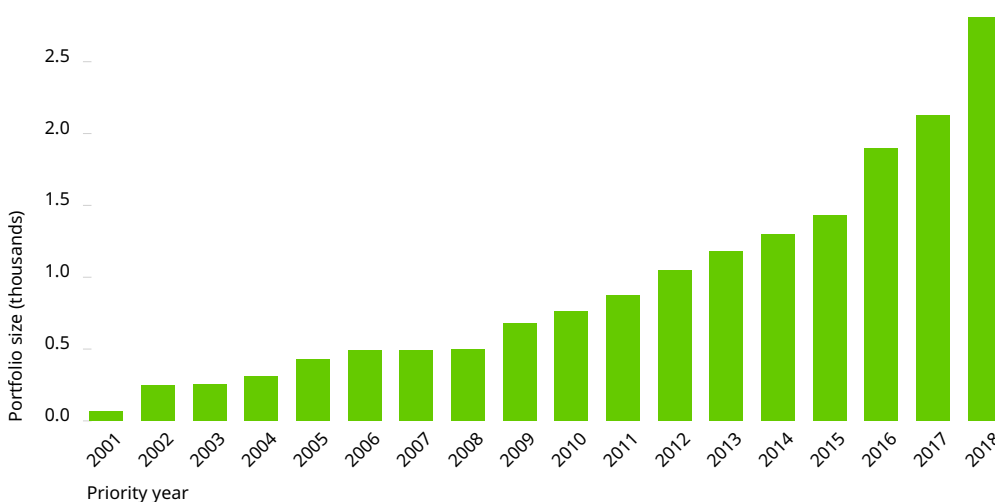
in other technology sectors, such as automation and genetic engineering, have also entered this space, although mainly used by conservation groups and science institutions. Examples include underwater drones that relocate farmed coral larvae to their natural habitat and genetically modifying coral so it can withstand higher temperatures. However, while techniques like the assisted relocation of species could present an adaptation response, they could also create risks related to invasive species. That said, technology may help marine environments overcome some climate change pressures – at least at a local level.

Patents and finance

Flood prevention and control

Global demand for flood protection solutions can be seen through innovation metrics such as patent applications. Worldwide, the number of flood and coastal defense patent families filed has grown year-on-year for the last two decades. In the last decade alone, the number has increased almost sixfold (figure 4.1). They relate mainly to constructions (nearly 75 percent), but also floodgates and earthworks (such as embankments). This suggests a continued interest in hard engineering solutions for coastal defense. Over half of all patent families originated in China. The Republic of Korea and Japan, followed by Canada, also account for a large proportion of the total (IPO, 2021). Growth trend and distribution of patents, with a heavy regional focus on Asia, broadly reflect realities on the ground in terms of flood event intensity, frequency and locality.

Figure 4.1 Number of active flood and coastal defense patent families worldwide by priority (first filing) year, 2001–2018



Source: Recreated graph from IPO, 2021.

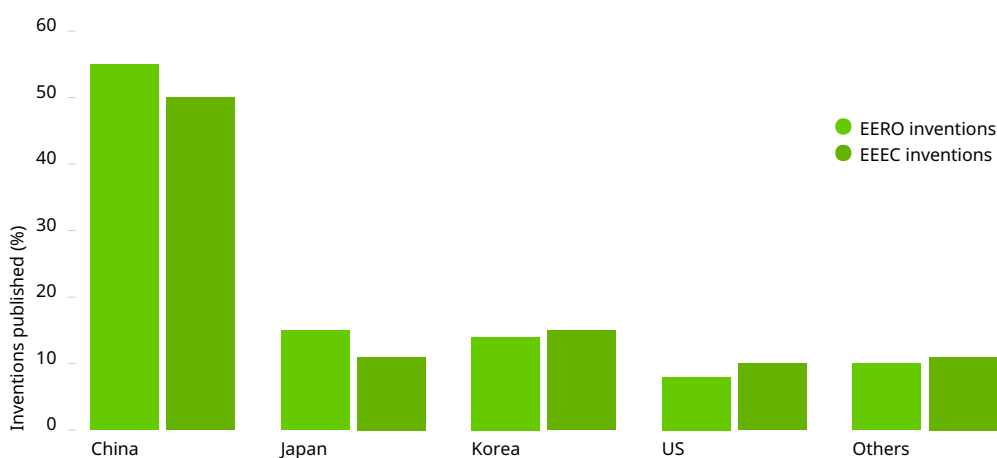
Solar-integrated and decentralized water management

Increased water scarcity has turned many countries toward technologies that desalinate seawater for drinking and other uses. For water management technologies such as desalination, saltwater intrusion barriers and filtration systems, data from the European Patent Office

suggests an 8 percent annual average growth of innovation, as measured by high-value patents in the years 1995–2015. These technologies also have high technology transfer rates – nearly twice that for coastal and river protection technologies such as dikes, dams and artificial reefs (Dechezlepretre et al., 2020). Desalination technologies are not new. However, although critics point to high-energy consumption rates, there are developments in renewable energy integration. An analysis of patent families relating to desalination and renewable energy integration found that most patents focus on solar thermal technology (Vegt et al., 2011).

Of the top 20 patent owners in the desalination space, the vast majority are Japanese companies. In 2011, the top two companies by number of patents were Mitsubishi and Hitachi. China has also emerged as a major player in water treatment and physical or chemical processes (Vegt et al., 2011). For example, in the last decade, China accounted for over half of inventions related to energy efficiency in reverse osmosis and electrochemical desalination technologies (figure 4.2) (IPOS, 2019).

Figure 4.2 Percentage of desalination technologies published by origin, 2009–2018



Note: EERO is energy efficiency in reverse osmosis; EEEC is electrochemical desalination technologies.
Source: Recreated graph from IPOS, 2019.

Innovations in water treatment technologies are not adaptation-specific. But they are key to responding to water challenges exacerbated by climate change. However, inventions are not always driven by local water demand. Countries such as Switzerland and Norway have strong markets in this sector despite high water availability, reflecting their overall strong innovation ecosystem. While a majority (80 percent) of water efficiency technologies occur in countries with low or moderate water scarcity, specialization also occurs in several countries with more severe water scarcity (Conway et al., 2015). Membrane-based water treatment is an example of a technology that has seen a high level of innovation. Japan has traditionally been the biggest player in this technology (Vegt and Iliev, 2012). However, China has overtaken Japan in recent years in patents published for biologically-based membranes (IPOS, 2019). A rising interest and need for more diverse and decentralized water systems is reflected in the patents for modular water technologies. Examples include turnkey water treatment solutions and modularization of desalination technologies (Vegt and Iliev, 2012).

Concentration of marine genome patents

Marine conservation in response to warming oceans and acidification has accelerated research into the genetics of marine organisms. This is with the aim of better understanding how to facilitate adaptation to environmental changes. Genomic sequences and other biomolecules sequenced and isolated from corals and other marine species respectively may be patented under certain conditions and for certain uses. A patent may grant private entities exclusive rights for that specific use of the sequence in research, development and commercialization. The majority of such patents are concentrated among just a few players, mostly in high-income countries. Much of the patent activity is concentrated in pharmaceuticals, peptides and biocides rather than in finding ways to enable marine species adaptation to climate change (WIPO, 2019).

Investment needs vary

Like other adaptation sectors, water and coastal adaptation is subject to uncertainties with regard to the accuracy of climate projections. This makes estimating financing needs challenging. However, the annual investment and maintenance costs of coastal protection have been projected to be USD 12–71 billion. Yet this is considered considerably less than the cost of damages in the absence of such investments (IPCC, 2019). Financing need for example for coastal flood defense varies widely among countries, with low-income, low-lying countries and small island states requiring substantial international support. The United Nations Environment Programme (UNEP, 2021a) estimates that the water sector in developing countries represents about 15 percent of total adaptation finance needs, after agriculture and infrastructure. In an analysis of 12 Pacific island states, 57 percent of built infrastructure was found to be located within 500 meters of a coastline, requiring a replacement value of USD 21.9 billion. Meanwhile, in West African fisheries, loss of coastal ecosystems and productivity are estimated to require 5–10 percent of the countries' GDP in adaptation costs (IPCC, 2019).

Infrastructure projects often a priority

Around one-fifth of adaptation projects funded by the top 10 bilateral donors are related to either water or infrastructure. The percentage of adaptation funding going toward water and sanitation is generally higher from multilateral development banks. However, these commitments are mainly as debt instruments, with only a small proportion provided as grants (UNEP, 2021a). Considering the growing adaptation finance need, investments in so-called no-regret technologies such as water efficiency could offer more predictable cost benefits. This is also evident in water-related climate finance, which is mainly directed toward large infrastructure projects for water resource management, water supply and sanitation. The European Investment Bank (EIB) has identified water scarcity and flooding as key investment areas, referring mainly to investments in engineered structures (EIB, 2021). A large focus on infrastructure-related investments risks technology "lock-in" and not meeting the needs of vulnerable communities most at risk. However, increasingly, multilateral climate funds are investing in adaptation to meet rural and community-scale water and sanitation challenges (Heinrich Böll Foundation, 2021).

Coastal protection

From massive seawalls to mangrove conservation, coastal communities around the world are implementing a range of solutions to protect themselves against rising water levels and strong winds. Sometimes these measures are sufficient. Other times retreat is the only option. When applied right, technology can mitigate or delay some of the worst impacts of climate change.

Coastal zones increasingly at risk

Sea temperature has already increased by 0.87°C since the 1850–1900 period. But it is expected to rise further by between 0.64°C and 0.95°C by 2050, depending on the climate change scenario (IPCC, 2019). Warmer oceans result in more frequent and extreme weather events exacerbating impacts on coastal zones. As the ocean heats, it expands. Together with melting of ice sheets and glaciers, this has already caused a 0.16 meter sea level rise during the period 1902–2015. The sea is now rising at a rate of 3.6 mm each year and this is expected to accelerate. Just a 0.15 meter further increase in sea level will mean 20 percent more people exposed to what used to be 100-year floods (IPCC, 2019). Increased climate-related pressures on coastal zones in the form of flooding, coastal erosion and changes in sea channel morphology are all of high economic and livelihood importance. However, coastal impacts are also influenced by several other human-induced factors. These factors include land subsidence due to groundwater extraction, pollution, habitat degradation and reef and sand mining (IPCC, 2019). There are several ways in which coastal zones can be adapted to meet imminent threats. Technology and innovation are part of the solution.



Beach nourishment: temporary but effective

Coastal erosion is a natural process exacerbated by more frequent and violent weather events, inducing large economic losses. A common method to mitigate coastal erosion is through adding sand to affected areas, so-called beach nourishment. Adding sand will delay the effects of the erosion process, but will normally not stop or change the erosion process significantly. It is therefore a temporary solution which must be maintained or repeated. Nonetheless, it can be an effective climate adaptation measure, and one of the few alternatives to building hard structures. Beach nourishment is relatively simple. It consists of moving similar particle size sand sourced on-shore or offshore to affected coastal zones. However, both the sourcing and depositing of sand may have negative environmental impacts. They include burying benthic marine life, altering currents and habitat morphology, temporary increased turbidity, and disturbance to source area habitats (Staudt et al., 2021). Therefore beach nourishment projects require thorough environmental impact assessment. Technologies commonly deployed include pumping sand from offshore barges using floating or submerged pipelines, spraying sand onto a beach (rainbowing), or dumping large quantities of sand using split-barges. Beach nourishment has been used worldwide for decades and is a well-proven method. Innovation is taking place in technologies for depositing sand. Improved understanding of coastal fluvial processes and hydrological modelling can optimize deposition effectiveness and minimize environmental disturbance. Such improved understanding also makes possible the further development of nature-based solutions.

Hard coastal protection methods

Other shoreline protection methods include hard structures like groynes, breakwaters and seawalls. Groynes are constructed perpendicular to the coastline. They protect against erosion by reducing alongshore drift and trapping sediment. Typically, a series of groynes is constructed. Groynes can be constructed out of a hard material such as concrete blocks, rubble, wood and steel, but rocks are most commonly used. Breakwaters are structures that extend into the sea to shelter vessels, protect shorelines or prevent navigation channels from silting up. They are typically built of rocks and concrete. Seawalls are hard, static, shore-based structures designed to protect a limited area from flooding, waves and erosion. They must be maintained, as they are constantly exposed to erosion. Hard structures can also have a significant impact on currents and sediment flow patterns and must be carefully designed to correspond to local coastal processes. Maladaptation may occur if the coastal dynamics are changed, potentially leading to increased erosion along adjacent shorelines. Advances in hydrodynamic modelling help maximize the protective effect of hard structures and minimize environmental impacts. However, hard protection measures along the coast can block socioeconomic opportunities for coastal populations. For example, by restricting easy access for those relying on fishing and other resources. Such solutions must therefore be implemented only after a thorough consultative process. This so they are adapted to local contexts and can be assessed alongside potential alternative nature-based adaptation solutions.

Multiple benefits from nature-based solutions

Artificial or reinforced reefs can protect coasts against erosion from wave energy and are less intrusive than above-surface structures. The restoration or even creation of reefs – including coral reefs – is attracting increasing attention as they are an important marine life habitat (see section on “Marine ecosystems”). Other nature-based solutions include coastal conservation measures such as mangrove restoration. Mangrove trees act as a natural storm barrier and can be a cost-effective alternative to hard structures (MMC, 2005). Covering vast coastal areas in the tropics and sub-tropics, these salt-tolerant trees and bushes occupy the intertidal coastal zone. Their root system slows sediment flow during tidal flooding and accumulates deposited sediment. Together with leaf litter this creates important wildlife habitats. But mangrove forests have been steadily on the decline due to massive infrastructure developments in coastal zones, agriculture and logging. However, many countries are now embarking on mangrove restoration projects. Methods include re-establishing natural water flows (e.g., by cleaning up or creating channels) or planting mangrove seedlings in coastal mudflats. Understanding the local ecosystem and selecting suitable species and locations will be critical to successful restoration (Teutli-Hernández et al., 2020).

Combining hard and nature-based solutions

Integrating hard structures and nature-based approaches could offer optimized, cost-effective and long-term solutions. Adaptation based on local natural processes may provide long-term protection through self-reinforcement and avoid creating new vulnerabilities to erosion. Dikes are hard structures that have protected coastal communities against flooding for centuries. Important advances have been made in their design and construction. Modern dikes are wider and less steep than traditional designs and have a strong core that better resists breaching. Overtopping of waves is less likely with wide dikes although more space is required. The slopes can be used for agriculture and recreational purposes. In Schleswig-Holstein in northwestern Germany, every dike must now include a 0.5 meter safety margin in case of sea level rise, with a further 0.5 meter as supplementary reserve to mitigate against strong sea level rise (Climate-ADAPT, 2015a). There are also specially designed dikes that allow overtopping by waves and have secondary parallel dikes to contain the overtopped water. Such double dikes can provide improved security against flooding. Dikes are often combined with nature-based elements. One of these could be coastal wetlands which can absorb excess water and dissipate wave energy thereby protecting against erosion. Coastal wetlands are brackish or saltwater-covered areas that are either temporary or permanent in nature. They can provide key environmental services such as fish and shellfish nurseries, bird habitats, water purification and recreational areas. Many wetlands have been drained or degraded by human activities. But wetland restoration and realignment with other coastal defense structures may provide efficient protection against increased sea levels and extreme weather events (Climate-ADAPT, 2015b).



Photo: Getty Images / ©Frans Sellies

Innovation example

Dutch sand motor: a nature-based solution

On the Delfland coast of the Netherlands, public and private actors have implemented a beach nourishment project that integrates localized natural processes. A huge amount of sand (21.5m³) extracted offshore was deposited along the coast in one operation, forming a hook-shaped peninsula. This structure protects against erosion and sea level rise. But more importantly it provides sand for redistribution further along the coast by local currents and erosion processes. Coastal degradation is delayed by creating a large repository of sand to feed coastal erosion processes. This so-called sand motor was implemented in 2011 and is expected to remain active for 20 years. Further beach nourishment is unnecessary during this period. In addition, the structure provides novel recreational opportunities and has created habitats for flora and fauna (Rijkswaterstaat, 2022; Climate-ADAPT, 2019b). This idea is being implemented in Benin and Togo as part of a World Bank-financed coastal protection project targeting 40 km of coastline (NL Netherlands, 2022).



Photo: Getty Images / © LBalls

Innovation example

Applying sophisticated coastal process modelling

The Adelaide shoreline in southern Australia has experienced continued partial coastal erosion and shoreline recession. Using MIKE 21 software from the DHI company, including models for hydrodynamic flow, waves and shoreline morphology and detailed local coastal models were created. Based on these models, six management scenarios were simulated. They comprised combinations of soft management options such as beach nourishment and hard structures. For each scenario, the morphological evolution of the entire West Beach shoreline was simulated for a 7.5-year period for comparative assessment of their respective pros and cons. Alternative management strategy modelling was a crucial element in developing the long-term coastal management strategy subsequently adopted by the South Australian Government (DHI, 2017; GSA, 2020).

Photo: Getty Images /©Bruskov



Innovation example

Re-establishment of hydrological conditions for mangrove

Mangrove forests are often destroyed by local infrastructure development. This makes coastal communities more vulnerable to climate change impacts. In Progreso on Mexico's Yucatan Peninsula, a highway construction disrupted the flow of tidal and surface runoff water. This increased salinity which then

destroyed mangrove and other natural vegetation. In response, hydro-dynamic modelling was used to identify the best sites for implementing mitigation measures. Natural tidal channels were recovered, new channels constructed and terrain levelled. Natural hydrological flow and salinity levels were both restored and the mangrove forests recovered. The mangrove forest that was recovered protects against weather events and coastal erosion. For a comprehensive guide to mangrove reforestation see Teutli-Hernández et al. (2020).

Technology solutions

Proven technologies

Split barge, dredging and pumping vessels for beach nourishment

Mavi Deniz

Photo: © Mavi Deniz



Mavi Deniz has a large fleet of vessels that can undertake various beach nourishment tasks. Split barges, as well as dredging and pumping vessels, are available. The company manufactures and supplies equipment, vessels and services to more than 55 countries worldwide. The Split Hopper Barge for example is a vessel designed to carry all kinds of dredged material, including sand for beach nourishment. The Barge can split along its longitudinal axis to discharge dredged material.

- Contracting type: Services
- Technology level: Medium
- Country of origin: Türkiye
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Small versatile dredging vessels

IMS Dredges



Photo: Getty Images / © Rike

IMS Dredges supplies one-truck transportable, self-propelled hydraulic dredges plus dredging systems for maintaining rivers, lakes, canals and inland waterways. The Versi-Dredge can construct a beach by pumping sand onto low-lying land and has replenished many beaches in Belize, Mexico and the Turks and Caicos. These relatively small units are versatile and deploy several patented technologies.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: United States
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Beach nourishment vessels

Boskalis



Photo: Getty Images / © Nigel Wiggins / EyeEm

Boskalis is a large Dutch company offering a variety of marine services. They include hard-structure costal protection and beach nourishment. The company has a large fleet of vessels operating worldwide. For beach nourishment, several vessels are used including a trailing suction hopper dredger. This dredger collects sand from the seabed and deposits it either through floating and submerged pipelines, rainbowing or offloading through the vessel bottom. The company is also involved in the development and implementation of nature-based costal protection methods.

- Contracting type: Services
- Technology level: Medium
- Country of origin: Netherlands
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Synthetic revetments, dikes, levees, jetties, groynes and breakwaters

TenCate Geosynthetics



Photo: Getty Images / © shunli zhao

Built coastal and marine infrastructure to protect from floods and erosion can comprise many types of materials. They include rock, concrete, stone and wood. Tencate Geosynthetics provides such solutions in a synthetic material. For example, the TenCate Geotube® is a large tube made of an engineered textile filled with sand that can be used as breakwaters, groynes and jetties. In terms of beach nourishment, the shoreline can be protected from wave impact energy by applying several kilometers of these tubes. The Geotube® can

also be deployed during land reclamation, wetland creation and to protect against hurricane and storm erosion.

- Contracting type: Service/For sale
- Technology level: Medium
- Country of origin: The Netherlands
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Biodikes

Practical Action



Photo: Getty Images / © CHUNYIP WONG

When engineered flood-protection structures such as gabion walls and concrete dikes are unsuitable or affordable, biodikes can be a low-cost alternative. Biodikes are constructed using locally-sourced materials such as sand, rocks, soil, shrubs and bamboo. The organization Practical Action has developed a technical brief (in English) which details how to build biodikes along a river. The brief covers technical aspects, as well as financial and social considerations. Principles include maintaining an adequate river bank slope and then

building a dike along the slope and length of the river using bamboo. The dike is then filled with sand bags and covered with fertile soil to provide a basis for vegetation. In addition to flood control, the technique can be used to manage slope instability in mountainous and hilly areas so as to mitigate against mudslides.

- Contracting type: Locally available materials
- Technology level: Low
- Country of origin: N/A
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Frontier technologies

Hydrological modelling DHI



Photo: Getty Images / © Mangiwau

DHI provides a set of software products (under the label MIKE Powered by DHI) for use in water environments to analyze, model and simulate various types of water-related challenges. For example, a multitude of coastal parameters, such as waves, sediment dynamics and ecological systems, can be modelled in 2D and 3D to support coastal engineering structures. Hydrological models can also be built so as to understand upstream hydrology and water flow feedback and interaction. This enables the development of strategies for managing

ivers, reservoirs and canals to reduce downstream flooding. While the technology is proven and has been used for decades, it is continuously evolving.

- Contracting type: Service
- Technology level: Medium
- Country of origin: Denmark
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Aerial imaging in support of wetland restoration Nearmap



Photo: Getty Images / © KNeville

Aerial imaging can support land managers in modelling water movement and landscape change. Nearmap provides high-resolution aerial satellite maps of urban areas across Australia. However, the technology has also recently been used by indigenous landowners to learn more about how water flows to wetlands and rivers. Combined with artificial intelligence tools, data from aerial imagery is fed into maps that aid wetland restoration by the Australian Nature Conservancy. Nearmap data complements manual and drone-based hydrological monitoring and shows changes over time.

- Contracting type: Service
- Technology level: Medium
- Country of origin: Australia
- Availability: Australia
- Contact: [WIPO GREEN Database](#)

Breakwater reef balls

Reef Innovations



Photo: Getty Images / © cookinate23

Reef Balls™ in coastal areas have the dual benefit of reducing wave impact while providing a habitat for marine life. A hollow concrete structure, Reef Balls™ can protect the coast against erosion by dissipating incoming waves. When placed in parallel to the shore, reef balls can act as a breakwater. Compared to traditional breakwaters, Reef Balls™ may provide additional economic benefits due to being fabricated on-site using a mold system and deployed using lift bags rather than barges and cranes.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: United States
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Horizon technologies

Wave conversion technology

Seabased

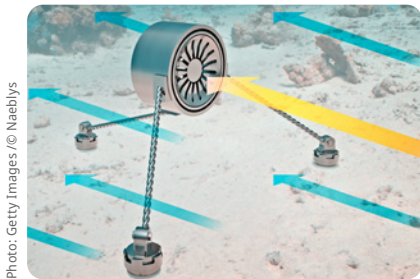


Photo: Getty Images / © Naabylis

Patents for leveraging the energy of waves date back to the 18th century. But wave energy is still considered to be in the developmental phase. Recent advances include solutions that integrate wave energy converters with coastal protection structures such as breakwaters. However, such structures are generally not located where wave intensity is highest. In order to provide the dual function of absorbing wave energy to produce energy, but also to reduce erosion by minimizing the impact of waves on the coast, wave farms have

been proposed as a solution. Wave farms have been shown to be able to influence coastal morphodynamics and reduce dune and beach erosion (Ozkan et al., 2022). One example of a company that produces wave energy converters (WEC) often used in wind farms is Seabased. The company develops floating buoy-type wave energy converters and has supplied its products to wave farms throughout Europe and in Africa.

- Contracting type: For sale
- Technology level: High
- Country of origin: Sweden
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Flood prevention and control

There is now high confidence that climate change has increased the likelihood and intensity of catastrophic floods. Usually physical barriers are put in place to try and control floods and limit damage. But increasingly, resilience is being strengthened by harnessing biodiversity and ecosystem services.

Floods on the rise

Impacts from floods such as threats to food security, health and livelihoods are greatest in vulnerable parts of Asia, Africa and South and Central America (IPCC, 2022). Floods are triggered by several phenomena. Causes exacerbated by climate change include prolonged heavy rainfall and storms, rapid snow melting and sea level rise. Heavy rainfall can lead to particularly intense and rapid floods, or flash floods. The more we build developments and pave surfaces, the less water is able to be absorbed into the soil to replenish groundwater reserves. There are also important combinations of climate impact to consider. For example, wildfires, themselves intensified by climate change, further increase flood effects by reducing the vegetation that would naturally absorb water and prevent run-off (Touma et al., 2022). Efforts to mitigate flood impacts need to address communities' social, economic and physical vulnerabilities. Ecosystem-based solutions are increasingly being integrated into climate adaptation plans to enhance the environment's natural ability to manage floods (IPCC, 2022).

Flood control systems

Europe and its low-lying countries the Netherlands, Denmark and Belgium lead in flood control technology. The simple sand bags stacked around homes have been elevated to modern flood barriers. These include super-absorbent powder, large-scale inflatable tubes and self-raising barriers for more rapid and effective deployment. On a structural level, dams designed specifically for flood control, such as flow-through dams, can reduce flood risk downstream. Other approaches divert floodwater away from affected areas and include diversion channels or pumping stations. Technological developments often focus on increasing ease of use, access and affordability of such adaptation solutions. Facing the dual challenge of increased population density and floods in major cities, more novel approaches are exploring innovative use of city infrastructure, such as combining parking structures with temporary water reservoirs.

Fighting nature with nature

When it comes to flooding, there is no blanket technology that can mitigate all risk and damage. Hard engineering practices and technologies can be effective on a local level. But best practice is increasingly pointing toward nature-based solutions for more holistic management of excess water flows. Such adaptation solutions often bring co-benefits with regard to ecosystems and livelihoods (IPCC, 2022). They aim to reduce flood volumes and delay downstream water flow by using natural structures and functions as part of catchments, floodplains, rivers and the coast. Increasingly popular measures include reconnecting floodplains to create storage ponds for water, creating tree and hedgerow structures to slow water, and reducing soil compaction to increase ground infiltration. Allowing flooding within coastal and wetland ecosystems can be a cost-effective approach (IPCC, 2022), as they naturally absorb and temporarily store a significant amount of water. Fortifying wetlands with enclosing structures can allow more water to be trapped and released when required. However, as recent events have shown, it is becoming devastatingly clear that there are limits to how far flood events can be controlled. Land reform and relocating settlements and infrastructure from flood-prone areas may sometimes be the best adaptation strategy. However, while relocation should be considered a last resort (UNHCR, 2014), coastal and flood hazard mapping can help guide planners and decision-makers in this process.

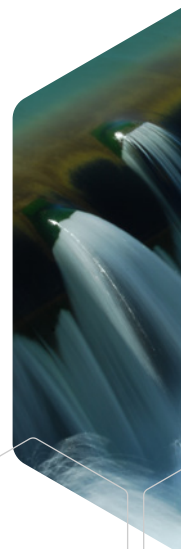
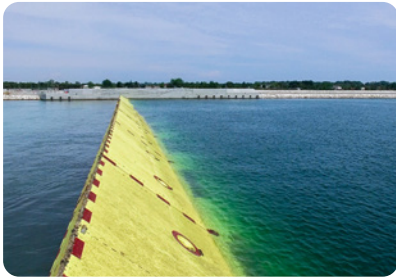


Photo: Getty Images / ©BankaPhotos

Photo: ©Ministero delle Infrastrutture e della Mobilità Sostenibili, Provveditorato Interregionale per il Triveneto concessionario, Consorzio Venezia Nuova



Innovation example Protecting Venice with mobile flood barriers

The Venetian Lagoon is an enclosed bay in which the city of Venice is situated. Over the centuries, the city has sunk several centimeters. This has been exacerbated by groundwater pumping from underneath the city and rising sea levels. In response to the increased threat of flooding, an integrated system of flood barriers named the Mose System has been installed to isolate the

lagoon from the sea during high tide. The Mose construction began in 2003 and was officially completed in 2021. It consists of a series of barriers and mobile gates. Seventy-eight bright yellow floodgates, or caissons, are situated at the bottom of the lagoon's three channel inlets. They have a total length of 1.6 km. When inactive, these 78 floodgates are filled with water. During high tide, compressed air is pumped into the floodgates causing them to rise. As the gates lift, a temporary dam is created. When the seawater level returns to normal, the gates fill again with water and sink back into their original resting position. The hinges keeping the floodgates in place have a calculated load capacity of 100 to 300 tons. This is enough to withstand a tidal wave (Kieckens, 2020). Such flood barriers have proven effective. But challenges include high cost, reliance on early warning systems due to length of time needed to close, and maintenance to prevent the structures clogging with sand (Adriadapt, 2022).

Photo: Getty Images / © Yevgeniy Sambulov



Innovation example Flow-through dams for flood control

Flow-through dams, aka perforation or dry dams, are built for downstream flood prevention. The main purpose of this type of dam is flood control. The dam opening (spillway) is at the same height as the river bed. Water is allowed to flow naturally when there is no excess water. But the opening slows the flow when water levels rise. One advantage compared to reservoir dams

built to store water is that sediment is more easily removed. Another is their more limited impact on biodiversity (e.g., by preserving fish migration routes) (Bertule et al., 2018). The dams can be built with materials such as bricks, concrete, timber and earth. In Japan, a flow-through dam is being built for the Asuwa River in the town of Ikeda. Called the Asuwagawa Dam, it is scheduled for completion by 2026. It is a gravity-type dam with large tunnels at its base for river water to flow through, except during a flood when water is pent up and gradually released downstream. In July 2004, torrential rains completely inundated the Japanese Fukui Prefecture. Thousands of houses were flooded and lives lost. It was as a result of this that local governments revived a several decades old plan to build the dam. Other suggestions for flood control had previously included widening the river embankment or building a multi-purpose dam.

