IAEA BULLETIN

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mitigation, monitoring and adaptation

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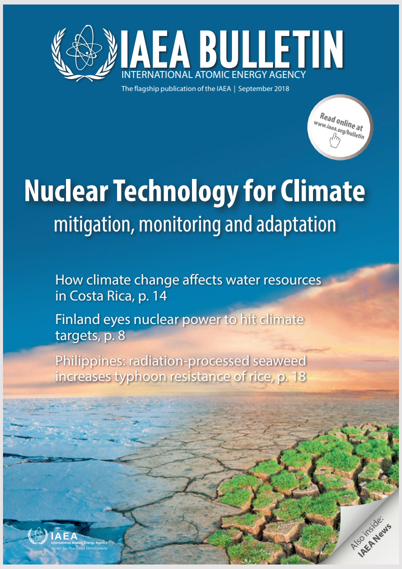

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International Atomic Energy Agency
Vienna International Centre
PO Box 100, 1400 Vienna, Austria
Phone: (43-1) 2600-0
iaeabulletin@iaea.org

Editor: Miklos Gaspar
Contributing Editor: Laura Gil
Design & Production: Ritu Kenn

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IAEA

The International Atomic Energy Agency's mission is to prevent the spread of nuclear weapons and to help all countries — especially in the developing world — benefit from the peaceful, safe and secure use of nuclear science and technology.

Established as an autonomous organization under the United Nations in 1957, the IAEA is the only organization within the UN system with expertise in nuclear technologies. The IAEA's unique specialist laboratories help transfer knowledge and expertise to IAEA Member States in areas such as human health, food, water, industry and the environment.

The IAEA also serves as the global platform for strengthening nuclear security. The IAEA has established the Nuclear Security Series of international consensus guidance publications on nuclear security. The IAEA's work also focuses on helping to minimize the risk of nuclear and other radioactive material falling into the hands of terrorists and criminals, or of nuclear facilities being subjected to malicious acts.

The IAEA safety standards provide a system of fundamental safety principles and reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from the harmful effects of ionizing radiation. The IAEA safety standards have been developed for all types of nuclear facilities and activities that serve peaceful purposes, as well as for protective actions to reduce existing radiation risks.

The IAEA also verifies through its inspection system that Member States comply with their commitments under the Nuclear Non-Proliferation Treaty and other non-proliferation agreements to use nuclear material and facilities only for peaceful purposes.

The IAEA's work is multi-faceted and engages a wide variety of partners at the national, regional and international levels. IAEA programmes and budgets are set through decisions of its policymaking bodies — the 35-member Board of Governors and the General Conference of all Member States.

The IAEA is headquartered at the Vienna International Centre. Field and liaison offices are located in Geneva, New York, Tokyo and Toronto. The IAEA operates scientific laboratories in Monaco, Seibersdorf and Vienna. In addition, the IAEA supports and provides funding to the Abdus Salam International Centre for Theoretical Physics, in Trieste, Italy.

Addressing climate change with the help of nuclear science

By Yukiya Amano, Director General, IAEA

> "The IAEA is committed to helping countries make optimal use of nuclear science and technology to protect the environment and help combat climate change."
>
> — Yukiya Amano, Director General, IAEA

More and more countries are using nuclear technology to combat climate change, the biggest environmental challenge of our time. Nuclear power, currently in use in around 30 countries and under consideration in almost as many, is an important source of clean, low-carbon energy. It undoubtedly has a significant role to play in reducing greenhouse gas emissions. However, the damage that climate change has already caused to the environment and the threat it poses to the livelihoods of entire communities also need to be addressed.

Non-power applications of nuclear science and technology are already making an important contribution. To showcase this contribution, as well as the use of nuclear energy, the 2018 IAEA Scientific Forum is devoted to *Nuclear Technology for Climate: Mitigation, Monitoring and Adaptation.*

Mitigation

Mitigating climate change — the ultimate goal — will require policies, approaches and technologies aimed at reducing the concentration of greenhouse gases in the atmosphere. The IAEA actively supports its 170 Member States in determining what benefits nuclear technology may offer as they work to achieve this goal.

On page 8 of this issue, we examine Finland's plans to increase the share of nuclear energy in its overall energy production from a third to a half by 2030, partly in order to meet its climate change-related commitments.

Agriculture is also a major source of greenhouse gases, including through the production and use of chemical fertilizers. Argentina, Brazil and Kenya are among the countries that the IAEA, in cooperation with the Food and Agriculture Organization of the United Nations (FAO), is supporting in the application of isotopic techniques to help farmers reduce their use of synthetic fertilizers by up to 90% (p. 10).

Monitoring

Nuclear science provides valuable data that help scientists better understand climate change. Armed with such data, policymakers are in a better position to adopt appropriate policies to protect the environment, and to monitor the effects of these policies using nuclear and isotopic techniques.

Harmful algal blooms, and the toxins they produce, threaten ecosystems and the livelihoods of communities which depend on the ocean. Previously found only in tropical and subtropical regions, they are increasingly present in temperate climates as well. The IAEA Environment Laboratories work with many countries on the characterization and monitoring of harmful algal blooms (p.12).

Costa Rica is using isotope hydrology to study rainfall patterns and manage underground water resources sustainably in the face of a changing climate (p. 14). The interaction between fast-moving neutrons and water molecules allows scientists to measure the water content in soils over large areas. This helps farmers manage their water resources and enables policymakers to devise appropriate conservation measures (p. 16).

Adaptation

While work on mitigation continues, the world needs to adapt to the consequences of climate change that are already making themselves felt. These include increasing water scarcity, more frequent natural disasters and unseasonably high temperatures, all of which threaten biodiversity and can result in significantly lower agricultural output. In that regard, new agricultural practices could be very beneficial.

In the Philippines, for example, scientists have used radiation to develop a new type of growth promoter that makes rice more robust, enabling it to withstand gusting typhoon winds (p.18). Zimbabwean farmers have been able to cope with drier weather in part thanks to a new cowpea variety developed at the laboratories run by the IAEA and the FAO (p. 20). Drip irrigation, a technique used throughout the world to conserve water, can be made more effective by using an isotopic technique (p. 22).

The IAEA is committed to helping countries make optimal use of nuclear science and technology to protect the environment and help combat climate change.

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World View

IAEA Updates

The IAEA and climate change: adaptation, monitoring and mitigation

By Noah Mayhew

Climate change is one of the biggest environmental challenges affecting humanity today, causing a dangerous rise in sea levels and disturbances to the water cycle and leading to more frequent extreme weather events. The IAEA helps Member States combat climate change on a variety of fronts: mitigating the production and release of greenhouse gases (GHGs) and monitoring and adapting to their negative effects.

Atmospheric levels of GHGs have fluctuated for billions of years, primarily due to natural orbital, solar and volcanic activities. Since the middle of the eighteenth century, anthropogenic factors have steadily increased the concentration of CO_2 in the Earth's atmosphere, from approximately 278 parts per million to over 400 parts per million as of 2016, according to the United Nations Framework Convention on Climate Change. This is in addition to substantial increases in the concentration of other potent GHGs, including methane and nitrous oxide.

"Dealing with the effects of climate change is not just one country's problem — it's the problem of the entire planet," said Martin Krause, Director at the IAEA's Department of Technical Cooperation. "That is why the IAEA supports its Member States in enhancing understanding of how nuclear science and technology can offset some of the consequences of climate change."

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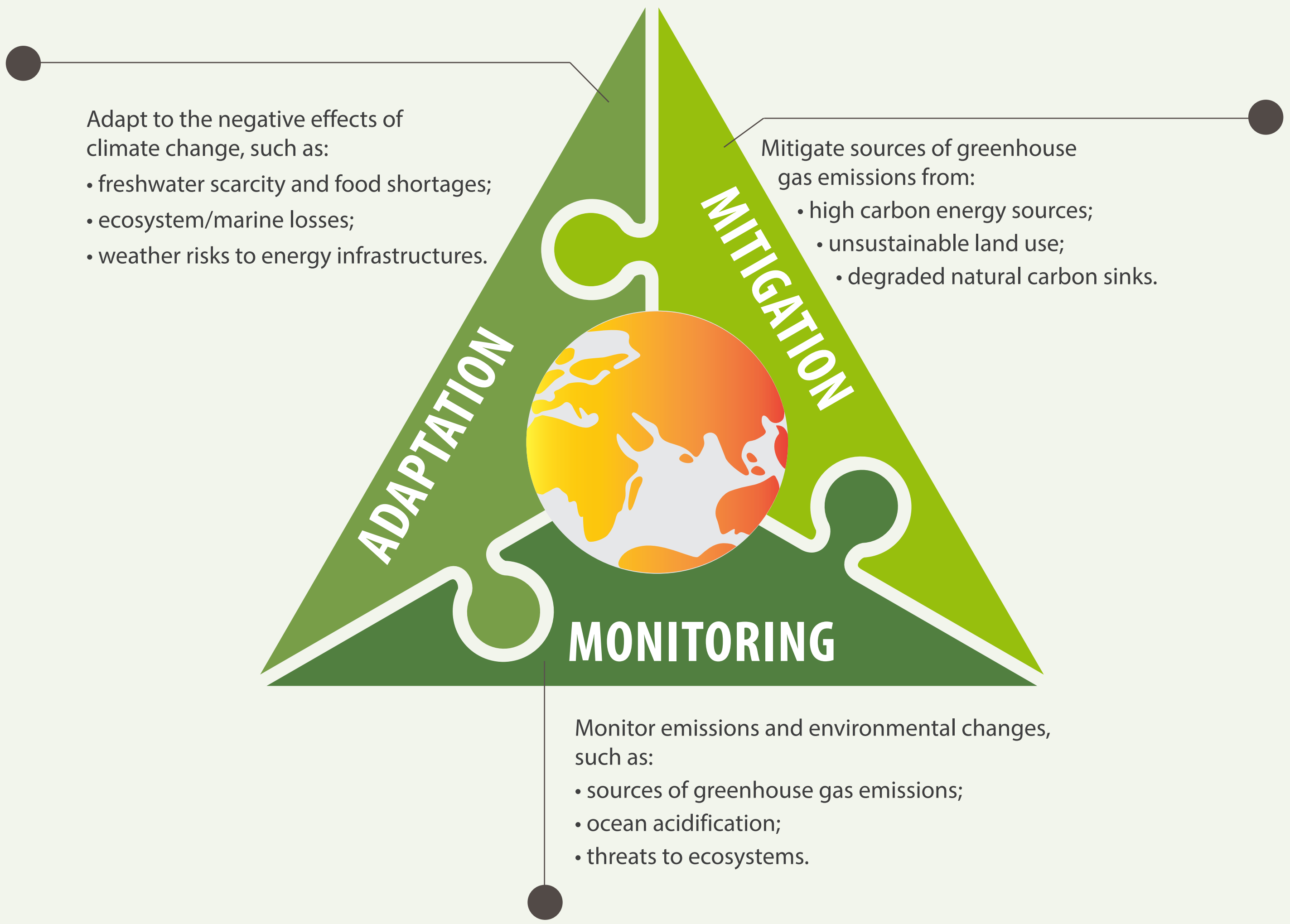
> — Martin Krause, Director, Department of Technical Cooperation, IAEA

Adaptation

Some of the most acute effects of climatic changes are global increases in water scarcity and food shortages, the loss of biodiversity and more frequent climate-induced natural disasters. Unseasonably high temperatures in winter and spring, unpredictable weather and very short rainy seasons contribute to water scarcity in many regions. This, in turn, greatly affects agricultural systems, global food chains and, in particular, small-scale farmers and herders.

