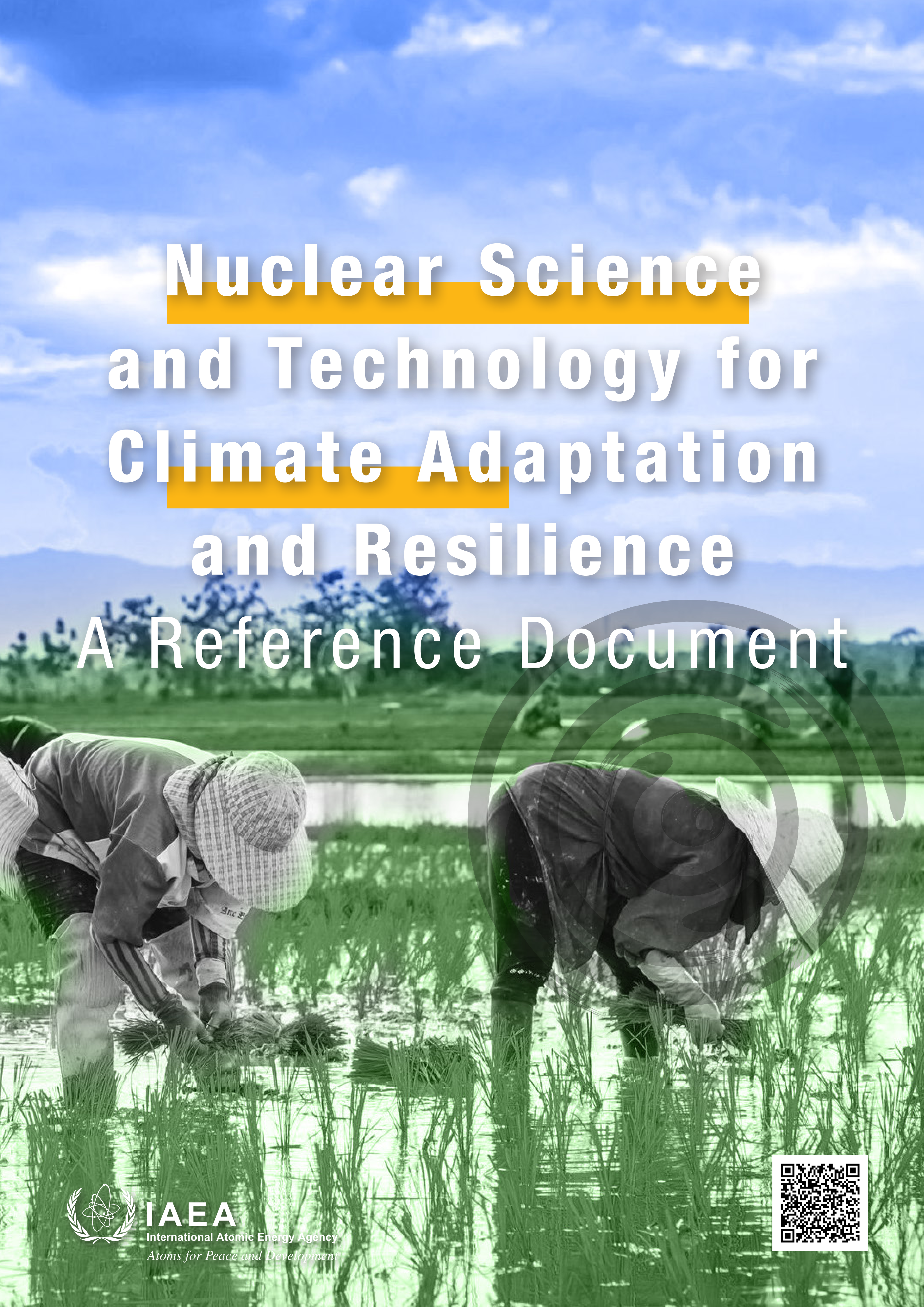
Nuclear Science and Technology for Climate Adaptation and Resilience

A Reference Document



IAEA
International Atomic Energy Agency
Atoms for Peace and Development

CONTENTS

Executive Summary

Climate action has become a matter of highest priority and urgency, as its effects are already severely impacting many regions of the world. The adoption of the Paris Agreement in 2015 with the specific goal of "holding the increase in the 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" was a landmark achievement. The upcoming climate conference, COP26, in Glasgow in late 2021 will review previous commitments and the status of implementation with the expectation to enhance and upgrade the measures.

For achieving the 1.5°C/2°C goal, countries have committed themselves to mitigate climate change by reducing anthropogenic greenhouse gas (GHG) emissions and to take measures to adapt to climate change. Projections show that temperatures will increase to 1.5°C above pre-industrial levels between 2030 and 2052 if emissions keep increasing at the current rate.

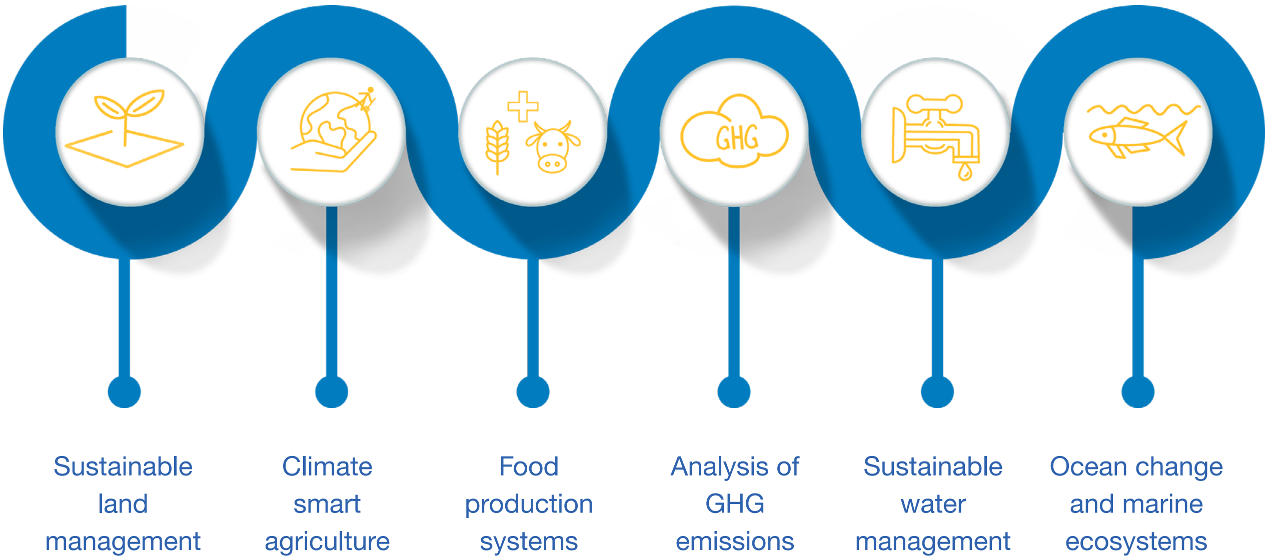
Climate change is expected to lead to an average global temperature increase, more frequent heat waves, and a geographical shift of climatic zones. Droughts will become more frequent, longer and more severe. A hotter climate will also influence the availability and quality of fresh water. Taken together, the consequences of climate change are bringing about broad and deep social and economic consequences, impacting the lives and livelihoods of billions of people.

While the main goal of the international community is to reduce GHG emissions, a suitable adaptation response is also needed. It requires commitments across a broad range of sectors spanning agriculture, energy, industry, health and the environment. Science plays a key role in adaptation planning. Decision-making on adaptation, including the various options considered, needs to be based on sound scientific, technical and socioeconomic data. Technologies, including nuclear technologies and techniques, can support the climate adaptation process. However, their successful transfer goes beyond the exchange of technological solutions. It requires enabling policy and regulatory environments, and, moreover, human and institutional capacities to deploy these specific technologies and techniques.