Technology solutions

Proven technologies

Breakaway walls

The US Department of Homeland Security



Photo: Getty Images / © Hans Hansen

Buildings elevated up to or above flood level as a flood adaptation measure often have open foundations consisting of columns or other structures. This is to allow waves and water to pass through at high velocity. However, breakaway walls allow foundations to be closed off and used for storage, parking or other purposes when water levels are normal. Breakaway walls are not part of a building's structural support. Their design and construction is such that they are intended to collapse under high flood and wind force without damaging the

rest of the building. The US Department of Homeland Security has published detailed design and construction guidance for breakaway walls which are publicly available.

- Contracting type: Locally available materials
- Technology level: Medium
- Country of origin: United States
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Light-weight flood protection barriers

Aquobex



Photo: Getty Images Plus / © BanksPhotos

Aquobex is a UK-based company offering more than 37 flood protection and barrier products. They range from flood-proof doors and vent covers to waterproofed walls and passive and mobile flood barriers. Examples include a light-weight flood barrier that can be mounted on sockets pre-installed on a doorway with a few screw caps.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: United Kingdom
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Multi-purpose mobile flood barriers

Water-Gate



Water-Gate barriers are an alternative to traditional sandbags for flood control, protection and prevention. The barriers can be installed during a flood and remain stable irrespective of water flow and direction, or slope of terrain. It is described as being ideal for flash floods. It can be installed in front of a door, window, garage, elevator door, parking lot, underground entrance or a similar place. It can also be installed directly along a coastal bank to prevent overflows in response to coastal flooding or rising sea level.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: Canada
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Flood bags containing super absorbent powder

QuickDam



QuickDam sells a range of flood protection products. Examples include flood bags containing super-absorbent powder that swells and turns into a gel-like substance on contact with flood water. As the bag swells and grows, it creates a barrier between the protected property and the water. Bags can be stacked one on top of another depending on the height needed for protection. They can for example be used to contain or divert flood water away from doors, windows and garages. While QuickDam provides products also suitable for saltwater, the flood bags are more appropriate for inland flooding.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: United States
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Low-level flood bags with super-absorbent polymer

Gravitas International Ltd



A HydroSack® is a barrier against low-level flooding activated on contact with water. The sack, or bag, contains a mixture of the super-absorbent polymer (SAP) commonly found in disposable diapers plus sustainably sourced wood pulp. Because bags weigh very little (less than 0.5 kg), they must be activated before being placed in position so as not to be displaced by floodwater. They are activated either by being soaked in a bucket of water for 2–3 minutes or dowsed in water using a hose. Once activated, the product is effective for up to 6 months. But

it does not revert to its original state once dry. The bags are claimed to be biodegradable and can be discarded on the ground after use.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: United Kingdom
- Availability: Europe
- Contact: [WIPO GREEN Database](#)

Temporary mobile flood barriers

NOAQ Flood Protection AB



Sandbag barriers for flood protection often require huge amounts of sand and manpower to build. This can be a limiting factor in the event of flash floods. One alternative is a temporary mobile barrier made of materials such as plastic that can be rapidly deployed to protect vital infrastructure, commercial properties and homes. NOAQ Flood Protection AB has developed such a barrier – the NOAQ Boxwall. Designed to be free-standing, lightweight and easy to handle, individual barrier components connect without needing any

tools and are anchored in place by utilizing only the weight of the floodwater itself. Available in two damming heights, 50 cm and one meter, an individual box weighs less than 1 percent of a corresponding sandbag and is faster to deploy.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: Sweden
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Large-scale flood barrier tubes

FloodBlock



Photo: Getty Images Plus / © oobqoo

FloodBlock inflatable barriers are another flood protection alternative to sandbags and aluminum barriers. They consist of inflatable tubes connected by aluminum junctions that fill with water once contacted by a flood. When filled, they transform into a flood barrier system that can stretch over long distances (up to 1,000 meters). The tubes have been specially developed so they can be set up within hours to manage larger-scale flood events and used by the private sector or municipalities. Versions include temporary structures and passive barriers installed over a longer period.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: United States
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Natural flood management

Scottish Environment Protection Agency



Photo: Getty Images Plus / © Instantis

Natural flood management (NFM) involves a variety of soft engineering and green infrastructure measures designed for flood control. The aim is to reduce floodwater volume and delay floods flowing downstream by protecting, restoring and optimizing the natural functions of catchments, floodplains, rivers and the coast. Coupled with hard engineering, natural flood management may help reduce flood risk downstream. Measures seek to create natural structures and reduce soil compaction to slow water and to increase ground

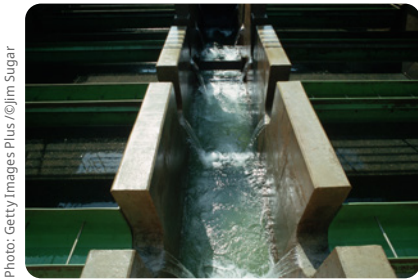
infiltration. The Scottish Environment Protection Agency has developed its *Natural Flood Management Handbook* as a practical guide to assessing the benefits of implementing such approaches.

- Contracting type: Free
- Technology level: Medium
- Country of origin: Scotland
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Frontier technologies

Prefabricated pumping stations

Grundfos



During heavy rainfall, stormwater pumping stations support flood control by pumping large volumes of water away from areas needing protection. The pumped water is then discharged into sewers or lakes. Compared to traditional concrete pumping stations cast on-site, prefabricated solutions are often more cost-effective and flexible, and can be installed quicker. Grundfos provides a variety of prefabricated pumping stations for drainage water, rainwater or wastewater. They may be made of materials such as polyethylene or polypropylene

which are generally more crack and leak resilient than concrete. The prefabrication comes with pipes, valves, pumps and level controllers (for fluid level measurement) pre-installed. The company has installed pumps in countries such as Malaysia to help meet their growing flood management needs.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: Denmark
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Self-closing flood barrier (SCFB)

Hyflo B.V.



The self-closing flood barrier design was developed in the Netherlands and commercialized in the late 1990s as an alternative flood protection measure when permanent structures are not a viable option. The barrier is not visible when resting vertically below ground within a steel or concrete trough. During a flood, water spills into the trough causing the barrier to float and rise automatically. Once the trough has filled, it is locked watertight. This overcomes the challenges of having to set up temporary structures stored off-site such as

flood-doors and floodgate systems, which rely on adequate warning time to put in place. The barrier can be built in various lengths, with a basin of high-density polyethylene, concrete or stainless steel.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: The Netherlands
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Horizon technologies

Hybrid flood defense systems

THIRD NATURE



Photo: © Third Nature

The concept developed by the Danish architectural practice THIRD NATURE (or TREDJE NATUR) is described as “pop-up climate change adaptation.” It explores how the joint challenge of major flooding and lack of parking space might be solved. This design “pop-up” envisions building a parking facility on top of a reservoir that fills with stormwater during heavy rain. The parking structure moves up and down as the reservoir fills and empties with water, corresponding to the height of the displaced water. Hydraulic and mechanical lifting and

steering mechanisms balance the weight of cars within the parking structure to ensure a secure and even vertical movement. The practice has teamed up with engineering companies COWI and RAMBØLL to develop structural models and financial calculations for the project. As cities become more crowded, such hybrid adaptation solutions could become increasingly relevant.

- Contracting type: N/A
- Technology level: High
- Country of origin: Denmark
- Availability: N/A
- Contact: [WIPO GREEN Database](#)

Mechanical jacks to raise houses during floods

FloodJack International Ltd



Photo: © FloodJack International

Driven by first-hand experience of devastating floods and the need for solutions to protect properties and residents, inventor Andrew Parker designed the FloodSafe House in 2012. The FloodSafe system is designed to detect a flood event. Detection triggers the house to rise above the floodwater on a specially designed mechanical jack system. The design has been developed for modular developments commonly used in affordable and social housing. A full-size prototype has been built and tested.

- Contracting type: N/A
- Technology level: High
- Country of origin: United Kingdom
- Availability: N/A
- Contact: [WIPO GREEN Database](#)

Water treatment

Over the past 100 years, global freshwater use has increased sixfold. By 2030, the world is likely to face a global water deficit of 40 percent. And already today over 2 billion people live in water-stressed areas (UNESCO, 2021). Technological innovation in water treatment has a critical role in making efficient use of the planet's precious water resources.

Global freshwater in decline

Less than 3 percent of Earth's water is freshwater. Due to its highly varied spatial and temporal distribution, freshwater access is becoming an increasingly critical challenge. Regions such as the Middle East and North Africa face the worst water scarcity (WRI, 2019). The agriculture sector uses up most of the freshwater – in very dry countries, irrigation may account for more than 90 percent of water withdrawals (UNESCO, 2021). More droughts, saltwater intrusion and seasonal variability are now amplifying competition for the water that remains. Meanwhile, the quality of water deteriorates, as heavier rainfall and surface water runoff carries with it fertilizers, oil, pesticides and other pollutants. The supply of water is increasingly uncertain. In many places, it is no longer possible to rely solely on the natural replenishment of water sources. Water treatment solutions and wastewater reclamation for agriculture has been practiced for centuries. Today, innovative technologies are enabling the extraction, management and treatment of water sources for use in biodiversity preservation, as drinking water, graywater, industrial process water and irrigation (Angelakis et al., 2018).

Water purification systems

There is huge climate adaptation potential in recycling wastewater. Yet only about half of global wastewater is adequately treated (Jones et al., 2021). Windhoek in Namibia is still one of only a few cities and places where wastewater is treated and turned into drinking water (World Bank, 2021b). High rates of water recycling are found in Australia, Europe and the Middle East (Dillon et al., 2019). Water from baths, showers and sinks (graywater) can be treated and reused for flushing toilets, doing laundry or irrigating gardens. Industrial-process water can be managed in closed circuits for temperature control, or reused through industrial symbiosis processes. In Egypt, drainage water from agriculture is collected through an extensive drainage network and mixed with freshwater for reuse (Abdel-Shafy and Mansour, 2013). The country is now set to become a world leader in water reuse by increasing its recycling capacity up to fivefold (Egypt Independent, 2022). The impact of climate change on the development of such technologies is already evident. Globally, the market for water recycle and reuse technologies is projected to increase from an estimated USD 15.3 billion in 2020 to more than 27 billion by 2026. Climate change impact and drought resilience measures are considered the main drivers (Research and Markets, 2022).

Making use of alternative water sources

Wastewater reclamation may help conserve freshwater. But there is also tremendous adaptation potential in making use of brackish water, harvested rain, saltwater, stormwater and other sources. One major future trend in the field of water reuse is the production of potable water for human consumption, particularly in megacities. Coupling advanced wastewater treatment facilities with seawater desalination plants may offer attractive ways of meeting this demand (Angelakis et al., 2018). Desalination technologies are becoming increasingly relevant in water-stressed regions. Some Middle Eastern countries rely on it for up to 90 percent of their drinking water (Padmanathan, 2022). Today, there are two main types of desalination technologies for saltwater and brackish water – membrane and thermal desalination. Membrane, or reverse osmosis (RO) desalination, uses osmosis to remove salt and other impurities by filtering water through semi-permeable membranes. Thermal desalination uses heat to evaporate and condense water. Despite considerable gains in efficiency, desalination technologies remain energy intensive and expensive. Moreover, the highly saline wastewater may present an environmental problem. Reverse osmosis has even been prohibited in parts of India, partly due to its wasteful use of water (Business Standard, 2021). However, several innovations focus on



Photo: Getty Images Plus / ©BNBB Studio

using renewable energy technologies such as wind, photovoltaic and concentrated solar power to improve the environmental and economic performance of desalination technologies.

Photo: Getty Images Plus / ©Johannes Laufs / EyeEm



Innovation example Supplying Windhoek's drinking water

The Goreangab Water Reclamation Plant was built in Windhoek, Namibia, in 1968. It is the world's longest-running treatment plant for recycling wastewater into drinking water. Driven by challenges such as a lack of perennial rivers, declining rainfall and increased evapotranspiration, the city of Windhoek became the first in the world to produce drinking water directly from

municipal wastewater. In 2002, the city built a new plant named the New Goreangab Reclamation Plant to benefit from more modern water treatment technologies. A combination of nine processes are employed to treat the water. Steps include pre-ozonation, coagulation/flocculation, dissolved air flotation, dual media filtration, ozonation, biological active carbon filtration, adsorption/active carbon filtration, ultrafiltration and chlorination. Once treated, the water is blended with treated surface water to produce drinkable reused water (Lafforgue and Lenouvel, 2015). To protect water sources from pollution, industries are located outside the city. Industrial waste is treated at a separate wastewater treatment facility. The new plant supplies more than 20,000 m³ of potable water daily to the capital's 350,000 residents (Onyango et al., 2014).

Photo: Getty Images / ©Abay/iss



Innovation example Desalination in Saudi Arabia

Saudi Arabia leads the world in desalination. The country has relied on desalinated seawater and wastewater since the 1950s and operates more than 30 desalination plants. Desalination accounts for 60 percent of water supply, with non-renewable groundwater (fossil water) supplying the remainder. With a growing population and expanding industrial sector, water demand is

expected to increase. Major new desalination projects are planned. A reverse osmosis plant was recently expanded to supply nearly 2 million people with a daily output of 450,000 m³. However, desalination comes at a great cost. It represents nearly 20 percent of total energy consumption in Saudi Arabia. This represents a significant source of GHG emissions, since the country's electricity is produced mainly from natural gas and crude oil (Demirbas et al., 2017). Progress is underway in renewable energy sources for desalination. In 2018, the world's first large-scale desalination plant powered solely by solar energy was built in the city of Al Khafji, where it provides water to 100,000 people. Solar-powered desalination plants in Saudi Arabia now save an estimated 1.5 million barrels of oil a day (US-Saudi Business Council, 2021). This represents a fraction of total energy demand. But more renewable initiatives and efficiency measures are planned.

Technology solutions

Proven technologies

Decentralized graywater recycling

Hydraloop Systems B.V.



Photo: © Hydraloop Systems

Water scarcity is driving a need to exploit alternative water solutions. Hydraloop provides decentralized graywater recycling systems for residential buildings and hotels. The system takes water from showers, washing machines and air conditioning units and treats it on the spot. The recycled water is then used for flushing toilets, laundry, irrigation and other non-potable uses. Depending upon user behavior, the system can reduce water consumption in a house by up to 45 percent.

Instead of relying on filters, membranes or chemicals to

clean the water, Hydraloop combines six technologies: sedimentation, floatation, dissolved air floatation, foam fractionation, an aerobic bioreactor and UV light disinfection.

- Contracting type: For sale
- Technology level: High
- Country of origin: The Netherlands
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Reverse osmosis of seawater

SafBon Water Technology



Photo: Getty Images / © tfromimages

Reverse osmosis (RO) is the most common desalination technology (Curto et al., 2021). During an osmosis process, water with different concentrations of salts for example is separated by a semi-permeable membrane. As these different concentrations come into contact through the membrane, water with a lower concentration naturally crosses over to water with a higher concentration until equilibrium is reached. In RO, pressure is added to highly concentrated water (e.g., seawater), forcing it through the membrane to obtain

clean, and salt-free water. SafBon Water Technology, part of Shanghai SafBon Water Service Co. Ltd, provides various RO treatment systems for seawater and brackish water. The technology has been developed as a modular system to enable shipping and installation worldwide. Water can be treated for municipal use as drinking water or to supply industrial sectors such power and mining.

- Contracting type: For sale
- Technology level: High
- Country of origin: China
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Multi-stage flash desalination (MSF)

Wärtsilä

Photo: © Wärtsilä



Multi-stage flash (MSF) desalination is a thermal desalination technology. This means it uses heat to evaporate and condense water to purify it. The Finnish company Wärtsilä's MSF system is applicable to seawater, industrial water and well water. It is capable of producing up to 1,500 tons of distillate a day. It is specifically designed for use onboard ships. But the company also provides land-based applications. In the MSF desalination system, incoming seawater is first heated in a heat exchanger. The water then enters different flash

chambers, where pressure is continually reduced and the water exposed to a series of explosive evaporations (flashing). The purified vapor is then condensed to leave behind salty brine. Meanwhile, the heated water helps preheat incoming seawater thereby reducing energy use. As heat transfer and evaporation are separated, the risk of scaling (caused by the salt) is reduced.

- Contracting type: For sale
- Technology level: High
- Country of origin: Finland
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Multi-effect distillation (MED)

IDE Technologies

Photo: Getty Images / © Reed Kaestner



Multi-effect distillation is a thermal desalination technology that uses waste heat from industrial processes or power production to distill seawater. IDE Technologies has developed a multi-effect distillation process in which seawater first enters a condenser that removes oxygen and heats the water moderately. From there, the seawater is led through a series of evaporators and condensers – called “effects” – in which waste heat is added through heat transfer tubes. It is then sprayed on to the hot tubes in the first effect. This evaporates some

of the water before it flows into the next effect. Here, the water condenses and provides heat for an additional evaporation process in the next effect, and so on until a final clear condensate is obtained.

- Contracting type: For sale
- Technology level: High
- Country of origin: Israel
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Solar-driven mini desalination plants

Elemental Water Makers



Elemental Water Makers has developed a solar-driven mini desalination plant suitable for use in off-grid rural areas. The plant is delivered in a container for speed and ease of installation and maintenance. Different sizes are available. Water production ranges from 5,300 to 40,000 liters a day. The process utilizes reverse osmosis technology. By reusing residual energy from the brine (the saltier water flow), energy input and number of solar panels can be reduced. The company also provides a desalination technology that uses solar or wind energy

to pump seawater into a tank positioned high on a hill. This is so that the system may use gravity to provide pressurized seawater for the reverse osmosis process. As this process is designed for continuous operation, storing water inside an elevated tank has an advantage with regard to fluctuating renewable energy technologies by providing a flow of seawater that is constant.

- Contracting type: For sale
- Technology level: High
- Country of origin: The Netherlands
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Solar water distillation

Millennium Electric T.O.U. Ltd



Solar water distillation is a relatively simple and cheap technology for purifying water from contaminants and salts. Water is placed in a basin to evaporate under high temperature. As it cools and condenses, water droplets are captured and channeled into a separate basin as clean water. Millennium Electric Ltd provide a solar distillation device that heats water to 130°C using a solar collector. As the water boils, evaporates and condenses, the distilled water is gathered into a separate tank for further use as irrigation and drinking water. The device can vary in size, ranging from 50 to 5,000 liters a day.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: Israel
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Frontier technologies

Closed circuit reverse osmosis desalination (CCRO)

DuPont Desalitec



Desalitec – now acquired by DuPont – has delivered a breakthrough in reverse osmosis desalination through its closed circuit reverse osmosis (CCRO) technology. It combines simple filtration principles with traditional RO cross flow. The system essentially recovers water treated at the end of the RO process and recirculates it a number of times, instead of passing it through a series of multiple membrane elements and stages. Passing it through several cycles enables more efficient water recovery, with recovery rates of up to 98 percent

in single-stage brackish systems. The CCRO system is claimed to reduce water waste by up to 75 percent and energy consumption by as much as 35 percent (Lenntech, 2021).

- Contracting type: For sale
- Technology level: High
- Country of origin: United States
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Membrane-aerated biofilm reactors (MABR)

Fluence Corporation



A membrane-aerated biofilm reactor (MABR) is a relatively new technology for aerobic wastewater treatment. It treats storm and sewage water using less energy and fewer chemicals. The technology promotes a high rate of oxygen transfer to the microbes, which break down pollutants in wastewater. MABR uses a permeable membrane to transfer oxygen directly to these microorganisms, as opposed to the traditional method of pumping air and diffusing it in the form of bubbles. Because it is a more passive form of aeration,

it requires less energy. Fluence Corporation offers MABR technology for small and medium-sized installations, as well as the retrofitting of existing plants. Energy savings as high as 90 percent are reported compared to conventional plants. This makes the technology suitable for use with alternative off-grid energy sources and decentralized treatment.

- Contracting type: For sale
- Technology level: High
- Country of origin: United States
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

UV disinfection of water

Solvatten

Photo: © Solvatten



Solvatten is a portable water treatment system for use by off-grid rural households. It uses ultraviolet (UV) light to disinfect water, while simultaneously using solar heat to warm it for domestic use. The technology consists of two 5-liter containers filled with water through an opening with a fabric filter. Units are then placed in direct sunlight to expose them to UV radiation. The combined heat (up to 75°C) and radiation purifies the water of pathogenic materials in under 6 hours. UV light damages the microorganisms' DNA of rendering them unable to

reproduce. An indicator tells a user that the water has been purified and is hygienic and ready for household use.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: Sweden
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Horizon technologies

Batch reverse osmosis

Purdue University

Photo: Getty Images / © Terry J



Traditional reverse osmosis (RO) relies on a constant flow of pressurized water fed through a membrane. Batch (RO) is a technique that processes water in batches, first releasing the outputs before taking in the next batch. But the breaks between batches – during which time no water is produced – may increase costs substantially. Researchers have now developed a variant of batch (RO) that uses a double-sided piston. While one side of the piston pushes seawater forward to be treated, the other side simultaneously fills the next batch of seawater to be

treated, and so on. The resultant reduction in downtime could enhance the commercial viability of batch (RO), while also significantly reducing the energy consumption of desalination processes.

- Contracting type: Research collaboration
- Technology level: High
- Country of origin: United States
- Availability: N/A
- Contact: [WIPO GREEN Database](#)

Freeze desalination

Photo: Getty Images / © Florencio Horcajo Alvarez



A category of desalination technologies currently under development focuses on freezing rather than heating feed water to extract freshwater. It does this for example by producing ice or other solids as an intermediate product. Technologies in this field include secondary refrigerant freezing (SRF), hydration (HY) and vacuum freezing (VF) desalination. Because ice contains only a small fraction of salt, such techniques can be used to produce freshwater from seawater (Curto et al., 2021). By freezing saltwater, a slurry of ice and brine is obtained

from which the brine is discarded. The ice that remains can then be melted to produce freshwater. Benefits include a reduced need for saltwater pretreatment, a lesser risk of corrosion and scaling and lower energy usage (Najim, 2022). Research into freezing desalination technologies started in the 1950s. But interest waned due to difficulty removing the ice produced in the process from the brine. No commercial plants are currently in operation. However, some research is addressing the technology with the aim of developing commercially viable alternatives with a smaller environmental footprint.

- Contracting type: Research collaboration
- Technology level: High
- Country of origin: N/A
- Availability: N/A
- Website: N/A

Water efficiency and conservation

When water is scarce, supply can be strengthened through water storage tanks and other solutions. Or we can try to reduce demand. To support these measures, proven and new technologies are helping us identify water sources and leaks, save water for when it is needed the most, and make sure it is used as efficiently as possible. This section looks at some innovative examples.

Freshwater on the decline

The projected impacts of climate change on groundwater levels are uncertain. But ever-increasing water demand, partly driven by climate change, has already lowered groundwater tables in many parts of the world. Combined with rising sea-levels, this has caused more saltwater intrusion into freshwater aquifers which degrades water quality (UNESCO, 2021). Many regions, particularly dry subtropical ones, now expect a significant reduction in both surface water and groundwater resources (IPCC, 2018). Cities such as Amman, Melbourne and Cape Town could see declines of between 30 and 49 percent (C40, 2018). In 2015–2018, Cape Town was close to running out of water, with large socioeconomic consequences and job losses in the agricultural sector (Nellie et al., 2018).

Reservoirs that help save water

Groundwater monitoring is challenging. But seasonal forecasting, hydrological modelling, geophysical surveys and remote sensing technologies are being used to assess current and future availability of surface and groundwater. Complex pipeline and canal systems can be used to convey surplus water from basins with water surplus to water-scarce basins, so-called inter-basin transfer (Bertule et al., 2018). A key adaptation measure for farmers, cities and communities is water storage in various forms. This can range from rainwater harvesting and improved soil

water storage to larger reservoirs such as multipurpose dams, lakes, tanks or water towers. Nature-based solutions can be instrumental in flood mitigation while also acting as reservoirs and replenishing groundwater. Wetlands for example are known to store enormous amounts of water. They do this in essence by first capturing and then retaining water long enough for it to infiltrate into the soil. Building micro-catchments such as terraces, sand dams, keylines, contour bunds and ridges also helps achieve the same effect. How much of the precipitation and runoff makes its way into groundwater is determined by factors such as soil characteristics, surface vegetation and landscape structures.

Technologies for water conservation

Managed aquifer recharge (MAR) technologies are one artificial approach to water storage gaining in prominence, especially in arid and semi-arid regions. Water is guided to underground aquifers through for example injection wells and infiltration basins. This technique has significant untapped potential and is considered ready for upscaling. The search for new application areas for MAR is driven by developments in water treatment technologies designed to ensure reclaimed water can be used safely. This is creating the potential for alternative water inputs to recharge aquifers. Among these are urban stormwater, treated sewage water and desalinated seawater. In India, the country with the highest MAR capacity, artificial recharge has been undertaken by government agencies. As water is often collected during monsoons, this shows that MAR could play a vital role in managing water-related disasters. Millions of structures for artificial recharge in various forms are now planned in urban and rural areas within India (Dillon et al., 2019).

A more efficient water management

Every drop counts when adapting to increased water scarcity. Storing and conserving water has little effect if out-paced by increased water demand. It is evident that the expansion of water storage has not been able to keep up with population growth (UNESCO, 2021). Demand for water to feed industry, agriculture and domestic use is expected to far outstrip supply in the future (Boretti and Rosa, 2019). In the agriculture sector, efficient irrigation technologies can help control water use. Precision farming has the potential for a more targeted application of water according to need (see chapter on Agriculture and forestry). For domestic use, household appliances such as faucet aerators and water-saving showers and toilets could be cost-effective ways to conserve water. In Beijing, such appliances were recently found to achieve 22 percent water use efficiency (Shi et al., 2022). Studies have also shown that smart water meters can trigger positive behavior change (Cominola et al., 2021). Metering is a technology area driven by digitalization and the need to reduce non-revenue water (NRW, water lost in distribution networks and so on). Indeed, water use efficiency is one of utility providers' most readily achievable goals. Especially considering that, globally, the volume of NRW is nearly 350 million cubic meters a day (Liemberger and Wyatt, 2018). Countries such as Denmark have managed to bring NRW down below 10 percent, with some utilities having eliminated it completely (Hvilshoj, 2015). Technologies that manage water pressure and detect leaks, such as sensors combined with internet of things (IoT) and information and communications technology (ICT), have played a key role. Together with automated control systems for water rationing, they make more effective water use possible (Oksen and Favre, 2020).

Photo: © Naireeta Services



Innovation example Managed aquifer recharge

Water is becoming increasingly scarce. Attention is turning to saving, storing and treating floodwater for a variety of applications. Managed aquifer recharge (MAR) is a technique for doing just that. Put simply, MAR captures water and injects it underground. It taps sources such as rainwater, stormwater and floodwater to replenish depleted groundwater aquifers. Methods

for implementing MAR incorporate the use of wells, boreholes, riverbank filtration and rainwater harvesting. Flood-MAR can range from the small-scale diversion of floodwater through existing sustainable urban drainage systems (SuDS) to the creation of large-scale water retention areas

and flood management infrastructure (UNESCO, 2022). Underground transfer of floods for irrigation (UTFI) is a form of MAR common around the Ganges River basin in India. UTFI uses wells to recharge groundwater basins with monsoonal runoff that could otherwise pose a potential flood risk downstream (Alam et al., 2020). Establishing UTFI wells has now become a local government priority in parts of India, with 50 new sites proposed for Rampur district alone. Meanwhile, on a local scale, farmers in India employ techniques such as Holiya to control localized flooding on their plots of land. This technique directs excess water into underground concrete pits through simple perforated pipes that can later be recovered for irrigation when required (Pavelic, 2019).

Photo: Getty Images / © bagi1998



Innovation example

Water pressure management in South Africa

A number of townships in the Emfuleni region in South Africa have achieved significant water savings. They have done so by incorporating innovative pressure management technologies into their water supply systems. High pressure in the water network had been identified as a key cause of damaged pipes and fixtures (combined with general deterioration due to lack of maintenance). This had led to approximately 80 percent of water supplied to the area being wasted. The pressure management system lowers the water pressure in the supply system during off-peak periods. At night, when demand is lowest, it further reduces the pressure. Controlling water pressure in the distribution network avoids damage. It has saved annually approximately 10 million m³ of water. This represents a 25 per cent reduction in the amount required from the water supplier, Rand Water. It took around nine months to install the advanced pressure management system in 2005. It is now among the largest single water pressure management installations in the world (Water Resources Group, 2012; Technolog, 2017).

Photo: Getty Images / ©Yuriy Kovtun



Innovation example

Reducing water usage in the fashion industry

The fashion industry uses a significant amount of freshwater. This is mainly due to high water demand from cotton. In addition, textile processing is a major source of water pollution, which further limits access to potable water for the rest of the world. But there are ways to save water. The Saitex denim factory in Viet Nam claims to recycle 98 percent of water through a closed-loop system and efficient jet washing machines. A five-step filtration process, including reverse osmosis, bacteria nanofiltration and evaporation separates toxic contaminants from used water which is recycled back into the manufacturing process. Also, jeans made from the denim are air dried to save energy. Compared to traditional denim production, which uses approximately 1,500 liters of water in a standard process, Saitex's water use is a modest 0.4 liters after recycling (Everlane, 2022).