To help communities and countries adapt, the IAEA supports activities in plant breeding, soil and crop management, livestock production and insect pest control. For example, Sudan is using nuclear science and IAEA assistance to help more than 35 million people cope with climate change. Activities include breeding new plant varieties that are drought and heat tolerant; setting up and optimizing irrigation systems that save water and fertilizer as well as improving crop yields; and combating disease-carrying insects with a nuclear-based insect pest

The IAEA has assisted Sudan in using nuclear technologies to combat the effects of climate change.
(Photo: N. Jawerth/IAEA)



control method called the sterile insect technique (SIT).

Monitoring

As the international community works towards long-term solutions to the consequences of climate change, reliable data on how GHGs cause the changes occurring on land, in the oceans and throughout the atmosphere are critical. The IAEA uses a variety of nuclear techniques, primarily isotopic, to identify and monitor the risks and threats associated with GHG emissions, and then shares that data with Member States to help further research and the formulation of sustainable climate policies. Costa Rica, for example, has worked with the IAEA to quantify carbon capture and monitor GHG emissions from the dairy and agricultural sectors. Data that Costa Rican scientists gain from stable isotope analysers, which help quantify carbon emissions, facilitate efforts to move farming towards carbon neutrality.

Mitigation

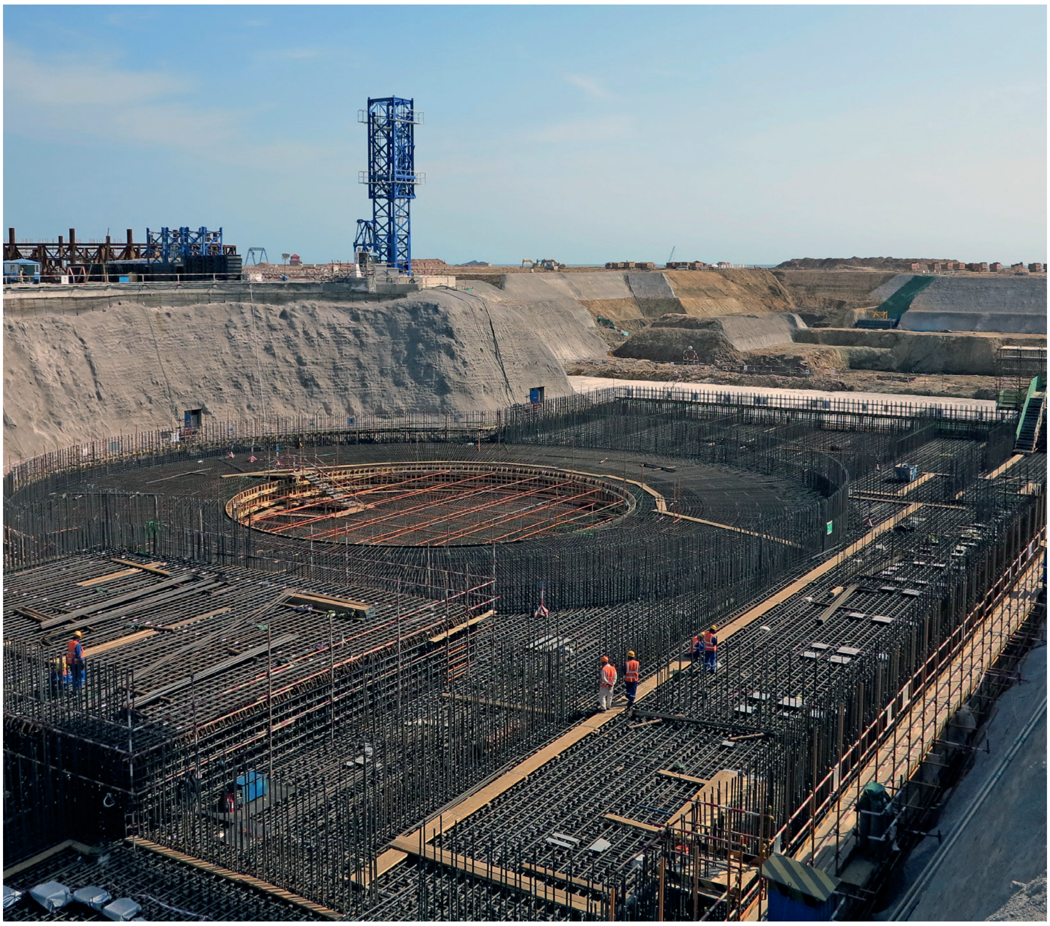
Mitigating climate change is the long-term goal, which requires approaches and technology that will reduce GHG emissions. The IAEA provides support to Member States to assess the development of their energy systems and helps them study how nuclear energy could play a role in energy generation. A well-informed and knowledgeable group of professionals is essential to develop and maintain sustainable national energy policies.

The IAEA is conducting a coordinated research project with Member States on how domestic energy policies can contribute towards countries' obligations under the 2015 Paris Agreement on climate change. Through adaptation to and monitoring of the adverse consequences of climate change and the mitigation of GHG emissions, the IAEA works with its Member States to preserve and restore the environment and protect energy systems from climate-related weather events and disasters.

The IAEA helps countries use nuclear science and technology to combat climate change.
(Infographic: R.Kenn/IAEA)

The IAEA supports Member States in the implementation of the Paris Agreement on climate change

By Noah Mayhew



Nuclear power plant under construction in China.
(Photo: C. Brady/IAEA)

"In the past, Croatia has participated in and benefited from various IAEA activities and managed to enhance its energy planning capabilities and deploy the IAEA energy system assessment tools."

— Mario Tot, Advisor, Croatian Energy Institute

The IAEA has partnered with 12 Member States in the development of effective climate change mitigation strategies through a coordinated research project (CRP). The objective of the CRP is to provide support in national evaluations of the potential role of nuclear power in mitigating greenhouse gas (GHG) emissions, as part of the preparation of country strategies under the Paris Agreement, reached in 2015 by the Parties to the United Nations Framework Convention on Climate Change (UNFCCC).

"It's about examining how nuclear power, together with other sources of low-carbon energy, can contribute to each Member State's unique energy and development objectives for decades to come," said Hal Turton, an energy economist at the IAEA.

This CRP builds on earlier initiatives, including a 2006-2009 project supporting Member States with GHG mitigation strategies and energy options for reaching Kyoto Protocol targets for 2008-2012.

One of the Paris Agreement's primary goals is to limit the increase in average global temperature to well below 2°C above pre-industrial levels and, if possible, to below 1.5°C. While challenging, this goal is technically feasible, but current climate policies would leave the planet with global temperatures between 2.6°C and 4.0°C above pre-industrial levels by 2100, according to Climate Action Tracker. Even with the pledges that Parties to the Paris Agreement have already made, the increase could end up as high as 3.2°C by 2100. Country research teams participating in the CRP are assessing national energy sector developments and analysing options to curb the increase in global temperature.

Fostering knowledge exchange

As part of this CRP, the IAEA supports the exchange of information and experience by hosting regular research coordination meetings. These meetings have facilitated extensive discussions on the development of national energy strategies, as well as information exchange between Member States and experts from the IAEA and other organizations.

The second of three meetings took place in Vienna in June 2018, marking the halfway stage of the CRP. Research teams gave presentations on policies, research progress and preliminary results. Many teams are using the established energy planning tools developed by the IAEA to explore alternative energy pathways suited to their unique conditions. The CRP will culminate with a third and final meeting in late 2019, where participating countries will present their detailed findings on the potential role of nuclear energy in national climate change mitigation over the coming decades.

Both the specific results and the foundation provided by this CRP are expected to contribute to the ongoing formulation and regular review of nationally determined contributions (NDCs) under the Paris Agreement.

“The CRP has been an excellent platform to drive and reflect on research on nuclear power in South Africa,” said Tara Caetano, a senior researcher at the country’s Energy Research Centre. The CRP annual meetings provide a platform to share researchers’ work, enabling them to learn from others and their respective country experiences, she added.

Use of IAEA tools for climate change mitigation and energy planning

Tools developed by the IAEA are helping Member States — including those participating in the CRP — to assess various options and strategies for their energy sector, including the role nuclear power can play in the future.

“In the past, Croatia has participated in and benefited from various IAEA activities and managed to enhance its energy planning capabilities and deploy the IAEA energy system assessment tools,” said Mario Tot, advisor at the Croatian Energy Institute. “We learn from others and we contribute for the benefit of others.”

Barakah nuclear power plant, United Arab Emirates.
(Photo: IAEA)

Over the last four decades, the IAEA has developed a suite of analytical tools that include:

- **EBS** (Energy Balance Studio) – to facilitate collection and organization of energy data;
- **MESSAGE** (Model for Energy Supply System Alternatives and their General Environmental Impacts) – to analyse energy supply strategies;
- **MAED** (Model for Analysis of Energy Demand) – to study future energy demand;
- **WASP** (Wien Automatic System Planning Package) – to plan power sector expansion;
- **FINPLAN** (Financial Analysis of Electric Sector Expansion Plans) – to assess financial implications of a power project;
- **SIMPACTS** (Simplified Approach for Estimating Impacts of Electricity Generation) – to analyse impacts on human health and agriculture of a power project;
- **ISED** (Indicators for Sustainable Energy Development) – to analyse and monitor sustainable energy development strategies;
- **CLEW** (Climate, Land use, Energy and Water) – to analyse interactions among key resource systems.

Finland eyes nuclear power to hit climate targets

By Jeffrey Donovan

The new Evolutionary Pressurised Reactor, built by a Franco-German consortium, on Olkiluoto Island in southwestern Finland. It is expected to provide 10 per cent of Finland's electricity when it becomes operational, probably in late 2018.
(Photo: S. Slavchev/IAEA)

Along the pine-lined shores of Finland's bucolic western coast, a clean energy vision of the Nordic country's future is quietly taking shape. On the tiny island of Olkiluoto, workers are applying the finishing touches to a new Evolutionary Pressurised Reactor (EPR) set to supply 10% of Finland's electricity needs. Like all nuclear power reactors, the massive 1600 MW unit will emit virtually no greenhouse gases (GHG) even as it churns out a steady stream of baseload electricity capable of providing power to millions of homes.

"Welcome to the future," said Pasi Tuohimaa, an executive with Teollisuuden Voima Oyj, the private Finnish company that owns and operates two older reactors at Olkiluoto as well as the new EPR reactor. Standing in the reactor hall of the new unit, due to begin operation in late 2018, Tuohimaa waxed philosophical: "Every morning, when I'm there watching myself in the mirror, I'm really thinking, 'I'm going to save the world — with nuclear.'"

The country of 5.5 million people has long relied on the atom to supply power and heating to households and energy-intensive industries — especially during the long, dark winters. Now, under a national energy and climate strategy that outlines Finland's contribution to the 2015 Paris Agreement to combat global warming, the Government envisions a mix of renewable sources and nuclear energy as the key to achieving its loftiest goal: becoming a carbon-neutral society by mid-century.

"The fact that nuclear energy production is carbon free is quite well accepted and understood in Finland in society, and this is of course promoting these new build projects."

— Liisa Heikinheimo, Deputy Director General, Energy Department, Ministry of Economic Affairs and Employment, Finland

"One cannot make a difference between climate policy and energy policy nowadays, and the main aim of Finnish energy policy is to lower greenhouse gas emissions," said Riku Huttunen, Director General of the Energy Department at the Ministry of Economic Affairs and Employment. "The most important instrument for that is renewable energy sources, but of course we should use all the possibilities to cut emissions and nuclear energy provides one good solution for that."