Climate adaptation covers a wide range of structural, social and institutional options intended to build resilience and reduce vulnerabilities in multiple areas. The IAEA expertise and experience is relevant for many of these areas: including land use and management, climate smart agriculture, food production systems, analysis of GHG emissions, management of water resources, coastal protection

What is the Climate Adaptation Reference Document?
This document presents all IAEA activities that are connected to climate adaptation. The document describes the global climate adaptation context; it articulates how nuclear techniques can contribute to climate adaptation and where the IAEA can add value; and it provides an analysis of the support given by the IAEA to its Member States. In the run up to COP26, this document positions the IAEA on an important issue of global concern: **climate adaptation**. The document seeks to lay the ground for enhanced engagements with Member States, partners and civil society. It provides a vision for the solutions and activities that the IAEA is offering to support Member States in implementing their nationally determined contributions (NDCs). Implementation of specific activities will happen through traditional modalities such as technical cooperation (TC) projects, coordinated research projects (CRPs), and other regular programme activities.

and ocean change. Nuclear techniques in these areas complement conventional climate adaptation and climate science technologies and approaches. The IAEA provides an integrated approach to the causes and effects of climate change and contributes to climate adaptation and climate science in six thematic areas:



Within each of these areas, nuclear technologies are deployed to advance climate science and/or to support Member States in adapting to climate change. For example, sustainable land management practices are being supported through the use of fallout radionuclides, which provide reliable information on soil erosion rates to assess climate change impacts on soil health and land degradation; or the application of isotopic techniques, which help to improve livestock feeding practices.

In the area of climate smart agriculture, isotopic signatures, biomonitoring and bioassays are used to monitor agrochemical inputs, as well as for the assessment of the transfer of chemicals to the environment and, ultimately, the food supply chain. Nuclear and stable isotope techniques are applied to unambiguously quantify processes associated to land-water management, including carbon sequestration and nitrous oxide emissions[1]. Isotopic techniques are also being used for agricultural water management, such as developing water-saving technological packages, determining sources of pollution, and tracking water movement and pathways in agricultural landscapes with different cropping systems and farming practices.

Food production systems benefit from nuclear techniques such as mutation breeding, which uses irradiation to speed up the natural process of mutation to produce new varieties of crop species that are adapted to abiotic stresses, rendering them able to thrive under changed environmental conditions. This technology has helped improve many crops so that they can perform better in harsh environments or be resistant to new pathogens.

Nuclear techniques offer substantial advantages over conventional techniques for the precise analysis and measurement of GHG emissions, for example, in the agricultural sector. Using stable isotopic techniques, the processes of release of greenhouse gases into the atmosphere can be identified. This enables the development of climate-smart technology packages to sustainably reduce emissions, improve resource use efficiency, and increase crop and animal productivity.

Another specific example where nuclear techniques are deployed is in the reconstruction of paleo-climates. Information on past climatic conditions derives mainly from stable isotope ratios, reflecting the prevailing climatic conditions during the formation of the paleoclimatic archive. This allows

[1] Through measuring nitrous oxide emissions, the information on excess nitrogen fertilizer applied can be fed back to farmers and lead to lower fertilizer use – thereby contributing not only to climate change adaptation but also mitigation[2] The carbon intensity of electricity production must decrease from a 463 g CO2/kW·h in 2019 [15] to less than 10-20 g CO2/kW·h in 2050

reconstructing past climates and validating models reproducing atmospheric processes.

To support sustainable water management, isotopic hydrology tools are used to assess local and regional water cycles by recognizing the unique isotopic fingerprint of water drops that can be tracked through the hydrological cycle. A better understanding of the sources of groundwater, its underground flows and its replenishment helps to determine how resilient groundwater is to climate change, as well as its vulnerability to pollution.

In the area of ocean change and coastal protection nuclear techniques are used to identify, source, and track the spatial and temporal drivers of ocean health and topics such as atmosphere/ocean exchange, marine radioactivity, coastal and marine carbon sequestration, sea-level rise and ocean acidification.

The IAEA, in accordance with its Statute, seeks to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world. Nuclear technologies, including those described above, undergo rigorous validation through IAEA's research activities. Once relevant nuclear techniques are vetted, they can then be transferred to all countries, especially developing Member States, through the IAEA technical cooperation programme.

The IAEA has a long history of supporting the research, development and uptake of specific nuclear techniques in the context of thematic areas relevant for climate adaptation. The IAEA applies nuclear science and technology as an alternative for, or to complement, existing conventional techniques and bring new solutions to support its Member States. The IAEA undertakes research activities in its own laboratories and also through its extended research networks, composed of research institutions, academia and reference laboratories.

The IAEA is engaged with its Member States on numerous technical cooperation projects relevant for climate adaptation and resilience in the six thematic areas described above. Many Member States have included climate adaptation actions in their nationally determined contributions (NDCs) and have started implementing these activities, often with support from international partners. The IAEA is complementing the support offered by other organizations through the transfer of validated technology and techniques for climate change adaptation and resilience building. From 2012 until 2020, the IAEA has supported 102 countries and territories in their efforts to adapt to climate change through 481 technical cooperation projects, with total disbursements of approximately €112 million. From the total number of projects, 89 are Regional and Interregional projects that contribute to climate adaptation efforts, with total disbursements of €51.7 million. Most projects are located in Africa, followed by Asia and the Pacific, Latin America and the Caribbean, and Europe and Central Asia. Over 70% of the IAEA's climate adaptation related projects focus on climate-smart agricultural practices and optimizing livestock and crop production.

Following the principles of results-based management, a results framework has been developed for the IAEA's work on climate adaptation. The overall objective of the IAEA's work on climate adaptation is *to contribute to climate change adaptation efforts through research and technical cooperation in nuclear science and technology*.

Key global challenges such as climate change need to be addressed in an integrated, systemic and inclusive manner, and partnerships facilitate comprehensive and sustainable solutions bridging the gap between research and policy impact. Scaling up IAEA support includes identifying and establishing meaningful partnerships to support countries towards the achievement of the UN Sustainable Development Goals (SDGs) and the implementation of the Paris Agreement.

2012–2020

102
countries and territories

481
projects

€112 M
disbursements

01

STRATEGIC CONTEXT

1. Strategic context

The global climate change policy and legal framework

The global climate change policy framework has been shaped by several events and resulting instruments, including the first World Climate Conference in 1979; the creation of the International Panel on Climate Change (IPCC) in 1988; the United Nations Framework Convention on Climate Change (UNFCCC) of 1992; the Kyoto Protocol of 1997 and its entering into force in 2005; and the Paris Agreement of 2015 with the specific goal of "holding the increase in the 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" [1].

With the aim of achieving the 1.5°C/2°C goal, countries have committed themselves to mitigate climate change by reducing anthropogenic GHG emissions, and to take measures to adapt to climate change, all the more as projections show that temperatures will increase to 1.5°C above pre-industrial levels already by between 2030 and 2052 if emissions keep increasing at the current rate [2].

Climate change risks and impacts – today and tomorrow

Today, it is universally recognized that climate action is a matter of urgency as effects and impacts of climate change are already felt in many parts of the world. The concentration of GHG in the atmosphere continues to rise to new records. Initial data indicates that the average global temperature for 2016–2020 is likely to be the warmest on record [3]. Between 2016–2019 a greater glacier mass was lost than in all other previous five-year periods since 1950. Oceans have warmed unabated since 1970 and have absorbed 20% to 30% of total anthropogenic CO2 emissions since the 1980s, causing accelerated ocean acidification. In sum, climate change is expected to lead to an average global temperature increase, more frequent heat waves and a geographical shift of climatic zones. Droughts will become more frequent, longer and more severe, which in turn will increase the risks of wildfires, also in previously unaffected areas. A hotter climate will also influence the availability and quality of fresh water. Rising sea levels will lead to more flooding and erosion around coasts, reduce freshwater availability and affect coastal biodiversity.