Technology solutions

Proven technologies

Micro-catchments for water harvesting

United Nations Economic and Social Commission for Western Asia (ESCWA)

Photo: Getty Images / © by Alfian Widiantono



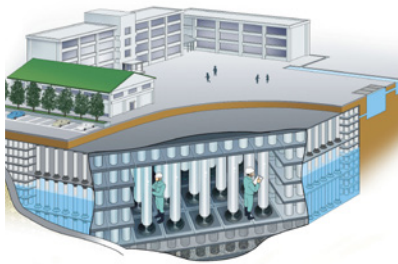
Micro-catchments such as bunds and ridges on farms help support water storage in the root zone of soil. They are a low-cost and easily implemented technique to adapt to water scarcity and enhance crop fruit tree yield and pasture shrubs. Although not itself a technology, the United Nations Economic and Social Commission for Western Asia (ESCWA) has developed a manual on micro-catchments for trainers and extension workers in the Arab region. It contains information, practical guidelines and examples that enable the technique appropriate for a particular site and crop to be selected and adopted.

- Contracting type: Locally available materials
- Technology level: Low
- Country of origin: N/A
- Availability: MENA region
- Contact: [WIPO GREEN Database](#)

Rainwater harvesting and underground storage

Totetsu Mfg. Co. Ltd

Photo: © Totetsu Mfg. Co. Ltd



Totetsu offers large-scale storage of harvested rainwater. Solutions include storage underground, aboveground and combinations. The system first purifies the water, removing over 95 percent of the sand and dust originally mixed in with the rainwater. Clean water is then stored in a tank for daily use, such as in agriculture. Additional sterilization and filtration stages can be added (not provided by company) in order to turn it into drinking water. The system uses a flexible structure with modules, which can be built, expanded and adapted to fit the

environment. It can sustain heavy vehicle loads and is earthquake-resistant. Replacing some of the traditional concrete-made structures with PVC reduces construction time and cost. Storage tanks can hold up to 50,000 m³ of water (Totetu, 2020).

- Contracting type: For sale and license
- Technology level: Medium
- Country of origin: Japan
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Smart water networks

Center for Environmental Sensing and Modeling (CENSAM)



Photo: Getty Images Plus / © R9_ReNaLdO

WaterWiSe is a wireless sensor network for online urban water distribution monitoring. It was developed by researchers at the Center for Environmental Sensing and Modeling (CENSAM) in Singapore. WaterWiSe integrates hardware and software to monitor hydraulic and quality indicators such as conductivity, dissolved organic matter, flow rate and pressure. The system uses sensors to detect leaks and predict pipe damage. Alerts and real-time notifications are made through a cloud-based infrastructure (Whittle et al., 2011). The technology was implemented by water analytics firm Visenti Pte Ltd, later acquired by Xylem.

- Contracting type: Service/Collaboration
- Technology level: High
- Country of origin: Singapore
- Availability: Singapore
- Contact: [WIPO GREEN Database](#)

Decision support system for water management

BIOFOS



Photo: Getty Images Plus / © Daniel Batakov

Decision Support Systems (DSS) is an integrated management tool. It allows a better understanding of the status of water resources and their users within a system. This can support the planning of appropriate adaptation interventions and their impact on water systems (Bertule et al., 2018). BIOFOS manages the wastewater treatment plant in the city of Copenhagen. It is presently being integrated into a Decision Support System to optimize treatment capacities so they can better handle stormwater. The system offers a fully

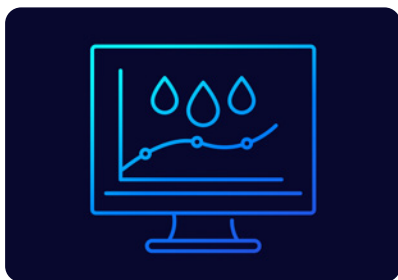
interoperable platform for a wastewater treatment plant and sewers. It is based on a series of level and flow sensors within a sewer network, as well as water data and flow forecasts. Such real-time control can reduce the flooding impacts and improve treatment capacity, for example by adapting treatment schemes to wet or dry weather conditions.

- Contracting type: Service
- Technology level: High
- Country of origin: Denmark
- Availability: Denmark
- Contact: [WIPO GREEN Database](#)

Real-time water monitoring

SmartHydro

Photo: Getty Images Plus / © Allaksei Brouka



SmartHydro is a company that provides water technology solutions for the efficient management of groundwater, surface or industrial waters. Smart sensors send information to a web platform that supports data monitoring online. It generates analysis on daily up to annual basis. Alerts are sent via text message to warn of any sudden changes to a monitored parameter.

- Contracting type: Service
- Technology level: High
- Country of origin: Chile
- Availability: Chile
- Contact: [WIPO GREEN Database](#)

Frontier technologies

Satellite-based leak detection systems

Suez

Photo: Getty Images Plus / © matsou



Satellite imagery overlaid on geographical information systems is a novel and cost-effective approach to leak detection. Suez and partner Utilis use imagery from satellite-mounted sensors. To this they apply radiometric correction (a preprocessing technique to remove noise, defective lines and so on) and filtering before running a patented algorithm that locates leaks by detecting treated water in the ground. The algorithm assesses pipe deficiencies by attributing a score to pipe segments showing leaks, as well as leak-location clusters

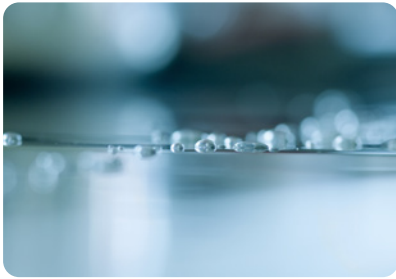
detected in one or more images. Data is then combined with GIS software to produce a single output where the pipes are scored on a 1–5 scale (where 5 indicates high levels of deficiency). A GIS-report and leak report are then shared with the user via a desktop or mobile application. Compared to traditional methods, large areas of land and pipework can be covered using fewer resources. Each satellite image is capable of covering a 3,500 km² area of land.

- Contracting type: Service/collaboration
- Technology level: High
- Country of origin: France
- Availability: United Kingdom
- Contact: [WIPO GREEN Database](#)

Water harvesting from air

Watergen

Photo: Getty Images Plus / © ZenShui/Ollion Dmmer



Watergen provides various atmospheric water generators that produce drinking water from air. A certain percentage of humidity is required (starting at 20 percent). Humid air is first filtered to remove dust and dirt particles. It is then led into a heat exchanger where it condenses into water. Once the water has been purified, minerals such as calcium and magnesium are added. Harmful microorganisms and particles are broken down and killed by UV light, before the water is finally stored in a built-in reservoir. The water continues to be

circulated through the UV lamp to keep it fresh. As drinking water is produced at source, water transportation is reduced. This is particularly suitable for hospitals, construction sites, small villages, first responders and other locations requiring a water source off the water-network. This type of generator could also supply temporary drinking water for people displaced during floods.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: Israel
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Seawater greenhouse

Seawater Greenhouse

Photo: © Seawater Greenhouse



Seawater Greenhouse specializes in the development and construction of greenhouses in arid environments using seawater as input water. Pumped seawater is used to humidify and cool the interior of the greenhouse, thereby saving significant amounts of freshwater. The water is further recycled for use in agriculture through evaporation and distillation. Modelling software simulates the growing environment to optimize the cooling effect. Most projects have been implemented in high-income countries. However, a recent collaboration

with the United Kingdom's Aston University (Akinaga et al., 2018) has resulted in a cheaper facility being built in Somaliland at a tenth of the cost.

- Contracting type: Service
- Technology level: Medium
- Country of origin: United Kingdom
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Circular shower system

Orbital Systems

Photo: Getty Images Plus / © Tasha Vector



Inspired by NASA space technology, Orbital Showers is a closed-loop shower system. The system saves up to 90 percent on water and 80 percent on energy compared to regular showers by purifying and recirculating the water used. A sensor measures the quality of drainage water every 20 seconds. Water of recyclable quality is led through a micro-filter to separate out larger particles, and then through a nanofilter for smaller particles. UV light is then applied to destroy harmful bacteria.

Once the water has been passed through a final-stage internal heater, it is ready for reuse. The system is connected to an app that shows household water savings.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: Sweden
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Horizon technologies

Water conservation at power plants

Infinite Cooling

Photo: Getty Images Plus / © RelaxFoto.de



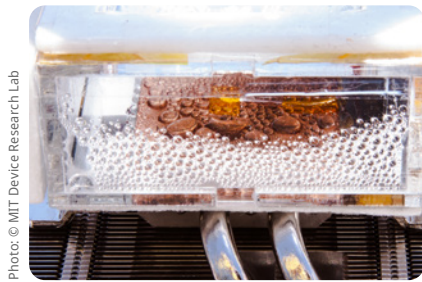
The electricity sector withdraws large amounts of water for cooling and other purposes. Significant water savings are possible through measures such as water reclamation, closed-loop water systems or dry cooling for turbines. At power plants, where cooling towers are typically used, evaporated water is lost into the atmosphere. Infinite Cooling is a company aiming to reduce water consumption in evaporative cooling tower systems. It uses charging electrodes at the outlet of the cooling towers that generate ions and charge the water

in the plume. A specially designed collector mesh placed on top of the cooling tower gathers the water droplets. They then condense and are collected with an electric field. The collected water leads to a reservoir and is ready for reuse. The solution saves more than 20 percent of water and can be retrofitted onto any cooling tower.

- Contracting type: For sale
- Technology level: High
- Country of origin: United States
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Desert water harvesting

Massachusetts Institute of Technology

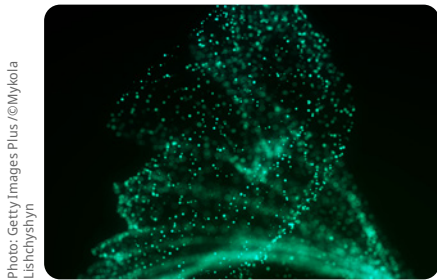


Researchers at Massachusetts Institute of Technology (MIT) have developed a device that extracts moisture from very dry air to produce water. The device, which would be suitable for desert environments, is powered by sunlight. It uses a novel material called metal-organic frameworks (MOFs) that pulls water into its many pores. Several liters of water a day can be captured by each kilogram of material (Oksen and Favre, 2020). Initial tests produced only a few milliliters of water. But researchers are aiming to scale the idea.

- Contracting type: Research collaboration
- Technology level: High
- Country of origin: United States
- Availability: N/A
- Contact: [WIPO GREEN Database](#)

Collective water data record keeping using blockchain

Water Ledger



Blockchain may play a role in improving water-trading systems by connecting an unspent surplus of water with consumers who need it. Blockchain can also improve water management, for example by initiating water right transfers based on reservoir water levels. By using decentralized digital ledger technology, blockchain can track ownership and enable fast and secure water rights transactions. Such a peer-to-peer system reduces the risk of fraud or data mismanagement. Blockchain also helps bypass a central authority and eliminates the need

for intermediary banks, thus reducing transaction costs. Water Ledger is a collaboration between companies Civic Ledger, WETx and Aqaix. It aims to deploy a blockchain-based system, mainly built on the Ethereum network, to manage smart contracts and the efficient distribution and trading of water rights.

- Contracting type: Research collaboration
- Technology level: High
- Country of origin: United States
- Availability: N/A
- Contact: [WIPO GREEN Database](#)

Marine ecosystems

Hundreds of millions of people rely on marine life and coral reefs to provide ecosystem services such as food and coastal protection (OECD, 2022b). Climate change and other human-induced threats are putting devastating pressure on these marine ecosystems. Traditional conservation is no longer enough. Specific measures to support climate-resilient marine ecosystems are increasingly called for – and technology could play a role.

Rainforests of the sea under threat

The world's coral reefs support more than a quarter of marine species. The economic importance of these goods and services is significant. The value of coral ecosystems alone is estimated at USD 172 billion a year (OECD, 2022b). In the last decade alone, around 14 percent of coral has been lost from the world's reefs. The main culprit has been the massive and recurring coral bleaching events caused by ocean warming. Moreover, increased CO₂ in the atmosphere also leads to ocean acidification which has increased by 30 percent over the last 200 years (NOAA, 2022b). A more acidic ocean is especially detrimental for hard-shelled sea life, including coral reefs. Other pressures come from coastal development, pollution, overfishing and tropical storms. The IPCC predicts that 90 percent of coral reefs could be destroyed in a 1.5°C climate change scenario. At a 2°C scenario they would be almost entirely lost to the marine ecosystem (IPCC, 2018). With more frequent mass bleaching events, reefs do not have enough time to recover. Furthermore, harmful algal blooms on reefs has increased by around 20 percent within the last decade (GCRMN, 2020). These blooms thrive in warming oceans. Meanwhile, higher temperatures and acidification is causing massive die-off in kelp forests, seagrass beds and other types of marine ecosystems crucial for marine life (Duarte et al., 2018). Heat is driving wild fish to seek cooler and deeper waters, altering their migratory patterns and decreasing fish catches (IPCC, 2022).

Artificial reefs, coral gardens and digital technologies

Artificial reefs are being created in locations the world over to help corals adapt to climate change. Of various shapes and materials, their impact has so far been limited. Challenges include maintenance and unintended negative effects on wildlife behavior. Coral gardening in which nursery-farmed corals are transplanted into reefs is more widely used. Techniques such as microfragmentation (breaking coral into tiny pieces) is speeding up the growth rate of farmed corals. Yet the impact is not expected to spread much beyond local ecosystems. Other adaptation techniques are now under development. They include assisted relocation of threatened species, developing climate-resilient coral species and coral microbiome manipulation (IPCC, 2019). Technology may play an important role in supporting such climate-resilient marine conservation efforts. Software programs and underwater images can be combined to reconstruct 3D maps of coral reefs, saving time and enabling analysis of reef status in new ways. On a more global scale, remote sensing technologies can map out climate impact on reef distribution and conditions in high resolutions and at more frequent intervals (Foo and Asner, 2019). Remote sensing and GPS technologies are especially relevant for their ability to track and manage data on species' migratory routes and human activities in real-time, allowing for a quick management response. Regular monitoring is key to informed management decisions. Knowing where and when coral reefs and other ecosystems are under climate pressure could guide scientists and governments toward better adaptation intervention points. Here, citizens are getting involved through open digital databases enabling crowdsourced data to map important species such as seagrass. Digital technologies are also enabling innovative adaptation measures such as mobile marine protected areas (mMPAs). Such mobile ocean sanctuaries have been proposed as a way of adapting to changes in species migration and shifts in space and time caused by climate change (Than, 2020).

Novel technologies in support of marine ecology

Harmful algal blooms are generally prevented or managed in one of two ways. By limiting nutrient-rich surface water runoff into waterways or controlling them through mechanical, biological or chemical means. Ecosystem conservation benefits from integrated measures. But

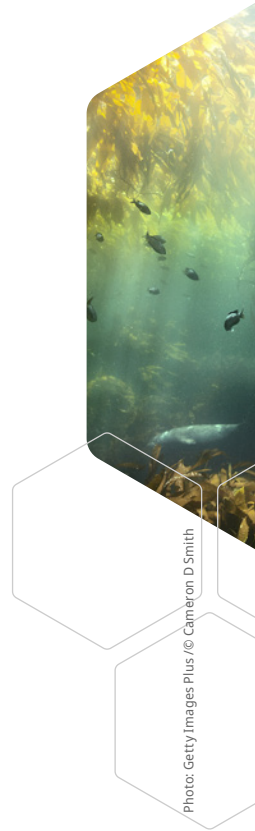


Photo: Getty Images Plus / © Cameron D Smith

novel technologies for managing climate-related threats such as harmful algal blooms are also being explored. For example, ultrasonic waves can be sent across the water surface to increase pressure around algae and limit their movement. With limited movement and access to sunlight and nutrients, algae die off and sink to the marine floor where they decompose. Innovative technologies also support coral reef conservation. Underwater drones and robots for example may make coral gardening processes more effective. Drones carry farmed coral larvae to designated reefs. Meanwhile, robots can automate time- and labor-intensive processes such as cleaning, feeding and growing more coral in a shorter amount of time. On the horizon, researchers want to know more about what is happening below the water surface. In the first ever sequencing of coral genome, DNA from nine species were sequenced in order to answer questions related to corals' adaptability, and what can be done to help them thrive in a changing environment.

Adapting coral reefs to climate change is particularly important for tropical coastal communities who rely on their services. However, marine ecosystems are complex and IPCC research shows that at high degree scenarios, many adaptation techniques will prove ineffective. Efforts like restoring and replanting coral could have a localized role. Yet only limited evidence on the relative costs and benefits of adaptation measures such as coral farming is available (IPCC, 2019). Reduction in global emissions, along with a stop to overfishing and pollution of oceans, is key to delivering a positive future for marine ecosystems and the people that depend on them. That we cannot adapt our way out of the climate crisis seems especially true for marine life.

Photo: Getty Images Plus /© Konstantin Trubavin



Innovation example **Biorock™ marine ecosystem restoration**

Biorock™ technology, invented in 1976 by marine scientist Wolf Hilbertz, is a cement-like building material that grows and forms layers of limestone over time. Small electric currents are passed between underwater metal electrodes. This causes dissolved minerals to accumulate and form a thick layer of limestone. This results in a growing and self-healing infrastructure

whose uses range from artificial reefs to breakwaters. Indeed, the material has multiple applications for regenerating coastal ecosystem services. They include coastal protection, coral and oyster reef restoration and erosion control, as well as the protection of seagrass, salt marsh, mangroves and other ecosystems. By providing space for settlement and growth, this technology supports ecosystems in surviving and recovering from threats such as warmer temperatures and ocean acidification. Supported by The Global Coral Reef Alliance, around 500 reef structures in more than 40 countries have been built based on Biorock™ technology, with a majority in Indonesia (GCRA, 2022).

Photo: Getty Images Plus /© Brook Peterson/Stocktrek Images



Innovation example **Remote sensing of kelp forests**

Healthy kelp forests provide a habitat for large marine populations, prevent erosion and sequester carbon dioxide. But they are disappearing, partly due to pollution and warming oceans. The Bay Foundation implements kelp forest restoration by relocating sea urchins to a non-kelp forest habitat and transplanting healthy kelp into newly urchin-free sites. Other

organizations, such as The Nature Conservancy, have worked both with researchers at universities and NASA to create the world's largest digital kelp forest map. The map – freely available through Kelpwatch.org – applies machine learning to over 35 years of remote sensing (satellite imagery) data in order to show changes in kelp cover over that period. Canopy-forming kelps are suitable for remote mapping, as they are distinctive when viewed from above, particularly within the infrared spectral region. At present, the map covers kelp forests from Baja California in Mexico to the Oregon–Washington state border in the United States. It is regularly updated to provide information on target areas most suitable for kelp restoration. This is a first step toward monitoring kelp forests and their dynamics at scale.

Technology solutions

Proven technologies

Artificial reefs

Reefmaker



Photo: Getty Images Plus / © Placebo365

Reefmaker's patented process for artificial reefs uses Florida limestone. This soft rock matches the pH levels of the ecosystems targeted and provides a good substrate for marine life, allowing it to grow naturally. The limestone is attached to a concrete structure in a sloping design to ensure durability while increasing surface area for reef. A special deployment vessel equipped with cranes has been designed for accurate placement of the artificial reefs out to sea. In addition to coral reef restoration, the limestone reefs can also be used for

oyster reef restoration, wave attenuation and erosion control. Structures can be designed to fit along the length of permanently fitted vertical poles attached to the sea bed. The aim is to keep the concrete proud of the marine floor and firmly retain the artificial reefs during extreme events like hurricanes. More than 50,000 reefs have been deployed along the US coast.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: United States
- Availability: United States
- Contact: [WIPO GREEN Database](#)

Seagrass monitoring and restoration

Project Seagrass



Photo: Getty Images Plus / © Reinhard Dirscherl

Almost 20 percent of the world's known seagrass has been lost (Dunic et al., 2021). Warming oceans are one of the factors affecting seagrass growth rate. Seagrasses provide food and habitat for numerous marine species. They are also important to conserve because of their huge capacity for carbon absorption. Research on seagrass restoration has focused on a variety of techniques and anchoring methods. Pilots have included large-scale transplantation trials with both manual and mechanical planting, including with artificial seagrass

and biodegradable pots. Traditionally, transplanted seagrass survival rates have been low. But recent transplants are increasingly surviving more than two years (Tan et al., 2020). Project Seagrass is an organization focused on the conservation of seagrass. It has planted more than a million seagrass seeds in more than 10 countries. The Seagrass Spotter is a global tool developed with the aim of helping people locate and identify seagrass in support of conservation efforts.

- Contracting type: Free
- Technology level: Low
- Country of origin: United Kingdom
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Ultrasound technology for algae control

LG Sonic



Warmer temperatures are exacerbating algal blooms, allowing them to grow thicker and float to the surface. Further blooming is promoted as the algae absorbs sunlight at the water surface. LG Sonic have developed a chemical-free algae treatment technology using low-power ultrasound. Ultrasonic waves are emitted in the top water layer from a device. This generates a constant pressure cycle around the algal cells. This pressure restricts the algae's movements, blocking its access both

to sunlight at the water's surface and nutrients at the bottom of the water column. Deprived of these inputs, algae sink to the bottom and decompose naturally without releasing toxins. The technology has been applied in more than 50 countries.

- Contracting type: For sale
- Technology level: High
- Country of origin: The Netherlands
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Coral gardening using microfragmentation

Coral Vita



Coral gardening, or coral farming, has become a widespread method for restoring degraded reefs at a local level. Coral fragments are collected from reefs and raised in farms until mature, before being installed at selected restoration sites. Coral Vita, a company based in The Bahamas, grows coral on land-based farms using a microfragmentation process. This process consists of breaking the coral into small pieces, which stimulates rapid healing and growth. It makes coral grow 25 times faster, growing coral in months rather than decades. The

company also applies an assisted evolution process that trains corals to survive in warmer, more acidic conditions by adjusting for these same conditions in growing tanks.

- Contracting type: Services
- Technology level: Medium
- Country of origin: The Bahamas
- Availability: The Bahamas
- Contact: [WIPO GREEN Database](#)

Coral reef mapping and monitoring

Allen Coral Atlas



Photo: © Allen Coral Atlas

The Allen Coral Atlas aims to provide high-spatial and thematic resolution, up-to-date global maps of the world's coral reefs, and a monitoring system to track changes in coral reefs over time. These and other emerging products of the Allen Coral Atlas support coral reef science, management, conservation, and policy around the world. The Atlas builds on satellite imagery and analytics supported by data on marine heatwaves, turbidity, wave modelling and other indicators. It also allows for the mapping of seagrass, microalgal mats

and other resources. It comes with a detection tool that tracks coral bleaching events in near real time. The Allen Coral Atlas was conceived and funded by Vulcan Inc. and brings together a team comprising of members from The Arizona State University Center for Global Discovery and Conservation Science, Earth-imaging company Planet and partners at the University of Queensland and the Coral Reef Alliance.

- Contracting type: Free
- Technology level: Medium
- Country of origin: Global collaboration
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Autonomous underwater vehicles for maritime monitoring

Huntington Ingalls Industries



Photo: © Huntington Ingalls Industries

REMUS is an autonomous underwater vehicle (AUV) that uses wings and small changes in buoyancy to move through the water. It is particularly suitable for long-term measurement of physical, chemical and biological oceanographic parameters. REMUS moves under water and regularly comes up to the surface in order to navigate using GPS. Here, it also transmits collected data and receives commands via satellite telemetry. The technology makes use of external sensors to continually scan the ocean to determine various water or environmental properties.

- Contracting type: For sale
- Technology level: High
- Country of origin: United States
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Frontier technologies

Autonomous underwater drones for reef protection

Queensland University of Technology

Photo: Getty Images Plus / © Humberto Ramirez



Researchers at Queensland University of Technology (QUT) in Australia have repurposed a drone to deliver coral larvae onto targeted reefs. The RangerBot is an underwater drone deployed in the Great Barrier Reef since 2018. This drone had previously been used to monitor reef status and protect coral from predatory starfish. Researchers first collected hundreds of millions of coral spawn during the massive spawning events that occur on the Great Barrier Reef. Most coral reproduce through spawning, releasing sperm and

eggs into the water at the same time. The spawn were reared into baby coral inside floating enclosures. The drone, renamed LarvalBot, then carried and released the coral larvae onto damaged reefs in order to help restoration.

- Contracting type: Research collaboration
- Technology level: High
- Country of origin: Australia
- Availability: Australia
- Contact: [WIPO GREEN Database](#)

Automated coral farming

Beyond Coral Foundation

Photo: © Beyond Coral



Coral farming activities can be time-consuming and repetitive tasks. This includes feeding and monitoring. A robot named CHARM automates such activities so as to make coral reef farming more efficient and halve labor costs. It also includes an inspection instrument to help catalog the coral and a soft bristle brush to clean away the algae that hinders coral growth. This patent-pending robot uses commercially available parts to make it more affordable. With the help of this robot, one aquaculture unit could grow up to 10,000 coral polyps a year.

- Contracting type: Research collaboration/Investment
- Technology level: High
- Country of origin: Australia
- Availability: Australia
- Contact: [WIPO GREEN Database](#)

3D-printed reefs

archiREEF

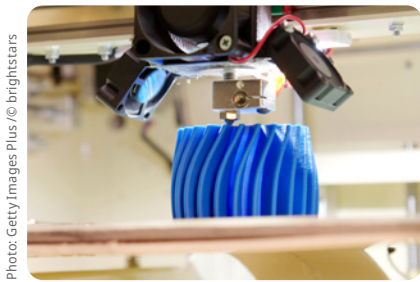


Photo: Getty Images Plus / © brightstars

Various groups and research institutions are exploring the potential of 3D-printed artificial reefs as a less labor-intensive marine restoration method. Among them are The University of Hong Kong and Hong Kong-based organization archiREEF. They have developed 3D-printed reef tiles for coral restoration. Artificial reefs are typically made of sand or limestone. This 3D-printed version is made of terracotta, which has similarities to the calcium carbonate found in natural coral reefs. The tiles are based on a hexagonal modular system to allow easy

expansion. According to the developers, the design can be tweaked for other marine ecosystems such as mangroves and oyster reefs.

- Contracting type: For sale
- Technology level: High
- Country of origin: China
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Horizon technologies

Coral genome sequencing

Great Barrier Reef Foundation + ReFuGe2020



Photo: Getty Images Plus / © Malakpet
Ps / 500px

The human genome was sequenced in 2003. More recently, the organization Great Barrier Reef Foundation, along with an international consortium of scientists named ReFuGe2020, sequenced the world's first coral genome along with co-existing organisms. DNA was sequenced from nine species of coral. The researchers also designed a way to fast track the sequencing process (Voolstra et al., 2015). The data obtained are freely available to the public through the Reef Genomics open access database to support new research. Several other

coral genomes have since been sequenced. Such research hopes to answer questions related to corals' behavior, and what can be done to help them adapt to changing environments.

- Contracting type: Research collaboration
- Technology level: High
- Country of origin: International
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Climate-resistant coral species

Oregon State University

Photo: Getty Images Plus / © Brett Monroe Garner



Researchers at Oregon State University have identified two common coral species that may be resilient to climate change impacts. The team subjected Hawaiian coral to a simulated ocean warming of up to 2°C for almost two years. Two-thirds of identified coral survived the simulated temperature increase. Unlike typical experiments on coral resilience, the researchers did not study the corals in a lab. Instead they built offshore tanks exposing the coral to more real-life weather conditions.

Of the corals exposed to acidification and warming temperatures, 46 percent of rice coral, 56 percent of lobe coral and 71 percent of finger coral survived. These findings can help inform active restoration work.

- Contracting type: Research collaboration
- Technology level: Medium
- Country of origin: United States
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

5 Cities

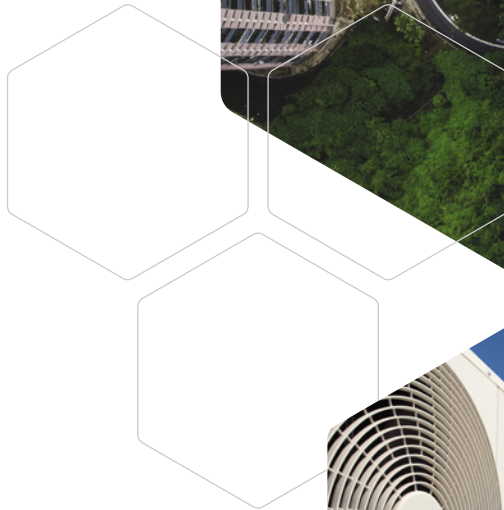




Photo: Getty Images/© ruffraldo

Technological developments and trends

Today, over half the world lives in cities, and the number is growing (UNDESA, 2018). Climate impacts such as heatwaves, floods and extreme weather events are becoming more intense and frequent. Urban areas have been hit hard. As cities look toward increasing their preparedness and capacity to adapt, technologies are offering part of the solution.

From cooling buildings, rainwater harvesting, protecting critical infrastructure to warning residents about a flood, this section showcases some well-established solutions. It also introduces technologies as yet on the horizon, and presents examples of innovative ways of using technology for climate adaptation. Nature-based and engineered solutions all have their important role to play.

Green and resilient cities

High levels of concrete in cities create a thriving environment for water to gather, multiplying the effects of floods and flash floods (Climate-ADAPT, 2016). Solutions such as permeable roads and drainage infrastructure offer some relief. But many cities are adapting to climate change consequences by applying nature-based solutions. A typical example is tree use. Trees provide cooling. But they also shade pedestrians, help manage stormwater runoff, improve air quality and stabilize soil structure to mitigate mudslides. Despite all this potential, many cities are reporting urban tree loss. While this highlights a bias favoring hard technologies over natural solutions, there is a growing consensus that nature needs to be reintroduced into urban areas. Adaptation solutions in cities are increasingly designed as multi-functional spaces that provide attractive locations for citizens. Although nature-based solutions can absorb climate impacts to a certain extent, it is clear that buildings, infrastructure and urban services must adapt. Melting roads, buckling railroads and flooded streets block access to public transport. More frequent power outages are also expected, as storms knock trees onto transmission lines, impacting critical services to hospitals, homes and industry. Many service providers and utilities are now planning for climate adaptation and mapping vulnerabilities in their systems.