Finland's embrace of nuclear power dates back to the late 1970s, when the first of its four existing nuclear power reactors — which provide one-third of Finnish electricity production — began operation. Besides a lack of indigenous fossil fuels, Huttunen said the most important reason for introducing nuclear power was to ensure plentiful energy

for the country's long winters, as well as its forestry, steel and chemical industries.

From energy security to greenhouse gas reduction

But as the goal of energy policy shifted in recent years to GHG reduction, other advantages of nuclear power came into focus. While the Government aims to phase out coal and increase the use of renewables, such as solar, wind and biofuels, to cut emissions by up to 95% by 2030, policymakers also say that achieving both energy security and climate goals will not happen through intermittent sources alone.

"Smart grids will help, but we would need a huge energy storage in order to manage with solar power and wind power only — and there are no such technologies yet," Huttunen said.

When the new reactors become operational at Olkiluoto and Hanhikivi, another plant planned for construction in the coming years, nuclear power may provide more than half of Finland's electricity production — all virtually free of GHG emissions. In addition, Finland is on track to become the first country to operate a deep geological repository for the permanent disposal of nuclear spent fuel. It is expected to begin operation in the mid-2020s.

"The fact that nuclear energy production is carbon free is quite well accepted and understood in Finland in society, and this is of course promoting these new build projects," said Liisa Heikinheimo, who is responsible for nuclear energy as Deputy Director General of the Energy Department at the Ministry of Economic Affairs and Employment. "Additionally, efforts in Finland to manage the disposal of spent nuclear fuel have also been important for the public acceptance of nuclear power."

Finland's energy and climate strategy also looks into the possibility of eventually relying on renewables for all the country's energy needs. But for now, Huttunen says that's not realistic — and not only for Finland.

"If we want to meet the Paris climate agreement goals — and at the moment we are far, far from the path — we have to take advantage of all low-carbon technologies," he said. "Whether individual countries want to do that is a political decision, but as a globe we also need nuclear power to reach the climate goals."

The Olkiluoto Nuclear Power Plant in southwestern Finland, where a new Evolutionary Pressurised Reactor is expected to come online near the end of 2018.

(Photo: S. Slavchev/IAEA)

Reducing greenhouse gas emissions in agriculture with the help of nuclear techniques

By Matt Fisher

Farmers are increasingly using sustainable agricultural methods to boost productivity while also reducing greenhouse gas emissions. In a series of research projects, coordinated by the IAEA in cooperation with the Food and Agriculture Organization of the United Nations (FAO), the effectiveness of environment-friendly farming methods is verified by stable isotope techniques.

Agriculture, particularly large-scale commercial operations, typically involves monoculture in conjunction with the use of large amounts of chemical fertilizers – often to the detriment of ecosystems. Monoculture is a practice in which the same crop is grown on the same plot of land year after year, leading to lower soil fertility. Farmers compensate for this reduced soil fertility by applying excessive quantities of chemical fertilizers, which contribute to climate change through their release globally of 1.2 million tons per year of nitrous oxide, a greenhouse gas 260 times more potent than carbon dioxide.

Cows grazing harvested paddy fields in an integrated cropping-livestock system.
(Photo: M. Zaman/IAEA)

The sustainable agricultural practices at the centre of the research projects offer cost-effective solutions to boost productivity while fighting climate change.

Brazil: organic fertilizers reduce costs and minimize environmental impact

Chemical fertilizers provide the soil with additional nitrogen to grow crops. Their use is often considered necessary in order for agriculture to be economically viable. But repeated use or overuse of these fertilizers is both expensive and bad for the ecosystem. In Brazil, farmers are turning to a technique known as green manuring, which involves the natural phenomenon of biological nitrogen fixation.

They plant various types of legume crops, such as jack beans and velvet beans, that have bacteria in their roots converting nitrogen captured from the air into an organic form suitable for consumption by other plants, hence fertilizing the soil. After the legumes are harvested and the crop residues left behind, primary crops such as grain and cereals are planted on the same field and benefit from the nitrogen now available in the soil, with only minimal amounts of chemical fertilizer added.

“Recent studies in Brazilian agriculture show that over 76% of all nitrogen in harvested grain and cereals is derived from biological nitrogen fixation, and less than 20% is from chemical fertilizers,” said Segundo Urquiaga, a research scientist at the Brazilian Agricultural Research Corporation. Green manuring is also helping farmers save money: organic manure is estimated to cost only about US $1 per kilogram of nitrogen, which could lead to savings of up to US $13 billion per year, he added.

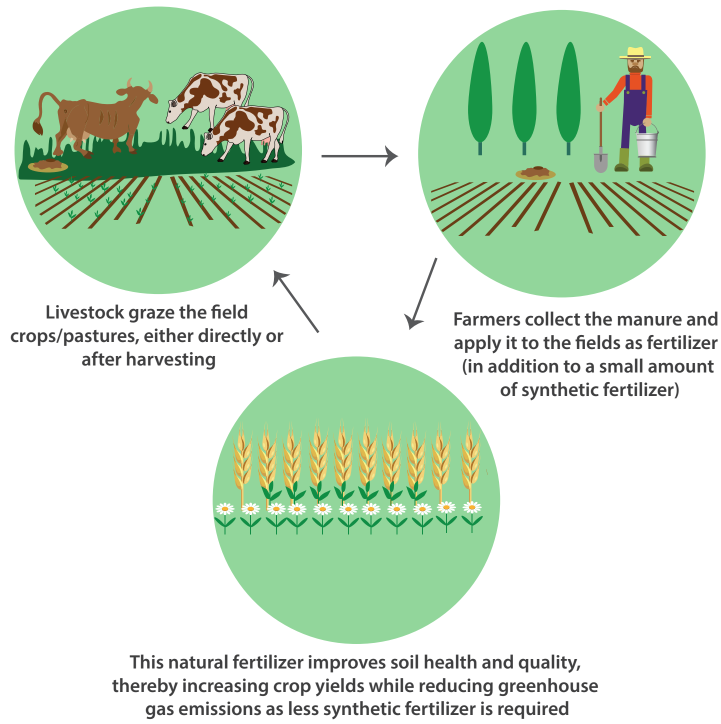
By embracing green manuring, Brazil is getting closer to achieving its greenhouse gas emissions target – a reduction of 43% by 2030 compared with 2005 levels. As agriculture is responsible for around 24% of global greenhouse gas emissions, the growing implementation of this practice will help Brazil meet this goal.

Integrated farming systems fight climate change and boost crop yields

Integrated cropping-livestock systems are another sustainable agricultural practice supported by nuclear techniques in the framework of a coordinated research project involving Argentina, Brazil, India, Indonesia, Kenya, Uganda and Uruguay. These practices are based on a simple concept: that crop yields can be maximized by recycling nutrients present in both animal manure and crop residues. This reduces the need for chemical fertilizers that release large quantities of greenhouse gases and thereby contribute to climate change. In an integrated cropping-livestock system, livestock may either graze the field crops directly or may be fed the crop after harvesting. Farmers then collect the manure from the livestock and use it as fertilizer, thereby returning many of the nutrients to the soil.

Farmers in Brazil are using integrated cropping-livestock practices in order to use their land more efficiently "We are moving towards the implementation of conservation agriculture, and we have seen the feasibility of such an approach involving integrated cropping-livestock systems," said Jeferson Dieckow, a soil scientist from the Federal University of Paraná in Brazil. As a result, greenhouse gas emissions from urine and dung have been reduced by 89%. Juan Cruz Colazo, a scientist at Argentina's National Institute of Agricultural Technology, says that Argentina has been able to cultivate crops that are more resistant to the effects of climate change. "We have benefited from this project by improving our agricultural soils through crop rotation," he said. "We have observed a 50% increase in organic carbon content in the soil, which enhances the resilience of the cropping system to climate variations that may otherwise impede crop yields."

How an integrated cropping-livestock system works



(Infographic: R Kenn/IAEA)

THE SCIENCE

Isotope tracers

To measure the impact of integrated crop-livestock practices and green manuring, scientists use stable isotopes which do not emit radiation, such as nitrogen-15 and carbon-13, on small experimental field plots. This allows them to track and analyse how efficiently crops consume nitrogen and how well carbon accumulates or is stored in the soil.

Using the nitrogen-15 technique, scientists can observe, over a period of several months, the amount of this isotope absorbed by the plants. This enables them to advise farmers on exactly how much animal manure and/or chemical nitrogen fertilizer they need to apply to their crops.

Carbon-13 is used to assess soil quality. As the soil is fertilized by the application of animal manure and crop residues, its content of organic carbon increases. By tracking the carbon-13 isotope, scientists are able to determine the stability and sources of carbon in soil and hence the status of the soil's fertility, which is crucial to ensure the optimal application of these sustainable agricultural practices.

Harmful algal blooms: nuclear techniques help reduce toxicity, prevent health impact

By Sarah Jones-Couture and Miklos Gaspar

IAEA researchers taking samples for toxin analysis using the Receptor Binding Assay technique.
(Photo: IAEA)

> "The impact of foodborne illnesses is of the same magnitude as illnesses like malaria and tuberculosis. More work is needed to gather data and develop methodologies so States can address this issue."
>
> *— Angelika Tritscher, Coordinator, Department of Food Safety and Zoonoses, World Health Organization (WHO)*

The geographical range and intensity of harmful algae blooms (HABs) have been increasing over the last decade, a change linked to global warming. An increasing number of countries are turning to nuclear science in order to identify and measure these blooms and the biotoxins they produce, and then – armed with the data – establish appropriate policies and countermeasures to control their impact more effectively.

Each year, HABs are responsible for the poisoning of thousands of people worldwide through consumption of contaminated seafood and inhalation of toxins. "Faced with the apparent increase in frequency, geographical distribution and intensity of such blooms, addressing them on a global scale has become urgent," said Marie-Yasmine Dechraoui Bottein, a research scientist at the IAEA Environment Laboratories in Monaco.

Microscopic algae at the base of the marine food chain provide nutrients for marine organisms and are responsible for producing more than half the earth's oxygen supply. However, factors such as the surface water temperature, the circulation of wind and water, the natural movement of nutrient-rich waters towards the surface or the accumulation of agricultural run-off into

Ocean acidification

Another impact of climate change on oceans is ocean acidification – an important area of research at the IAEA.

The increased amount of carbon dioxide in the atmosphere means more carbon dioxide in the oceans – making the ocean more acidic and threatening oceanic habitats. The IAEA works with Member States to use nuclear techniques to measure ocean acidification – which in turn will allow policy-makers to introduce measures to control it.

Nuclear and isotopic techniques are powerful tools for studying ocean acidification and have contributed widely to investigating past changes in ocean acidity and potential impacts on marine organisms. Researchers at the IAEA Environment Laboratories use calcium-45 to examine the growth rates in calcifying organisms such as corals, mussels and other molluscs, whose skeletons and shells are composed of calcium carbonate. Tracers are also used to determine how ocean acidification is affecting the physiology of marine organisms, as well as the impact of a combination of stressors, such as ocean acidification, increases in temperature and contaminants.

the sea can trigger algal blooms, which can sometimes include toxic species.