For many countries, the Paris Agreement's global goal of "enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change" is not an abstract future aspiration, but a necessity here and now, grounded in today´s reality. Agriculture, for example, is intimately and inextricably linked to climate, and the impacts of climate change on agriculture are already severe in many parts of the world. If current trends continue, depending on the location, agricultural yields could decrease significantly due to high temperatures, water shortages, extreme weather events and less suitable land for production. This will reduce food availability, and thereby put food security at risk, particularly in sub-Saharan Africa, Southeast Asia and Central and South America. Most affected would be the 500 million small-scale farming households worldwide, and other vulnerable populations, not only in terms of decreased income opportunities, but, also and even more importantly, in decreased food security.

"Holding the increase in the 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."

– Paris Agreement, 2015

20-30%
of total anthropogenic CO2 emissions are absorbed by oceans

The risks and effects of climate change also threaten the achievement of many other UN Sustainable Development Goals (SDGs). The

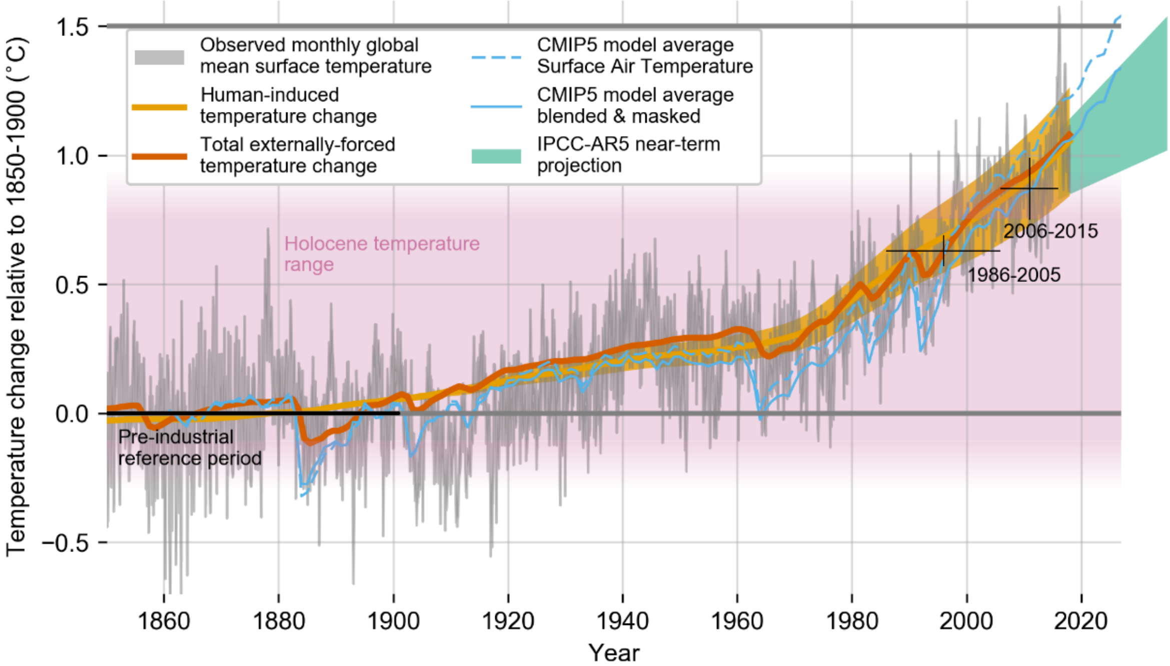
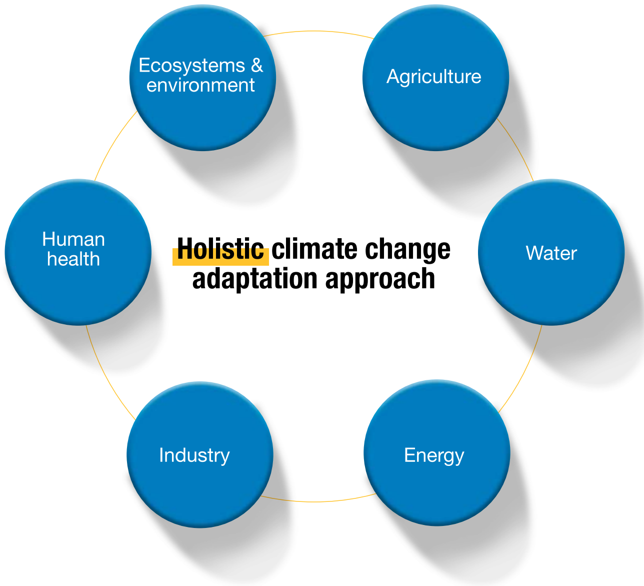


FIG. 1 Global Temperature change relative to 1850-1900 [2].

predicted or already existing risks and impacts of climate change will disproportionately affect the most vulnerable countries and populations. Many developing countries and vulnerable and marginalized groups or individuals in societies, such as women, minorities, indigenous people, youth and children do not have the necessary capacities and abilities to respond to the effects and impacts of climate change [4].

Climate change adaptation

Throughout history, people have adapted to the impacts of weather and climate. However, the unprecedented rate of climatic changes is projected to bring about novel risks and hazards not yet experienced. The effects and impacts of climate change are complex, broad and interdependent, which requires considering multiple interrelated sectors, including agriculture, water, energy, industry, human health, ecosystems, and the environment. Adaptation and mitigation are closely interrelated: adaptation strategies, plans and actions often produce mitigation co-benefits. Mitigation co-benefits might, for instance, arise from adaptation measures such as climate-smart agriculture, reducing food waste, or improving



energy efficiency. At the same time, there can also be trade-offs between mitigation and adaptation, occurring when bioenergy crops, reforestation or afforestation compete with land needed for food crops, which, ultimately, can undermine food security, livelihoods, or ecosystem functions.

The great majority of developing countries have highlighted agriculture in their national mitigation and adaptation plans and measures [5]. In many developing countries agriculture is an important sector, contributing 10–20% of gross domestic product (GDP) in lower-middle-income countries, and over 40% in low-income countries [6]. Any climate change related impacts on the agricultural sector will thus also have wider economic and social consequences. According to the IPCC, an estimated 23% of total anthropogenic GHG emissions between 2007–2016 derived from Agriculture, Forestry and Other Land Use (AFOLU), second only to the energy sector [7] [8]. The importance of food systems and agriculture is reflected in the Paris Agreement, which emphasizes "the fundamental priority of safeguarding food security and ending hunger, and the particular vulnerabilities of food production systems to the adverse impacts of climate change".

When devising their national adaptation plans, countries have a broad range of adaptation (and mitigation) options available, which can be divided into three categories: structural/physical, social and institutional. The options under each category are manifold and dependent on the given context in which they are to be applied. Specific adaptation options often overlap and are pursued simultaneously as part of broader adaptation plans. Figure 2 provides a rough overview.

The actual success of implementing adaptation policies, strategies, plans, and actions depends on many factors, including the degree of uncertainty of particular risks and hazards, the enabling policy, legal and institutional environment, and the accessibility of technology, available economic, natural and human resources. In fact, where one or more of these factors is not adequately balanced, the result will be maladaptation, where for instance measures taken in one sector or target group increase the vulnerability of another, or where short-term outcomes prevail over medium- and long-term actions [9].

Adaptation gaps and challenges

In recent years adaptation has gained importance and increased attention vis-à-vis mitigation. Many countries have adopted, or are in the process of adopting, national-level adaptation planning instruments. Increasingly, countries have actionable adaptation policies in place with clear guidance on their implementation. Overall, the number of adaptation projects in developing countries (supported by multilateral and bilateral funds) is increasing.[2] Similarly, adaptation finance is gaining traction and the range of available financing modalities, public, private and blended, is broadening.