Adapting buildings to hot and wet conditions

Low-tech solutions for managing heat have sufficed in many regions in the past. They include cross-ventilation, fans, insulation and shading. However, such options are increasingly inadequate due to more extreme heatwaves. This is especially the case for the more vulnerable parts of the world's population. Reflective and vegetated roofs and facades are growing in popularity. But the installation of air conditioners to manage rising urban temperatures is increasing rapidly worldwide (IEA, 2018). Their energy use and refrigerant gasses are significant contributors of greenhouse gas emissions. Much innovation is therefore focused on making mechanical cooling systems more efficient. Recent years have seen technological advances in areas such as desiccant cooling and radiative cooling. Technology is also helping to regulate temperatures better in real-time. As many cities become digitized and interconnected, the internet of things (IoT) and sensors in cities can enable smart heating and automated shutters.

Addressing vulnerability of systems

The interconnectedness of urban networks may also exacerbate vulnerability. To avoid this, decentralized infrastructure and services could help remove single points of failure (IPCC, 2022).

Distributed water treatment as back-up systems for example allow water to be treated at the point of use during a crisis. Meanwhile, distributed and local storage of water can mitigate risks related to hydropower generation, river flow management and so on. Decentralization may also improve people's access to new technologies. For early warning systems, it is often imperative to get communities and citizens involved (Sufri et al., 2020). Interestingly, technologies not originally intended as adaptation solutions have sometimes been used as such. Examples include social media apps Twitter or Snap Map. Originally intended for sharing opinions or leisure photos, they have also been used for things like citizen mapping of floods in real-time. Cities face varying levels of climate risk. Identifying these risks is key. Engaging schools, religious institutions and community centers in monitoring climate impact indicators could play an important educational role while also complementing authorities' weather monitoring efforts.

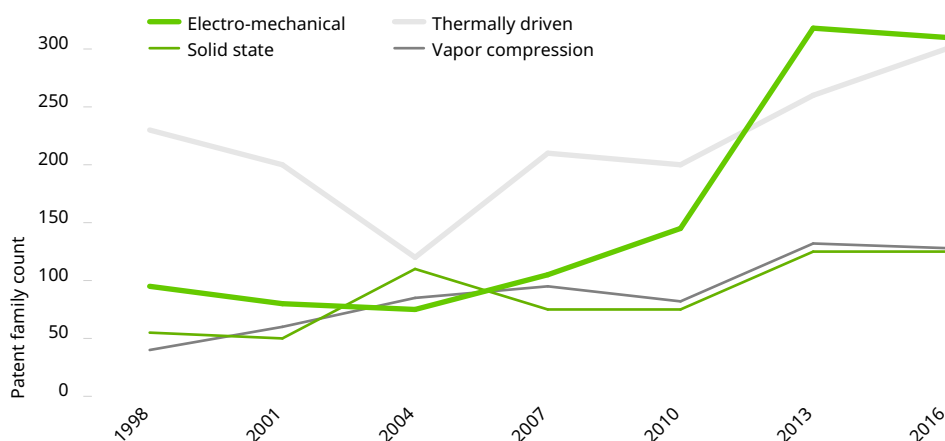
Patents and finance

Urban resilience multifaceted

General patent trend assessments in this sector are few. Strengthening the resilience of cities often involves holistic techniques and approaches unsuitable for patenting, for example green space integration in urban planning. Many solutions for cities, such as those related to flood defense systems, overlap with technologies presented in the chapter on Water and coastal regions. For example, surface, ground and rainwater collection represents a major part of water-related technology patents. Water storage is another rapidly growing area of invention, which may reflect the increased risks to water supply (Leflaive et al., 2020).

The heating, ventilation and cooling sector is another key area where patent activity may reflect the climate impact already felt by cities. Efficient and clean energy cooling systems are essential for responding to warmer temperatures in cities. Although more recent patent analysis is needed, a study commissioned by WIPO in 2012 showed a significant increase in patent activity related to solar cooling from 2005 and onwards (Kunz et al., 2012). Meanwhile, the last 10 years has seen significant patenting activity growth in the field of active cooling (i.e., as an alternative to vapor compression cooling systems). This has mainly been driven by a surge in patenting activity in China (Renaldi et al., 2021). However, conventional technology patents remain dominated by established manufacturers from the United States and Japan (Renaldi et al., 2021). Of the four main cooling technology categories, electro-mechanical and thermally-driven cooling recorded the sharpest growth during the period studied, whereas patent applications for vapor-compression and solid-state technologies saw a more conservative growth (figure 5.1). A recent study highlights magnetic and absorption cooling as promising alternative cooling technologies in these categories (Renaldi et al., 2021).

Figure 5.1 Trends in cooling technology patent application showing yearly patent family count, 1998–2016



Source: Recreated from Renaldi et al., 2021.

Adaptation finance gap in cities

There is huge potential in climate-proofing urban infrastructure and services. Up to USD 4 trillion worth of assets are at risk from climate change in cities worldwide (CDP, 2022). The World Bank has estimated that investing USD 1 trillion in climate-resilient infrastructure in developing countries would generate USD 4.2 trillion in benefits (Hallegatte et al., 2019). Managing climate risk in cities and settlements requires a mix of infrastructure, nature-based, institutional and sociocultural interventions. The adaptive capacity of cities can be significantly increased through investments in infrastructure and solutions that are nature-based (IPCC, 2022). However, climate finance toward cities, as in other sectors, tends to focus on mitigation solutions such as low-carbon transport and energy efficiency improvements to buildings. Indeed, under 10 percent of overall climate finance directed toward cities is linked to adaptation and resilience building. This is primarily related to water and wastewater projects, followed by disaster risk management. Furthermore, while many international funds support adaptation measures, there is a large gap in climate finance at city level. This is especially the case in rapidly urbanizing cities in Africa and South Asia (CPI, 2021).

Infrastructure a top priority

City and local governments remain key actors for facilitating adaptation, as well as public utilities and public services enterprises. Although data access is challenging, it is estimated that urban adaptation funds flow mainly from multilateral development finance institutions, followed by national sources and bilateral support. Multilateral climate funds also play an important role (Richmond and Upadhyaya, 2021). Overall, investments often focus on hard protection measures and infrastructure. Looking at a selection of developing countries' most recent adaptation finance needs, infrastructure accounted for 22.6 percent (UNEP, 2021a). Private and business sector investments in key infrastructure, housing construction and insurance could help scale action. But they risk excluding the priorities of the poor (IPCC, 2022). Global financing structures too are sometimes ineffective in responding to the needs of the urban poor. Locally managed funds may create better targeted solutions (Smith et al., 2014).

Urban planning

Climate change is increasing cities' exposure to heatwaves, floods and extreme weather events. From stormwater management to cool pavements, this section examines some of the ways in which technologies contribute to resilient and green cities. In the face of climate change, cities are rising to the challenge using a combination of engineered solutions and blue-green infrastructure.

Cities exposed to floods, as temperatures rise

Flooding and drought are expected to increase in cities. This impacts freshwater availability, regional food security and industrial outputs, but human health and comfort also (IPCC, 2022). Of 530 cities worldwide that reported their climate hazards in 2018, 71 percent said floods were their top concern, followed by extreme heat (CDP, 2018). In some large cities, for example Jakarta and Semarang in Indonesia, climate change-related flooding risk is exacerbated by the rapid sinking of land (subsidence) due to groundwater over-extraction (Bott et al., 2021). Regionally, urban areas in Africa and Asia are considered most at risk. In East and West Africa, urban land in flood zones and drylands exposed to high-frequency floods is expected to increase by as much as 2,600 percent by 2030 (IPCC, 2022). Meanwhile, car fumes, dark rooftops and tall concrete buildings in close proximity are all factors trapping heat and creating the so-called urban heat island effect (IPCC, 2022; Takebayashi and Moriyama, 2020). Many cities and settlements are in desperate need of climate-resilient urban planning to better manage these hazards and risks, and reduce vulnerability.

Managing water through gray, green and blue infrastructure

In responding to extreme weather events and flood, densely populated urban areas often turn to engineered solutions. They include pumping stations, reservoirs and expanding sewer capacity (if there is one). However, greater attention is paid to green and blue infrastructure in city planning. The IPCC (2022) has highlighted the importance of such nature-based solutions. Starting in peri-urban areas, measures such as hill-slope and coastal zone reforestation can help reduce flood hazard in cities. City planners are also recognizing the ability of green spaces such as parks to temporarily hold excess water by turning into lakes during flood events. Similarly, green roads can be designed to detain and hold back water in smaller side streets (EEA, 2018). Large-scale installation of rainwater harvesting systems and city-wide green roofs could reduce total discharge by up to 15 percent, depending on the city (Cristiano et al., 2021). Blue infrastructure on the other hand includes lakes, wetlands and bioswales, which are shallow channels covered in vegetation that capture and infiltrate stormwater runoff. In Europe, many urban innovations have been pilot tested. But their up-scaling remains challenging. In Central and South America, the adoption of nature-based solutions and green-gray infrastructure is still emerging (IPCC, 2022). While integrated and hybrid approaches are increasingly called for, there is still a strong bias toward gray infrastructure in most parts of the world. Flood protection in coastal cities for example often takes the form of sea walls and levees (see chapter on Water and coastal regions).

Green cities absorb and cool

Parks, green spaces and urban planning choices such as street orientation and building density all help decrease outside air temperature. Trees and vegetation areas lower temperatures by providing shade, as well as cooling from evapotranspiration (IPCC, 2022). Increasingly, cool pavements (containing for example solar radiation-reflecting additives) are being recognized for their significant temperature reduction potential in an urban environment (Kappou et al., 2022), while permeable roads contribute to managing storm water runoff. NASA has estimated that a white roof could be 23°C (42°F) cooler than a black roof on the hottest day of a New York summer (NASA, 2012). Meanwhile, some cities are offering cooling centers for vulnerable populations who may not have access to air conditioning, or cannot afford the electricity bills during peak temperatures.



Photo: Getty Images/© piccra

Innovation example France's response to the 2003 European heatwave

The 2003 European heatwave caused more than 15,000 casualties in France. It served as a wake-up call for many cities to take action on reducing climate risks in urban areas. The following year, the country drew up the National Heat Wave Plan built on national forecasting and alert systems. Despite hotter summers since, the

death toll has been significantly lowered. In addition to a major effort to issue warning messages in time, the plan includes measures such as cooling rooms at senior centers, replacing tarmac at playgrounds with more heat reflective materials, and mandatory insulation in construction regulation. This reflects a growing awareness of the benefit of an integrated response to risks like heatwaves, compared to stand-alone technologies and projects. Since 2012, French construction standards for new buildings and, to a lesser extent for existing buildings, have included requirements regarding comfort during heatwaves. In Paris, adding parks and green spaces has been another key solution to heatwaves. Urban greening is most effective when green spaces are watered during a heatwave. Doing so increases the cooling effect from evapotranspiration. A simulation was made of the potential effects of some measures introduced in Paris, namely applying new construction standards, behavior change in relation to air-conditioning use, and urban greening. If fully implemented, these measures could potentially reduce night-time temperatures by as much as 4.2°C (Viguié et al., 2020).



Photo: Getty Images / © chinaface

Innovation example The Qunli stormwater park in China

“Sponge City” is a term for green infrastructure approaches that combine methods. Combinations include methods such as permeable paving, bioretention (removing pollutants from stormwater runoff), urban vegetation and rainwater collection. Planned at an urban scale, such nature-based solutions can help mitigate stormwater runoff and flooding, improve water quality

and recycle rainwater for on-site use. Many solutions are well suited for low-cost implementation. However, they do require careful coordination, planning and a knowledge of local conditions such as soil status to maximize benefit at the city or community scale. Several cities are experimenting with the “Sponge City” approach. They include San Salvador and a number of cities in China. Notably, the city of Harbin in Northeast China has implemented an integrated urban water management (IUWM) strategy to mitigate serious waterlogging. The strategy included revitalizing a dying wetland in the middle of the city surrounded by roads and large development projects. Ponds and mud flats were created around the wetland. A cost-benefit analysis of the urban construct looked at the likely construction and maintenance fees in relation to air quality improvement, rainwater harvesting and flood-risk reduction. It concluded that, although long-term maintenance of the ponds and mud flats may be costly, the social and environmental impact would be positive due to their flood handling capacity (Fan and Matsumoto, 2019).



Photo: Getty Images / © olo

Innovation example Kuala Lumpur’s Stormwater Management and Road Tunnel (SMART Tunnel)

Malaysia’s SMART Tunnel is a stormwater drainage tunnel built to alleviate flooding in the center of Kuala Lumpur. It stretches for nearly 10 km between two locations where the rivers Klang, Ampang and Gombak meet. This makes it the longest stormwater drainage tunnel in Southeast Asia. The system was built to

divert large volumes of water from flood-prone areas via a holding pond, a bypass tunnel and a reservoir to store the water. At the same time, the opportunity was taken to integrate a motorway into the system to relieve traffic congestion at the main city center gateway. To protect drivers, automated flood control gates have been installed at either end of the tunnel, operated by a hydraulic system. Ventilation and escape shafts are also available at 1 km intervals. During the March 3, 2009, Kuala Lumpur flashfloods, the SMART system successfully diverted a total 700,000 m³ of floodwater from the holding pond via the tunnel. This avoided the overflowing of the area around Masjid Jamek LRT station (Government of Malaysia, 2022). In 2021, the tunnel claimed a new record by diverting nearly 5 m³ of floodwater from the Klang River to the reservoir (Smarttunnel, 2021).

Technology solutions

Proven technologies

Blue-green urban planning framework

Climate-KIC, Imperial College London



Photo: Getty Images / © bluejayphoto

Many cities lack a holistic approach to nature-based solutions to increase resilience. Instead solutions such as providing shade from the sun are applied in a mono-functional way. The Blue Green System project is a methodology and set of tools developed by researchers at Imperial College London, with the support of Climate KIC. The System helps city planners and developers integrate green space, trees and natural flood management into projects. Researchers now provide expertise through services connected

to disseminating the blue-green solutions. Thirteen demo sites have been created in different countries to demonstrate solutions such as urban lakes and bioswales, as well as green roofs equipped with sensors for predicting stormwater collection and thermal insulation benefits. The framework is applicable at building, neighborhood and city-scale and suitable both for new and retrofit developments.

- Contracting type: Service
- Technology level: Medium
- Country of origin: United Kingdom
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Stormwater management software

United States Environmental Protection Agency



Photo: Getty Images / © Larisa Rurdenko

The EPA's Storm Water Management Model (SWMM) is an open source public software free for use worldwide. It can be used by local, state and national actors for the planning, analysis and design of stormwater and drainage systems. By evaluating gray infrastructure such as pipes and storm drains, this tool can be used to develop stormwater control solutions to reduce urban runoff and discharge. It can also be used to map flood plains and design strategies to avoid sewer overflows. For example, various combinations of green

infrastructure (including rain gardens, bioretention cells, green roofs and bioswales) can be modelled to determine their effectiveness in managing runoff.

- Contracting type: Free
- Technology level: Medium
- Country of origin: United States
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Underground bioretention and water storage

Treebuilders



Treebuilders underground bioretention system serves two functions: bioretention and underground water filtration and water storage. The technology is described as a “submerged rain garden.” It exists of soil-containing modular units to support large tree growth combined with on-site stormwater management through absorption, evapotranspiration, interception and filtration. The underground structure avoids taking up extra space in crowded cities. Instead, enough space is provided underground to allow the tree roots to grow,

its absence often preventing urban trees from thriving. The modular units simultaneously treat stormwater runoff at source rather than allowing it to enter sewers untreated.

- Contracting type: Service
- Technology level: Medium
- Country of origin: The Netherlands
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Soakaway crates for stormwater collection

ACO



Soakaway is a sub-surface drainage technology that manages surface water and stormwater runoff on site. It is essentially a pit with several holes in the ground that collects rainwater before further dispersing into the earth. Filling the holes in the pit with materials such as stones and rubbles slows the infiltration of water into the ground, instead of discharging it immediately to an offsite location such as a sewer. ACO StormBrixx is an example of a plastic geocellular soakaway system for the attenuation and infiltration of water. The

design consisting of brick-bonding and cross-bonding is flexible. It can be used across various construction environments either as a standalone solution or part of an integrated sustainable urban drainage (SuDS) scheme.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: United Kingdom
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Large-scale rainwater catchment system

Aarhus Vand

Photo: Getty Images / © San Francisco Chronicle/Hearst Newspapers via Getty Images / Contributor



Residents of a new housing estate Nye in Aarhus, Denmark, are using treated rainwater for their washing machines and toilets. The project was carried out by Aarhus Vand, a public utility water company. The technology consists of a system where rainwater collected from roofs is drained into a basin, or artificial lake, together with other rainwater and surface water flows. A water treatment plant located near the basin filters the water to a good standard. From the plant, this water is channeled first into water reservoirs then into

homes via a separate piping system for use by washing machines and toilets. By reusing treated rainwater on a larger scale, up to 40 percent of drinking water is saved.

- Contracting type: Service
- Technology level: Medium
- Country of origin: Denmark
- Availability: Denmark
- Contact: [WIPO GREEN Database](#)

Retrofit cool pavement coating

EnduraBlend

Photo: Getty Images / © Yung Getty



EnduraBlend is a retrofit solution for “hot” pavements. It is in the form of a reflective coating that decreases solar absorption. Reflective treatments for paved surfaces like Endurablend can help reduce heatwave duration and severity. The company’s Pavement Surface Coatings contain special infrared solar reflective pigments that reduce asphalt pavement temperature. The result is a lower heat index, lower energy costs (for cooling in nearby buildings) and better air quality. In addition, Endurablend extends pavement life-time

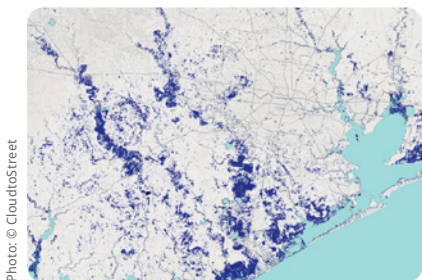
by protecting the asphalt surface from petroleum, salt and de-icing materials, as well as UV degradation. Endurablend has an expected lifespan of 10 years in heavy traffic and extreme weather conditions.

- Contracting type: For sale
- Technology level: Low
- Country of origin: United States
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Frontier technologies

Open source flood tracking

Cloud to Street



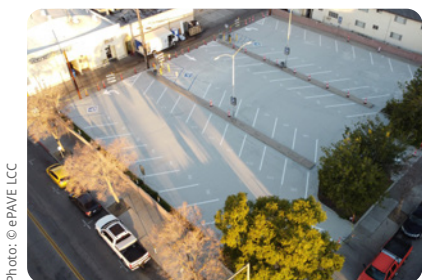
Cloud to Street's free Global Flood Database offers an overview of flood exposure around the world. The database is the world's largest collection of flood maps. It combines 15 years of data on 913 floods with human settlement maps across 169 countries to help scientists, governments and financial institutions prepare better and protect against flood-risk. Through the use of satellites and artificial intelligence, floods can be tracked in near real-time anywhere in the world to insure risk and save lives. Maps can be downloaded from 15 public and

private satellites, down to 250 m resolution. The company also offers paid services and claims to have provided support to 28 governments worldwide, including to the Republic of Congo, where floods could quickly be identified to relocate at-risk refugees, secure emergency aid and provide targeted relief.

- Contracting type: Service
- Technology level: High
- Country of origin: United States
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Cool pavements

ePAVE



Dark pavements absorb from 80 to 95 percent of heat. They add to global warming by radiating heat into the atmosphere where it is trapped by the greenhouse effect. Cool paving materials reduce urban temperature and make cities more comfortable during hot weather. ePAVE is a cool pavement product with a patented formula. It is engineered to provide asphalt and concrete surfaces with a layer of protection that also has climate adaptation benefits. The technology consists of a two-component polymer cement composite. The first

component is a dry ingredient powder, the second a liquid polymer emulsion resin. The reflective coating is said to mitigate the urban heat island effect by reflecting solar radiation. This lowers surface and ambient air temperatures, while improving air quality.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: United States
- Availability: United States
- Contact: [WIPO GREEN Database](#)

Horizon technologies

AI-driven satellite solution for green space

Husqvarna



Photo: Getty Images / © Darryl Fonseka

Husqvarna Urban Green Space Index (HUGSI) is an AI-driven satellite solution focusing on urban green space. The tool measures and analyzes urban green space in selected cities worldwide. It does so by applying computer vision and deep learning techniques to satellite imagery. The aim is to provide objective and continuous quantifications of urban green space and allow cities to track their development and benchmark against global standards. To date, over 250 cities in 60 countries have been ranked according to indicators such as health of urban vegetation, tree coverage and urban green space distribution.

- Contracting type: Service
- Technology level: High
- Country of origin: Sweden
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Pedestrian navigation tool for cool streets

Barcelona Regional Urban Development Agency



Photo: Getty Images / © Vera Tikhonova

Summers in Barcelona are becoming increasingly hot due to climate change. Cool Walks is an app developed by a public agency in Barcelona that allows pedestrians to choose the shadiest path to where they want to go. By picking the starting point and destination for your walk, as well as the time of day, recommended routes are provided. Using LIDAR, high-resolution models of ground elevation (including trees and buildings) were created. Combined with manually-gathered data, this allows the app to model direct sunlight and shade,

and guide pedestrians toward shady sidewalks, drinking fountains or places to shelter. Similar digital tools for helping citizens navigate cities through various climate impacts could become commonplace in the future.

- Contracting type: Free
- Technology level: Medium
- Country of origin: Spain
- Availability: Barcelona
- Contact: [WIPO GREEN Database](#)

Buildings

Heatwaves are associated with increased mortality and health risks. The impact will be greatest on cities compared to rural areas due to the heat island effect (IPCC, 2022). The need for buildings to offer heat relief has accelerated innovation in cooling technologies. At the same time, buildings themselves must stay protected from climate-related hazards such as floods. This section presents some inspiring examples.

The pressure to adapt is building

It is “virtually certain” that warm daily temperature extremes will increase globally throughout the 21st century (Allen et al., 2012). The increase will be both in frequency and magnitude, with heat-stressed cities an enhanced risk. In Africa, it is projected that more than 40 million city dwellers may be exposed to extreme heat within the next 40 years (IPCC, 2022). In highly humid conditions, temperatures get dangerous at around 35°C. At this point the human body can no longer cool itself by sweat alone (Sherwood and Huber, 2010). As the climate warms, the requirement for buildings and housing to offer a cooling effect and provide thermal safety and comfort increases. At the same time, building design demands an increased resilience against excessive rainfall, floods, snow, tornados and wildfires in different parts of the world. These demands are difficult from a planning perspective. Buildings represent long-term investments planned for decades into the future (Pyke et al., 2012). Strengthening buildings’ adaptiveness and resilience to extreme heat and weather events will require a combination of hard technologies to strengthen and protect, and soft approaches such as climate proofing through building codes.

Cool and green buildings

Buildings have traditionally relied on “passive” cooling technologies like natural ventilation, window orientation, insulation and shutters. As cities adapt to increasingly hot temperatures, such approaches are no longer adequate. The International Energy Agency (IEA) estimates a staggering 5.6 billion air-conditioning units will be in use by 2050, up from 1.6 billion today (IEA, 2018). Much effort is now being given to technologies that enhance the energy efficiency of such units, as their currently large carbon footprint is actually exacerbating cooling need, often referred to as the “cold crunch” (IPCC, 2014). In countries like Switzerland, environmental policies even limit their installation. Mechanical cooling systems’ high energy use is triggering innovative approaches to green heating and cooling. They include solar-powered air conditioners, desiccant cooling and absorptive cooling from industrial waste heat. Meanwhile, so-called free cooling uses lake and sea water, whereas dry cooling is applicable to more water scarce zones. Some innovators are modernizing ancient Persian wind towers and looking toward advanced natural ventilation systems. Conventional insulation materials are commonly obtained from petrochemicals. But interest in recycled or green insulation materials (such as hemp, flax and wool) is growing. Meanwhile, cities like Singapore and Paris are cooling roofs with vegetation and reflective surfaces for heat relief – a rational approach, as over 60 percent of most urban surfaces is either roof or pavement (IPCC, 2014). Green rooftops and facades can reduce temperatures, harvest water and improve poor air quality which is otherwise worsened by climate change. Cool roofing products use highly reflective materials that lower roof temperatures.

Water harvesting and hazard-proofing

Green roof installation could reduce rainfall runoff by over 50 percent due to the vegetation absorbing the water. If half the roofs within a region were covered, a total runoff reduction of 7.5 percent could be achieved (Mentens et al., 2006). Alternatively, water can be captured through water harvesting technologies. These capture and filter rainfall and runoff from roofs and building exteriors for storage in tanks either above or below ground. The growing interest in water harvesting technologies is also due to the added benefit of alleviating water scarcity surges. Advances in filtering systems, sensors and pumps allow the water to be reused on demand for use in toilets, washing machines and by outside taps. However, this requires additional piping systems. Various regions, such as Haryana state in India, have mandated the installation of rainwater harvesting systems for groundwater recharge. This applies to all

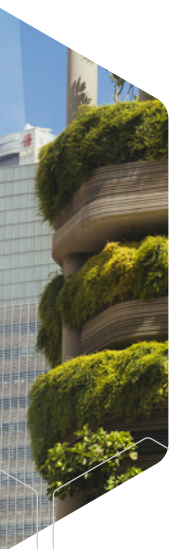


Photo: Getty Images / © Naomi Rahim

new buildings, irrespective of the roof area. Buildings are also adapting to extreme weather and floods through technologies that pump floodwater away from basements (sump pumps), reinforce concrete and water-proof building envelopes (such as roofs, doors and exterior walls).

Some of the technologies described have been integrated into urban planning concepts such as the sponge city design, so as to maximize benefits beyond the scale of buildings. As a result, these technologies could bring additional benefits to the region as a whole. However, there are huge variations in the impacts experienced and communities' abilities to adapt. Many of the most at-risk regions from flooding are in Asia (Nicholls et al., 2007). For populations living in informal settlements and housing the only solutions to flooding might include digging trenches around houses, building small retaining walls to prevent water from flooding in or raising houses a couple of meters above ground. While this may alleviate some flooding problems, it is inadequate in adapting to flash floods. This further points to a discrepancy between the supply of and demand for technologies and solutions in relation to their accessibility for regions most in need of climate adaptation.



Photo: Getty Images / © Nikada

Innovation example Singapore's "Garden City"

A strong rise in economic prosperity triggered tall and densely built architecture in Singapore. The city started profiling itself as a "Garden City" through a plan dating back to 1967 focusing on intensive tree-planting and parks. Studies show green roofs reduce median surface temperature by 30°C in hot and humid cities (Jamei et al., 2021). Today, new developments in Singapore

must include greenery, for example in rooftops and facades. As a result, the city has more than 140 ha of sky-rise greenery, with plans to increase this to 200 ha by 2030 (Government of Singapore, 2022). In Marina Bay, located in a central Singapore, all developments must comply with a 100 percent greenery replacement policy. This stipulates that any ground-level greenery lost to development must be replaced with greenery planted in high-rise terraces and gardens. Singapore also boasts the world's tallest public housing development – the Pinnacle@Duxton. This is a collection of seven 50-storey buildings connected by gardens on the 26th and 50th floors (Kolczak, 2017). Singapore's current sky-rise greenery incentive schemes fund up to 50 percent of rooftop and vertical greenery installation costs, with the objective of mitigating the urban heat island effect and improving air quality (Government of Singapore, 2022).



Photo: Getty Images / © kkong5

Innovation example New York's cool roofs and cooling centers

The New York "CoolRoofs" initiative has covered more than 500,000 m² of roof space on over 600 buildings in a white reflective coating. This is to moderate the urban heat island effect and reduce the negative impact from projected future extreme heat events. The city estimates that these reflective surfaces reduce cooling costs by 10 to 30 percent and shrink the city's carbon footprint by

1 ton of CO₂ a year for every 232 m² covered. In 2011, it was legislated that 75 percent of roof area on all new or substantially renovated low-slope roofs must have specific thresholds for minimum solar reflectance and maximum thermal emittance. To provide further cooling services, the city is making use of what is terms "cooling centers." These are public spaces like libraries, community centers and senior centers cooled with conventional air-conditioning (NYC Business, 2022).

Photo: © Services Industriels Genevois



Innovation example Geneva's lake water cooling system

GeniLac is the biggest thermal exchange network in Geneva. The network uses water from Lake Lemman to cool and heat city-center buildings. By adding a heat pump, it also provides heat. For 10 years the company SIG (Services Industriels Genevois) has utilized the lake as a natural and local resource for cooling and heating United Nations buildings (including that of WIPO) and those of other international organizations and companies in the city. Lake water is used to cool buildings in summer and the heat pump to heat them in winter. Heat pumps are directly based in each building. Water is pumped into an underground reservoir to a depth where the temperature is fairly constant. It is then piped toward a heat exchanger for cooling or a heat pump for heating. Cold or hot return water is then returned to the lake.

Technology solutions

Proven technologies

Green roofs for tilting and tiled roofs

Plantika

Photo: Getty Images / © Marcin Szmyd



Retrofitting roofs with greenery or creating green roofs on sloping surfaces can be challenging. Plantika provides a lightweight, modular green roof system that enables extensive roof greening on sheet metal and tile roofs (for both existing and sloping roofs). This avoids time-consuming and costly planning and construction measures. The top vegetation layer consists of between five and eight different low-maintenance species such as grasses, herbs and sedums. Sedum plants are succulents able to store water in their leaves, and better at withstanding different weather events.