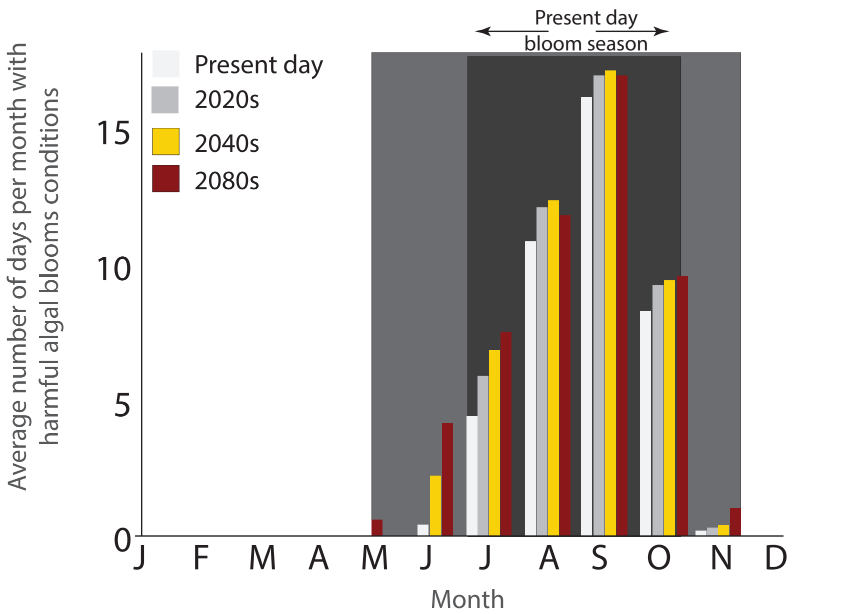
Although strategies to control the impact of planktonic toxic HABs, which float in the water, are well defined, there remain gaps in the scientific understanding of those on the ocean floor, known as benthic species. Environmental changes linked to climate change could make matters worse in tropical areas, as dead coral reefs constitute good habitats for macroalgae, said Clemence Gatti, a research scientist at the Louis Malardé Institute in French Polynesia. With the increasing number of corals dying, a proliferation in benthic HABs and associated health risks are likely. Likewise, with temperatures increasing globally, tropical toxic species thrive in expanded areas of the subtropics and temperate seas and oceans.

One of the most common illnesses is ciguatera fish poisoning — a non-bacterial seafood intoxication caused by ingesting fish that has been contaminated by ciguatera toxin from benthic HABs. Ciguatera, previously limited to tropical and subtropical regions, has now spread to Europe's coastal waters.

"It is a complex disease, still poorly understood," Gatti said. "It can express itself through 175 different symptoms that can last for months or even decades, which makes its diagnosis and management a challenge for physicians."

The IAEA is working with scientists from around the world to develop the capacity to accurately detect toxins in the environment and seafood, so that they can implement countermeasures such as fishery closures and bans on eating seafood when there is an elevated risk of poisoning (see The Science box).

Projected changes to the harmful algal bloom season in a future warmer climate



Source: phys.org

Angelika Tritscher, coordinator in the Department of Food Safety and Zoonoses at the World Health Organization (WHO), emphasized that "the impact of foodborne illnesses is of the same magnitude as illnesses like malaria and tuberculosis." She added that "more work is needed to gather data and develop methodologies so States can address this issue."

The IAEA will continue working with other United Nations agencies to address the emerging risks caused by HABs. "A better assessment of risks associated with HABs will help reduce their impact on human health, the economy and society at large," said Dechraoui Bottein. "This will contribute to the achievement of the Sustainable Development Goals."

THE SCIENCE

Measuring biotoxins in seafood

The IAEA works with experts in Member States to develop the capacity to detect and measure biotoxins in seafood. By using nuclear and isotopic techniques, researchers can accurately measure biotoxins and study the way they are transferred from organism to organism, making their way up the food chain and potentially reaching our plates.

The radioligand receptor binding assay (RBA) is one of the nuclear techniques used. It is based on the specific interaction between the toxins and the receptor they bind (pharmacological target), in which a radiolabelled toxin competes for a limited number of receptor binding sites with the toxin in the sample being analysed, allowing quantification of the toxicity of the sample.

How climate change affects water resources in Costa Rica

By Laura Gil

Scientists prepare samples of spring water for the analysis of noble gases in Heredia, Costa Rica.
(Photo: L. Castro/ESPH)

> "While we have always had regulations in place to protect our water, the difference is that now we can be more precise, more efficient."
>
> — *Ricardo Sánchez-Murillo, Coordinator, Stable Isotopes Research Group, National University of Costa Rica, Heredia*

Sitting on the thin stretch of land that separates the Pacific from the Caribbean, Costa Rica has in recent years experienced above-average ocean temperatures and the first hurricane ever recorded. With the help of the IAEA, its scientists are now turning to isotopic techniques to monitor these extreme weather events and protect the country's water and population, in a region that has been identified as an area that could be particularly affected by climate change.

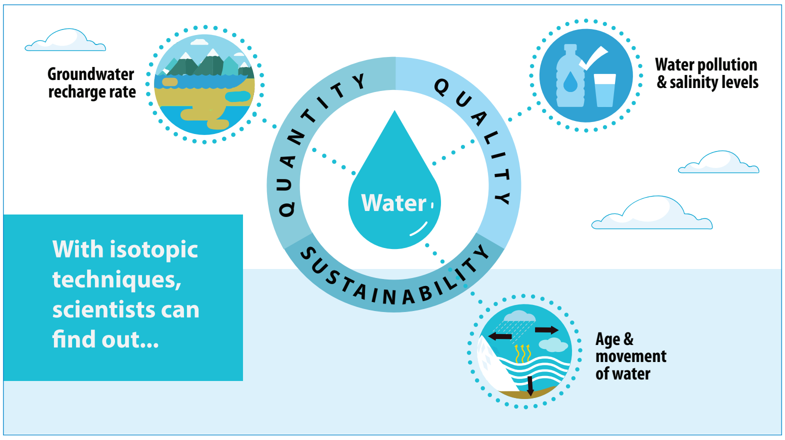
"Water has memory," said Ricardo Sánchez-Murillo, coordinator of the Stable Isotopes Research Group at the National University of Costa Rica in Heredia. "With isotopes, we can record this memory and use the current information we gather in precipitation to understand past climate events and improve Costa Rica's planning to face future meteorological events, including hurricanes." In 2015, after a severe drought period, Central America saw one of the strongest El Niño Southern Oscillations — a warming of the ocean surface that has been happening in the region for centuries. One year later, Costa Rica faced the first hurricane recorded to date in the southernmost region of Central America.

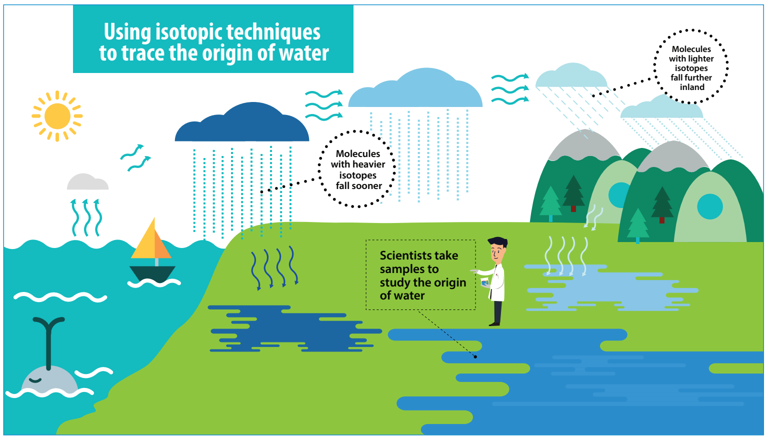
"We didn't have any historical records of hurricanes impacting Costa Rica," Sánchez-Murillo said. "So we were susceptible and suffered the consequences, because we didn't know how to respond."

Such phenomena carry with them a collection of isotopic fingerprints that scientists like Sánchez-Murillo can capture using special nuclear-derived techniques. Once recorded, they use the isotope data, coupled with climatic models and past climatic records, to predict the frequency, magnitude and intensity of future meteorological events and inform authorities, who in turn can be better prepared. The science behind this is called isotope hydrology (see box below).

"We now have the tracers, which act as a sentinel," Sánchez-Murillo said. "These techniques give us the capacity to see what conventional instruments cannot reach. Where conventional methods cannot see, isotopes can."

Using isotopic techniques to study poorly understood water systems, experts are also finding solutions to water challenges related to climate change that are affecting even the wettest regions, including Costa Rica. With these techniques, scientists can determine the quantity and quality of water supplies. They use naturally occurring isotopes as tracers to find out where groundwater comes from, if it is recent or old, if it is being recharged or polluted, and how it travels.





(Infographic: F. Nassif/IAEA)

Through the IAEA's technical cooperation programme, hydrologists in Costa Rica have received support and training to develop a monitoring network that traces precipitation and underground water processes.

Understanding rainfall patterns helps hydrologists know where, when and how water is recharged — information that is key to devising land and water management plans. With isotopes, they have studied water in the Central Valley, a biological corridor between the Pacific and Caribbean slopes that supplies drinking water to approximately a fifth of Costa Rica's population, around one million people. And today, they know the exact height and zones from which aquifers get new water.

"Understanding the key factors controlling rainfall patterns and their relationship with groundwater recharge is essential for government and environmental agencies to prioritize resources and efforts," Sánchez-Murillo said. "Now that we know the critical recharge areas and how groundwater travels, we can prioritize the conservation of these areas over commercial activities."

Impacting policy

The work by Sánchez-Murillo and his team is intended to enable the government to target conservation measures at the most critical areas of recharge. This would, in turn, allow residents, farmers, or businesses to continue developing activities without having a negative impact on the sources of water.

"While we have always had regulations in place to protect our water, the difference is that now we can be more precise, more efficient," Sánchez-Murillo said. "We know exactly which areas need special attention, and we know how to protect them to ensure water supply for now and the coming decades."

THE SCIENCE

Isotope hydrology

Every water molecule has hydrogen and oxygen atoms, but these are not all the same: some atoms are lighter and some are heavier.

"All natural waters have a different hydrogen and oxygen isotopic composition," said IAEA isotope hydrologist Lucía Ortega. "We use this isotopic composition as the fingerprints of water."

As water evaporates from the sea, molecules with lighter isotopes tend to preferentially rise. As rain falls, molecules with heavier isotopes fall sooner. The further the cloud moves inland, the higher the proportion of molecules with light isotopes in rain.

When water falls to the earth, it fills lakes, rivers and aquifers, Ortega said. "By measuring the difference in the proportions between the light and heavy isotopes, we can estimate the origin of different waters."

In addition, the abundance of naturally occurring radioactive isotopes present in water, such as tritium and noble gas isotopes dissolved in the water, can be used to estimate groundwater age — from a few days to one millennia. "And this is key to help us assess the quality, quantity and sustainability of water," she said.

Using cosmic rays to measure moisture levels in soil

By Bettina Benzinger and Nicole Jawerth

The cosmic ray neutron sensor helps farmers measure water levels in soil.
(Photo: IAEA)

> **“Looking at different scenarios supports decision making; for instance, which crops to plant to better manage scarce water resources.”**
> *— Ameerah Hanoon Atiyah, Scientist, Ministry of Science and Technology, Iraq*

Neutrons propelled to Earth by cosmic rays from space are helping scientists in more than 25 countries to measure water in soil and help farmers save water and adapt to climate change. With a cosmic ray neutron sensor, scientists track these fast-moving neutrons in the atmosphere to determine how much water is already in the soil and when the farmer needs to add water to help crops thrive even in harsh climate conditions.

“My country is affected by climate change and drought,” said Imad-eldin A. Ali Babiker, an agricultural scientist at Sudan’s Agricultural Research Corporation in the Ministry of Agriculture and Forestry and a participant in one of several training courses supported by the IAEA in collaboration with the Food and Agriculture Organization of the United Nations (FAO) and other international organizations. “Training to use the cosmic ray neutron sensor has opened a new window for us to manage soil water content.”