Monitoring, reporting and evaluating are crucial for setting a baseline against which to measure any progress. Strengthening the understanding of climate change impacts begins with having a set of agreed-upon metrics for adaptation measures to gauge their effectiveness or impact [10] [11]. Despite being a difficult undertaking, the wider social, economic and environmental benefits of adaptation need to be quantified, and their communication to decision-makers and practitioners improved to facilitate and enhance their uptake on the ground.

Increasing the understanding of adaptation furthermore involves improving countrywide access to climate relevant data and information on adaptation planning and implementation. This would allow assessing climate change impacts, as well as the effectiveness of specific adaptation measures, providing the basis for choosing and designing adequate adaptation options. Decision-making on adaptation needs, options, and implementation should be based on sound scientific, technical and socioeconomic data.

Similar to the role of science, data, and information in climate change adaptation, the successful transfer of technology goes beyond the exchange of technological solutions and requires enabling policy and regulatory environments, and, moreover, adaptive capacities, to absorb, employ and tailor these technologies, methods or techniques [12]. 'Hard' technological solutions alone will in many cases be insufficient for adaptation, at least if they are not accompanied by 'soft' measures aimed at building adaptive capacities.

[2] For instance, the Adaptation Fund, the Green Climate Fund and the Least Developed Countries Fund together have reached more than 20 million direct and indirect beneficiaries and trained more than half a million people on climate resilience measures. See: [30]

Physical

- Engineering
- Discrete technology
- Use of ecosystems and their services

Coastal protection structures; new crop and animal varieties; efficient irrigation; water saving technologies; conservation agriculture; food storage and preservation facilities; wetland conservation and restoration; and adaptive land use management.

Social

- Educational
- Informational
- Behavioural

Awareness raising; extension services; knowledge-sharing and learning platforms; international conferences and research networks; early warning and response systems; systematic monitoring; longitudinal data sets; soil and water conservation; changing livestock and aquaculture practices; crop-switching; and changing cropping practices, patterns, and planting dates.

Institutional

- Laws and regulations
- Government policies and programmes

Taxes and subsidies; insurance; water regulations and agreements; definition of property rights and land tenure security; (marine) protected areas; integrated water resource and coastal zone management, and ecosystem-based management.

FIG. 2. Adaptation options [9].

Climate change adaptation and the impact of COVID-19

The short-, medium-, and long-term socioeconomic consequences of the global COVID-19 pandemic will have implications for countries' abilities to plan, finance, and implement climate change adaptation actions, given the additional pressure on both public and private finances. Climate change adaptation, mitigation or environmental sustainability may lose ground on the political agenda, also because of resources being shifted and reallocated towards managing the pandemic and it impact. In response to this post COVID-19 recovery plans could specifically integrate climate adaptation measures beyond a focus on economic growth stimulus [13] [14].

Climate change and gender

Women are often more vulnerable to the impacts of climate change, and this can be further compounded by sociodemographic factors such as age and wealth. In many rural economies and resource-based livelihood systems, it is well established that women have poorer access than men to financial resources, land, education, health, and other basic rights [15]. Women are also largely under-represented in decision-making processes at all levels, including in research, science, and technology. Recognizing gender differences in climate change vulnerability and adaptation can enable gender-sensitive responses that help reducing the impact of climate change on both women and men.

02

THE ROLE OF NUCLEAR TECHNOLOGIES

2. The role of nuclear technologies

Climate adaptation covers a wide range of structural, social and institutional measures intended to build resilience and reduce vulnerabilities in multiple areas, many of which are relevant to the mandate of the IAEA. These include land use and management, climate smart agriculture, food production systems, analysis of GHG emissions, management of water resources and ocean and coastal protection.

Description of nuclear technologies for climate change adaptation

Nuclear techniques complement conventional climate adaptation and climate science technologies and approaches. The IAEA promotes an integrated approach to address the causes and effects of climate change, in order to develop and apply mitigation measures, and contributes to climate adaptation and climate science in the following key areas:

Sustainable land management

Assessing climate change impacts on soil health and land degradation

Each year an estimated 36 billion tonnes of soil are lost through human activity and changes in land use, and this is further aggravated by climate change due to the increasing frequency of extreme weather events, which accelerate soil degradation. Traditional monitoring and modelling techniques to assess soil erosion/sedimentation require a large number of parameters and many years of measurements. The use of fallout radionuclides (FRNs) provides reliable and foundational information on soil erosion rates over different time spans [17] [18]. The FRN technique makes use of artificial radionuclides (e.g. caesium-137) that originate from thermonuclear weapon tests in the 1950s–1960s, geogenic radioisotopes (e.g. lead-210) and cosmogenic radioisotopes (e.g. beryllium-7). During erosion and deposition processes these FRNs move with the soil particles and can hence be used to trace the amount of soil eroded over large areas and over extended periods of time. Isotopic techniques can likewise be used to assess sediment sources of erosion in watersheds, thus facilitating targeted and better soil conservation practices.

What are isotopic techniques?

Stable isotopes are non-radioactive forms of atoms with unique properties that can be used by measuring their amounts and proportions in samples, for example in water samples. Naturally occurring stable isotopes of water and other substances are used to trace the origin, history, sources, sinks and interactions in water, carbon, and nitrogen cycles, and for provenance of goods and materials. Stable isotopes can also be used as tracers, which are deliberately added to a system that is to be studied, such as in agriculture or nutrition, to make it easier to distinguish the different sources [16]. It can be used in a broad variety of applications, including water and soil management, environmental studies, food safety testing, ocean and climate change, nutrition assessment studies and forensics.

Optimizing the use of water in agriculture?

Isotopic techniques can be utilized to optimize the use of water in agriculture. The IAEA is working with local scientists in several regions most affected by climate change to improve food security through enhanced water management.

In partnership with the Food and Agriculture Organization of the United Nations (FAO), the IAEA provides expert advice, consumables, laboratory, and field equipment on the use of isotopic techniques to track water use. Local scientists learn how to use isotopic techniques to determine the right amount of water needed at the right time to enhance the production of high-value crops. Knowledge is then transferred to assist small-holder farmers, mostly women, in improving the water- and nutrient-use of high-value crops, improving the socio-economic situation of local communities.

Nuclear Techniques and Drip-Irrigation for Smart Agriculture

Drip irrigation technologies have contributed to an increase in crop yields of 60% for farmers in this internally displaced camp in Abuja, Nigeria. (Photo: F. Abayomi/ Federal University of Oye Ekiti)

In Nigeria for example, scientists have been working with the IAEA and FAO since 2018 to help farmers use drip irrigation systems to grow food in the face of harsh climate conditions. The assistance began with training 60 national agricultural experts and providing laboratory and field equipment, and in 2020 it led to the establishment of small-scale drip irrigation systems for food production in a camp for the internally displaced persons in Abuja, where mainly women and children live. The new irrigation systems have helped increase yields of crops such as cucumber, watermelon and okra by 60%, while decreasing water use by 45% compared to other methods. Following the success in Abuja, it is now being planned to expand the use of small-scale drip irrigation to more of these camps throughout the country.

Improving livestock feeding to minimize greenhouse gas emissions

Demand for animal products is growing at an unprecedented rate, especially in developing countries where many livestock keepers rely on cut-and-carry indigenous grasses and natural grazing, including trees and shrubs, to feed their animals. The nutritional value of these forages seldom meets the requirements of the animal and is a key limitation to ruminant production. Inadequate animal nutrition results in more GHG output per unit of animal product. Moreover, the expansion of pasture further degrades natural grasslands and threatens biodiversity. With conventional techniques scientists and producers are not able to accurately predict livestock feed intake and its nutritional value without which it is difficult to determine the amount and type of supplements required to optimize livestock production. The stable carbon isotope composition in plant and faecal samples, however, can determine dry matter intake and its plant proportions. This technique combined with near infrared reflectance spectroscopy (NIRS) can facilitate the design of diets and supplements required to cover the nutritional needs of animals to optimize production. Such livestock feeding strategies improve feed conversion efficiency, increase production per animal, while reducing the GHG emission per unit of animal product thus mitigating the impact of livestock production on climate change.