- Contracting type: For sale
- Technology level: Low
- Country of origin: Austria
- Availability: Austria
- Contact: [WIPO GREEN Database](#)

Green facades

Respyre



Photo: Getty Images / © moomusician

Green spaces on buildings can be added to facades, as well as roofs. Green facades can serve as shade, cooling buildings and urban space through transpiration. Species such as moss are particularly well suited for green facades. This is because they have rhizoids instead of roots and therefore do not require deep soils to grow. The company, a Technical University of Delft spin-off, has developed a patent-pending bioreceptive concrete solution. Once hardened, the bioreceptive concrete's surface is conducive to moss growth. Specific

characteristics making Respyre's concrete bioreceptive include its porosity and water retainment, micropore texture, acidity and nutrients that are included in the mixture.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: The Netherlands
- Availability: The Netherlands
- Contact: [WIPO GREEN Database](#)

Wall-fitted rainwater catchment system

Rainwater HOG



Photo: © Rainwater HOG

The Rainwater HOG is a decentralized water storage system resembling water-filled building blocks. The blocks and can be fitted to building exteriors. This modular rainwater collection system was designed for residential and commercial buildings, particularly in tight spaces. Several HOGs can be connected together and store water in different orientations. They can also be sized to allow designers and engineers to use the stored water as thermal mass inside a structure. Pipework is minimal to facilitate easy installation. The water can for example be used for toilet flushing and laundry use.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: United States
- Availability: United States
- Contact: [WIPO GREEN Database](#)

Rooftop rainwater harvesting

Stormsaver Ltd



Photo: Getty Images / © Kulkann

Stormsaver is the largest dedicated rainwater harvesting company in the United Kingdom. The company offers commercial and residential rainwater harvesting for buildings of different sizes. In their systems, rainwater is channeled from the roof of a building, filtered for large debris, and led into an above or under ground storage tank. Various functionalities avoid disturbing fine sediments at the bottom of a tank, prevent rodent entry and keep water quality high. The system also comprises sensors and a pump that lead and filter water from the tank for on-demand supply to various levels in the building.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: United Kingdom
- Availability: United Kingdom
- Contact: [WIPO GREEN Database](#)

Building envelope waterproofing and foundation drainage

Nilex



Photo: Getty Images / © Animalflora

A drain is installed along the foundation of a building to collect excess groundwater and drain it away from the building. Nilex's NuDrain Sheet Drain product can be used both horizontally and vertically against retaining and foundation walls, bridge abutments, under slabs and so on. It quickly redirects water away from such surfaces and channels water to a collection system.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: Canada
- Availability: Canada, United States
- Contact: [WIPO GREEN Database](#)

Double- and triple-paned windows with insulating gas

Singapore Safety Glass PTE Ltd (SSG)

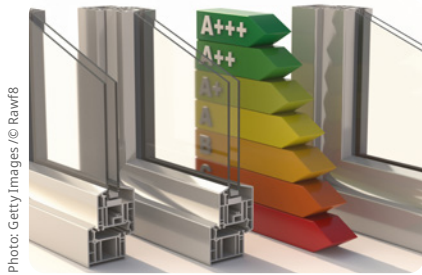


Photo: Getty Images / © Rawif8

Among the window products provided by company SSG, the DuraComfort comprises two or more layers of insulating glass units with a cavity between. The perimeters of the window frames are filled with desiccant to absorb moisture. The cavity between the glass sheets can be filled with a gas such as air, argon and krypton to provide further insulation. Argon and krypton is more expensive than air but provide better insulation. These windows are particularly suitable for buildings with very high heating or cooling requirements, especially in places requiring temperature and humidity to be controlled.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: Singapore
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Ventilated facade

Eliane TEC



Photo: Getty Images / © Lari Bat

Eliane TEC provides ventilated facades that regulate temperature, air and light. The ventilated facades are integrated into a building's envelope to create a gap between the exterior and inner walls. As air circulates between the walls during warm weather, it gets heated through a "chimney effect," whereby air is pushed upwards and building temperature reduced. Conversely, during cold weather, the air gap instead balances the temperature of the building and reduces moisture risk.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: Brazil
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Frontier technologies

Mediterranean seagrass as insulation

NeptuTherm



Photo: Getty Images / © Scott O'Neill

Natural alternatives to synthetic insulation materials are becoming increasingly popular. They include hemp, cellulose (waste paper), reed, elephant grass, cork and sheep's wool. One innovative alternative is using Mediterranean seagrass (*Posidonia oceanica*, or "Neptune grass") as insulation. This provides warmth in winter and coolness in summer. The company NeptuTherm is collecting seagrass balls from Albania and Tunisia and transforming them into insulation material for buildings. They claim the material is soundproof, mould resistant

and biodegradable. The grass grows at several dozen meters below the surface and is torn loose from the seabed during storms, forming fist-sized balls which then wash up on beaches.

- Contracting type: For sale
- Technology level: Low
- Country of origin: Germany
- Availability: Germany
- Contact: [WIPO GREEN Database](#)

Thermocrete concrete with cooling effect

Prism Johnson Limited

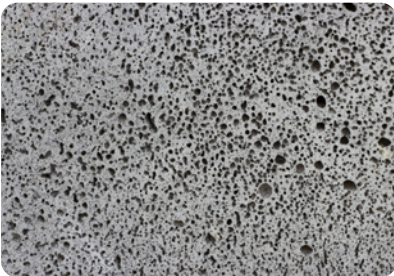


Photo: Getty Images / © Tatiana

Thermocrete is a concrete mixed with Thermocol (polystyrene) balls. These balls act as air cavities, isolating and reducing heat transfer through the material, with a cooling potential of 2°C to 3°C.

Thermocrete is often used in chimney constructions but also available as a construction panel material. Novel alternatives to concrete and polystyrene are under development. They include products made from biodegradable materials such as agricultural waste and fungi. Market availability at present is limited. But will

likely grow with increased demand (UNEP, 2021b). Prism Johnson Limited is a building materials company that operates 97 ready-mix concrete plants in India. Thermocrete is included in their product list.

- Contracting type: Service
- Technology level: Medium
- Country of origin: India
- Availability: India
- Contact: [WIPO GREEN Database](#)

Horizon technologies

Radiative cooling

SkyCool Systems



Photo: © SkyCool Systems Inc.

SkyCool Systems is a startup that has developed a thin film coating and rooftop cooling panel. Combined, they reject heat through radiative cooling even below ambient air temperature while under direct sunlight. Radiative cooling is an emerging technology able to function without the need for electricity. The technology exploits the fact that a surface looking skyward emits more thermal radiation than it receives. The thin film acts as a mirror, reflecting the Sun's light and heat thereby keeping fluid-filled panels below the film cool. The panels can be connected to an air-conditioning and refrigeration system so it runs more efficiently.

- Contracting type: Collaboration
- Technology level: High
- Country of origin: United States
- Availability: N/A
- Contact: [WIPO GREEN Database](#)

Desiccant-enhanced evaporative air conditioner (DEVap)

National Renewable Energy Laboratory (NREL)



Photo: Getty Images / © kaiguo

NREL has developed the concept of a desiccant-enhanced evaporative air conditioner (DEVap). Desiccants are substances that absorb moisture from air. They are typically found in the small packets included in the packaging when you buy certain products. Moisture in the air is often a barrier for air-conditioner efficiency. The DEVap air conditioner uses membrane technology to combine the efficiency of evaporative cooling with the drying potential of liquid desiccant salt solutions. Essentially, the system uses water and liquid desiccant

to draw in air from outside, dehumidify it and return cool, dry air. The technology is now being further developed for commercialization together with partners such as Synapse. It has the potential to save 50 to 90 percent on energy compared to other advanced solutions on the market today.

- Contracting type: N/A
- Technology level: High
- Country of origin: United States
- Availability: N/A
- Contact: [WIPO GREEN Database](#)

Floating houses

BACA Architects Ltd



Floating houses and islands have been around for many centuries and are an established technique in countries such as Peru (Uros Islands) and Iraq (Al-Tahla floating islands). However, rising sea-levels and increased flood events are leading to such ideas being adopted in other parts of the world, and with them the modernization of floating homes. The BACA floating house is one example. BACA Architects has developed the United Kingdom's first amphibious house. Located on the Thames riverbank, the house rests on the ground during dry conditions but rises up in its dock and floats during a flood event. The entire house thus rises and falls with the water level while remaining in position. Utilities are connected by flexible cabling and service pipes designed to extend up to 3 m. This protects key services during flood events.

- Contracting type: Service
- Technology level: High
- Country of origin: United Kingdom
- Availability: United Kingdom
- Contact: [WIPO GREEN Database](#)

Advanced wind towers

Free Running Buildings



Ancient Persian wind catchers, or bâdgirs, have mostly been replaced with modern air-conditioning systems. But wind catchers are now being revitalized through modern design. Free Running Buildings has developed a wind tower technology that provides passive building ventilation and cooling. It can lower the temperature of incoming air by between 3–6°C and demands less energy than other cooling systems. With modern air-conditioning systems being major energy consumers, such innovative approaches toward natural ventilation

and cooling systems are gaining attention. The company, in collaboration with Qatar University, has adapted this technique for the 2022 FIFA World Cup in Qatar. The cooling technology has been installed at the 40,000 seat Khalifa International Stadium in Doha.

- Contracting type: Service
- Technology level: High
- Country of origin: United Kingdom
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Infrastructure and services

Extreme weather events risk disrupting access to electricity, transport and water. Cities must strengthen the resilience of utilities, service providers and critical infrastructure against external shocks, and prepare them for changes in resource availability.

Damages to infrastructure and services far reaching

Urban infrastructure and the systems that provide transportation, electricity and water are becoming increasingly interdependent. Growing trends such as electric vehicles link together the key services of energy and transport. As power outages due to extreme weather events increase, such networks may represent new vulnerabilities to climate risk. Higher complexity, automated systems and smart urban solutions can not only alleviate but also enhance climate impact and cause a multiplier effect. Impacts from a damaged bridge, dam or power cable can extend far beyond immediately affected areas to cause widespread regional disruption. For extractive and manufacturing industries operating through global supply chains, the damage can extend even further. OECD modelling of potential impacts of a major flood in Paris found that infrastructure would suffer 30 to 55 percent of any direct damage caused by a flood. Moreover, disruption to transport and electricity, rather than the direct damage from the flood itself, would cause up to 85 percent of business losses (OECD, 2018).

Protecting energy assets from hazards

Disrupted energy supply-risk can be reduced through strengthening buildings' resilience to weather events such as extreme heat (IPCC, 2014). In the United States, a 2020 heatwave caused power shortages, as electricity demand soared when homes and businesses turned on air conditioning for heat relief (Ziaja and Chhabra, 2021). However, beyond focusing on buildings themselves, adapting larger energy networks and infrastructure – such as energy generation, transmission and distribution systems – is fast becoming a priority in many countries. In The Bahamas, 2,000 distribution poles and nearly 300 transmission poles had to be replaced after Hurricane Matthew in 2012 (Isaacs, 2018). Vulnerability to such energy supply disruptions can be reduced through decentralized energy generation, for example through micro- or mini-grids. This is especially the case for underserved or isolated populations (IPCC, 2022). Other ways the energy sector is adapting include increasing transmission tower height, underground cabling of distribution lines, designing wind turbines able to withstand high wind speeds, using stainless steel to reduce corrosion from water damage and installing heat-resistant solar panels. For regions heavily reliant on imported energy such as small island states, future energy security could be enhanced through a bi-directional charging mechanism for e-vehicles that allows the vehicles to double as a power supply source.

The road to resilient road and water networks

Devastation from extreme weather events is increasing the pressure on national road and water networks. Cyclone Idai in 2019 damaged an estimated 20 percent of Mozambique's national road network and destroyed 20 bridges (World Bank, 2019). This is not unique to the continent. Climate-related transport and energy infrastructure damage is projected to reach from 10s to 100s of billions of US dollars under moderate-to-high emissions scenarios (IPCC, 2022). Elevating bridges and roads, improving drainage capacity and introducing vegetation and permeable surfaces can improve resilience to water-related hazards to an extent. Meanwhile, trees can protect roads against high temperatures that would otherwise cause asphalt to expand and eventually crack or even melt. Maintenance is a critical issue. Drains and riverbeds require systematic desilting, and trees must be regularly pruned to avoid them falling and blocking roads during extreme weather events. Other options for heat management include applying reflective materials and coatings to roads and pavements, selecting more heat-resistant asphalt binders (Climate-ADAPT, 2019a) and preparing the steel for rail tracks to withstand hotter temperatures. Once damage has occurred, drone use in disaster management can help authorities and first responders map out where the damage is by quickly reconnoitering larger areas of the road network.



Photo: Getty Images © aydinmutlu

Urban infrastructure and services must also adapt to changes in water availability. It is projected that approximately 350 million more people in urban areas will be exposed to water scarcity due to severe droughts at a 1.5°C warming (IPCC, 2022). By building bigger water storage tanks, as well as the reservoirs or infrastructure needed for aquifer storage and recovery, exposed cities and regions such as the Emirate of Abu Dhabi are preparing for seasonal or extended drought (US EPA, 2012; Sadhasivam and Mohamed, 2018). Other cities are applying sensors and internet of things (IoT) technologies to increase the efficiency of water supply networks. For more information on water conservation technologies as well as flood defense systems, see chapter on Water and coastal regions.

Photo: Getty Images / © Jirobbk



Innovation example

Adapting Japanese trains to extreme heat and floods

Extreme heat can cause railroad tracks to buckle, as the steel expands. This puts stress on the ties, ballasts and rail anchors that fix the tracks to the ground. Japan is a global leader in railway infrastructure. In response to climate warming, Japan Railways has raised the standard maximum performance temperature of its railroads from

60°C to 65°C. Japan Railway has also developed maintenance vehicles able to detect openings in joints caused by heat stress (OECD, 2018). Meanwhile, after recent typhoons, East Japan Railway experienced considerable infrastructure damage, with millions of US dollars worth of rail cars and bullet trains having to be replaced. Steps have now been taken to adapt their infrastructure to climate change. They include lifting transformer substations and holding yards for shinkansen bullet trains by 10 meters to avoid future flood damage (Nagao, 2019).

Photo: Getty Images / © metamorworks



Innovation example

Fog computing technologies for water management in Spain

Potable water is a precious resource in southeastern Spain. The city of València has deployed innovative IoT technologies to manage water resources more efficiently. Fog computing is a type of distributed computing that connects a data cloud service to a number of “peripheral devices” which can amass large

amounts of raw data via for instance sensors. By processing data where it is generated or used rather than within a central cloud, bandwidth and wireless network infrastructure pressure can be reduced. It also enables operations to continue during network outages. LivingFog is an open source fog computing platform that enables cities to work with smart city solutions. València has used the technology to deploy more than 420,000 smart household water meters that periodically report readings to data centers through wireless networking. EMIVASA, a public-private water utility company, uses the transferred data to detect water leaks or other incidents causing abnormal water usage. This can lead to considerable water resource savings. Through a prototype platform called LivingFog this technology has now been integrated with a so-called LoRaWan software to enable the detection of leaks within minutes of their occurring instead of days so as to optimize water consumption (Tech4Good, 2022).

Technology solutions

Proven technologies

AI-based utility risk management

Urbint



Photo: Getty Images / © prvetik

Climate change poses a heightened risk to vital infrastructure such as electricity grids. Extremes of heat or cold may overwhelm capacity and damage equipment. Urbint is a leading AI platform for predicting and stopping threats to critical infrastructure and workers – climate change threats included. Examples include the analysis of wind speed and duration to advise power companies. The company's risk management software helps customers identify and prioritize safety and reliability threats, by leveraging relevant data and AI. The product is used by many of the largest energy and infrastructure companies in North America.

- Contracting type: Service
- Technology level: High
- Country of origin: United States
- Availability: United States
- Contact: [WIPO GREEN Database](#)

Monitoring and management platform for utilities

Mobi-Water



Photo: Getty Images / © Jasmin Merdan

Mobi-Water manufactures digital monitoring systems for a range of customers, including water utilities and factories. The system provides real-time data on water availability and consumption provided by tank level sensors and smart meters. Tracking is through an app, dashboard or SMS. By gathering data to generate analytics, water usage can be predicted and water shortages mitigated.

- Contracting type: Service
- Technology level: Medium
- Country of origin: Kenya
- Availability: Kenya
- Contact: [WIPO GREEN Database](#)

Remote urban water monitoring system

Develiot

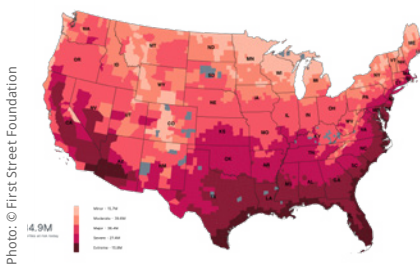


Develiot offers tools for use by water utilities to decrease water loss through the digitalization of water supply networks and tracking of water consumption. By tracking watercourse parameters – such as water level, water velocity, water temperature and environmental data – the company supports utilities and cities in taking proactive decisions in response to floods or drought. Relevant data can be captured remotely and in real-time through pulse meters and water monitoring stations.

- Contracting type: Service
- Technology level: High
- Country of origin: Bulgaria
- Availability: Bulgaria
- Contact: [WIPO GREEN Database](#)

Flood and fire risk assessments at property level

First Street Foundation



First Street Foundation is a non-profit research and technology group. They offer both publicly available and paid for risk information related to floods and fires. The data is backed by peer reviewed models building on open science from decades of published research. One of the tools on offer is Flood Factor. This is a free online tool that shows whether a property has been flooded during any major event in the past, is currently at risk, and how that risk changes over time. It can also help estimate damage costs associated with flooding or highlight

infrastructure and community risk. First Street has a wide user-base, including power and utility companies, insurance companies, construction and engineering firms.

- Contracting type: Service/Free
- Technology level: High
- Country of origin: United States
- Availability: United States
- Contact: [WIPO GREEN Database](#)

Distributed renewables

Nayo Tropical Technology Ltd



Photo: Getty Images / © Bilanol

Solar Home Systems, micro-grids and mini-grids are all examples of distributed renewables. Such renewables are increasingly part of a global trend toward resilient power systems. Nayo Tropical Technology is a cleantech company and a mini-grid supplier providing renewable energy-distributed generation projects, including hybrid and solar mini-grids in and around Nigeria.

- Contracting type: For sale
- Technology level: High
- Country of origin: Nigeria
- Availability: Nigeria
- Contact: [WIPO GREEN Database](#)

Decentralized water treatment and storage systems

Fluence Corporation



Photo: © Fluence Corporation LCC

Resiliency in water infrastructure can be enhanced through decentralized water treatment and storage systems. Treating water at point of use can make water treatment more fit for purpose and effective compared to treating all water to a potable standard. Also decentralized water storage could be used for river flow management, irrigation or in emergency situations. Fluence is a company that provides modular, decentralized water and wastewater treatment solutions for remote locations. Water treatment systems are built

into steel shipping containers. Transportation and site preparation is easy and installation quick. The technology has been developed for use in resorts and recreation sites. But similar solutions could potentially be used in emergency situations. For example, storms and hurricanes where central water supplies may be damaged or contaminated.

- Contracting type: For sale
- Technology level: Medium
- Country of origin: United States
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Climate risk analytics

Jupiter



Jupiter provides a broad range of climate risk analytics products for both public and private sector organizations. They are intended for activities such as infrastructure resilience engineering. Solutions assess the impact of flooding, wildfires, extreme heat, drought, wind and precipitation through spatial resolutions down to street level. Projections are delivered via geospatial web-based applications, direct data transfer or reports and cover time horizons of up to 80 years.

Jupiter's climate risk analysis is applied in several sectors

including water. Climate insights help identify investments needed for pipelines and storage facilities. The products also apply to the energy sector in relation to electricity generation, transmission and distribution systems.

- Contracting type: Service
- Technology level: High
- Country of origin: United States
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

No-dig pipe replacements

NO-DIG



Proper maintenance of water pipes is key to avoiding leaks and loss of non-revenue water. NO-DIG has developed a hydrostatic pipe bursting machinery for underground pipe replacement. The machine replaces the existing pipeline by first pushing a solid steel rod through the pipe via two excavation points. Once the rod has been inserted along the length of pipe between the two excavation points, a bursting head is lowered into one end and connected to the steel rod. A replacement pipe made of polyethylene is then connected to the

bursting head. Using static force, the bursting head and new pipe are pulled through the existing pipe, thereby displacing it. This process eliminates the need to dig up the ground along the entire pipe system.

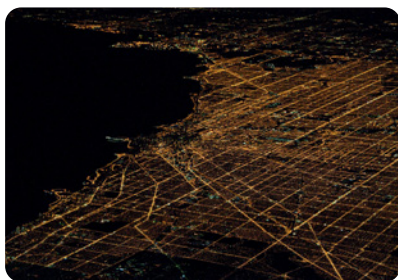
- Contracting type: Service
- Technology level: High
- Country of origin: Denmark
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Frontier technologies

Smart grids

Sunverge

Photo: Getty Images / © Andy A. Widmer / EyeEm



Storm-related power outages are happening more often. More fluctuations in supply and grid system instability mean grids need to be smarter. Smart grids and meters can enable for example automatic adaptation to varying demand and power flows. This would support a more balanced network during both normal and emergency situations such as extreme weather events. A smart grid might also enable more dispersed generation sources and local energy storage. This would strengthen overall system resilience by making reliable back-up power

available during power outages. Sunverge provides an energy storage system and software. This automatically collects and stores power from renewable energy sources during the day for peak-time use or when the grid goes down. The company also enables utilities to tie distributed energy resource networks into virtual power plants. During storm alerts the battery systems can then jointly be directed to charge up.

- Contracting type: Service
- Technology level: High
- Country of origin: United States
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Reduced thermal conductivity and temperature of asphalt pavements

PLATIO

Photo: Getty Images / © rryree1



Extreme temperatures can cause asphalt cracking, rutting or even melting. Asphalt pavement temperature depends among other things on the material's thermal properties. Adaptation measures to hot temperatures include using cool paving materials with low thermal conductivity or high specific heat capacity, or increasing thermal resistance through thick pavement layer design. Researchers in Malaysia have reviewed the state-of-art in different cooling strategies for asphalt pavements.

Approaches such as air void content and using low-density materials were found to potentially have a considerable positive effect on the thermal properties of asphalt. Open void structures and exposed surfaces allow air currents to flow through the pavement and reduce heat pressure on the pavement. However, for smaller surfaces more advanced approaches such as photovoltaic pavements and water-filled or air-filled pipes placed within pavements could reduce surface temperature by up to 5.5°C (Aletba et al., 2021). A few companies, including start-up PLATIO, are now producing solar pavements. They are an expensive option but could have both climate mitigation and adaptation benefits.

- Contracting type: For sale
- Technology level: High
- Country of origin: Hungary
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Mesh messaging: emergency communication during internet blackouts

Briar

Photo: Getty Images / © Elena Penkute / EyeEm



Mesh-based apps help people connect to nearby contacts without internet access in the event of an internet blackout. This could happen for example if internet infrastructure is affected by floods. Briar, Bridgefy and Signal Offline are three such mesh-based apps. Mesh messaging, also called “off-the-grid-messaging,” enables data to be transmitted between devices over a short range (typically 50–100 meters) without needing an internet connection. By using a device’s Bluetooth or Wifi as a transport medium, the

message travels between devices until it reaches its intended recipient. Briar is one such peer-to-peer technology which enables mobile devices to connect directly to each other via WiFi without any intermediate access points. Messages are encrypted for high-level privacy, which is why the app was originally intended for activists and journalists. However, the technology has potential for use in emergency situations as well.

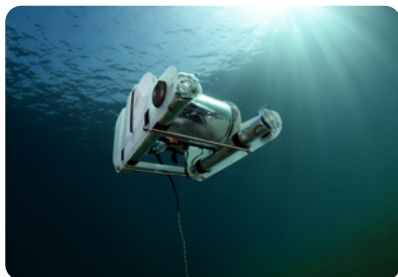
- Contracting type: Free
- Technology level: High
- Country of origin: United Kingdom
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Horizon technologies

Underwater robots for off-shore wind farms

Danish Technical University

Photo: Getty Images / © Humberto Ramirez



Rising sea levels and increased storm frequencies pose risks for offshore wind farms and turbine efficiency. This is due to a reliance on structural stability within the seabed. Through the use of sub-sea robots for turbine platforms, underwater monitoring can help inspect and detect repairation needs. Researchers at the Danish Technical University (DTU) have worked on a modular robot for use in offshore wind-turbine platforms. The robot can be used for inspection and also carry out underwater repair and maintenance on foundations and

rigs. Because the robot is modular, each individual part of the robot can work alone or in unison with other parts. It can also be permanently installed on an underwater foundation where it can monitor and operate irrespective of weather conditions.

- Contracting type: N/A
- Technology level: High
- Country of origin: Denmark
- Availability: N/A
- Contact: [WIPO GREEN Database](#)

Typhoon-proof wind turbines

Challenergy

Photo: Getty Images / © Jason Jones Travel Photography



A Japanese startup, Challenergy, has developed typhoon-proof wind turbines. These are uniquely shaped in order to withstand powerful winds and abrupt changes in wind direction. Built as a vertical axis wind turbine, turbines have three vertical cylinders instead of a propeller. The turbines are intended for use in remote areas, such as remote Philippine islands, that often lack sufficient power infrastructure while also being exposed to extreme weather events.

- Contracting type: N/A
- Technology level: High
- Country of origin: Japan
- Availability: N/A
- Contact: [WIPO GREEN Database](#)

Early warning systems, modelling and monitoring

How can cities prepare for the future and monitor climate threats? From community-based assessments to national multi-hazard warning systems, innovative solutions are giving citizens access to the right information when they need it most.

Knowledge saves lives

In great part due to improved early warning systems, deaths related to climate disasters have decreased almost threefold since the 1970s. Yet, more than 90 percent of deaths from disasters such as droughts, storms, floods and extreme temperature have occurred in developing countries (WMO, 2015) – especially in Asia (Hu, Zhang et al., 2018). In India, thousands of people measure river water levels across the country every hour using simple stream gauges (Mathison et al., 2015). But this does not tell them exactly when and where disaster will strike. And response times are not always quick enough. Effective early warning systems require knowledge about risks and the technologies for monitoring and communicating warnings. But they are equally reliant on the strong readiness, response capacity and engagement of communities (Sufri et al., 2020).

Modelling and monitoring city-level impacts

Climate model projections on the regional or local scale are often highly uncertain. However, the field of regional climate modelling has advanced steadily since the late 1980s, achieving more accurate, localized projections. Statistical down-scaling and modelling techniques such as Stepwise Cluster Analysis (SCA) can help obtain higher-resolution and small-scale climate information. Meanwhile, vulnerability mapping, inundation mapping and flood modelling have become common practice and an integral part of flood risk management. For real-time information on rising water levels or extreme weather events, cities rely on technologies as diverse as sensors, tide gauges and satellites. With increased connectedness of all sorts of units, sensors not originally intended for rainfall and weather data can be leveraged to vastly increase the number and distribution of data collection spots, thus providing a data-foundation for modelling and early



Photo: Getty Images / © janiecbros

warning systems (Oksen and Favre, 2020). But many cities lack meteorological measurements inside the urban environment. In general, there are severe gaps in weather and hydrological observation networks in Africa, in the Pacific and Caribbean island states, and in some parts of Latin America (WMO, 2021). Local networks for climate information can help respond to some of these needs, by engaging schools and community centers in the collection of basic information like temperature profiles, relative humidity, and wind speed and direction.

From remote sensing to knocking on doors

Global positioning systems (GPS), remote sensing (RS) technologies and geographic information systems (GIS) are at the heart of many early warning systems and response actions. They enable real-time monitoring and analysis of large volumes of spatial data. They can therefore support action in preparation and response to climate hazards. Once a disaster hits, these same technologies are needed again for search and rescue operations, and for evaluating damage and reconstruction needs. For example, GIS can be used to identify the shortest and easiest routes between shelter centers and victims, while avoiding dangerous areas. But early warning systems need not be complex. The United Nations has pledged full coverage to the entire global population within the next five years (UNFCCC, 2022c). But approximately one-third of people have no access to early warning systems (WMO, 2021). Irrespective of whether a system is set up on a national, regional or local level, it must be inclusive and transcend technology, language and literacy barriers. This could mean communicating through mobile devices or sirens, using pictures or pictograms as well as words, or complementing technology-based warning signals by going door to door in a community. It could also mean engaging communities not only as receivers of warnings, but also as mobilizers. For example in Indonesia, religious institutions have been identified as actors who would strengthen the chain of local early warnings in coastal cities (Rahayu et al., 2020). In other cases, the power of social media has been harnessed to map out disasters in real-time, showcasing the benefits of a decentralized ownership and provision of data.



Photo: Getty Images / © conceptualmotion

Innovation example

Multi-hazard early warning systems in Shanghai

Natural disasters often have a domino effect. Having an integrated early warning system can prepare cities and communities for multiple hazards, such as storm surges and typhoon-triggered floods. One of the first examples of multi-hazard early warning systems (MHEWS) was set up in Shanghai, a megacity of over 23 million people. Through a single system, alerts are provided on 14 categories of weather condition. They include climate-related disasters such as extreme heat, floods, tropical storms and typhoons (WMO, 2015). The system was set up to provide warnings based on color-coded warning signals with three to four levels – red, orange, yellow or blue – depending on severity. Integrated warning systems place extra demand on coordination and joint response mechanisms between agencies, cities and regions, and need to actively involve at-risk communities. They also require robust technologies to support accurate hazard descriptions and communicate warnings efficiently. On a technical level, the Shanghai MHEWS combines various platforms for monitoring, detecting and forecasting multiple hazards. These are integrated with mechanisms for dissemination of alerts via text messages, TV, radio, web, public electronic screens and billboards, and many other media (Shanghai Meteorological Bureau, 2010). In 2009, the Regional Integrated Multi-Hazard Early Warning System (RIMES) was registered at the United Nations with the aim of strengthening National Meteorological and Hydrological services in countries in Asia and Africa. On a global level, the International Network of Multi-hazard Early Warning Systems provides resources such as a checklist to help countries set up key elements of an integrated warning system.