The cosmic ray neutron sensor is a device that can measure moisture levels by detecting fast moving neutrons in the soil and in the air just above the soil (see The Science box.) it is faster, more portable and can more easily cover an area compared to traditional methods.

Since 2013, scientists at the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture have been testing and calibrating the cosmic ray neutron sensor, including a mobile version that comes in the form of a backpack. “Studies in crops like maize have shown that scheduling irrigation using the cosmic ray neutron sensor can save up to 100 mm of irrigation water each season — which is equivalent to 1 million litres of water per hectare and a huge amount in water-scarce regions — by optimizing how much water a farmer needs to use and when, while even improving crop yields,” said Ammar Wahbi, a soil water scientist in the Joint FAO/IAEA Division.

More than 300 scientists worldwide have been trained to use this neutron-sensing technology in courses designed to develop technical skills and the ability to apply the skills for decision making. The courses include instruction on how to use the AquaCrop simulation model, a software developed by the FAO to accurately simulate expected crop growth and water consumption under different scenarios.

In Iraq, these courses have helped scientists identify crops suited to the country’s climate conditions, said Ameerah Hanoon Atiyah, a scientist from Iraq's Ministry of Science and Technology. "Looking at different scenarios supports decision making; for instance, which crops to plant to better manage scarce water resources."

Traditional methods capture information only a few centimetres surrounding the probe, which makes large-scale surveys both time and labour intensive. The cosmic ray neutron sensor, in contrast, can provide results immediately for a 20-hectare area without disturbing the soil and the vast web of interrelated organisms and structures the soil contains.

"Traditional methods involve taking several soil samples, drying them in an oven for 48 hours and measuring the weight difference between the original and the dried samples," explained Trenton Franz, a hydrogeophysicist from the University of Nebraska-Lincoln and an expert involved in the FAO/IAEA training courses.

As of 2018, more than ten national and regional research and technical cooperation projects related to cosmic ray neutron sensors are planned or ongoing in 15 countries. Through these projects, experts have received or are going to receive their own devices to apply what they learn through the training courses.

THE SCIENCE

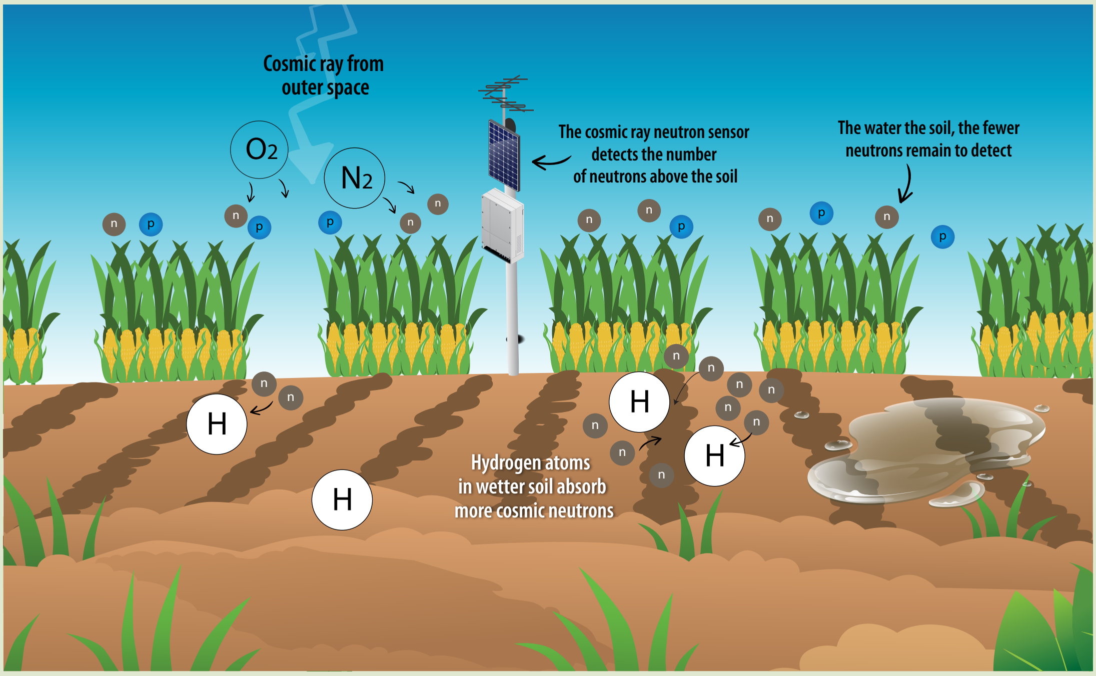
How the cosmic ray neutron sensor works

The cosmic ray neutron sensor detects and counts the number of neutrons in the soil and in the air just above the soil. Scientists use this information to determine the moisture levels in the soil.

The neutrons are produced by incoming high-energy cosmic rays (mainly protons) from outside the solar system. These collide with atoms — mainly nitrogen and oxygen — in the Earth's upper atmosphere. These atoms break apart into subatomic particles such as protons and neutrons, which rain through the atmosphere and continue to collide with other atoms as they fall.

By the time the neutrons reach the Earth's surface, they are very fast-moving. Their energy is absorbed by atoms in the environment, with hydrogen atoms absorbing most of this energy. This absorption slows the neutrons down.

As most of the hydrogen in the terrestrial environment is found in water in soil, scientists can count the number of fast neutrons in and around the soil to determine how much water is present. Drier soil has more fast-moving neutrons, while wetter soil has fewer because more hydrogen from the water is available to absorb the energy.



(Infographic: R. Kenn/IAEA)

Philippines: radiation-processed seaweed increases typhoon resistance of rice

By Laura Gil

The weather resistance of rice increases when treated with irradiated seaweed.
(Photo: IAEA)

"Carrageenan plant growth promoter is the answer to harvest shortage. This technology increases harvest yield and, with it, farmers' livelihoods."

— Lucille Abad, Chief, Atomic Research Division, Philippine Nuclear Research Institute

Researchers in the Philippines have found that an extract of seaweed, when processed with radiation, can make plants more resistant to typhoons and boost rice production by 20–30%. The extract, called carrageenan, comes from algae that is abundant in the sea. While carrageenan is already used widely as a gelling agent and thickener in the preparation of processed foods, this is the first time researchers — with the support of the IAEA — have applied it on a large scale as a plant growth promoter.

"It worked from the very first day I used it," said Isagani Concepción, a supervising engineer and part-time farmer at San Manuel in the central province of Tarlac. Concepción's four-hectare rice field was used for testing. After he applied the modified carrageenan, he noticed a 30% increase in production. "I used to get 291 cavans, now I get 378. Even spraying only a small dose is as effective as using organic fertilizer." One cavan is a sack of approximately 50 kg.

Plants also started growing more extensive roots, sturdier stems and more tillers. This, Concepción said, has made them resilient to typhoons. In Bulacan, Typhoon Lando in 2015 devastated all the control plants, which were not given irradiated carrageenan. Those treated with the new growth promoter remained standing.

For farmers in East Asia, the irradiated product is pertinent at a time when — according to projections by the United Nations' Intergovernmental Panel on Climate Change — rising temperatures will heat the oceans. The implication for farmers is that warming oceans can lead to more intense and frequent typhoons.

Agricultural researchers at the National Crop Protection Center of the University of the Philippines in Los Baños tested the benefits of carrageenan as a plant growth promoter on more than 5000 hectares. The IAEA provided the irradiators and the training of local experts on their use. In a study in Pulilan, a central province of Bulacan, researchers found that sprayed areas produced crops with yields 65% above that of the control group, while using only half of the recommended fertilizer dose.

"The first difference we noticed was that its fertilizing effect lasted a long time," said Joselito Colduron, a farmer in Bulacan. "And that the grain-bearing tip part of the stem was full to the brim."

Radiation replacing chemicals

The technology consists of subjecting the material to radiation to reduce the molecular weight of carrageenan and thereby increase its effectiveness. Carrageenan is a mixture of natural polymers derived from weeds, with high molecular weight, explained Sunil Sabharwal, radiation processing specialist at the IAEA. Irradiation with gamma rays degrades the natural Carrageenan into smaller oligomers with comparatively low molecular weight, which are known to stimulate plant growth.

"We do with radiation what others do with chemicals, but the use of chemicals often produces residues that can be harmful to people and the environment," said Lucille Abad, Chief of the Atomic Research Division at the Philippine Nuclear Research Institute (PNRI), part of the Department of Science and Technology.

Farmers realized that plants also grew resilient to insects and arthropods such as centipedes when treated with radiation-processed carrageenan. At the same time, the population of spiders, which kill virus-carrying green leafhopper, increased. "We didn't need to use pesticides because we realized more friendly insects chased away the pests. These insects have helped to decrease the number of the pests, and we have stopped using insecticides," said Colduron.

The technology also affects weight. Farmers recorded an increase of around 9% per sack. And the increase in grain weight affects the rice stalk and ear length, which have improved, according to observations made comparing carrageenan-fed plants with conventional farming.

"Carrageenan plant growth promoter is the answer to harvest shortage," Abad said. "This technology increases harvest yield and, with it, farmers' livelihoods."

Industrial applications of radiation technology

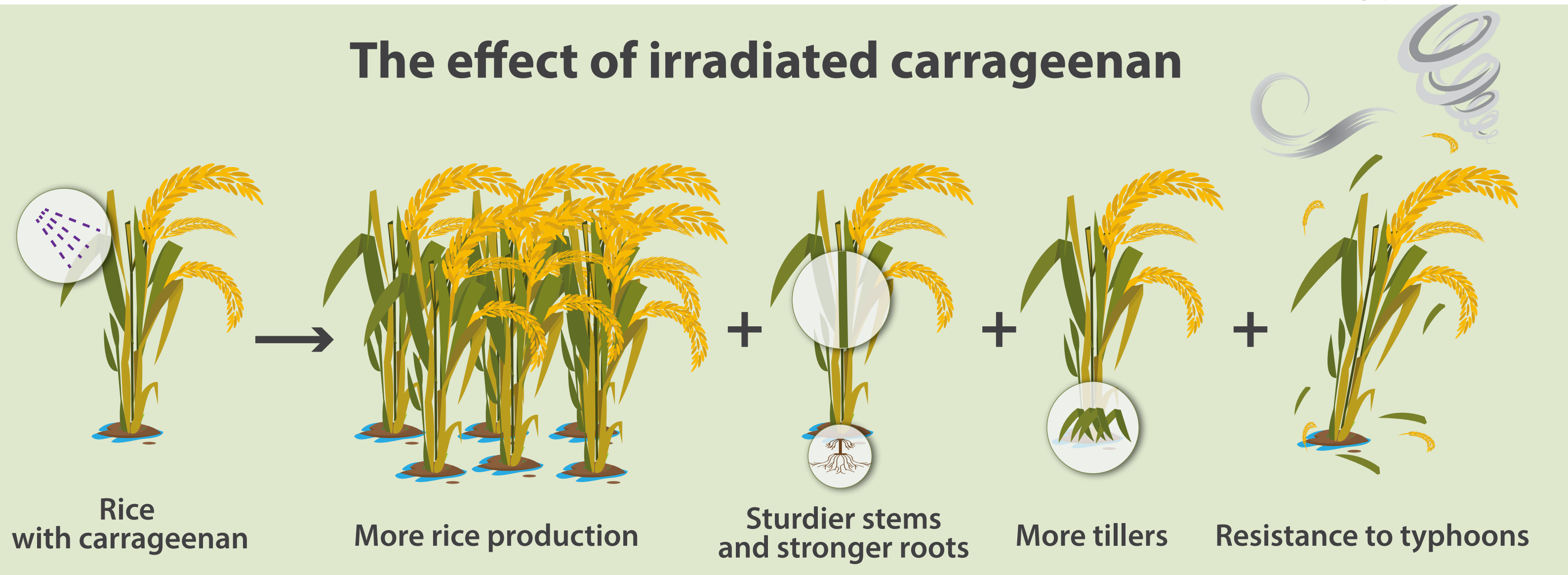
The initial research on modified irradiated carrageenan took place at PNRI. Two facilities — a semi-automated gamma irradiation facility and an electron beam facility established with IAEA assistance — are what researchers at the institute use to meet the needs of clients from industry, academia and research.