Improved Soil and Nutrient Management Practices Increase Rice Yields in Lao PDR

The IAEA, in cooperation with FAO, supported farmers in Lao PDR and managed to increase rice yields through better soil and nutrient management practices using nuclear techniques. Trials conducted on farmers' fields showed that by applying chemical fertilizers and manure in an optimized way, rice yields have increased from 3.16 to 5.1 tonnes per hectare (60% increase). The IAEA, through its technical cooperation programme, has trained researchers in using the stable isotope nitrogen-15 to quantify the amount of nitrogen plants take up from fertilizers, and then determine the precise amount of fertilizer that farmers should use at various stages of the crop's life and how best to incorporate locally available rice straw and animal manure as a source of nutrients. The IAEA and experts from the National Agriculture, Forestry and Rural Development Research Institute (NAFRI) developed an easy-to-use brochure for farmers, in the Laotian language. Fifty-seven farmers from four villages in Vientiane province have been trained in the pilot phase of the programme [19].

Climate smart agriculture

Monitoring agrochemical inputs for improving food safety

Climate change affects the distribution of insect and fungal pests, and therefore patterns of agrochemical usage, with the subsequent risk of chemical residues in food in regions where they were previously not found. Stable isotopes of major elements have been successfully applied to trace and monitor sources and transport of solutes in agroecosystems. Depending on the origin of the polluting source, the isotopic signature of these elements can be used to fingerprint and trace the source. Combining these isotopic signatures with other analytical approaches including biomonitoring and bioassays, along with risk assessment tools, allows monitoring of agricultural inputs and the transfer of these chemicals to the environment and the food supply chain. The results of these studies allow continuously assessing, adapting, and improving climate-smart agricultural practices to enhance land sustainability and food safety.

Developing innovative land and water management technology packages

Agriculture accounts for approximately 70% of freshwater use globally, yet in many places the efficiency of water use is very low. With climate change and increasing demand for water, there is a need for improving agricultural water use efficiency. The use of carbon-13, oxygen-18, hydrogen-2 (deuterium) and nitrogen-15 is an integral part of agricultural water management, as they are used in developing water-saving (more crop yield per drop) technological packages, determining sources of pollution, and tracking water movement and pathways in agricultural landscapes with different cropping systems and farming practices.

The importance of water availability in the surface rooting zone has become evident, with climate change affecting rainfall patterns and crop production, particularly in already water-scarce or water-stressed regions. The use of cosmic ray neutron sensors (CRNSs) for measuring landscape surface soil water has become increasingly important [20]. The advantage of the CRNS technology is that it provides an area-wide scale, in contrast to conventional techniques which measure mainly at field scale (point level).

The CRNS covers a circular area of about 20 ha, up to a depth of 70 cm, giving an average value for soil water content, making the technology a good tool for filling the gap between point sensors and large-scale remote sensing satellite derived soil-water content and its calibration.

Agriculture, water scarcity, low soil fertility and climate change are closely interlinked. For example, more intense and frequent droughts or increased variability in precipitation affect land degradation and water availability to the extent that agricultural production and outputs are threatened. Currently the IAEA supports 38 countries in Africa through a portfolio of technical cooperation projects improving the management of water and soil for agriculture through the introduction of water-saving irrigation techniques which enable farmers to maximize agricultural output while minimizing water and fertilizer input, thereby adapting to the effects of climate change.

Nuclear science helps women farmers in Sudan leave poverty behind. (Photo: N. Jawerth/IAEA)

Enhancing carbon sequestration through innovative land-water management practices

Soil microorganisms affect the emission of GHG. Soil microorganisms depend on the availability of substrates as well as suitable abiotic conditions (e.g. moisture). For instance, heavy rainfall can boost microbial activity and lead to peak emissions. On the other hand, waterlogged conditions, as in wetlands, may trigger methane emissions but impede CO2 respiration due to the lack of oxygen, whereas nitrous oxide emissions may be limited because of anoxic conditions. This can only be identified by stable isotope tracing methods. Thus, soil moisture conditions and/or dynamics can either minimize or enhance GHG emissions and in turn affect carbon sequestration. Suitable water management in line with other management options such as nutrient supplies and soil amendments (e.g. biochar) may alleviate peak microbial activities, while enhancing carbon sequestration. Nuclear and stable isotope techniques provide the scientific backbone to unambiguously quantify the processes associated with land-water management options, including carbon sequestration and nitrous oxide emissions.

Food production systems

Developing improved drought- and heat-tolerant crop varieties using mutation techniques

The effects of climate change pose stresses of various kinds, biotic and abiotic, to crop varieties. Many varieties are grown in specific regions as they have been adapted to local climatic conditions as well as farmers´ and consumers´ preferences. Enhanced or new stresses such as long periods of drought, sea water infiltration or new crop diseases/strains are threatening these local varieties.

Mutation breeding produces new varieties of crops that are adapted to abiotic stresses through inducing genetic changes and developing varieties that in addition to their original traits have traits that make them thrive under changed environmental conditions [21]. This technology has helped to rapidly improve many crops to perform better in harsh environments or to be resistant to new pathogens.

Mutation breeding has many comparative advantages: it is cost-effective, quick, proven and robust. It is also transferrable, ubiquitously applicable, non-hazardous and environmentally friendly. More than 3300 mutant varieties of over 210 plant species have officially been released for commercial use in more than 70 countries as indicated by the voluntarily contributed records in the FAO/IAEA Mutant Variety Database.

Mutation breeding has a proven track record of generating large numbers of new crop varieties for a wide range of traits including enhanced yield, resistance to stress, earlier maturity, shorter plant height, quality of produce, etc. Genetic improvement of traits, such as resistance to pests, diseases, and weeds, is more sustainable and environmentally

Socioeconomic Impact Assessment of Mutation Breeding

The social and economic impact assessment of the crop mutation breeding programme under the Regional Co-operative Agreement for Research, Development and Training Related to Nuclear Science and Technology for Asia and the Pacific (RCA) is a pioneering effort in identifying and assessing the impact of IAEA-supported plant breeding activities in Asia and the Pacific, spanning nearly twenty years and 22 countries.

The impact assessment found that over the past 20 years the RCA has supported a significant body of mutation breeding projects, including over 7300 promising breeding lines with superior quality traits to previous crops, and 254 mutant varieties of crops certified and officially released. Key impacts of this work that are relevant for climate change adaptation include:

- Greater yield productivity, with a 32.7% increase in total production over their respective control crops;
- Increased food supply, adding an extra 34.8 million tonnes of produce from 2000 to 2019;
- Reduced use of agricultural inputs by 21% for chemical fertiliser, 17% for pesticides, 12% for irrigated water, and increased soil fertility by 8% (weighted averages by crop volumes 2000–2019);
- Higher market prices due to improved nutritional and environmental quality traits.

friendly than the use of chemicals. Mutation breeding is advantageous over conventional breeding as it introduces novel genetic diversity in plant populations, thereby offering a wider range of selection for improved traits. It is therefore faster and more robust than conventional breeding, it is ubiquitously applicable, and does not involve the use of genetic engineering.