Photo: Getty Images / © Muhammad Anndad Hossain

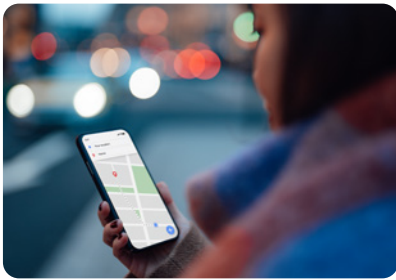


Innovation example Multi-country datasets for early warning systems in Bangladesh

Bangladesh is one of the most vulnerable countries in the world when it comes to cyclones and storms. The country witnesses on average five to six cyclones a year along the coast. In addition, it is one of the most flood-prone countries, with water often overflowing from three large river systems – the Brahmaputra, Ganges and

Meghna. Bangladesh has taken several steps toward improving its early warning systems. Rather than opting for more advanced technological systems, the goal has been to increase response times so as to provide warnings at least 12–24 hours in advance. This has meant simplifying modelling in some cases, such as in riverine discharge modelling. Other models such as the one for storm surge were upgraded to forecast total water level estimates by incorporating wave and tidal inputs. A key contribution to the success of the system been made by data and technologies provided through a number of collaborations, including with the Japan Meteorological Agency (JMA), the Bangladesh Navy (digital elevation models), and through the Delft Flood Early Warning System (FEWS). Many factors determine the number of fatalities caused by an extreme weather event. It is therefore difficult to measure the direct impact of early warning systems. However, having a fairly good idea of what is coming and when will enable preparedness and increase resilience.

Photo: Getty Images / © Oscar Wong



Innovation example Community-based risk assessments and open mapping

During a 2014 flood in Jakarta, Indonesia, a twitter application (PetaJakarta¹) engaged communities in managing an effective flood response. Within 24 hours of onset, 150,000 tweets were collected to dynamically map where the flooding was across the city (Holderness and Turpin, 2015). Traditionally, communities have been

engaged in collecting information and data through participatory methods such as Participatory Vulnerability and Capacity Assessments (PVCAs). These often result in maps of hazards, flood extent, exposure and risk. Mobile phone and applications use is now enabling faster and broader ways to collect data in real-time through community engagement. Information can also be digitized to better merge with other types of information and reach key stakeholders, for example through shared open databases such as OpenStreetMap (OSM). In least developed countries, where human and technological capacity for disaster risk monitoring may be low, mobile technologies can help overcome major obstacles in flood response and recovery. Another example is the 2010 Haiti Earthquake where humanitarian responders had little or no access to detailed maps. Voluntary contributors rapidly began mapping road networks using satellite images and OpenStreetMap. The organization Humanitarian OpenStreetMap Team has now engaged nearly 400,000 community mappers to map nearly three million roads and over 130 million buildings.

1 Now replaced by PetaBencana.id, an expanded disaster mapping service currently deployed for Jabodetabek (greater Jakarta), Surabaya and Bandung.

Technology solutions

Proven technologies

In situ automated weather monitoring

Campbell Scientific



Photo: Getty Images / © Terryf13D

Campbell Scientific provides in situ weather monitoring with digital sensors and using solar panels to ensure power supply. Their Automatic Weather Stations (AWSs) and meteorological instruments measure all common parameters (i.e., temperature, wind speed and direction, solar radiation and precipitation). They are suitable for monitoring conditions in urban areas and during extreme weather events. The weather stations are also suitable for weather condition monitoring over an extended period of time without intervention. A cloud-

based software allows data to be visualized in real-time. This lends itself well to research and for educational purposes where weather data displayed on public screens can raise awareness. The company has worked with the University of Birmingham to upgrade 26 weather stations supplying urban climate data across multiple city locations. The technology is also used by the Belgian city of Antwerp to monitor the urban heat island effect (Urban Climate Service Centre, 2015).

- Contracting type: For sale
- Technology level: Medium
- Country of origin: United Kingdom
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Electronic sirens and city early warning systems

Telegrafia Company a.s.



Photo: Getty Images / © Hhakim

Telegrafia has implemented warning systems in over 80 countries. Its product portfolio consists of various forms of electronic siren for industrial use or public mass warnings. Sirens can be used as stand-alone devices or part of networks, either stationary or mobile (e.g., for installation on cars). The company also offers communication infrastructure, monitoring stations and sensors. Their city early warning system warns against floods, fires or other natural disasters and consists of a network of up several hundred sirens. A main control

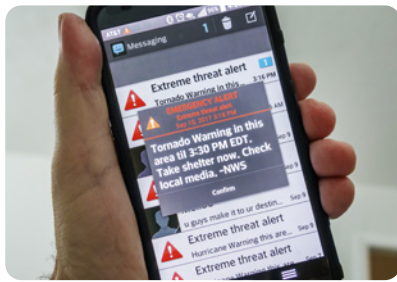
center (or district control center in larger cities) monitors and controls sirens and communication channels, and supports automated first responder notifications. The company's own software applications are available for monitoring, control of electronic warning systems and for managing emergency rescue processes.

- Contracting type: For sale/service
- Technology level: Medium
- Country of origin: Slovakia
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Wireless emergency alerts

US Federal Communications Commission

Photo: Getty Images / © Jeff Greenberg / Contributor



Wireless Emergency Alerts (WEA) are a system of emergency messages used in the United States. These are sent directly to people's phones by authorized government authorities. The messages typically consist of less than 90 characters and can be used to send warnings about emergencies such as extreme tornados and severe flash floods. When an area is about to be hit by a storm, an alert is issued and picked up by cell towers in the affected area. They then transfer the alert to the phones connected to that cell tower. By operating

through only those cell towers in the affected area, cell networks are not overloaded by millions of text messages and outages avoided.

- Contracting type: Free
- Technology level: Medium
- Country of origin: United States
- Availability: United States
- Contact: [WIPO GREEN Database](#)

Weather and climate messages for remote communities

Werner Labs Inc.

Photo: © Peter Fisher, Meteorological Service of New Zealand Limited (MetService)

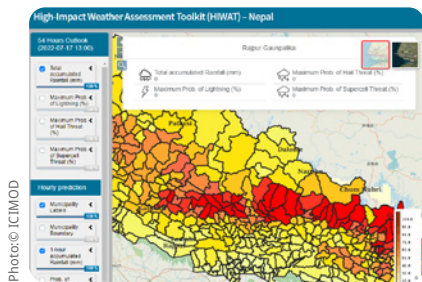


"Chatty beetles" are two-way text messaging devices suitable for rough terrains and remote communities. Communities like those on Pacific islands where over 100 chatty beetles have been deployed. The devices are part of a system that uses a constellation of private communication satellites provided by the company Iridium. It is an important tool for disseminating early warning signals and messages back out to distant communities without need of internet access. The devices instead receive and send text alerts via email and mobile phones using radio and the internet (RANET).

- Contracting type: For Sale
- Technology level: Medium
- Country of origin: United States
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

High-impact Weather Assessment Toolkit (HIWAT)

ICIMOD



HIWAT are a set of web-based tools that provides guidance on hazard and weather forecasts to forecasters and decision-makers. The tools are tailored for the Hindu Kush-Himalayan (HKH) region and further customized for Bangladesh and Nepal at the local level. These tools use a mesoscale numerical weather prediction model and the global precipitation measurement (GPM) constellation of satellites. The toolkit provides projections of weather events such as lightning strikes, high-impact winds, extreme rainfall and hail.

- Contracting type: Collaboration
- Technology level: Medium
- Country of origin: United States
- Availability: HKH region
- Contact: [WIPO GREEN Database](#)

Frontier technologies

Unmanned drones for hurricane forecasting

Raytheon Technologies



Originally developed for the military, the Raytheon Coyote is a small unmanned aircraft system (UAS) that can track and model hurricanes. Once launched from an aircraft, the drone can gather data from up to 50 miles away. It can fly at altitudes too low or dangerous for manned aircraft and provide forecasters with real-time data on atmospheric air pressure, temperature, moisture, wind speed and direction, as well as surface temperature (NOAA, 2016). Together with the US National Oceanic and Atmospheric

Administration (NOAA), the system was deployed to collect data during Hurricane Edouard in 2014 and Hurricane Maria in 2017.

- Contracting type: For Sale/Service
- Technology level: High
- Country of origin: United States
- Availability: United States
- Contact: [WIPO GREEN Database](#)

AI-based flood prediction

Google Flood Forecasting Initiative



Photo: Getty Images / © Laurence Dutton

Google's Flood Forecasting team complements efforts by governments to provide early warning systems to populations living in flood-risk areas. Their modelling systems for flood prediction collect thousands of satellite images to build digital models of the terrain and simulate thousands of possible scenarios of how the rivers could behave. Simulations and high-quality elevation maps are cross-referenced with measurements sent from by government. Alerts can then be sent to individuals via different channels, with a claimed 90 percent accuracy.

So far, Google has sent out over 100 million Android notifications in India and Bangladesh to people in flood-risk areas (Sharma, 2021).

- Contracting type: Free
- Technology level: High
- Country of origin: United States
- Availability: India, Bangladesh (plans for expansion in South Asia and South America)
- Contact: [WIPO GREEN Database](#)

Horizon technologies

Virtual sensors for weather data collection

Ericsson

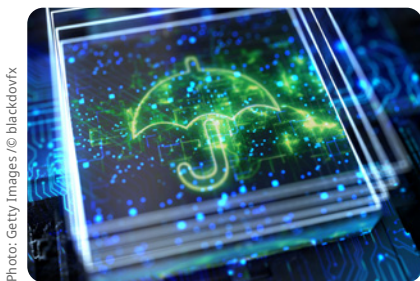


Photo: Getty Images / © blackdovix

Ericsson and the Swedish Meteorological and Hydrological Institute (SMHI) have developed a method for reporting on precipitation using telephone network microwave data. The "Ericsson Weather Data" initiative builds on the knowledge that microwaves are sensitive to raindrops, and offer higher temporal and spatial resolution compared to existing radar solutions. As rain falls across the telephone network, real-time rainfall maps can be made by analyzing microwave signal loss patterns. This solution may be of particular interest to

countries that lack an extensive weather-monitoring network but do have a microwave-based telephone network. It has been tested in Sweden, Germany and Rwanda, and aims to provide a high degree of early warning system foresight without the need for weather stations (Oksen and Favre, 2020). Recent research on such microwave backhaul technologies from communication networks has suggested great potential for precipitation and flood monitoring in urban areas (Han et al., 2020).

- Contracting type: Research cooperation
- Technology level: High
- Country of origin: Sweden
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Crowd-sourcing disaster data through social media

Snapchat



Ordinary citizens and volunteers on the ground may become important actors in collecting and analyzing climate and disaster data around the world. Through a process known as “Groundtruthing” satellite data is verified on the ground. This is done using crowdsourced “pin drops” and pictures sent by people whose mobile devices have cameras. Groundtruthing allows authorities to tap into localized data, study disasters, build automated land-use classification algorithms and better understand how people experiences these in real-time.

One example is the social media company Snapchat’s map function called Snap Map. The map is part of a social media app with millions of followers used for sharing short temporary video clips of people’s lives, pinned to a certain geographical spot. Although the app was not developed for disaster data reporting, its millions of users may give it a far wider reach than the fit-for-purpose apps. The use of social media has the potential to offer insights into how hurricanes, storms and floods unfold so as to guide first responders to critical intervention points.

- Contracting type: Free
- Technology level: Medium
- Country of origin: United States
- Availability: Worldwide
- Contact: [WIPO GREEN Database](#)

Citizen-based early warning system

FloodCitiSense



FloodCitiSense has developed an early warning system app for use by citizens and authorities in response to urban rainfall flooding. To date, the tool has been piloted in European cities Brussels, Rotterdam and Birmingham. Citizens observations are a key component in responding to the need for dispersed rainfall data. Citizens are engaged to place low-cost rainfall sensors at their homes. The data obtained is entered into an app where citizens can make reports of rainfall intensity in real-time.

- Contracting type: Collaboration
- Technology level: Medium
- Country of origin: Belgium
- Availability: N/A
- Contact: [WIPO GREEN Database](#)

6 Conclusion and recommendations

This publication provides an overview of the role technology can play in adapting to climate change. It showcases more than 200 technologies that provide much needed solutions, but many more exist which to our knowledge are not inferior to the ones included here. Technology cannot solve climate change nor can it be seen as quick fix. But it can provide solutions that together with other initiatives, policies, instruments, projects, programs and new ways to live, work, produce and consume may bring about the increasingly urgent changes needed.

By sifting through the many sources, technology descriptions and analyses that have gone into the making of this publication, it is possible to draw out some observations and recommendations. It is hoped these may be relevant for those who have a say on how to increase the development and deployment of innovative technologies in support of climate change adaptation.

Adaptation technologies are available

Probably the first and most important conclusion of this publication is that there are technologies available for almost any challenge. They are not necessarily a full solution, nor are they necessarily cheap and simple to deploy. But the magnitude and diversity of innovation – and, frankly speaking, ingenuity – is in our opinion simply impressive. This gives hope. It gives grounds for optimism. It means that we may be able to live with climate change impacts we cannot mitigate against. Or at least some of the impacts. It will cost us. It will demand sacrifices. And it will force us to change and make compromises. But there is a way. And in the end, the cost of not acting now may be so much higher. And there is a further challenge and that is to ensure uniform access across all solutions, including for those most in need.

Bias toward “hard” technologies

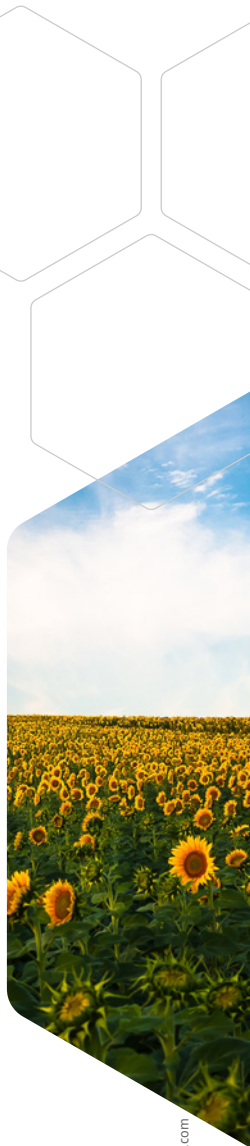
In general, there seems to be more hard structure-based solutions than there are solutions that actively exploit the beneficial forces within nature, namely nature-based solutions. The technology landscape here may change, as increasing attention, as well as formal recognition, is now being directed at nature-based solutions. Many are also no-regret solutions, meaning they will provide benefits even if the climate change impact they address turns out to be less than expected.

Distinction between mitigation and adaptation not always clear cut

Many technologies effectively blur the dichotomy between mitigation and adaptation. The conceptual division between the two can be a practical one when it comes to classifying, organizing and understanding climate action. But oftentimes this is more concept than reality, as many technologies effectively contribute to both mitigation and adaptation rather than either one or the other. Therefore when it comes to the deployment of technologies and solutions, it may be less relevant or useful to maintain this division. And they should certainly not be seen as two opposing or even competing concepts. Mitigation and adaptation are both necessary when dealing with climate change risks.

Mitigation prioritized, but adaptation funding is increasing

That said, there is a marked difference between mitigation and adaptation with respect to innovation level, technological solutions, funding and attention. In every case mitigation comes out in front. This should not necessarily be seen as wrong, as it makes good sense to prevent an impending threat rather than have to find ways of living with it. Financial flows can be seen to be heavily focused on mitigation solutions but also increasingly going into adaptation. If this process continues there is reason to believe that adaptation will stop being overshadowed by mitigation to the same extent as now. Benefits from adaptation technologies and projects may be harder to quantify compared, for example, to measured emissions reductions from mitigation technologies. This may deter private sector investment. Making adaptation projects



more measurable may help drive investment in adaptation technologies. But indicators should avoid over-simplification and the monetization of adaptation to a point where it fails to address vulnerability.

Adaptation technologies are often multipurpose

We have seen how adaptation technologies, from nature-based solutions to hardware, can be incredibly multifaceted. For instance, a simple tree offers multiple adaptation benefits, from cleaning air and filtering water to sun and wind protection. Meanwhile, drones are being creatively used for monitoring, sowing mangrove seeds, nurturing corals, monitoring soil, crop, insect and forest data, spraying fertilizers, controlling forest fires and guiding livestock through sustainable grazing patterns. Combining functions can save money while at the same time providing adaptation co-benefits. An example is the technology field of early warning, where multi-hazard warning systems are reporting on multiple threats.

Context-specific implementation critical to avoid maladaptation

Technology solutions can be more or less complex. They range from large advanced installations demanding specialized technical and managerial skills and large investments to simple techniques requiring no additional equipment whatsoever. They are all relevant. Their feasibility is determined to a great extent by context. Indeed, adaptation planning is most often highly localized, diverse and its success depends on several factors.

While technology may offer many viable and feasible solutions, they may not always work as expected. Very few technologies are plug and play. Planning for adaptation is complex, and many risks hard to predict or estimate, or even understand. This can result in a wrong choice of technology; or if not that, the capacity to implement and maintain a particular technology is not present. Maladaptation is a term that unfortunately often applies. Indeed, it is by studying cases of maladaptation that we may learn what the risk factors are that led for instance to an unwanted increase in a target group's climate change vulnerability instead of a reduction as planned. Thorough and high-quality Environmental and Social Impact Assessments, which in most countries are mandatory for larger projects and as such are already mainstreamed, may help prevent maladaptation.

Hi-tech can have global relevance

We see that highly advanced technologies are not reserved for developed countries but can have a transformational impact in low-income countries as well. Mobile devices, possibly powered by off-grid electricity supply, may tap into sophisticated data from satellites and advanced sensors. Many devices may also be used as sensors or reporting tools and themselves able to improve early warning systems and provide critical information about an ongoing extreme weather event. Such technologies are paving the way for new safety nets such as weather-indexed crop insurance.

Make a solution good business

As we have said, there are many solutions out there, some more fanciful than others. For many it is too early to say whether they will survive real-world deployment and deliver what they promise. Economic feasibility is in many cases of crucial importance. If a technology solves a critical issue, and maybe even lowers greenhouse gas emissions, but also makes good business sense, then deployment can be fast and widespread. One emerging technology area that we will continue to watch closely is the advanced technologies promising to optimize farming. These include drones, self-driven equipment, artificial intelligence and others grouped under the term precision agriculture.

Innovation patents for adaptation technologies concentrated in few developed countries

So where does all this innovation and technology come from? Patent analyses indicate that it originates in a few developed countries and that innovation transfer is modest and far below the

level of mitigation technologies. This could lead to a discrepancy between where technologies are developed and where they are needed most. But patents do not always reflect innovation on the ground. Adaptation technologies from developing countries seem to be far less visible. This may be because they are simpler, less commercially oriented and developed with a local context in mind. However, such solutions may be exactly what is needed in many other places. Therefore there may be a need for a stronger exposure of adaptation technologies from developing countries.

Support the innovation ecosystem

Innovation ecosystem is a convenient term under which to group all the many factors that make it possible for an inventor to develop, finance, publicize, market, protect and benefit from an innovation. The innovation ecosystem, or rather the many factors that lie behind it, benefits not only technological development. It also enables technology receivers to adopt and adapt technologies to their specific context. Intellectual property right is an important factor here. And patent systems generate an enormous amount of publicly available technology information. This information enables authorized use of inventions in countries where a patent has been granted, free use in countries where a patent has not been granted, and further development into new patentable inventions.

Climate change adaptation is global

Finally, it is important to keep in mind that climate change adaptation is not solely a developing country phenomenon. Neither is it limited to civil society nor the private or public sector. Instead it needs strong involvement from every stakeholder. Every country faces a serious challenge from climate change. But developing countries are often more vulnerable than others, either because they lack a strong foundation for implementing adaptation measures, or because they are most exposed to impacts, which is the case for some small island states. Access to adaptation solutions may also be highly unequal. Gender, education, social status, ethnicity and poverty are among the many factors that may present barriers to obtaining and deploying solutions.

The very complexity and diversity of adaptation means that communities have to be prepared for more than just increasingly frequent floods and hotter weather. There are many other disruptions, some hard to predict. To a large extent, being adaptation-capable means being part of a community that has the resources, power, institutions, capability and knowledge to act, develop and adapt.

Bibliography

- AAI (2022). Africa adaptation initiative. Africa Adaptation Initiative (AAI). Available at: <https://africaadaptationinitiative.org> [accessed August 2022].
- Abdel-Shafy, H. and M. Mansour (2013). Overview on water reuse in Egypt: Present and future. *J. Sustainable Sanitation Practice*, 14, 17–25.
- Adaptation Fund (2022). Innovation funding. Adaptation Fund. Available at: www.adaptation-fund.org/apply-funding/innovation-grants [accessed September 2022].
- Adriadapt (2022). Storm surge gates/flood barriers. Available at: <https://adriadapt.eu/adaptation-options/storm-surge-gates-flood-barriers/#:~:text=Storm%20surge%20gates%2Fflood%20barriers%20are%20fixed%20installations%20that%20allow,spring%20tides%20to%20prevent%20flooding> [accessed October 2022].
- African Union (2022). *African Union climate change and resilient development strategy and action plan (2022–2032)*. Addis Ababa: African Union. Available at: <https://au.int/en/documents/20220628/african-union-climate-change-and-resilient-development-strategy-and-action-plan>.
- Agrawala, S., C. Bordier, V. Schreitter and V. Karplus (2012). *Adaptation and innovation: An analysis of crop biotechnology patent data*. OECD Environment Working Papers, Paris: OECD. Available at: www.oecd-ilibrary.org/environment/adaptation-and-innovation_5k9csvgvntt8p-en.
- Akinaga, T., S. Generalis, C. Paton, O. Igobo and P. Davies (2018). Brine utilisation for cooling and salt production in wind-driven seawater greenhouses: Design and modelling. *Desalination*, 426, 135.
- Alam, M.F., P. Pavelic, N. Sharma and A. Sikka (2020). Managed aquifer recharge of monsoon runoff using village ponds: Performance assessment of a pilot trial in the ramganga basin, India. *Water*, 12.
- Aletba, S.R.O., N. Abdul Hassan, R. Putra Jaya, E. Aminudin, M.Z.H. Mahmud, A. Mohamed and A.A. Hussein (2021). Thermal performance of cooling strategies for asphalt pavement: A state-of-the-art review. *Journal of Traffic and Transportation Engineering (English Edition)*, 8(3), 356–73.
- Allen, C.D., D.D. Breshears and N.G. McDowell (2015). On underestimation of global vulnerability to tree mortality and forest die-off from hotter drought in the Anthropocene. *Ecosphere*, 6(8), 1–55.
- Allen, S., V. Barros, O. Cardona, S. Cutter, O.P. Dube, K. Ebi, J. Handmer, A. Lavell, M. Mastrandrea, G. McBean, R. Mechler and N. Nicholls (2012). Managing the risks of extreme events and disasters to advance climate change adaptation. Special report of Working Groups I and II of the Intergovernmental Panel on Climate Change. New York, NY: Cambridge University Press.
- ALM (2021). Organic fertilizers market – Opportunities and forecast 2021–2030. Allied Market Research. Available at: www.alliedmarketresearch.com/organic-fertilizers-market-A14536 [accessed October 2022].
- Altieri, M. and P. Koohafkan (2008). *Enduring farms: Climate change, smallholders and traditional farming communities*. Environment and Development Series. Penang, Malaysia: Third World Network (TWN). Available at: www.researchgate.net/publication/252167278_Enduring_Farms_Climate_Change_Smallholders_and_Traditional_Farming_Communities.
- Angelakis, A., T. Asano, A. Bahri, B. Jiménez and G. Tchobanoglous (2018). Water reuse: From ancient to modern times and the future. *Frontiers in Environmental Science*, 6, 26.

- Azis, F., M. Rijal, H. Suhaimi and P.E. Abas (2022). Patent landscape of composting technology: A review. *Inventions*, 7 (2) Available at: www.mdpi.com/2411-5134/7/2/38.
- BBC (2015). Enigma of the trees that resist wildfires. Available at: www.bbc.com/news/science-environment-34116491 [accessed October 2022].
- Beacham, A.M., L.H. Vickers and J.M. Monaghan (2019). Vertical farming: A summary of approaches to growing skywards. *The Journal of Horticultural Science and Biotechnology*, 94(3), 277–83.
- Begum, S. (2022). Mangroves thrive in UAE desert to help fight climate change. *The Straits Times*. Available at: www.straitstimes.com/world/middle-east/mangroves-thrive-in-uae-desert-to-help-fight-climate-change [accessed October 2022].
- Bergh, J. van der and I. Savin (2021). Impact of carbon pricing on low-carbon innovation and deep decarbonisation: Controversies and path forward. *Environmental and Resource Economics*, 80(4), 705–15. Available at: <https://link.springer.com/article/10.1007/s10640-021-00594-6> [accessed October 2022].
- Bertule, M., L.R. Appelquist, J. Spensley, S.L.M. Trærup and P. Naswa (2018). *Climate change adaptation technologies for water: A practitioner's guide to adaptation technologies for increased water sector resilience*. UNEP-DTU Partnership. Available at: https://backend.orbit.dtu.dk/ws/portalfiles/portal/145967791/CC_Adaptation_technologies_for_water_red.pdf.
- Bjornlund, V., H. Bjornlund and A.F. Van Rooyen (2020). Why agricultural production in Sub-Saharan Africa remains low compared to the rest of the world – A historical perspective. *International Journal of Water Resources Development*, 36(sup1), S20–S53.
- Bloomberg (2022). China plans to feed 80 million people with 'seawater rice'. Available at: www.bloomberg.com/news/articles/2022-02-19/chinese-scientists-discover-how-to-grow-seawater-rice [accessed May 2022].
- Bonis-Profumo, G., R. McLaren and J. Fanzo (2019). Ravaged landscapes and climate vulnerability: The challenge in achieving food security and nutrition in post-conflict Timor-Leste. *Advances in Food Security and Sustainability*, 4, 97–132.
- Boone, R., R. Conant, J. Sircely, P. Thornton and M. Herrero (2018). Climate change impacts on selected global rangeland ecosystem services. *Global Change Biology*, 24(3), 1382–93.
- Boretti, A. and L. Rosa (2019). Reassessing the projections of the World Water Development Report. *npj Clean Water*, 2.
- Bott, L.-M., T. Schöne, J. Illigner, M. Haghshenas Haghghi, K. Gisevius and B. Braun (2021). Land subsidence in Jakarta and Semarang Bay – The relationship between physical processes, risk perception, and household adaptation. *Ocean & Coastal Management*, 211, 105775.
- Brown, C. (2015). Improving modern agriculture through 'intercropping'. *Yale Environment Review*.
- Buras, A., A. Rammig and C.S. Zang (2021). The European forest condition monitor: Using remotely sensed forest greenness to identify hot spots of forest decline. *Frontiers in Plant Science*, 12.
- Burney, J., L. Woltering, M. Burke, R. Naylor and D. Pasternak (2010). Solar-powered drip irrigation enhances food security in the Sudano-Sahel. *Proceedings of the National Academy of Sciences of the United States of America*, 107, 1848–53.
- Business Standard (2021). SC says NGT ban on water purifiers where TDS below 500 mg per litre. Available at: www.business-standard.com/article/current-affairs/sc-stays-ngt-ban-on-water-purifiers-where-tds-below-500-mg-per-litre-122030100625_1.html [accessed October 2022].
- C40 (2018). *The future we don't want: How climate change could impact the world's greatest cities*. Urban Climate Change Research Network (UCCRN). Available at: www.c40.org/wp-content/uploads/2021/08/1789_Future_We_Dont_Want_Report_1.4_hi-res_120618.original.pdf.

CDP (2018). Cities at risk: Dealing with the pressures of climate change. Carbon Disclosure Project (CDP). Available at: www.cdp.net/en/research/global-reports/cities-at-risk [accessed October 2022].

CDP (2022). Climate change. Carbon Disclosure Project (CDP). Available at: www.cdp.net/en/climate [accessed October 2022].

CERF (2020). *CERF allocation report on the use of funds and achieved results. Eastern Africa rapid response locusts response 2020*. Central Emergency Response Fund (CERF). Available at: https://cerf.un.org/sites/default/files/resources/20-RR-EAF-40783_Eastern%20Africa_CERF_Report-regularpdf.pdf.

CGIAR (2021). Innovation: Fertilizer microdosing. Consultative Group on International Agricultural Research (CGIAR). Available at: www.cgiar.org/innovations/fertilizer-microdosing [accessed October 2022].

Chang, S., E.L. Mahon, H.A. MacKay, W.H. Rottmann, S.H. Strauss, P.M. Pijut, W.A. Powell, V. Coffey, H. Lu, S.D. Mansfield and T.J. Jones (2018). Genetic engineering of trees: Progress and new horizons. *In Vitro Cellular & Developmental Biology – Plant*, 54(4), 341–76.

CIAT (2014). Submission from the International Center for Tropical Agriculture (CIAT) on behalf of the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), to UNFCCC SBSTA 42 on issues related to agriculture in response to SBSTA decision FCC/SBSTA/2014/L.14. The International Center for Tropical Agriculture (CIAT). Available at: https://unfccc.int/files/documentation/submissions_from_non-party_stakeholders/application/pdf/516.pdf [accessed October 2022].