"We irradiate food to reduce the microbial load for food safety purposes," said Luvimina Lanuza, Head of Irradiation Services at PNRI. "This includes spices, herbal products, dehydrated vegetables, cosmetic raw materials and accessories."

Irradiation, Lanuza said, has many advantages over other, chemical-based methods. For example, irradiation is a cold process that enables modification of plastic materials without melting them. Gamma rays are highly penetrating, which means they can irradiate food products in their final packaged form. In 2017 alone, PRNI staff irradiated 1400 cubic metres of food and non-food products.

"We are expecting to increase this by next year," Lanuza said. Through an IAEA technical cooperation project, they are upgrading the gamma irradiation facility from a semi-automated to a fully automated one. "We hope that with the upgraded facility we can increase our services and cater to the needs of the medical industry, too, to sterilize medical devices."

(Infographic: R. Kenn/IAEA)



New mutant cowpea variety helps Zimbabwe's farmers in drought prone areas

By Aabha Dixit and Svetlomir Slavchev

The new cowpea variety — CBC5 — developed in Zimbabwe through mutation breeding using irradiation.
(Photo: Prince M. Matova/Crop Breeding Institute, Zimbabwe)

> "We are combating climate change with advanced technology that has generated drought tolerant cowpeas."
>
> — *Tafirenyika Gumbomunda, Farmer, Zimbabwe*

Zimbabwean farmers have seen a 10-20% increase in their cowpea yields thanks to the use of a new variety bred using nuclear techniques. The new variety, developed with the support of the IAEA and the Food and Agriculture Organization of the United Nations (FAO), was released in November 2017. It has shown increased drought tolerance and insect resistance, enabling farmers to better cope with the effects of climate change, particularly in more drought prone areas.

"Climate change, drought, insect pests and diseases and poor soil fertility affect us poor people. We used to predominantly grow maize but have now complemented our food basket with cowpeas," said farmer Tafirenyika Gumbomunda. "We are combating climate change with advanced technology that has generated drought tolerant cowpeas."

The new cowpea variety — called CBC5 — was developed using irradiation, a process often used to generate new and useful traits in crops (see The Science box).

A new drought tolerant cowpea variety

Cowpea is among the four most important legumes produced and consumed in Zimbabwe — and plays a key role in contributing to the country's food supply. As a subsistence crop, it is mainly grown by resource-poor farmers, said Prince Matova, a plant breeding scientist at Zimbabwe's Ministry of Agriculture Crop Breeding Institute (CBI). "Unlike other crops, cowpea requires less water and is better suited for poor soils and drier climates. Research underway aims to make this crop even more drought tolerant, nutrient dense and more acceptable to farmers and consumers." Cowpeas are natural, rich sources of protein, zinc, iron and vitamins.

A niche crop, cowpea grows in the drier areas of Zimbabwe and other parts of sub-Saharan Africa that receive an average of only 250-300 mm of rainfall per year, Matova said, adding that "it is a worry that crop production has been impacted by the effects of climate change."

"Farmers are also losing their livestock due to starvation as there is barely any grass to feed the livestock in most of these areas particularly during the drier seasons," he said. Cowpea foliage can be used as livestock fodder, supplementing stock feed during the off season when pastures are dry. "This new mutant cowpea variety produces high fodder yield, which can be used by farmers to support their crop-livestock farming systems," Matova added.

Cowpea provides food for the family and the cash generated from its sale can help pay for school fees, said farmer Gumbomunda.

Technology transfer, research, laboratory support and delivery

The CBI sent the cowpea seeds for irradiation to the Plant Breeding and Genetics Laboratory of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture in Seibersdorf, Austria, and then the seeds were returned to the Institute for selection of varieties with favourable traits from among the many mutants developed.

"Upon receiving the seeds, mutant populations were generated, and selected plants with improved traits were advanced and tested for drought tolerance and yield," Matova said.

The IAEA, through its technical cooperation programme, has helped Zimbabwean scientists with training and equipment. CBI staff and collaborating partners have received training on breeding techniques, including methodologies for selection of preferred mutant varieties.

Cowpea farmers with harvested new cowpea mutant variety (CBC5) in Matebeleland South, Zimbabwe.

(Photo: Prince M. Matova/Crop Breeding Institute, Zimbabwe)

Four plant breeders have been trained on the use of fast and efficient drought and insect pest screening methods through fellowships, said Matova. Training was also provided in marker assisted selection techniques, an indirect selection process in which traits of interest are selected in the laboratory based on genetic markers.

In addition, infrastructure support included the establishment at CBI of a molecular laboratory and three screen houses for drought and insect pest tolerance screening. This assistance has enabled a fast process for cowpea variety development, evaluation and selection of mutant lines. The support has also contributed to making future variety development more rigorous and efficient, he highlighted.

THE SCIENCE

Crop mutation breeding

Spontaneous mutation of plants regularly occurs in nature, whereby they adapt constantly to the changing environment — and it can take thousands of years. Scientists can speed up this process by using nuclear techniques.

Mutation breeding is a process to develop plants with desired traits, but faster than conventional breeding. It is based on the induction of heritable genetic changes (mutations) in plant material using gamma rays, X-rays or other irradiation sources.

Improved varieties of crops are bred to thrive in harsh conditions, or to improve their nutritional value, resistance to diseases or pests, to grow in saline soils or to use water and nutrients more efficiently. The individual plants, after selection for the improved agronomic traits, are then multiplied and distributed to farmers.

Drip irrigation explained

Drip irrigation is a water application technique aimed at improving water use to maximize crop yield. It involves slowly applying water directly to plant roots in order to minimize evaporation and leakage. Nuclear techniques are used to determine the precise amount of water a plant needs and the appropriate application times and intervals.

Scientists use a neutron probe to monitor moisture levels in soil. During measurements, the probe emits fast neutrons that collide with the hydrogen atoms of water in the soil. The collision slows down the neutrons, and the higher the number of hydrogen atoms, the more the neutrons slow down. The change in neutron speed is detected by the probe and provides a reading that corresponds to the moisture level in the soil.

Water is a vital resource for food production: an estimated 70% of fresh water usage in the world is for agriculture, and the demand is growing. The Food and Agriculture Organization of the United Nations (FAO) foresees that by 2050 water demand for agriculture will increase by 50% due in part to population growth.

— *By Margot Dubertrand*

(Photo: N. Jawerth/IAEA)

The role of nuclear techniques in climate-smart agriculture

By Christoph Müller

Christoph Müller is a Professor of Experimental Plant Ecology at Justus Liebig University Giessen. He is also a Professor at University College Dublin. His main research areas include the effect of climate change on ecological processes, elemental cycles in terrestrial ecosystems and production processes of climate-relevant trace gases.

Our current challenge in agriculture is to increase production to feed a growing human population, while keeping environmental costs to a minimum. Climate-smart agriculture (CSA) refers to those agricultural systems that are highly productive and have low environmental footprints. These systems' management options enhance the transfer of atmospheric carbon, or carbon dioxide, to the soil for long-term storage, limiting the emission of greenhouse gases (GHGs) to the atmosphere.

The tricky part, however, is that these systems' productivity is not solely dependent on absolute carbon content. It also depends on the ratio of carbon to all other essential nutrients that plants need for growth. Therefore, the key to sustainable CSA systems is to ensure appropriate management of nutrients — in particular, nitrogen.

Through the groundbreaking 19th-century discoveries of Justus Liebig and others, it became known that plants take up nitrogen predominantly in mineral form. This discovery led to the development of chemical fertilizer strategies and, ultimately, to the "green revolution" — a set of technology transfer methodologies that led to increased agricultural production worldwide and helped to feed an ever-increasing population, especially in developing countries in the 1960s.

But this progress came with a side-effect. Plants started to take up more nitrogen, and so did the microbes. It is the uptake by these microbes that is chiefly responsible for the 25% increase in atmospheric nitrous oxide (N_2O) levels. Nitrous oxide not only has climate warming potential, but it is also an effective ozone-depleting gas with an atmospheric lifetime of over 100 years.

The challenge in CSA systems is to decouple synthetic fertilizer application from population growth: to feed people without adding more nitrogen. One way to do so is to supply nitrogen to the plants by converting unavailable nitrogen stored in soil organic matter into available nitrogen, for example, ammonium, nitrate or plant-available organic substrates. The effectiveness of this nitrogen use in agricultural systems can be evaluated with something called nitrogen use efficiency: the ratio between nitrogen input and nitrogen harvested in the plant.

CSA systems strengthen the capacity of the soil to store nutrients and water through management options that increase soil organic matter content, making soil resilient to climate change. This increase in soil fertility will, in the long term, increase the capacity of the soil to supply nitrogen internally. By taking into account soil-borne nitrogen supply, less fertilizer can be applied and nitrogen use efficiency enhanced.

Where nuclear comes in

The effect of agricultural practices on carbon storage and internal nitrogen supply dynamics can only be assessed and quantified with nuclear and isotopic techniques using nitrogen-15 and other isotopes. With nitrogen-15, it is possible to quantify the supply of nitrogen originating from various inputs, including fertilizer and soils. The technique also allows scientists to identify

The role of the IAEA in climate-smart agriculture

The IAEA, in cooperation with the Food and Agriculture Organization of the United Nations (FAO), helps Member States apply nuclear and related techniques to sustainably increase agricultural productivity, adapt and build resilience of agricultural and food security systems to climate change, and reduce greenhouse gas emissions in agriculture, taking into account national and local specificities and priorities.

which legume crops best capture atmospheric nitrogen through biological nitrogen fixation, improving soil fertility and enhancing soil quality and health.

It is important to evaluate CSA techniques that aim to reduce emissions of greenhouse gases such as N_2O. With the help of nitrogen-15 or oxygen-18 labelling techniques, it is possible to identify and quantify the exact source of N_2O production. This enables researchers and land users to opt for proper mitigation strategies to reduce its emission. One other way of reducing N_2O emissions is to enhance the conversion of N_2O to environmentally benign N_2 through management options that optimize the carbon supply or increase the pH of the soil. One way or the other, it is essential to measure both the N_2O and N_2 emissions. To quantify N_2 emissions from soil, the only method available is based on the nitrogen-15 labelling of nitrate.

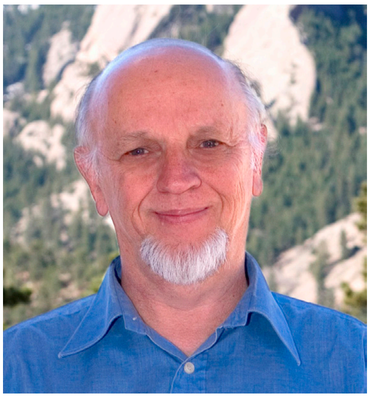
Nuclear techniques play an essential role in evaluating the management options used in CSA. Basic scientific methods related to the use of nuclear techniques enable scientists to quantify the effects that management options have on the dynamics of nitrogen in plant-soil-atmosphere systems. We often find that nuclear techniques are the only option for evaluating CSA practices, in terms of both the effect on carbon storage in soil and the processes that are responsible for the release of climate-relevant gases.