Mutation breeding versus genetically modified organisms (GMOs)

Mutations are spontaneous random changes in the genome of organisms that naturally occur during their lifetime. While mutations induced by traditional mutagenesis techniques are no different from spontaneous naturally occurring mutations, the process of mutagenesis helps to speed up naturally occurring genetic variability, which is an important requirement for crop improvement and adaptation to its changing environment. The mutation induction process (mutagenesis) used in plant mutation breeding has established a long safety record, as plant mutation breeding has been used since the 1930s as a means of enhancing crop improvement, contributing to global food security, and increasing genetic diversity. In contrast, GMOs are developed using known molecular information to introduce genes into an organism or edit genes within an organism with specific DNA integration sequences and techniques. As opposed to this, mutation breeding uses external agents such as radiation to induce natural changes in the genome, in a manner akin to spontaneous evolution but at a faster pace. Mutation breeding does not involve the introduction of genetic material into an organism.

Broadening existing genetic resistance in crop plants to combat transboundary plant pests

Diseases are among the major obstacles hindering the productivity of crops and losses can be devastating for both the farmer and the community. While yield losses caused by pests can range anywhere between 20% and 40% of global agricultural productivity, disease assessments and the losses arising can be oversimplified as they often are unable to quantify both direct and indirect losses [22]. Changing climatic conditions help spread diseases to new destinations and intensify their impact. Outbreaks and expansions can cause huge losses to crops, threatening the livelihoods of farmers and the food and nutrition security of millions of people. Also, varieties released as resistant become susceptible after years or decades of cultivation due to pathogen evolution and adaptation to these varieties. Thus, breeding disease resistant crop varieties is a continuous challenge for plant breeders.

Genetic diversity for broadening pest and disease resistance in many cultivated crops is limited, or non-existent, especially in vegetatively propagated crops. Artificial induction of mutations is one of the most effective approaches to increase the genetic

Drought-tolerant Crops in Zambia Increase Farmers' Income

Kalaluka Munyinda, Lecturer at the Department of Plant Science, in the experimental field of the University of Zambia. (Photo: University of Zambia)

In Zambia, two new varieties of cowpea, a grain legume that is predominantly cultivated in Africa as a major source of protein, have been released to offer significantly improved yields and quality to farmers and the community at large. These varieties were developed using radiation-induced novel genetic variation followed by selection for improved performance through the process of mutation breeding. The new varieties of cowpea mature earlier and therefore require less water and can withstand drought better. They produce higher yields than local varieties under drought conditions and they also perform better under pressures from certain diseases and pests. Developed using nuclear technologies, specifically gamma-ray induced new genetic diversity, seeds of these varieties are being made available to farmers.

signature and therefore the biodiversity of crops. Applying a nuclear technique such as mutation breeding is one of the primary sources for rapidly creating additional genetic variation in plants and an effective approach to induce resistance to diseases in crops. This is most useful if desired traits are not present in the gene pool or their introgression would take excessive time to remove undesirable characteristics in the end product.

Controlling animal pests and diseases

Climate change and variations in rain and temperature patterns have affected migration of people, animals and vectors causing the emergence and re-emergence of animal and zoonotic diseases. Devastating animal disease outbreaks (e.g. lumpy skin disease, African swine fever, peste des petits ruminants, avian influenza, Rift Valley fever) occur in areas where they were previously unknown, threatening animal and public health.

The application of nuclear and related techniques supports the early, rapid, and confirmatory diagnoses and control of animal and zoonotic diseases. Nuclear techniques, including immunological and molecular techniques are developed, validated, adapted, and deployed to identify animals and vectors carrying specific pathogens to prevent and control the spread of emerging or re-emerging diseases to other livestock and/or humans.

Climate change also affects the spread of insects to higher latitudes and altitudes, contributing to the introduction and expansion of new pest species into previously free areas. Insect pest range expansion also impacts the established ecological balance in the invaded areas and can cause major pest outbreaks. The sterile insect technique (SIT) can address this problem by responding to the spread of pests through containment, suppression or eradication in newly infested areas. It can also address the problem of outbreaks and invasions of a species to free areas and support its eradication and the re-establishment of pest free areas where possible [23] [24].

The sterile insect technique

The SIT is an environmental-friendly insect pest control method involving the mass-rearing and radiation-induced sterilization of a specific target pest. It follows the systematic area-wide release of the sterile male insects by air over defined areas, where they will mate with wild females resulting in no offspring and a declining pest population. The SIT is among the most environment-friendly insect pest control methods ever developed. Irradiation, such as with gamma rays and X rays, is used to sterilize mass-reared male insects so that, while they remain sexually competitive, they cannot produce offspring. The SIT does not involve transgenic (genetic engineering) processes.

Jointly with the FAO, the IAEA assists its Member States in developing and adopting nuclear-based technologies such as SIT for optimizing agricultural insect pest management practices that support the intensification of crop production and the preservation of natural resources.

Integrated with other control methods, the SIT has been successful in controlling a number of high-profile insect pests, including fruit flies; tsetse flies; screwworm; moths; and mosquitoes. In several countries where the technology has been applied, retrospective economic assessment studies have shown a very high return on investment. Benefits of using the technology include: a significant reduction in crop and livestock production losses; protection of the horticultural and livestock industries through prevention of pest introductions; providing conditions for commodity exports to high value markets without quarantine restrictions; protecting and creating jobs; significant reduction in production and human health costs; and environmental protection through a reduced use of insecticides [24] [25].

Damaged fruit. (Photo: L. Potterton/IAEA)

Sterile Insect Technique in the Balkans

Increased temperatures can facilitate the spread of crop pests like fruit flies. Over the past decade, the IAEA helped countries in the Balkans and the Eastern Mediterranean through a series of regional TC projects to suppress the Mediterranean fruit fly by applying the SIT.

For example, in Croatia, the integration of SIT into a broader package of fruit fly control methods, has led to a decrease of Mediterranean fruit flies in the Neretva Valley by 73% in fig crops and 86% in mandarins. Overall crop production has seen an annual increase of 20%, which has helped bring an estimated €30 million in additional income to local farmers each year.

Enhancing post-harvest food safety and trade to reduce food waste and loss

Food irradiation enhances food safety and helps prevent foodborne illnesses. It also prolongs food quality and so minimizes food waste. Irradiation not only controls foodborne microbes, but also prevents the spread of insect pests and is used to guarantee trade of fruits and vegetables across quarantine boundaries. Irradiation can also be used to produce shelf-stable rations in times of emergency. Due to climate change, certain insects are now found in locations where they never existed before with food being one of the vehicles. Using food irradiation can help control this spread.

The IAEA supported nuclear and isotopic techniques to analyse ethephon residues in pineapples from Benin. This ultimately enabled farmers to export pineapples again to the European Union following the set-up of a food safety surveillance system. (Photo: M. Gaspar/IAEA)

Monitoring residues and contaminants in food

Climate change directly impacts food safety as regards microbiological hazards including bacteria, viruses and parasitic protozoa, naturally occurring toxins such as mycotoxins and toxic metals, and veterinary drug and pesticides residues among others. Climate change also influences environmental contamination and chemical residues in the food chain.

Fungal toxins such as mycotoxins, are already being found in crops in regions where the climate did not previously support fungal growth. There is an increased risk of mycotoxin production as crops are harvested and stored with higher levels of moisture (a condition for mycotoxin elaboration) than under normal conditions. Also, mycotoxins endemic to tropical regions are expected to become more common in temperate zones as temperatures increase. Nuclear techniques such as radio receptor assay methods (based on radiolabeled tracers) are supporting the testing of mycotoxins.

The same technology can be used to control veterinary drug residues. Climate change could result in a higher risk of exposure to existing as well as emerging pathogens and related diseases including zoonoses. Certain endemic pathogens are also becoming resistant. Veterinary drugs are increasingly needed to control these diseases and pathogens/pests, resulting in residues that could impact consumer safety and therefore trade.

Climate change also precipitates algal blooms thus increasing the risk of consumer exposure to toxins in seafood. These hazards can be tested and monitored using radio receptor binding assay techniques. Other contaminants which are spreading faster due to climate change and for which nuclear/isotopic techniques can be used include toxic metals and persistent environmental contaminants.