Cleantech Group (2021). Genetic engineering for crops and food: Climate adaptation, resilience, and food security through innovation. Available at: www.cleantech.com/genetic-engineering-for-crops-and-food-climate-adaptation-resilience-and-food-security-through-innovation [accessed October 2022].

Climate-ADAPT (2015a). Adaptation or improvement of dikes and dams. The European Climate Adaptation Platform Climate-ADAPT. Available at: <https://climate-adapt.eea.europa.eu/metadata/adaptation-options/adaptation-or-improvement-of-dikes-and-dams> [accessed July 2022].

Climate-ADAPT (2015b). Restoration and management of coastal wetlands. The European Climate Adaptation Platform Climate-ADAPT. Available at: <https://climate-adapt.eea.europa.eu/metadata/adaptation-options/restoration-and-management-of-coastal-wetlands> [accessed July 2022].

Climate-ADAPT (2016). Urban. The European Climate Adaptation Platform Climate-ADAPT. Available at: <https://climate-adapt.eea.europa.eu/en/eu-adaptation-policy/sector-policies/urban> [accessed October 2022].

Climate-ADAPT (2019a). Climate proofed standards for road design, construction and maintenance. Available at: <https://climate-adapt.eea.europa.eu/metadata/adaptation-options/climate-proofed-standards-for-road-design-construction-and-maintenance> [accessed October 2022].

Climate-ADAPT (2019b). Sand motor – Building with nature solution to improve coastal protection along Delfland coast (the Netherlands). The European Climate Adaptation Platform Climate-ADAPT. Available at: <https://climate-adapt.eea.europa.eu/metadata/case-studies/sand-motor-2013-building-with-nature-solution-to-improve-coastal-protection-along-delfland-coast-the-netherlands> [accessed July 2022].

Climate-ADAPT (2019c). Use of adapted crops and varieties. The European Climate Adaptation Platform Climate-ADAPT. Available at: <https://climate-adapt.eea.europa.eu/en/metadata/adaptation-options/use-of-adapted-crops-and-varieties> [accessed October 2022].

CMI (2022). MENA drip irrigation system market 2022 analysis by market trends (drivers, constraints, opportunities, threats, challenges and investment opportunities), size, share and outlook. Coherent Market Insights (CMI). Available at: www.digitaljournal.com/pr/mena-drip-irrigation-system-market-comprehensive-research-future-trends-industry-analysis-segments-and-competitive-landscape-jain-irrigation-systems-ltd-netafim-ltd-eurodrip-sa [accessed October 2022].

Cominola, A., M. Giuliani, A. Castelletti, P. Fraternali, S. Herrera, J.C. Guardiola, J. Novak and A.-E. Rizzoli (2021). Long-term water conservation is fostered by smart meter-based feedback and digital user engagement. *npj Clean Water*, 4, 29.

Conway, D., A. Dechezleprêtre, I. Haščič and N. Johnstone (2015). Invention and diffusion of water supply and water efficiency technologies: Insights from a global patent dataset. *Water Economics and Policy*, 01, 1550010.

Cowan, Y., E. O'Brien and N. Rakotomalala-Rakotondrandria (2014). *Community-based early warning systems: Key practices for DRR implementers*. OCHA and FAO. Available at: www.fao.org/publications/card/en/c/57c0a761-8d31-4f0f-8a07-27e1ea0568d5.

CPI (2021). *Global landscape of climate finance 2021*. Climate Policy Initiative (CPI). Available at: www.climatepolicyinitiative.org/publication/global-landscape-of-climate-finance-2021.

Cristiano, E., S. Farris, R. Deidda and F. Viola (2021). Comparison of blue-green solutions for urban flood mitigation: A multi-city large-scale analysis. *PLoS ONE*, 16(1), e0246429.

CTCN (2017). *CTCN taxonomy*. Copenhagen: UN Climate Technology Centre & Network (CTCN). Available at: www.ctc-n.org/resources/ctcn-taxonomy.

CTCN (2022). Adaptation Fund Climate Innovation Accelerator (AFCIA). UN Climate Technology Centre & Network (CTCN). Available at: www.ctc-n.org/technical-assistance/adaptation-fund-climate-innovation-accelerator-afcia [accessed September 2022].

Curto, D., V. Franzitta and A. Guercio (2021). A review of the water desalination technologies. *Applied Sciences*, 11(2).

Day, R., P. Abrahams, M. Bateman, T. Beale, V. Clotthey, M.J.W. Cock, Y. Colmenarez, N. Corniani, R. Early, J. Godwin, J. Gomez, P. González-Moreno, S. Murphy, B. Opong-Mensah, N. Phiri, C. Pratt, S. Silvestri and A. Witt (2017). Fall armyworm: Impacts and implications for Africa. *Outlooks on Pest Management*, 28, 196–201.

Dechezlepretre, A., S. Fankhauser, M. Glachant, J. Stoeber and S. Touboul (2020). *Invention and global diffusion of technologies for climate change adaptation: A patent analysis*. Washington, DC: World Bank. Available at: <https://openknowledge.worldbank.org/handle/10986/33883>.

Demirbas, A., A.A. Hashem and A.A. Bakhsh (2017). The cost analysis of electric power generation in Saudi Arabia. *Energy Sources, Part B: Economics, Planning, and Policy*, 12(6), 591–96.

Derpsch, R., T. Friedrich, A. Kassam and L. Hongwen (2010). Current status of adoption of no-till farming in the world and some of its main benefits. *International Journal of Agricultural and Biological Engineering*, 3(1), 1–25.

DHI (2017). DHI protecting Australian beaches through Shoreline Modelling. Danish Hydrological Institute (DHI). Available at: www.dhigroup.com/presences/apac/australia/news/2017/07/dhi-protecting-australian-beaches-through-shoreline-modelling [accessed August 2022].

Dillon, P., P. Stuyfzand, T. Grischek, M. Lloria, R.D.G. Pyne, R.C. Jain, J. Bear, J. Schwarz, W. Wang, E. Fernandez, C. Stefan, M. Pettenati, J. van der Gun, C. Sprenger, G. Massmann, B. R. Scanlon, J. Xanke, P. Jokela, Y. Zheng, R. Rossetto, M. Shamruk, P. Pavelic, E. Murray, A. Ross, J.P. Bonilla Valverde, A. Palma Nava, N. Ansems, K. Posavec, K. Ha, R. Martin and M. Sapiano (2019). Sixty years of global progress in managed aquifer recharge. *Hydrogeology Journal*, 27(1), 1–30.

Duarte, B., I. Martins, R. Rosa, A. Matos, M. Roleda, T. Reusch, A. Engelen, E. Serrao, G. Pearson, J. Marques, I. Caçador, C. Duarte and A. Jueterbock (2018). Climate change impacts on seagrass meadows and macroalgal forests: An integrative perspective on acclimation and adaptation potential. *Frontiers in Marine Science*, 5.

Dubbeling, M. and H. de Zeeuw (2011). *Urban agriculture and climate change adaptation: Ensuring food security through adaptation*. In Otto-Zimmermann, K. (ed.) Resilient cities. Local sustainability series, volume 1. Dordrecht: Springer. https://doi.org/10.1007/978-94-007-0785-6_44

Dunic, J., C. Brown, R. Connolly, M. Turschwell and I. Côté (2021). Long-term declines and recovery of meadow area across the world's seagrass bioregions. *Global Change Biology*, 27.

EEA (2018). *10 case studies: How Europe is adapting to climate change*. Luxembourg: European Environment Agency (EEA). Available at: <https://climate-adapt.eea.europa.eu/en/about/climate-adapt-10-case-studies-online.pdf>.

EPO (2022a). Espacenet patent search. European Patent Office (EPO). Available at: <https://worldwide.espacenet.com> [accessed July 2022].

EPO (2022b). Sustainable technologies. European Patent Office (EPO). Available at: www.epo.org/news-events/in-focus/classification/classification.html [accessed July 2022].

Egypt Independent (2022). Egypt to become largest country in the world in water reuse. Available at: <https://egyptindependent.com/egypt-to-become-largest-country-in-the-world-in-water-reuse-ministry> [accessed October 2022].

EIB (2021). EIB climate adaptation plan. European Investment Bank (EIB). Available at: www.eib.org/en/publications/the-eib-climate-adaptation-plan [accessed October 2022].

European Commission (2013). *An EU Strategy on adaptation to climate change*. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Brussels: European Commission.

European Commission (2021). *Forging a climate-resilient Europe – The new EU strategy on adaptation to climate change*. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Brussels: European Commission.

Evans, R. and E. Sadler (2008). Methods and technologies to improve efficiency of water use. *Water Resources Reserach*, 44(7).

Everlane (2022). The world's cleanest denim factory. Available at: www.everlane.com/denim-factory [accessed October 2022].

Fan, X. and T. Matsumoto (2019). GIS-based social cost-benefit analysis on integrated urban water management in china: A case study of sponge city in Harbin. *Sustainability*, 11(19). Available at: www.mdpi.com/2071-1050/11/19/5527.

FAO (2012a). *Factsheet: Smallholders and family farmers*. Rome: Food and Agriculture Organization of the United Nations (FAO). Available at: www.fao.org/fileadmin/templates/nr/sustainability_pathways/docs/Factsheet_SMALLHOLDERS.pdf.

FAO (2012b). Livestock and landscapes. Food and Agriculture Organization of the United Nations (FAO). Available at: www.fao.org/3/ar591e/ar591e.pdf [accessed October 2022].

FAO (2015). *Climate change and food security: Risks and responses*. Rome: Food and Agriculture Organization of the United Nations (FAO). Available at: www.fao.org/3/i5188e/I5188E.pdf.

FAO (2017). Chinese scientists develop rice that grows in seawater, potentially creating food for 200 million people. Food and Agriculture Organization of the United Nations (FAO). Available at: www.fao.org/in-action/agronoticias/detail/en/c/1060351 [accessed October 2022].

FAO (2018). Women, agriculture and ICTs. E-agriculture. Food and Agriculture Organization of the United Nations (FAO). Available at: www.fao.org/e-agriculture/news/women-agriculture-and-icts [accessed August 2022].

FAO (2020). *Global forest resources assessment 2020*. Rome: Food and Agriculture Organization of the United Nations (FAO). Available at: www.fao.org/documents/card/en/c/ca9825en.

FAO (2021a). Climate change fans spread of pests and threatens plants and crops, new FAO study. Food and Agriculture Organization of the United Nations (FAO). Available at: www.fao.org/news/story/en/item/1402920/icode/#:~:text=FAO%20estimates%20that%20annually%20up,insects%20at%20least%20%2470%20billion.

FAO (2021b). A high-tech response is helping countries win battle against Desert Locust. Food and Agriculture Organization of the United Nations (FAO). Available at: www.fao.org/news/story/pt/item/1397940/icode.

FAO (2021c). The state of food and agriculture 2021. Food and Agriculture Organization of the United Nations (FAO). Available at: www.fao.org/3/CB4476EN/online/CB4476EN.html [accessed August 2022].

FAO (2021d). *The state of the world's land and water resources for food and agriculture – Systems at breaking point*. Synthesis report. Rome: Food and Agriculture Organization of the United Nations (FAO). Available at: www.fao.org/3/cb7654en/online/cb7654en.html [accessed October 2022]

FAO (2022a). Genetically modified crops: Safety, benefits, risks and global status. Food and Agriculture Organization of the United Nations (FAO). Available at: www.fao.org/policy-support/tools-and-publications/resources-details/en/c/1477336/ [accessed July 2022].

FAO (2022b). Small family farmers produce a third of the world's food. Food and Agriculture Organization of the United Nations (FAO). Available at: www.fao.org/news/story/en/item/1395127/icode [accessed September 2022].

FAO (2022c). Water: Key facts. United Nations Food and Agriculture Organization (FAO). Available at: www.fao.org/water/en/#:~:text=FAO%20estimates%20that%20irrigated%20land,improved%20irrigation%20management%20and%20practices [accessed October 2022].

FAO and FILAC (2021). *Forest governance by indigenous and tribal people: An opportunity for climate action in Latin America and the Caribbean*. United Nations Food and Agriculture Organization (FAO) and Fund for the Development of Indigenous Peoples of Latin America and the Caribbean (FILAC). Santiago, Chile: FAO. Available at: www.fao.org/documents/card/en/c/cb2930en.

Fischer, G., F. Tubiello, H. Velthuisen and D. Wiberg (2007). Climate change impacts on irrigation water requirements: Effects of mitigation, 1990–2080. *Technological Forecasting and Social Change*, 74, 1083–107.

Foo, S.A. and G.P. Asner (2019). Scaling up coral reef restoration using remote sensing technology. *Frontiers in Marine Science*, 6.

Forbes (2018). Smart dust is coming, are you ready? *Forbes*. Available at: www.forbes.com/sites/bernardmarr/2018/09/16/smart-dust-is-coming-are-you-ready/?sh=745edf6c5e41 [accessed October 2022].

Friedman, R., E. Mackenzie, R. Baiga, K. Inape, S. Crimp and M. Howden (2022). Designing climate information services to enhance resilient farming activities: Lessons from Papua New Guinea. *Frontiers in Climate*, 4, 871987.

Gao, S.-K., C.-C. Geng, J. Yingchao, Z.-K. Li and C.-G. Zhou (2019). Density-dependent growth and fitness in *dastarcus helophoroides* (coleoptera: Bothrideridae). *Insects*, 10.

GCA (2020a). How trees can help us adapt to the effects of climate change. Global Center on Adaptation (GCA). Available at: <https://gca.org/how-trees-can-help-us-adapt-to-the-effects-of-climate-change> [accessed October 2022].

GCA (2020b). *State and trends in adaptation report 2020*. Rotterdam: Global Centre on Adaptation (GCA). Available at: <https://gca.org/reports/state-and-trends-in-adaptation-report-2020.>

GCA (2021). *Green bonds for climate resilience: A guide for issuers*. Global Center on Adaptation (GCA). Available at: <https://gca.org/wp-content/uploads/2021/11/A-guide-for-issuers-Full-report-online.pdf.>

GCA (2022). The global commission on adaptation – Global center on adaptation. Global Center on Adaptation (GCA). Available at: <https://gca.org/about-us/the-global-commission-on-adaptation> [accessed October 2022].

GCF (2022). *Annual results report*. Green Climate Fund (GCF). Available at: www.greenclimate.fund/sites/default/files/document/20220412-arr2021.pdf.

GCRA (2022). Biorock. Global Coral Reef Alliance (GCRA). Available at: www.globalcoral.org/biorock-coral-reef-marine-habitat-restoration [accessed October 2022].

GCRMN (2020). *The sixth status of corals of the world: 2020 report*. The Global Coral Reef Monitoring Network (GCRMN). Available at: <https://gcrmn.net/2020-report>.

Gellatly, K. and D.T. Dennis (2011). Plant biotechnology and GMOs. In Moo-Young, M., (ed.) *Comprehensive biotechnology*. Cambridge, MA: Academic Press, 10–23.

Gershon, L. (2020). The global suppression of indigenous fire management. JSTOR Daily. Available at: <https://daily.jstor.org/the-global-suppression-of-indigenous-fire-management> [accessed October 2022].

Gerster-Bentaya, M. (2013). Nutrition-sensitive urban agriculture. *Food Security*, 5, 723–37

Gilbert, N. (2009). Digital soil map for Africa launched. *Nature News*, 13 January. Available at: www.nature.com/articles/news.2009.17,

Gondim, R., M.A. Castro, A. Maia, S. Evangelista and S. Fuck Jr (2012). Climate change impacts on irrigation water needs in the Jaguaribe river basin. *JAWRA Journal of the American Water Resources Association*, 48 (2) 355–65.

González Guzmán, M., F. Cellini, V. Fotopoulos, R. Balestrini and V. Arbona (2022). New approaches to improve crop tolerance to biotic and abiotic stresses. *Physiologia Plantarum*, 174(1).

Google (2022). Google patents. Google. Available at: www.google.com/?tbp=pts [accessed July 2022].

Government of Malaysia (2022). Stormwater Management and Road Tunnel (SMART). Available at: <https://smarttunnel.com.my/about-us> [accessed October 2022].

Government of Singapore (2022). Gardens in the sky. Available at: www.nparks.gov.sg/skyrisegreenery [accessed October 2022].

Goyal, M.R. (2012). *Management of drip/trickle or micro irrigation*, 1st edition ed. New York: Apple Academic Press.

GSA (2020). *Managing Adelaide's beaches: Past, present and future*. Adelaide: Government of South Australia (GSA). Available at: <https://cdn.environment.sa.gov.au/environment/docs/adelaide-beaches-past-present-future-june-2021.pdf>.

Hallegatte, S., J. Rentschler and J. Rozenberg (2019). *Lifelines: The resilient infrastructure opportunity*. Sustainable infrastructure series. Washington, DC: World Bank. Available at: <https://openknowledge.worldbank.org/handle/10986/31805>.

Han, C., J. Huo, Q. Gao, G. Su and H. Wang (2020). Rainfall monitoring based on next-generation millimeter-wave backhaul technologies in a dense urban environment. *Remote Sensing*, 12, 1045.

Heinke, J., M. Lannerstad, D. Gerten, P. Havlík, M. Herrero, A. Notenbaert, H. Hoff and C. Müller (2020). Water use in global livestock production – Opportunities and constraints for increasing water productivity. *Water Resources Research*, 56.

Heinrich Böll Foundation (2021). 10 things to know about climate finance. Available at: https://issuu.com/heinrichbollfoundationnorthamerica/docs/hbs-10things2021-book?embed_cta=embed_badge&embed_context=embed&embed_domain=climatefundsupdate.org&utm_medium=referral&utm_source=climatefundsupdate.org [accessed October 2022].

- Holderness, T. and E. Turpin (2015). From social media to geosocial intelligence: Crowdsourcing civic co-management for flood response in Jakarta, Indonesia. In Nepal, S., C. Paris and D. Georgakopoulos, eds., *Social Media for Government Services*. Cham: Springer International Publishing, 115–33.
- Hötte, K. and S.J. Jee (2022). Knowledge for a warmer world: A patent analysis of climate change adaptation technologies. *Technological Forecasting and Social Change*, 183, 121879.
- Hu, H., T. Lei, J. Hu, S. Zhang and P. Kavan (2018). Disaster-mitigating and general innovative responses to climate disasters: Evidence from modern and historical China. *International Journal of Disaster Risk Reduction*, 28, 664–73. Available at: www.sciencedirect.com/science/article/pii/S004016252200395X [accessed October 2022].
- Hu, P., Q. Zhang, P. Shi, B. Chen and J. Fang (2018). Flood-induced mortality across the globe: Spatiotemporal pattern and influencing factors. *Science of the Total Environment*, 643, 171–82.
- Hvilshoj, S. (2015). Reduction of non-revenue water around the world. International Water Association. Available at: <https://iwa-network.org/reduction-of-non-revenue-water-around-the-world/#:~:text=Around%20the%20world%20we%20still,per%20cent%20non%2Drevenue%20water> [accessed October 2022].
- Ibrahim, A., R.C. Abaidoo, D. Fatondji and A. Opoku (2016). Fertilizer micro-dosing increases crop yield in the Sahelian low-input cropping system: A success with a shadow. *Soil Science and Plant Nutrition*, 62(3), 277–88.
- ICRAF (2020). The land degradation surveillance framework. World Agroforestry Center [International Council for Research in Agroforestry] (ICRAF). Available at: <https://worldagroforestry.org/output/land-degradation-surveillance-framework> [accessed October 2022].
- IEA (2018). *The future of cooling: Opportunities for energy-efficient air conditioning*. International Energy Agency (IEA). Available at: https://iea.blob.core.windows.net/assets/0bb45525-277f-4c9c-8d0c-9c0cb5e7d525/The_Future_of_Cooling.pdf.
- IFAD (2009). *Livestock and climate change*. International Fund for Agricultural Development (IFAD). Available at: www.uncclearn.org/wp-content/uploads/library/ifad81.pdf.
- IFAD (2022). China national engineering research centre of Juncao technology. International Fund for Agricultural Development (IFAD). Available at: <https://ruralsolutionsportal.org/en/w/china-national-engineering-research-centre-of-juncao-technology> [accessed October 2022].
- IFPRI (2010). *What is the irrigation potential for Africa?* International Food Policy Research Institute (IFPRI). Available at: www.ifpri.org/publication/what-irrigation-potential-africa.
- IPBES (2019). *The global assessment report on biodiversity and ecosystem services: A summary for policymakers*. Bonn, Germany: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). Available at: https://ipbes.net/sites/default/files/2020-02/ipbes_global_assessment_report_summary_for_policymakers_en.pdf.
- IPCC (2014). Buildings. In *Climate change 2014: Mitigation of climate change. Contribution of Working Group III to the fifth assessment report of the Intergovernmental Panel on Climate Change*. Cambridge, UK and New York, USA: Intergovernmental Panel on Climate Change (IPCC).
- IPCC (2018). *An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty: Summary for Policymakers*. Geneva: IPCC, WMO, UNEP. Available at: www.ipcc.ch/sr15.
- IPCC (2019). *IPCC special report on the ocean and cryosphere in a changing climate: Summary for policymakers*. Geneva: IPCC, WMO, UNEP. Available at: www.ipcc.ch/srocc/download-report.
- IPCC (2022). *Working Group II sixth assessment report: Impacts, adaptation and vulnerability – Summary for policymakers*. Geneva: Intergovernmental Panel on Climate Change (IPCC). Available at: www.ipcc.ch/working-group/wg2.

IPO, UK (2021). *Flood and coastal defences*. Newport, UK: The Intellectual Property Office (IPO UK). Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1031155/Flood-and-coastal-defences.pdf.

IPOS (2019). *Technology scan: Energy efficient desalination technologies*. Intellectual Property Office of Singapore (IPOS). Available at: www.ipos.gov.sg/docs/default-source/default-document-library/tech-scan---energy-efficient-desalination-technologies.pdf.

Isaacs, S.L. (2018). *Many lessons on energy from impacts of recent hurricanes*. The Government of Bahamas. Available at: <https://reliefweb.int/report/bahamas/many-lessons-energy-impacts-recent-hurricanes>.

Jamei, E., H.W. Chau, M. Seyedmahmoudian and A. Stojcevski (2021). Review on the cooling potential of green roofs in different climates. *Science of the Total Environment*, 791, 148407.

Jones, E., M. van Vliet, M. Qadir and M. Bierkens (2021). Country-level and gridded estimates of wastewater production, collection, treatment and reuse. *Earth System Science Data*, 13, 237–54.

JRC (2022). Seasonal trends for EU countries. European Commission Joint Research Centre (JRC). Available at: <https://effis.jrc.ec.europa.eu/apps/effis.statistics/seasonaltrend> [accessed October 2022].

Kabiri, S., F. Degryse, D.N.H. Tran, R.C. da Silva, M.J. McLaughlin and D. Losic (2017). Graphene oxide: A new carrier for slow release of plant micronutrients. *ACS Appl Mater Interfaces*, 9(49), 43325–35.

Kappou, S., M. Souliotis, S. Papaefthimiou, G. Panaras, J. A. Paravantis, E. Michalena, J.M. Hills, A.P. Vouros, A. Ntymenou and G. Mihalakakou (2022). Cool pavements: State of the art and new technologies. *Sustainability*, 14(9). Available at: www.mdpi.com/2071-1050/14/9/5159 [accessed October 2022].

Khan, Z., D. Amudavi and J. Pickett (2008). Push-pull technology transforms small farms in Kenya. PAN North America Magazine. Available at: www.push-pull.net/panna2008.pdf.

Kieckens, E. (2020). Venice keeps feet dry thanks to the Moses Dam. Available at: <https://innovationorigins.com/en/venice-keeps-feet-dry-thanks-to-the-moses-dam> [accessed October 2022].

Kirk, A., D. Blood and P. Gutierrez (2022). Europe's record summer of heat and fires – Visualised. *The Guardian*. Available at: www.theguardian.com/environment/ng-interactive/2022/jul/26/how-europe-has-been-hit-by-record-fire-damage-and-temperatures.

Kolczak, A. (2017). This city aims to be the world's greenest. *National Geographic*. Available at: www.nationalgeographic.com/environment/article/green-urban-landscape-cities-Singapore [accessed October 2022].

Kozłowski, T.T. and S.G. Pallardy (1997). Cultural practices and reproductive growth. In Kozłowski, T.T. and S.G. Pallardy, eds., *Growth control in woody plants*. San Diego: Academic Press, 394–435.

Krishnan, A. (2022). How AgTech is changing East African economies. Overseas Development Institute (ODI). Available at: <https://odi.org/en/insights/how-agtech-is-changing-east-african-economies> [accessed September 2022].

Kunz, D., H. Müller and C. Soltmann (2012). *Patent landscape report on solar cooling technologies*. Geneva: World Intellectual Property Organization (WIPO). Available at: www.wipo.int/edocs/pubdocs/en/patents/948/wipo_pub_948_3.pdf.

Ky-Dembélé, C., J. Bayala, D.S. Dayamba, C. Adeyemi, P. Dorward, A. Agali, A. Diakite, R.B. Zougmore and N. Lamien (2020). Taking the participatory integrated climate services for agriculture (PICSA) approach to extension actors for strengthening resilience in Africa: Five years' experience in West Africa. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Available at: <https://ccafs.cgiar.org/resources/publications/taking-participatory-integrated-climate-services-agriculture-picsa> [accessed October 2022].

Lafforgue, M. and V. Lenouvel (2015). Closing the urban water loop: Lessons from Singapore and Windhoek. *Environ. Sci.: Water Res. Technol.*, 1, 622–31.

Leflaive, X., B. Kriebel and H. Smythe (2020). Trends in water-related technological innovation: Insights from patent data, OECD Environment Working Papers 161. OECD Publishing. Available at: <https://www.oecd-ilibrary.org/content/paper/821c01f2-en>

Lenntech (2021). Closed circuit reverse osmosis. Available at: www.lenntech.com/products/membrane/ccro.htm [accessed October 2022].

Lens (2022). The lens – Free and open patent and scholarly search. LENS.ORG. Available at: www.lens.org/lens [accessed July 2022].

Li, J., L. Pu, M. Han, M. Zhu, R. Zhang and Y. Xiang (2014). Soil salinization research in China: Advances and prospects. *Journal of Geographical Sciences*, 24(5), 943–60.

Liemberger, R. and A. Wyatt (2018). Quantifying the global non-revenue water problem. *Water Supply*, 19(3), 831–37.

LSE (2022). The national strategy for climate change adaptation – Climate change laws of the world: China. London School of Economics (LSE) Graham Research Institute on Climate Change and the Environment. Available at: <https://climate-laws.org/geographies/china/policies/the-national-strategy-for-climate-change-adaptation> [accessed August 2022].

MarketsandMarkets (2021). Hydroponics market report. Available at: www.marketsandmarkets.com/Market-Reports/hydroponic-market-94055021.html#:~:text=Countries%20such%20as%20the%20Netherlands,use%20of%20climate%20control%20technologies [accessed October 2022].

Mathison, C., A.J. Wiltshire, P. Falloon and A. Challinor (2015). South Asia river flow projections and their implications for water resources. *Hydrology and Earth System Sciences Discussions*, 12, 5789–840.

McKinsey (2022). Precision forestry: A revolution in the woods. McKinsey. Available at: www.mckinsey.com/industries/paper-forest-products-and-packaging/our-insights/precision-forestry-a-revolution-in-the-woods [accessed October 2022].

Mekonnen, M.M. and A.Y. Hoekstra (2016). Four billion people facing severe water scarcity. *Science Advances*, 2(2), e1500323.

Mentens, J., D. Raes and M. Hermy (2006). Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century? *Landscape and Urban Planning*, 77(3), 217–26.

Metinko, C. (2022). Why VC investors are plowing record sums into agtech. *Crunchbasenews*. Available at: <https://news.crunchbase.com/startups/agtech-startups-vc-funding-data>.

MIT (2017). Watering the world: New design cuts costs, energy needs for drip irrigation, bringing the systems within reach for more farmers. Massachusetts Institute of Technology (MIT). Available at: <https://news.mit.edu/2017/design-cuts-costs-energy-drip-irrigation-0420> [accessed October 2022].

MMC (2005). *Natural hazard mitigation saves: An independent study to assess the future savings from mitigation activities. Volume 1 – Findings, conclusions, and recommendations*. Washington, DC: Multihazard Mitigation Council (MMC). Available at: www.nibs.org/resource/resmgr/MMC/hms_vol1.pdf.

Nagao, R. (2019). Flooded Japan bullet train yard to be raised 10 meters. *Nikkei Asia*. Available at: <https://asia.nikkei.com/Economy/Natural-disasters/Flooded-Japan-bullet-train-yard-to-be-raised-10-meters> [accessed October 2022].

Najim, A. (2022). A review of advances in freeze desalination and future prospects. *npj Clean Water*, 5(1), 15.

NAS (2016). *Genetically engineered crops: Experiences and prospects*. Washington, DC: National Academies of Sciences, Engineering, and Medicine (NAS). Available at: www.cleantech.com/genetic-engineering-for-crops-and-food-climate-adaptation-resilience-and-food-security-through-innovation.

NASA (2012). Bright is the new black: New Yorks roofs go cool. Available at: www.nasa.gov/topics/earth/features/ny-roofs.html [accessed October 2022].

Nellie, D., M. van der Merwe and L. Dougan (2018). Cape of storms to come. *Daily Maverick*. Available at: <https://features.dailymaverick.co.za/cape-of-storms-to-come/cape-of-storms-to-come-part-1.html> [accessed October 2022].