Nuclear techniques play an essential role in evaluating options used in climate-smart agriculture. Here, Christoph Müller is leading a group of experts from IAEA Member States in the analysis of the nitrogen content of the soil in a field study.

(Photo: IAEA)

The role of nuclear energy in meeting the Paris Agreement climate targets

By Tom M.L. Wigley



Tom M. L. Wigley is a climate scientist at the University of Adelaide. Previously he served as Director of the Climatic Research Unit at the University of East Anglia. His main research areas include climate data analysis and climate, sea level and carbon cycle modelling. He has been named a Fellow of the American Association for the Advancement of Science thanks to his contributions in these areas.

The potential role of nuclear energy in meeting the targets to limit global warming under the Paris Agreement on climate change depends primarily on what emissions reductions are needed. It is a two step process: we have to make sure that we are working with realistic targets before we can assess how nuclear can help.

Realistic targets

The Paris Agreement, a landmark agreement to combat climate change that builds on the United Nations Framework Convention on Climate Change (UNFCCC), specifies the global warming targets in two ways:
Article 2.1 (a):
Holding the increase in global average temperature to well below 2°C above pre industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre industrial levels …
Article 4.1:
Parties aim to … achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century …
The Agreement further states, in Article 4.1, that emissions reductions should be made "in accordance with the best available science …"

There are some problems with that.

First, Article 2.1 (a) requires temperatures to be kept below the specified warming targets at all times. While this is technically possible, albeit highly unlikely, it would be much easier to allow some warming overshoot until temperatures eventually return to within the stated targets. That, however, raises another scientific question: how large and long lasting can the overshoot be and still meet the more general UNFCCC goal of "avoiding dangerous anthropogenic interference with the climate system", 'anthropogenic interference' here being a reference to the pollution caused by human activities.

Second, the goal in Article 4.1 is, based on the best available science, potentially inconsistent with Article 2.1 (a). If temperature overshoot is permitted, as I think is necessary, there is no need to drop CO_2 emissions to zero before the end of the century in order to reach the 2°C target, which is how Article 4.1 is often interpreted. It is possible even to meet the 1.5°C target with appropriate overshoot without entering negative emissions territory (see Figure). Negative emissions would, however, be necessary with a smaller-scale overshoot, beginning in around 2060, which is consistent with Article 4.1. If that were the case, residual, long-lasting ocean and terrestrial sinks would eventually allow emissions to return to above zero.

Those issues are illustrated in the Figure, where the CO_2 emissions have been derived first by specifying a warming trajectory – see the upper panel, with two cases for the 1.5°C target – and then by running a climate model in inverse mode to back out the required fossil CO_2 emissions (see the middle panel). These allow us to calculate the corresponding CO_2 concentration trajectories.

Nuclear?

What role might nuclear energy play in meeting the emissions trajectory targets indicated in the middle panel of the Figure? We can answer this question, in part, by using results generated with integrated assessment models (IAMs) — energy economics models used to project future energy demand details and consequences — published in the United States Climate Change Science Program.

Three well-established, internationally recognized, integrated assessment modelling teams were tasked to develop a range of policy-driven mitigation scenarios using IGSM, MERGE and MiniCAM models. Targets in those scenarios were achieved by:

- reducing end-use energy demand, such as through conservation and efficiency improvements;
- increasing energy production from biomass, non-biomass renewables – mainly wind and solar – and nuclear; and
- through carbon capture and storage.

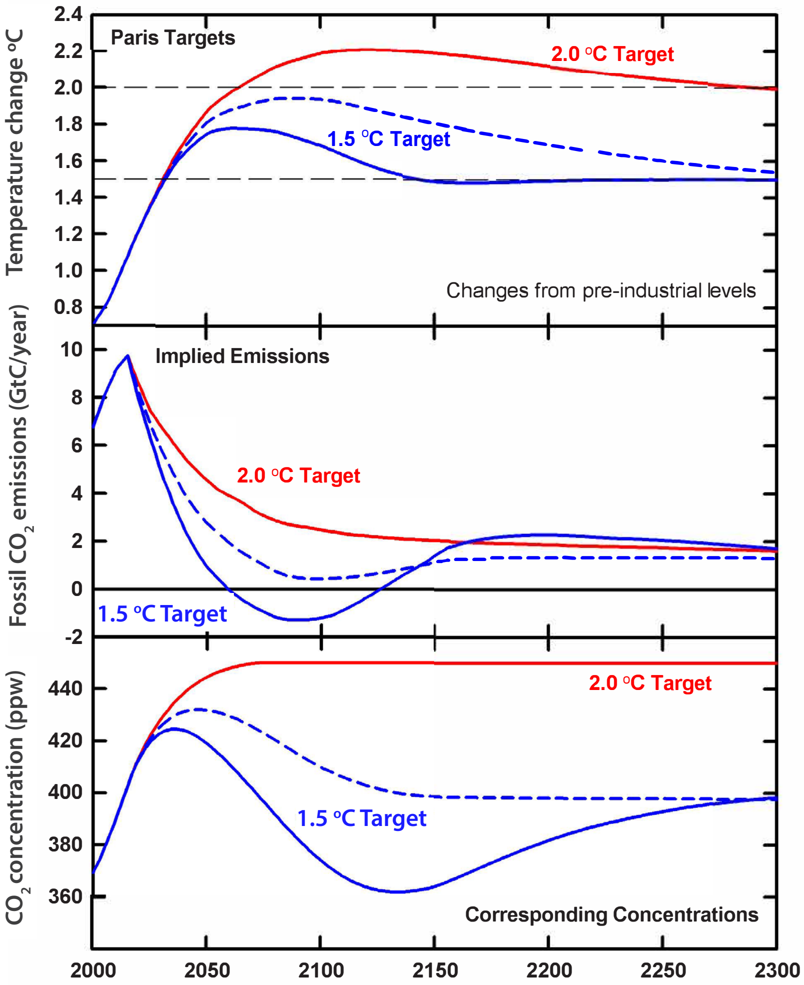
CO_2 emissions reductions in all the scenarios, including the reference scenarios, occur both spontaneously – i.e. in the absence of new mitigation policies – and as a result of the policies implemented. This means that even in the reference scenarios there are increases in carbon-free energy technologies to the extent that 19–29% of primary energy (PE) production is carbon-free by 2100. Further massive reductions in CO_2-producing PE are, however, still required to meet the 2°C target.

The Table below shows a model-by-model percentage breakdown of contributions to overall PE reductions by 2100, relative to the reference PE levels.

The IGSM model is a clear outlier in terms of energy demand reductions. That is because the model developers assumed that changes in nuclear energy production would be minimal, owing primarily to anti-nuclear sentiment on the part of the public. With the role of nuclear minimized, most of the emission cuts would need to come from reductions in demand. The other two models give breakdowns that are quite different from IGSM, and they attribute a much greater role to nuclear.

To put some flesh on the percentages, nuclear PE values in exajoules (EJ) for 2100 per model are as follows: 238 EJ with the MERGE model (for a total 491 EJ of PE); 185 EJ with the MiniCAM (total: 1288 EJ) and only 20 EJ with the IGSM (total: 1343 EJ). In 2000, the 451 nuclear power reactors still operating today generated roughly 8 EJ of electricity, which is equivalent to some 26 EJ of PE, meaning that the IGSM model actually projects a decrease in nuclear energy production. The MERGE and MiniCAM models project increases by a factor of nine and seven respectively from 2000 to 2100.

There is firm evidence, however, that emphasis on nuclear could grow at a much faster rate, as seen in the rapid historical growth in France and Sweden when those countries decided to "go nuclear". If that happens, nuclear could – and should – play a far greater role than the models described above might suggest.



If a temporary overshoot of the Paris Agreement targets is allowed, CO_2 emissions do not need to become negative.

(Source: Wigley, Climatic Change 147, 31–45, 2018)

There are manifest advantages in pursuing nuclear more aggressively. First and foremost, nuclear is the only energy source that can provide carbon-free, continuous (base-load) power, with a footprint much smaller than that of renewables. Perceived disadvantages are largely illusory: recent construction and electricity generation cost estimates for small modular reactors are at least as competitive as for fossil fuel and renewable technologies; waste problems can potentially be resolved with fourth generation technologies; modern reactors are passively safe; and proliferation risks are minimal. In the climate context, with its challenging targets, to ignore a significant role for nuclear would, in my view, be foolhardy.

Model	Demand	Biomass	Renewables	Nuclear	Carbon capture	Residual
IGSM	50.4%	17.3%	3.3%	1.5%	16.8%	10.7%
MERGE	27.6%	17.5%	12.3%	16.0%	21.1%	5.6%
MiniCAM	18.7%	17.9%	13.7%	14.4%	22.8%	12.5%

The contribution of various sources to the reduction of primary energy production. Residual refers to amounts of PE production still emitting CO_2.

Institutional donors from three countries contribute to IAEA laboratory modernization

Nuclear research institutions from Poland, Morocco and the Philippines have contributed close to €30 000 towards the ongoing modernization of the IAEA's nuclear applications laboratories in Seibersdorf, Austria.

"The work of the IAEA in the areas of radiation protection, radiation dosimetry and nuclear medicine, among others, is crucially important to serve the needs of Member States and for the advancement of science," said Andrzej Chmielewski, Director General of Poland's Institute of Nuclear Chemistry and Technology. "With our contribution, we hope to add to the IAEA's capacity to carry out research and development and training."

Besides the institute from Poland, two other institutions have made contributions: the Philippines' Nuclear Research Institute and Morocco's National Centre for Energy, Science and Nuclear Techniques.

The modernization includes the construction of two new buildings: a new Insect Pest Control Laboratory and the Flexible Modular Laboratory, which will house the Animal Production and Health Laboratory, the Food and Environmental Protection Laboratory and the Soil and Water Management and Crop Nutrition Laboratory. It also includes the enhancement of the remaining laboratories, acquisition of new equipment and infrastructure upgrades.

"We are happy to have such great support from institutions that recognize the importance of the work we are doing in nuclear applications," said Andy Garner, Laboratory Coordinator, who is in charge of the laboratory modernization project at the IAEA. "We will continue to foster partnerships with national institutions as well as with private companies to enhance the IAEA's capacity to deliver quality support to our Member States."

He added that Member States are recognizing new channels by which to contribute to the ongoing modernization work, and that institutions represent one such avenue.

Cash contributions to the modernization, primarily made as extrabudgetary contributions from national governments, have amounted to over €32 million since 2014.

— By Matt Fisher

Tackling childhood obesity in Europe with the help of nuclear techniques: IAEA symposium at the European Congress on Obesity

Childhood obesity is on the rise worldwide and is quickly becoming one of the most serious public health challenges of the 21st century, according to the World Health Organization (WHO). An IAEA project presented at the 2018 European Congress on Obesity (ECO 2018) last May is helping nutrition and health professionals in ten countries in Europe assess body composition using stable isotope techniques. The data gathered will allow policy makers to design interventions to prevent and control childhood obesity.

The symposium titled 'Assessing body composition for better understanding of risks related to childhood obesity and designing effective interventions', organized by the IAEA, was held as a parallel session during ECO 2018. Case studies from Bosnia and Herzegovina and Latvia were presented on how the deuterium oxide dilution technique is used to accurately measure body fat as a risk factor for obesity among school-age children in the respective countries. Information generated from this project will contribute to the formulation of policies and interventions to reduce obesity in Europe. The two countries are already involved in the WHO-led Childhood Obesity Surveillance Initiative.