The monitoring of irrigation water for contaminants is another area in which nuclear and isotopic techniques contribute. Droughts are known to increase chemical contamination of water. Use of such water for crops or by animals can result in foodborne diseases.

Responding rapidly to food safety incidents and emergencies

Climate change has far-reaching impacts on food safety. The food supply is vulnerable to frequent shocks such as extreme weather events. These extreme weather events also have disruptive effects on food inspection, testing and control and provide increased opportunities for misuse of chemicals, food fraud and food processing shortcuts, posing additional food safety risks.

Nuclear and related techniques help to rapidly and effectively respond to food safety incidents and emergencies. Portable and field-deployable screening methods enable rapid investigation of unknown causes of food safety incidents, while both field and laboratory-based techniques allow identification of the contaminants, determination of their origins and traceback of contaminated foods to facilitate their control.

Developing nuclear and genomic tools for animal breeding and reproduction

Livestock production does not only suffer from climate change, it also contributes to it. Improving productivity per animal could reduce the number of livestock, reducing emissions while enhancing food security. Appropriate animal selection and breeding are important levers for raising livestock productivity. However, most current traditional methods are slow and take several years to achieve results. Consequently, low producing animals are kept for a long time and in larger numbers. Advances in genomics can speed up the process.

Zaw Oo, a dairy farmer in Myanmar, can fit more cows into his small stall after switching to artificial insemination, prepared using nuclear techniques. (Photo: M. Gaspar/IAEA)

The breeding potential of an animal can now be estimated as early as on the day of its birth by looking at specific areas of its DNA or genome map responsible for the production traits of interest. Genome maps are produced by a nuclear technique known as radiation hybrid mapping. Gamma rays are used to construct radiation hybrid panels that enable the mapping of several DNA markers and putting together the whole genome map of an animal. Once the full genome is mapped, tens of thousands of such markers are combined onto a DNA chip, which can be used to determine the breeding potential of an animal. Application of DNA chips derived from radiation hybrid maps to screen and choose the best animals has revolutionized the breeding of animals to increase production. This way, fewer but better producing livestock can be reared, thus reducing GHG emissions.

Analysis of GHG emissions

Assessing emissions from crop and livestock production

Agricultural and land management activities account for approximately one quarter of global GHG emissions, mainly caused by chemical fertilizers, livestock production, deforestation and draining of wetlands [26]. Nuclear techniques offer substantial advantages over conventional techniques for the measurement of GHG emissions. Using stable isotopic techniques, the processes of release of greenhouse gases into the atmosphere can be identified. This enables the development of climate-smart technology packages to sustainably reduce emissions, improve resource use efficiency and increase crop and animal productivity.

Providing standards to calibrate carbon isotope ratios

The IAEA provides the standards necessary to calibrate carbon isotope ratio measurements worldwide on a common scale. As the custodian of this scale, it keeps the primary standard used by a large number of laboratories worldwide, ensuring comparability of all such data which can be used for climate change monitoring. Carbon isotope ratios provide information on carbon dioxide in the atmosphere including the sources of greenhouse gases.

The changing concentration of carbon dioxide in the atmosphere and its definitive allocation to source is also expressed in the carbon isotopic signature. Data covering the last thousand years have been recovered from measurements of glacier ice and air entrapped in snow allowing the calculation of carbon fluxes and release of carbon dioxide from fossil fuel on a global level.

Sustainable water management

Isotope hydrology uses isotopes to track the movement of water through the hydrological cycle, to trace the original source of groundwater, and to examine mixing processes within different components of the hydrological cycle (precipitation, surface water, groundwater). Although there are many useful isotope tracers in hydrology, the two most common are stable isotopes of oxygen and hydrogen, as these elements make up the water molecule. The share of the different oxygen and hydrogen isotopes in precipitation is governed by the hydrological and climatic conditions at the time, particularly temperature. The result is a unique isotopic fingerprint that can be tracked through the hydrological cycle. Other stable isotopes, such as those of nitrate, can be used to fingerprint pollution sources and evaluate water quality. In addition, radioisotopes such as tritium, carbon-14 and certain isotopes of the noble gases are used by hydrologists to estimate groundwater age, i.e.,

The Importance of Monitoring – The Global Network of Isotopes in Precipitation (GNIP)

The Brazilian Geological Survey (CPRM) team after the set-up of the Recife Isotope monitoring station.
(Photo: R. Kirchheim/CPRM)

In collaboration with the World Meteorological Organization, as well as Member States' governmental and academic institutions, the IAEA has coordinated a global monitoring programme called the "Global Network of Isotopes in Precipitation" (GNIP). Started in 1960 as a monitoring network for atmospheric tritium fallout in the times of thermonuclear testing, GNIP has evolved over the last 60 years to become the world's leading and spatially most comprehensive dataset for stable and radioactive oxygen and hydrogen isotopes in precipitation, comprising over 1100 monitoring sites and generating over 130 000 individual monthly isotopic records. This unique global isotope database represents a critical tool used in many disciplines, ranging from isotope hydrology and ecology to animal migration and forensics. It is also at the forefront of IAEA's climate observation efforts and is widely used to validate models reproducing atmospheric processes [27] [28] [29]. As the ability of these models to predict complex precipitation processes improves, it drives demand for increased temporal resolution of GNIP data to better portray the evolution of precipitation in response to climate change. Currently, there are over 350 active GNIP sites involving more than 100 institutions who collect precipitation samples.

The Central American Dry Corridor

The Central American Dry Corridor experienced water shortages which led to crop failure and food scarcity, affecting 3.5 million people over the past five years. Lack of access to adequate water supply systems was exacerbated by economic instability. A better understanding of linkages between rain, surface runoff, and groundwater recharge is crucial to improve water management plans. Reliable and up-to-date hydrological information is required to implement public water policies and measures.

The IAEA helped affected countries to understand the local water cycle and quantify fluxes and interactions between rainfall, runoff, and groundwater replenishment in the Central American Dry Corridor. Isotopic monitoring of precipitation and of selected springs and wells in each country helped identify critical recharge zones and their connectivity with surface water systems [30].

the amount of time water has been present in the aquifer system and isolated from the atmosphere. Both stable isotopes and radioisotopes can be used to understand the processes that affect the availability and movement of water through the hydrological cycle and how these processes are affected by climate change.

Monitoring shrinking wetlands and the impact on groundwater recharge

Replenishment of the groundwater system is crucial for sustainable water resource use. Wetlands are often supported during the dry season by discharge from groundwater systems, whereas during the wet season, wetlands help to purify water and replenish the groundwater system. Worldwide, wetlands are under pressure from conversion to agricultural land, water abstraction and diversions, and climate change leading to substantial reduction in the surface area of wetlands in many regions. The reduction of wetlands creates serious problems for groundwater quantity and quality and is also responsible for the release of large quantities of carbon that is stored in wetlands. Isotopes enable evaluation of the hydrological and ecological connection between groundwater and wetlands and allow quantification of water balances. Understanding interactions in the water cycle and providing accurate water balances help water managers determine the ecological reserve, the minimum amount of water needed to sustain the natural environment. Maintenance of the ecological reserve under changing climate conditions is critical to sustain wetlands and the important biological functions they perform to mitigate water quality issues and store carbon.

Evaluating groundwater age and sustainability

Groundwater sustainability is intrinsically linked to the age and volume of a groundwater system. Fossil groundwater systems are not in contact with the modern atmosphere, whereas young groundwater systems are. This implies that young groundwater systems are being actively recharged, but also that they are vulnerable to the impacts of climate change. Fossil groundwater systems are not being actively recharged and hence are less vulnerable to climate change; however, the lack of active recharge raises questions about the sustainability of such systems. Being able to differentiate between young and fossil groundwater systems requires knowledge of the groundwater age. Tritium, carbon-14, isotopes of dissolved noble gases and other long-lived radioisotopes are powerful dating tools used in isotope hydrology studies enabling groundwater age dating from about one year up to one million years. Tracking of groundwater ages allows the evaluation of the impact of changing precipitation patterns on groundwater resources and the assessment of the sustainability of current abstraction practices.