Nicholls, R.J., S. Hanson, C. Herweijer, N. Patmore, S. Hallegatte, J. Corfee-Morlot, J. Chateau and R. Muir-Wood (2007). *Ranking of the world's cities most exposed to coastal flooding today and in the future: Executive Summary*. Organisation for Economic Co-operation and Development (OECD).

Nishimoto, R. (2019). Global trends in the crop protection industry. *Journal of Pesticide Science*, 44(3), 141–47.

NL Netherlands (2022). Sand engine principles to replenish African coastline: Dutch Water Sector. Netherland Water Sector. Available at: www.dutchwatersector.com/news/sand-engine-principles-to-replenish-african-coastline.

NOAA (2016). NOAA and Raytheon improve unmanned aircraft to collect hurricane weather data. National Oceanic and Atmospheric Administration (NOAA). Available at: <https://research.noaa.gov/article/ArtMID/587/ArticleID/553/NOAA-and-Raytheon-improve-unmanned-aircraft-to-collect-hurricane-weather-data> [accessed October 2022].

NOAA (2022a). Carbon dioxide peaks near 420 parts per million at Mauna Loa observatory. National Oceanic and Atmospheric Administration (NOAA). Available at: <https://research.noaa.gov/article/ArtMID/587/ArticleID/2764/Coronavirus-response-barely-slows-rising-carbon-dioxide> [accessed August 2022].

NOAA (2022b). Ocean acidification. National Oceanic and Atmospheric Administration (NOAA). Available at: www.noaa.gov/education/resource-collections/ocean-coasts/ocean-acidification#:~:text=Because%20of%20human%2Ddriven%20increased,the%20ocean%20becomes%20more%20acidic [accessed August 2022].

NYC Business (2022). NYC CoolRoofs. City of New York (NYC). Available at: www1.nyc.gov/nycbusiness/article/nyc-coolroofs [accessed October 2022].

O'Connor, R., A. Dixit and A. Dinshaw (2022). 3 things to know about the adaptation components of countries' updated NDCs. World Resources Institute (WRI). Available at: www.wri.org/insights/3-things-know-about-adaptation-components-countries-updated-ndcs [accessed October 2022].

ODI (2018). How AgTech is changing East African economies. Overseas Development Institute (ODI). Available at: <https://odi.org/en/insights/how-agtech-is-changing-east-african-economies> [accessed October 2022].

OECD (2018). *Policy perspectives – Climate resilient infrastructure*. Organisation for Economic Co-operation and Development (OECD). Available at: www.oecd.org/environment/cc/policy-perspectives-climate-resilient-infrastructure.pdf.

OECD (2022a). *Aggregate trends of climate finance provided and mobilised by developed countries in 2013–2020*. Paris: Organisation for Economic Co-operation and Development (OECD). Available at: www.oecd.org/finance/aggregate-trends-of-climate-finance-provided-and-mobilised-by-developed-countries-in-2013-2020-d28f963c-en.htm.

OECD (2022b). *OECD work in support of a sustainable ocean*. Paris: Organisation for Economic Co-operation and Development (OECD). Available at: www.oecd.org/environment/2022-OECD-work-in-support-of-a-sustainable-ocean.pdf.

- Oksen, P. and L. Favre (2020). *Innovative technology in the Water, Sanitation and Hygiene (WASH) sector*. Global Challenges in Focus. Geneva: World Intellectual Property Organization (WIPO). Available at: www.wipo.int/publications/en/details.jsp?id=4497&plang=EN.
- Onyango, L., G. Leslie and J.G. Wood (2014). *Global potable reuse case study 4: Windhoek, Namibia*. Brisbane, Australia: Australian Water Recycling Centre of Excellence. Available at: <https://vuir.vu.edu.au/32234/1/WQ+Case+Study+4+-+Windhoek+Namibia+100815.pdf>.
- Ouoba, N., L.D. Phung, A. Sasaki, D.V. Pham and T. Watanabe (2022). Drip fertigation with treated municipal wastewater and soil amendment with composted sewage sludge for sustainable protein-rich rice cultivation. *Environmental Technology & Innovation*, 28, 102569.
- Ozkan, C., T. Mayo and D.L. Passeri (2022). The potential of wave energy conversion to mitigate coastal erosion from hurricanes. *Journal of Marine Science and Engineering*, 10(2). Available at: www.mdpi.com/2077-1312/10/2/143 [accessed October 2022]
- Padmanathan, P. (2022). How technology and entrepreneurship can quench our parched world. Available at: www.weforum.org/agenda/2022/06/technology-and-entrepreneurship-can-quench-our-parched-world [accessed October 2022].
- Pavelic, P. (2019). Mitigating floods for managing droughts through aquifer storage. An examination of two complementary approaches. World Bank. Available at: <https://openknowledge.worldbank.org/bitstream/handle/10986/33244/Mitigating-Floods-for-Managing-Droughts-through-Aquifer-Storage-An-Examination-of-Two-Complementary-Approaches.pdf?sequence=5> [accessed October 2022].
- Pixley, K.V., J.B. Falck-Zepeda, R.L. Paarlberg, P.W.B. Phillips, I.H. Slamet-Loedin, K.S. Dhugga, H. Campos and N. Gutterson (2022). Genome-edited crops for improved food security of smallholder farmers. *Nature Genetics*, 54(4), 364–67.
- Poonam, S. (2022). No power, no fans, no AC: The villagers fighting to survive India's deadly heatwaves. *MIT Technology Review*. Available at: www.technologyreview.com/2022/07/05/1054750/how-indian-villagers-are-coping-with-the-deadly-heatwaves [accessed August 2022].
- Popp, D. (2019). *Environmental policy and innovation: A decade of research*. Cambridge, MA: National Bureau of Economic Research. Available at: www.nber.org/system/files/working_papers/w25631/w25631.pdf.
- PRC (2013). *National Strategy for Climate Change Adaptation*. Beijing: Government of the People's Republic of China (PRC).
- PRC (2022). China prioritizes mitigation, adaptation in addressing climate change. The State Council. The People's Republic of China (PRC). Available at: https://english.www.gov.cn/statecouncil/ministries/202206/15/content_WS62a99e7dc6d02e533532c317.html [accessed August 2022].
- Pyke, C.R., S. McMahon, L. Larsen, N.B. Rajkovich and A. Rohloff (2012). Development and analysis of climate sensitivity and climate adaptation opportunities indices for buildings. *Building and Environment*, 55, 141–49.
- Qian, Q., F. Zhang and Y. Xin (2021). Yuan Longping and hybrid rice research. *Rice* (N Y), 14(1), 101.
- Qin, Y. and A. Horvath (2020). Use of alternative water sources in irrigation: Potential scales, costs, and environmental impacts in California. *Environmental Research Communications*, 2.
- Rahayu, H., L. Comfort, R. Haigh, P. Amaratunga and D. Khoirunnisa (2020). A study of people-centered early warning system in the face of near-field tsunami risk for Indonesian coastal cities. *International Journal of Disaster Resilience in the Built Environment*, 11(2). Available at: www.emerald.com/insight/content/doi/10.1108/IJDRBE-10-2019-0068/full/html.
- Reliefweb (2022a). An alarming cycle of drought, malnutrition and disease in Baidoa – Somalia. Reliefweb. Available at: <https://reliefweb.int/report/somalia/alarming-cycle-drought-malnutrition-and-disease-baidoa> [accessed October 2022].

Reliefweb (2022b). Pakistan: 2022 monsoon floods – Situation Report No. 7 (as of 23 September 2022) – Pakistan. Reliefweb. Available at: <https://reliefweb.int/report/pakistan/pakistan-2022-monsoon-floods-situation-report-no-7-23-september-2022> [accessed October 2022].

Renaldi, R., N.D. Miranda, R. Khosla and M.D. McCulloch (2021). Patent landscape of not-in-kind active cooling technologies between 1998 and 2017. *Journal of Cleaner Production*, 296, 126507.

Research and Markets (2022). Global water recycle and reuse technologies market 2022: Climate change and drought resilience compels adoption of water reuse. Available at: www.globenewswire.com/en/news-release/2022/03/18/2405982/28124/en/Global-Water-Recycle-and-Reuse-Technologies-Market-2022-Climate-Change-and-Drought-Resilience-Compels-Adoption-of-Water-Reuse.html [accessed October 2022].

Reytar, K., D. Levin, E. Goldman, F. Stolle, M. Weisse and P. Potapov (2022). 36 countries are gaining more trees than they're losing. World Resources Institute (WRI). Available at: www.wri.org/insights/tracking-global-tree-cover-gain?utm_campaign=wridigest&utm_source=wridigest-2022-06-29&utm_medium=email&utm_content=learnmore [accessed October 2022].

Richmond, M. and N. Upadhyaya (2021). *An analysis of urban climate adaptation finance*. Climate Policy Initiative (CPI). Available at: www.climatepolicyinitiative.org/publication/an-analysis-of-urban-climate-adaptation-finance.

Rijkswaterstaat (2022). The sand motor. Rijkswaterstaat, Ministerie van Infrastructuur en Waterstaat. Available at: <https://dezandmotor.nl/en/%202022>.

Rivera-Ferre, M.G., F. López-i-Gelats, M. Howden, P. Smith, J.F. Morton and M. Herrero (2016). Re-framing the climate change debate in the livestock sector: Mitigation and adaptation options. *WIREs Climate Change*, 7(6), 869–92.

Rojas-Downing, M.M., A.P. Nejadhashemi, T. Harrigan and S.A. Woznicki (2017). Climate change and livestock: Impacts, adaptation, and mitigation. *Climate Risk Management*, 16, 145–63.

Rose, D. (2020). The fourth agricultural revolution is coming – but who will really benefit? University of Reading. Available at: <https://research.reading.ac.uk/research-blog/the-fourth-agricultural-revolution-is-coming-but-who-will-really-benefit> [accessed August 2022].

Rydhmer, K., E. Bick, L. Still, A. Strand, R. Luciano, S. Helmreich, B. Beck, C. Grønne, L. Malmros, K. Poulsen, F. Elbæk, M. Brydegaard, J. Lemmich and T. Nikolajsen (2022). Automating insect monitoring using unsupervised near-infrared sensors. *Scientific Reports*, 12.

Sadhasivam, S. and M.M. Mohamed (2018). Assessment of aquifer storage and recovery (ASR) feasibility at selected sites in the emirate of Abu Dhabi, UAE. *Environmental Earth Sciences*, 77, 1–20.

Sakr, G., I. Elhadj and G. Mitri (2011). Efficient forest fire occurrence prediction for developing countries using two weather parameters. *Engineering Applications of Artificial Intelligence*, 24(5), 888–94.

Schipper, E.L.F. (2020). Maladaptation: When adaptation to climate change goes very wrong. *One Earth*, 3(4), 409–14.

ScienceDaily (2022). Study reveals an unprecedented change in Europe's fire regime: Spring and summer seasons with a high fire risk. ScienceDaily. Available at: www.sciencedaily.com/releases/2022/06/220630114543.htm [accessed August 2022].

SEBI Livestock (2022). Livestock & climate resilience. The Centre for Supporting Evidence Based Intervention (SEBI) in Livestock. Available at: <https://projects.livestockdata.org/livestock-climate-resilience/#> [accessed October 2022].

Sebnie, W., M. Mengesha, G. Girmay, T. Feyisa, B. Asgedom, G. Beza and D. Dejene (2020). Evaluation of micro-dosing fertilizer application on sorghum (*Sorghum bicholor* L) production at Wag-Lasta Areas of Amhara Region, Ethiopia. *Scientific Reports*, 10(1), 6889.

Shanghai Meteorological Bureau (2010). Overview of Shanghai multi-hazard early warning system and the role of meteorological services. Available at: https://ane4bf-datap1.s3-eu-west-1.amazonaws.com/wmocms/s3fs-public/news/related_docs/Shanghai_MHEWS_CostaRica.pdf [accessed October 2022].

Sharma, B. (2021). Google's AI-based flood forecasting system is saving lives in India: Here's how. *India Times*. Available at: www.indiatimes.com/technology/news/google-ai-based-flood-forecasting-india-553906.html#:~:text=The%20AI%20employs%20two%20primary,areas%20that%20will%20be%20flooded [accessed October 2022].

Sherwood, S.C. and M. Huber (2010). An adaptability limit to climate change due to heat stress. *Proceedings of the National Academy of Sciences*, 107(21), 9552–55.

Shi, L., L. Wang, H. Li, Y. Zhao, J. Wang, Y. Zhu and G. He (2022). Impact of residential water saving devices on urban water security: the case of Beijing, China. *Environmental Science: Water Research & Technology*, 8(2), 326–42.

Shoham, J. (2020). The rise of biological products in the crop protection and plant nutrition markets. IHS Markit. Available at: <https://ihsmarkit.com/research-analysis/the-rise-of-biological-products-in-crop-protection-and-nutriti.html> [accessed October 2022].

Singh, A. (2021). Soil salinity: A global threat to sustainable development. *Soil Use and Management*, 38.

Six, D. (2019). *Forest health and biotechnology: Possibilities and considerations*. Washington, DC: National Academies Press.

Smarttunnel (2021). 0924HRS *Info terkini*. Twitter.

Smith, B., D. Brown and D. Dodman (2014). *Reconfiguring urban adaptation finance*. London: International Institute for Environment and Development (IIED). Available at: <https://iied.org/10651iied>.

Staudt, F., R. Gijsman, C. Ganal, F. Mielck, J. Wolbring, H.C. Hass, N. Goseberg, H. Schüttrumpf, T. Schlurmann and S. Schimmels (2021). The sustainability of beach nourishments: A review of nourishment and environmental monitoring practice. *Journal of Coastal Conservation*, 25(2), 34.

Sufri, S., F. Dwirahmadi, D. Phung and S. Rutherford (2020). A systematic review of community engagement (CE) in disaster early warning systems (EWS). *Progress in Disaster Science*, 5, 100058.

Summers, H., H. Karsten, W. Curran and G. Malcolm (2021). Integrated weed management with reduced herbicides in a no-till dairy rotation. *Agronomy Journal*, 113.

Tabrizi, S. (2021). *Indigenous peoples and climate technologies*. Copenhagen: UNEP DTU Partnership. Available at: <https://tech-action.unepccc.org/publications/indigenous-peoples-and-climate-technologies>.

Takebayashi, H. and M. Moriyama (2020). Chapter 1 – Background and purpose. In Takebayashi, H. and M. Moriyama, eds., *Adaptation measures for urban heat islands*. Cambridge, MA: Academic Press, 1–8.

Tan, Y.M., O. Dalby, G.A. Kendrick, J. Statton, E.A. Sinclair, M.W. Fraser, P.I. Macreadie, C.L. Gillies, R.A. Coleman, M. Waycott, K.-j. van Dijk, A. Vergés, J.D. Ross, M.L. Campbell, F.E. Matheson, E.L. Jackson, A.D. Irving, L.L. Govers, R.M. Connolly, I.M. McLeod, M.A. Rasheed, H. Kirkman, M.R. Flindt, T. Lange, A.D. Miller and C.D.H. Sherman (2020). Seagrass restoration is possible: Insights and lessons from Australia and New Zealand. *Frontiers in Marine Science*, 7.

Taylor, R. and D. Zilberman (2015). The diffusion of process innovation: The case of drip irrigation in California. In *2015 AAEA & WAEA Joint Annual Meeting, July 26–28, San Francisco, California*. Agricultural and Applied Economics Association.

Tech4Good (2022). The living fog platform for smart city management. Available at: <https://marketplace.intelligentcitieschallenge.eu/en/solutions/livingfog> [accessed October 2022].

Technolog (2017). Controlling water pressure in Sebokeng. Available at: www.technolog.com/case-studies/advanced-pressure-management-2 [accessed October 2022].

Teutli-Hernández, C., J.A. Herrera-Silveira, D.J. Cisneros-de la Cruz and R. Román-Cuesta (2020). *Mangrove ecological restoration guide: Lessons learned. Mainstreaming Wetlands into the Climate Agenda: A multi level approach (SWAMP)*. Bogor, Indonesia: CIFOR/CINVESTAV-IPN/UNAM-Sisal/PMC. Available at: www.cifor.org/publications/pdf_files/Books/2020-Guide-SWAMP.pdf.

Than, K. (2020). Q&A: Making the case for mobile marine protected areas. Available at: <https://earth.stanford.edu/news/qa-making-case-mobile-marine-protected-areas#gs.ekplbm> [accessed October 2022].

The University of Arizona (2019). Agrivoltaics proves mutually beneficial across food, water, energy nexus. Available at: <https://news.arizona.edu/story/agrivoltaics-proves-mutually-beneficial-across-food-water-energy-nexus> [accessed October 2022].

Thompson, P.L. and E.A. Fronhofer (2019). The conflict between adaptation and dispersal for maintaining biodiversity in changing environments. *Proceedings of the National Academy of Sciences*, 116(42), 21061–67.

Totetu (2020). Introduction to the universal water storage system. Available at: www.totetu.com/wp-content/uploads/2020/12/english.pdf [accessed October 2022].

Touma, D., S. Stevenson, D.L. Swain, D. Singh, D.A. Kalashnikov and X. Huang (2022). Climate change increases risk of extreme rainfall following wildfire in the western United States. *Science Advances*, 8(13), eabm0320.

TT:Clear (2022). Technology needs assessment. UNFCCC. Available at: <https://unfccc.int/ttclear/ttna> [accessed October 2022].

UNDESA (2018). 2018 revision of world urbanization prospects. United Nations Department of Economic and Social Affairs (UNDESA). Available at: www.un.org/development/desa/publications/2018-revision-of-world-urbanization-prospects.html#:~:text=Today%2C%2055%25%20of%20the%20world's,increase%20to%2068%25%20by%202050 [accessed October 2022].

UNEA (2022). Proceedings, report, ministerial declaration, resolutions and decisions UNEA 5.2. United Nations Environment Programme (UNEP). Available at: www.unep.org/environmentassembly/unea-5.2/proceedings-report-ministerial-declaration-resolutions-and-decisions-unea-5.2.

UNEP-DTU (2021). *Taxonomy of climate change adaptation technology. A guidebook for countries conducting a technology needs assessment for adaptation*. Copenhagen: United Nations Environment Programme- Danish Technical University (UNEP-DTU) Partnership, Green Technology Center. Available at: <https://tech-action.unepdtu.org/publications/report-taxonomy-of-climate-change-adaptation-technology>.

UNEP (2021a). *Adaptation gap report 2021: The gathering storm*. Nairobi: United Nations Environment Programme (UNEP). Available at: www.unep.org/resources/adaptation-gap-report-2021.

UNEP (2021b). *A practical guide to climate-resilient buildings and communities*. Nairobi: United Nations Environment Programme (UNEP). Available at: <https://wedocs.unep.org/xmlui/bitstream/handle/20.500.11822/36405/Adapbuild.pdf>.

UNESCO (2021). *The united nations world water development report 2021: Valuing water*. Paris: United Nations Educational, Scientific and Cultural Organization (UNESCO). Available at: www.unwater.org/publications/un-world-water-development-report-2021 [accessed October 2022].

UNESCO (2022). *The united nations world water development report 2021: Groundwater-making the invisible visible*. Paris: United Nations Educational, Scientific and Cultural Organization (UNESCO). Available at: <https://www.unwater.org/publications/un-world-water-development-report-2022> [accessed October 2022].

UNFCCC (2022a). NAP central. United Nations Framework Convention on Climate Change (UNFCCC). Available at: www4.unfccc.int/sites/NAPC/Pages/Home.aspx [accessed August 2022].

UNFCCC (2022b). National adaptation programmes of action. United Nations Framework Convention on Climate Change (UNFCCC). Available at: <https://unfccc.int/topics/resilience/workstreams/national-adaptation-programmes-of-action/introduction> [accessed August 2022].

UNFCCC (2022c). UN early warning systems must protect everyone within five years. United Nations Framework Convention on Climate Change (UNFCCC). Available at: <https://unfccc.int/news/un-early-warning-systems-must-protect-everyone-within-five-years> [accessed October 2022].

UNFCCC (2022d). UNFCCC climate finance data portal. United Nations Framework Convention on Climate Change (UNFCCC). Available at: <https://unfccc.int/climatefinance?home> [accessed September 2022].

UNHCR (2014). *Planned relocation, disasters and climate change: consolidating good practices and preparing for the future*. Sanremo, Italy: United Nations High Commissioner for Refugees (UNHCR). Available at: www.unhcr.org/54082cc69.pdf.

UNPDF (2017). Enhancing capacity of developing countries to achieve sustainable agriculture through the transfer of Juncao technology for alleviating poverty and promoting productive employment. United Nations Peace and Development Trust Fund (UNPDF). Available at: www.un.org/en/unpdf/sdg-2017-01 [accessed October 2022].

Urban Climate Service Centre (2015). Urban climate monitoring. Available at: www.urban-climate.eu/c/8/ [accessed October 2022].

US-Saudi Business Council (2021). Water in Saudi Arabia: Desalination, wastewater and privatization. Available at: <https://ussaudi.org/water-in-saudi-arabia-desalination-wastewater-and-privatization> [accessed October 2022].

US EPA (2012). *Adaptation strategies guide for water utilities*. United States Environmental Protection Agency (EPA). Available at: www.klimatilpasning.dk/media/654883/adaptation_strategies_guide_for_water_utilities.pdf.

USDA (2022). Virtual Fencing. A climate adaptation strategy. United States Department of Agriculture (USDA). Available at: www.climatehubs.usda.gov/hubs/northwest/topic/virtual-fencing-climate-adaptation-strategy [accessed October 2022].

Vegt, H. van der and I. Iliev (2012). *Patent landscape report on membrane filtration and uv water treatment*. Geneva: World Intellectual Property Organization (WIPO). Available at: www.wipo.int/publications/en/details.jsp?id=232.

Vegt, H. van der, I. Iliev, Q. Tannock and S. Helm (2011). *Patent landscape report on desalination technologies and the use of alternative energies for desalination*. Geneva: World Intellectual Property Organization (WIPO). Available at: www.wipo.int/edocs/pubdocs/en/patents/948/wipo_pub_948_2.pdf.

Velasco-Muñoz, J.F., J.A. Aznar-Sánchez, A. Batlles-delaFuente and M.D. Fidelibus (2019). Rainwater harvesting for agricultural irrigation: An analysis of global research. *Water*, 11(7).

Viguié, V., A. Lemonsu, S. Hallegatte, A.-L. Beuland, C. Marchadier, V. Masson, G. Pigeon and J.-L. Salagnac (2020). Early adaptation to heat waves and future reduction of air-conditioning energy use in Paris. *Environmental Research Letters*, 15(7), 075006.

Voolstra, C., D. Miller, M. Ragan, A. Hoffmann, O. Hoegh-Guldberg, D. Bourne, E. Ball, H. Ying, S. Foret, S. Takahashi, K. Weynberg, M. van Oppen, K. Morrow, C.X. Chan, N. Rosic, W. Leggat, S. Sprungala, M. Imelfort, G. Tyson, K. Kassahn, P. Lundgren, R. Beeden, T. Ravasi, M. Berumen, E. Abel and T. Fyffe (2015). The ReFuGe 2020 Consortium – using “omics” approaches to explore the adaptability and resilience of coral holobionts to environmental change. *Frontiers in Marine Science*, 2.

Water Resources Group (2012). A catalogue of good practices in water use efficiency: A pilot phase report. 2030 Water Resources Group. Available at: <https://2030wrg.org/catalogue-good-practices-water-use-efficiency-pilot-phase-report> [accessed October 2022].

WEF (2018). *Innovation with a purpose: The role of technology innovation in accelerating food systems transformation*. Geneva: World Economic Forum (WEF). Available at: www3.weforum.org/docs/WEF_Innovation_with_a_Purpose_VF-reduced.pdf.

Whittle, A., L. Girod, A. Preis, M. Allen, H. Lim, M. Iqbal, S. Srirangarajan, C. Fu and K. Wong (2011). Waterwise@sg: A testbed for continuous monitoring of the water distribution system in Singapore. ASCE Water Distribution Systems Analysis Conference.

Wiebe, K., H. Lotze-Campen, R. Sands, A. Tabeau, D. van der Mensbrugghe, A. Bieweld, B. Bodirsky, S. Islam, A. Kavallari and D. Mason-D'Croz (2015). Climate change impacts on agriculture in 2050 under a range of plausible socioeconomic and emissions scenarios. *Environmental Research Letters*, 10(8).

Williams, T., C. Wilson, P. Wynn and D. Costa (2021). Opportunities for precision livestock management in the face of climate change: A focus on extensive systems. *Animal frontiers: The review magazine of animal agriculture*, 11, 63–8.

WIPO (2019). *Patent landscape report: Marine genetic resources*. Geneva: World Intellectual Property Organization (WIPO). Available at: www.wipo.int/publications/en/details.jsp?id=4398&plang=EN.

WIPO (2022a). *Global innovation index 2022. What is the future of innovation-driven growth?* Geneva: World Intellectual Property Organization (WIPO). Available at: www.wipo.int/global_innovation_index/en.

WIPO (2022b). IPC GREEN inventory. World Intellectual Property Organization (WIPO). Available at: www.wipo.int/classifications/ipc/green-inventory/home [accessed July 2022].

WIPO (2022c). IPO GREEN. World Intellectual Property Organization (WIPO). Available at: www3.wipo.int/wipogreen/en/ipo-green/index.html [accessed September 2022].

WIPO (2022d). PATENTSCOPE. World Intellectual Property Organization (WIPO). Available at: www.wipo.int/patentscope/en/index.html [accessed July 2022].

WIPO (2022e). PCT – The international patent system. World Intellectual Property Organization (WIPO). Available at: www.wipo.int/pct/en/index.html [accessed July 2022].

WIPO (2022f). WIPO publications. World Intellectual Property Organization (WIPO). Available at: www.wipo.int/publications/en/index.html [accessed August 2022].

WIPO GREEN (2022). WIPO GREEN database of needs and green technologies. World Intellectual Property Organization (WIPO). Available at: <https://wipogreen.wipo.int/wipogreen-database/database> [accessed July 2022].

WMO (2015). Multi-hazard early warning systems vital for managing growing risks. World Meteorological Organization (WMO). Available at: <https://reliefweb.int/report/world/multi-hazard-early-warning-systems-vital-managing-growing-risks> [accessed October 2022].

WMO (2021). 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 (2022). Press release: This heatwave is the new normal. World Meteorological Organization (WMO). Available at: <https://public.wmo.int/en/media/news/%E2%80%9C-heatwave-new-normal%E2%80%9D-says-wmo-secretary-general> [accessed August 2022].

World Bank (2019). Mozambique: Cyclone Idai and Kenneth emergency recovery and resilience project. The World Bank. Available at: <https://projects.worldbank.org/en/projects-operations/project-detail/P171040> [accessed October 2022].

World Bank (2020a). Digital ag series: Use of technology and data to aggregate retail demand in African cities – Learning from Twiga Foods in Kenya. Available at: <https://olc.worldbank.org/content/digital-ag-series-use-technology-and-data-aggregate-retail-demand-african-cities-learning> [accessed October 2022].

World Bank (2020b). The locust crisis – The World Bank’s response. The World Bank Group. Available at: www.worldbank.org/en/news/factsheet/2020/04/27/the-locust-crisis-the-world-banks-response [accessed October 2022].

World Bank (2021a). *Opportunity assessment to strengthen collective land tenure rights in FCPF countries: Social inclusion in climate finance*. Washington, DC: World Bank. Available at: <https://openknowledge.worldbank.org/handle/10986/36499>.

World Bank (2021b). Scaling up water reuse: Why recycling our wastewater makes sense. Available at: <https://blogs.worldbank.org/climatechange/scaling-water-reuse-why-recycling-our-wastewater-makes-sense> [accessed October 2022].

Woznicki, S., A. Nejadhashemi and M. Parsinejad (2015). Climate change and irrigation demand: Uncertainty and adaptation. *Journal of Hydrology: Regional Studies*, 34.

WRI (2019). 17 countries, home to one-quarter of the world’s population, face extremely high water stress. World Resources Institute (WRI). Available at: www.wri.org/insights/17-countries-home-one-quarter-worlds-population-face-extremely-high-water-stress [accessed October 2022].

Yuan, X. (2019). China’s agricultural technical cooperation: A case study on juncao aid projects in Papua New Guinea and Fiji. In Huang, M., X. Xu and X. Mao, eds., *South-south cooperation and Chinese foreign aid*. Singapore: Palgrave Macmillan, 143–59. Available at: https://link.springer.com/chapter/10.1007/978-981-13-2002-6_10.

Zafar, M.M., A. Razzaq, M.A. Farooq, A. Rehman, H. Firdous, A. Shakeel, H. Mo and M. Ren (2020). Insect resistance management in *Bacillus thuringiensis* cotton by MGPS (multiple genes pyramiding and silencing). *Journal of Cotton Research*, 3(1), 33.

Zhou, J., S. Chen, W. Shi, R. David-Schwartz, S. Li, F. Yang and Z. Lin (2021). Transcriptome profiling reveals the effects of drought tolerance in Giant Juncao. *BMC Plant Biology*, 21.

Zhou, X., P. Zhang, F. Zhao and G. Yu (2020). Super moisture absorbent gels for sustainable agriculture via atmospheric water irrigation. *ACS Materials Letters*, 2, 1419–22.

Zhu, X., R. Clements, J. Haggard, A. Quezada and J. Torres (2011). *Technologies for climate change adaptation – Agriculture sector*. UNEP DTU Partnership. Available at: https://backend.orbit.dtu.dk/ws/portalfiles/portal/5706575/Technologies_for_Climate_Change_Adaptation_Agriculture_sector.pdf.

Ziaja, S. and M. Chhabra (2021). Climate adaptation for energy utilities: Lessons learned from California’s pioneering regulatory actions. *Frontiers in Climate*, 3.

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