Growing burden of childhood obesity

Every third eleven-year-old child in Europe and Central Asia is overweight or obese, according to the WHO. Changes in dietary habits, sedentary lifestyles and lack of physical activity are the leading causes of rising obesity rates. Without interventions, overweight and obese children will likely stay overweight or obese into adulthood and will be at increased risk of developing non-communicable illnesses, such as diabetes and cardiovascular diseases, at a younger age.

"Closely linked to regional WHO strategies on childhood obesity and on the prevention of non-communicable diseases, the project will provide a much-needed evidence base to formulate policies and design effective interventions," said Inese Siksna, a nutritionist at Latvia's Institute of Food Safety, Animal Health and Environment.

Accurately monitoring obesity

During the symposium, IAEA experts discussed how body composition can be used as a tool to accurately monitor obesity, and representatives of the WHO and other partners discussed the importance of using accurate data, obtained with the help of stable isotope techniques, in policy making.

Aida Filipović Hadžiomeragić, from the Public Health Institute of Bosnia and Herzegovina, noted the importance of the collaboration in sharing expertise and knowledge. "Previously held workshops and trainings have greatly assisted representatives from Bosnia and Herzegovina, such as doctors, nurses and technicians to gain the necessary skills and expertise to assess body composition using the deuterium dilution technique by Fourier Transform Infrared Spectroscopy (FTIR) and bioelectrical impedance, and to use accelerometery to measure physical activity levels and sedentary behaviour among children," she said.

The IAEA has supplied FTIR equipment to authorities in Albania, Bosnia and Herzegovina, Greece and Montenegro to help with the analysis of deuterium enrichment in saliva samples from all ten participating countries. The project is implemented through the IAEA technical cooperation programme.

The deuterium dilution technique may also be used as a reference method to validate existing approaches to screening and monitoring obesity in Latvia, Siksna said.

The symposium was organized in collaboration with the World Health Organization-European Regional Office, the European Association for the Study of Obesity and N8 AgriFood, a multidisciplinary research programme across eight universities in the north of England.

The countries participating in the project are Albania, Bosnia and Herzegovina, Greece, Hungary, Latvia, the former Yugoslav Republic of Macedonia, Moldova, Montenegro, Portugal and Ukraine. The IAEA is assisting countries in the overall coordination of the project and in providing equipment, expertise and training.

— By Mariam Arghamanyan

IAEA guidance on managing disused radioactive sources now available

The Guidance on the Management of Disused Radioactive Sources, endorsed by the 61st IAEA General Conference in September 2017, is now available on the IAEA's web site. The document stands as supplementary guidance to the Code of Conduct on the Safety and Security of Radioactive Sources, along with the Guidance on the Import and Export of Radioactive Sources.

Millions of radioactive sources are in use around the world in medicine, industry, agriculture and research. Sources may remain radioactive long after the end of their useful life, so it is essential that they be safely managed and securely protected. The Code of Conduct and its supplementary documents foster management and protection by providing guidance on the development, harmonization and implementation of national policies, laws and regulations, and by promoting international and regional cooperation among Member States.

"The Guidance promotes a more rigorous radiation safety and security culture, which will be further enhanced once Member States put the recommendations of the Guidance into practice," said Hilaire Mansoux, Head of the IAEA's Regulatory Infrastructure and Transport Safety Section.

The Guidance, which is not legally binding, describes a variety of options for the management and protection of disused radioactive sources and outlines the responsibilities of relevant parties, including regulatory bodies. It emphasizes disposal as the final management option for disused sources and encourages countries to have national policies and strategies to manage disused radioactive sources in a safe and secure manner. It also contains provisions on bilateral relations, including advice on the return of sources in cases where such arrangements have been agreed.

Muhammed Khaliq, Head of the IAEA's Nuclear Security of Materials and Facilities Section, noted that the Guidance, once applied, will strengthen nuclear security as well.

"The effective and continuous regulatory and management control of radioactive sources, from cradle to grave, is of utmost importance for the prevention of malicious acts with harmful radiological consequences," he said.

Member States make what is called a political commitment to the Code and its supplementary guidance in an official letter to the IAEA, in which they affirm their decision to act in line with the recommendations. Of the IAEA's 170 Member States, 137 have so far expressed commitment to the Code of Conduct and 114 to the Guidance on the Import and Export of Radioactive Sources.

The IAEA supports Member States in the implementation of the Code of Conduct and Guidance documents through projects and information exchange. This includes a formal process that was established in 2006. The first international meeting for the exchange of experience on the implementation of the Guidance on the Management of the Disused Radioactive Sources is planned for 2020 in Vienna.

— By Matt Fisher

At IAEA meeting, nuclear power newcomer and operating Member States discuss funding for waste management and decommissioning

One of the prerequisites for the sustainability of nuclear power programmes is timely and effective management of the spent fuel and radioactive waste that result from the operation and decommissioning of nuclear power plants. Estimating the related liabilities and securing funds to meet these are both subject to considerable uncertainty: they are processes that need to be managed regularly over the very long timeframes involved. The main issues — from funding schemes to technical risk assessment in support of waste management and the decommissioning of nuclear facilities — were discussed at a recent IAEA Technical Meeting.

Representing 21 nuclear power operating and embarking countries, 34 experts attended the IAEA's first Technical Meeting on Funding for Waste Management and Decommissioning, which took place in Vienna from 9 to 12 July 2018.

The participants shared their perspectives on ways of addressing costing and funding issues related to waste management and decommissioning and presented country-specific examples and case studies.

"To ensure that governments, regulatory bodies and owner/operators establish adequate and reliable policies and funding schemes, the IAEA recommends the elaboration of robust plans at an early stage so that the funds are available when the time comes to decommission or to manage waste," said Dohee Hahn, Director of the IAEA's Division of Nuclear Power, in his address to the participants.

The meeting chairperson, Chantal Spinoy from Electrabel, Belgium, noted the importance of stakeholder involvement in the whole process: "Engaging relevant stakeholders with shared responsibilities is crucial when taking long-term decisions related to financial liabilities: it is the only way to make sure that sufficient funds are available to cover the future costs of decommissioning and final disposal of radioactive waste," she said. "This is challenging because of the significant uncertainty around costs in the decades to come."

Discussions at the meeting focused on three major areas: (1) basic principles of funding schemes and identifying sources of risk and risk mitigation approaches; (2) cost estimation for spent fuel and radioactive waste management and for the decommissioning of nuclear facilities; and (3) dealing with risks and uncertainties in the management of spent fuel and radioactive waste.

Estimating the costs associated with projects and activities related to the decommissioning of a nuclear power plant and the disposal of spent fuel, as well as identifying the relevant cost drivers and ways to pay for these costs, were major topics explored. Representatives of countries with operating nuclear power plants and with direct experience in developing and implementing policies to fund waste management and decommissioning presented their perspectives, challenges and lessons learned through case studies.

As far as funding schemes are concerned, the meeting allowed experienced countries to share their best practices for risk mitigation when developing financial plans for such long term projects.

"The meeting has clearly highlighted the importance of basing funding schemes on the 'polluter pays' principle," said Richard Ström of the Swedish Radiation Safety Authority. "In this regard, Sweden emphasizes such risk mitigation strategies as establishing a separate fund to cover expected costs, continuously recalculating the fees involved, and providing guarantees for fees that have not yet been paid, as well as to account for unexpected cost overruns."

In addition, the meeting provided a platform for nuclear newcomers to learn from the experience of established nuclear countries with regard to decommissioning policies and strategies, which should stand them in good stead as they begin to develop their own cost estimation approaches, identify funds and make provisions for future decommissioning activities.

Given that Ghana is currently in the initial phase of its nuclear power project and is drawing up a comprehensive report on the subject, Festus Brew Quansah, a financial analyst at the Ghana Atomic Energy Commission, emphasized that attending the meeting had been both timely and important.

"The country experiences shared were very insightful and will help Ghana's nuclear energy programme implementing organization to contextualize a programme for funding waste management and future decommissioning," he said.

"In particular, obtaining up-to-date information on the need for clear policy direction, appropriate funding schemes, a strong institutional framework to execute the programme and a clear regulatory mechanism to ensure sufficient funds for the programme has been very important for us," he added. "I can go back to Ghana with new ideas to share with my team and government."

— By Jennet Orayeva

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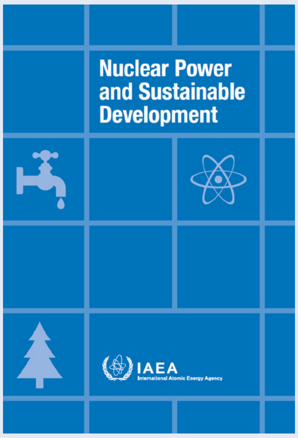
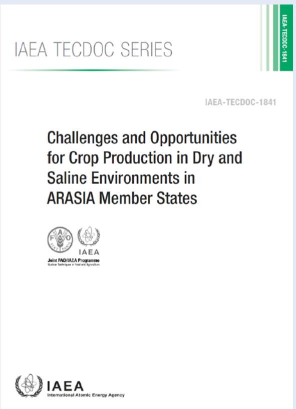


Nuclear Power and Sustainable Development

explores the possible contribution of nuclear energy to sustainable development through a large selection of indicators. It reviews the characteristics of nuclear power in comparison with alternative sources of electricity supply, according to economic, social and environmental pillars of sustainability. The findings summarized in this publication will help the reader to consider, or reconsider, the contribution that can be made by the development and operation of nuclear power plants to more sustainable energy systems.

Non-serial Publications; ISBN: 978-92-0-107016-6; English edition; 45.00 euros; 2016

https://www-pub.iaea.org/books/IAEABooks/11084/Nuclear-Power-and-Sustainable-Development

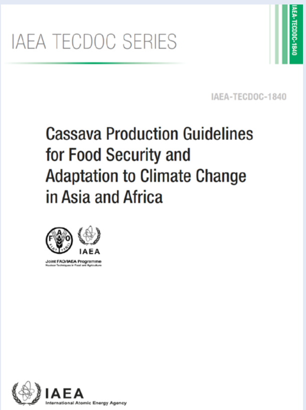


Challenges and Opportunities for Crop Production in Dry and Saline Environments in ARASIA Member States

serves as a reference guide on agriculture in dry and saline environments, in particular those located in the Middle East. All information and recommendations in this guide are based on successful and sound practices applied in sustainable cropping of salt-affected soils. It will help scientists and farmers select management alternatives in such environments in their own countries. The publication also focuses on the possible use of isotopic techniques in dealing with salinity and drought conditions affecting crop production.

IAEA-TECDOC-1841; ISBN: 978-92-0-101918-9; English edition; 18.00 euros; 2018

https://www-pub.iaea.org/books/IAEABooks/12305/Crop-Production



Cassava Production Guidelines for Food Security and Adaptation to Climate Change in Asia and Africa

is intended to assist Member States in enhancing their cassava production. It provides information on the best farm management practices and the role of nuclear and isotopic techniques to better understand nitrogen uptake. The guidelines presented provide an integrated and crop-need-based nutrient, weed, insect pest and disease management plan for growing cassava. By using these improved crop management methods, farmers can optimize cassava yields and minimize production costs. At the same time, the methods contribute to a reduction in land degradation due to soil erosion, particularly on sloping lands, thereby protecting the local environment. The intended result is enhanced quality and market value of cassava products.

IAEA-TECDOC-1840; ISBN: 978-92-0-101718-5; English edition; 18.00 euros; 2018

https://www-pub.iaea.org/books/IAEABooks/12311/Cassava-Production

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