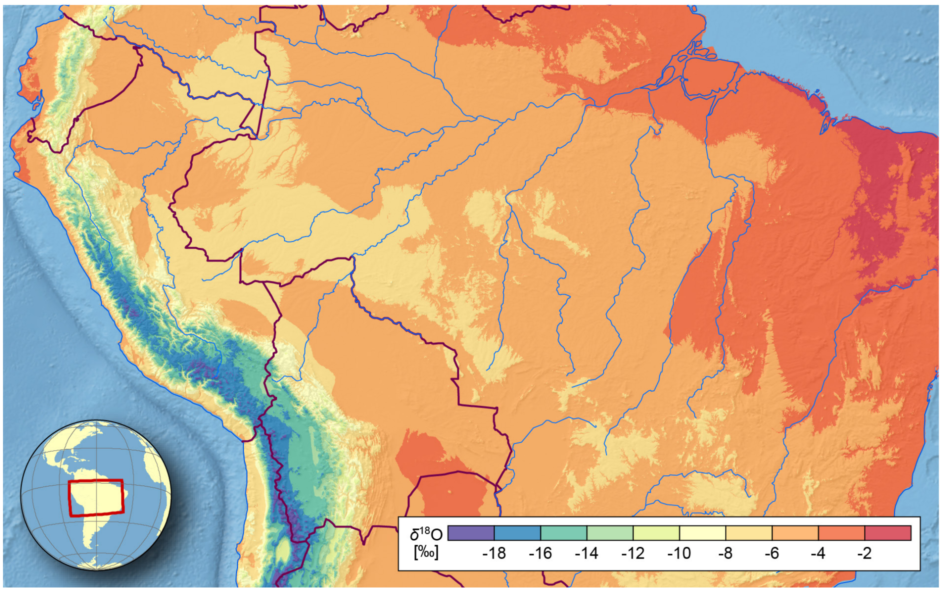
Sustainable Water Resource Management in the Sahel Region

Groundwater collection from hand pumps in the Sahel, northern part of Ghana. (Photo: Ghana Atomic Energy Commission)

The Sahel is a region of about 5 million km2 extending from Senegal to Sudan, representing the transitional climate zone from the Sahara Desert to the tropical savannas. This zone is characterized by recurrent surface water droughts linked to changed climate patterns, resulting in severe water shortages, with detrimental impacts on local societies and economies. As a result, groundwater is rapidly replacing surface water as a source of potable and domestic water. Isotope tools have enabled a network of 13 countries to obtain a first broad overview of shallow groundwater resources in five basins: the Lullemeden Aquifer System, the Liptako-Gourma-Upper Volta System, the Senegalo-Mauritanian Basin, the Chad Basin and the Taoudeni Basin. Large quantities of good quality groundwater have been identified in several areas, an important finding for the drought-prone Sahel region. The relationship between surface water and groundwater in many areas is now better understood.

Managing water quality

Population growth and the rapid co-development of agricultural and industrial sectors in recent decades have significantly altered the global nitrogen cycle. Substantial increases in anthropogenic atmospheric emissions of nitrogen oxide (NOx) compounds are transferred to the world's water ways via precipitation, while increased nitrogen loadings in surface water bodies, often derived from fertilizer and manure, contribute to biodiversity loss and reductions in water quality. Climate change is exacerbating the disruption of the nitrogen cycle through increased temperatures that accelerate biological processes resulting in nitrate accumulation in soil and water systems. The stable isotopes of nitrate can be used to trace the origin of NOx sources (vehicles, electricity generation, industries, biomass burning, fertilizers, sewage, and manure) as well as the processes that nitrogen undergoes in the atmosphere and hydrosphere. This information aids in the understanding of ecosystem adaptation to the N-cycle disruption and informs the implementation of beneficial land and agricultural management strategies to mitigate increasing nitrogen pollution in the Earth's groundwater, rivers, lakes, drinking water reservoirs, and oceans. The IAEA is at the forefront of analytical advances that make it easier for Member States to obtain nitrate isotope information, and it supports Member States in implementing nitrate monitoring programmes.



The latest version of IAEA's Regionalized Cluster-based Water Isotope Prediction (RCWIP) isoscape presents in rich detail the elevation gradients of oxygen-18 in precipitation over the Amazon basin. [31]

Isoscapes as a snapshot of climate

To adapt water resource management practices to the impact of climate change using isotope hydrology tools, it is necessary to know how water isotopes vary spatially and temporally. Monitoring of water isotopes at selected and distributed sites generate isotope records as a function of location over time. This data is used to create isoscape maps, which enable an understanding of the local hydrological behaviour. Isoscape maps are essentially contour maps showing the variation in isotopes across a region either in precipitation or groundwater. Temporal trends in local hydrological behaviour are flagged by changes in isoscapes over time. The IAEA is currently working towards the generation of isoscapes of naturally occurring tritium, adding a new dimension for water authorities to understand where water is being actively replenished and how this might change in response to changing precipitation patterns.

Reconstructing the paleo-climate

Information on past climatic conditions derives mainly from stable isotope ratios measured in paleoclimatic archives such as ice cores. These ratios reflect the prevailing climatic conditions during the formation of the natural conserved archive. By deciphering the factors controlling isotope variability under present climatic conditions, it is possible to reconstruct past climatic conditions and develop climate and hydroclimatic impact models for the future. In addition to the stable isotopes, radioactive isotopes, such as carbon-14 or uranium and thorium isotopes, help provide the age information required for the precise dating of the paleoclimatic record.

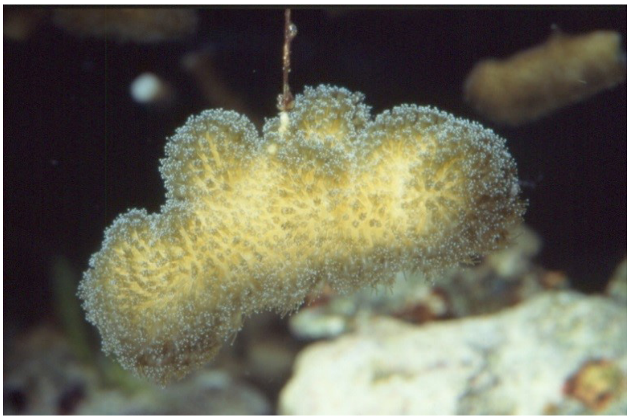
Although the GNIP isotope data are primarily used in the context of water resources assessment and management, this database is widely utilized to reconstruct past climates and validate models reproducing atmospheric processes. It has also provided support to modelling work of the IPCC.

Ocean change and marine ecosystems

Nuclear technologies, such as isotopic age determination, custom radiotracer applications to assess biological stress from diverse contaminants or forensic source tracking provide useful insights into the consequences of climate change and ocean change impacts on marine ecosystems and coastal structures. A portfolio of nuclear techniques addresses topics such as atmosphere/ocean exchange, coastal and marine carbon sequestration, sea-level rise, ocean acidification, warming and deoxygenation and the fate and transport of radioactive, inorganic and organic contaminants and biotoxins associated with harmful algal blooms.

Addressing marine plastic pollution augmented by climate change

Nuclear and isotopic technologies employ gamma, beta and alpha emitting radioisotopes to assess the fate and biological consequences of global plastic pollution in the ocean. One of the consequences of climate change is stark changes in hydrologic patterns around the globe, including increased intensity of storms. Changes in precipitation and runoff will impact the discharge of terrestrial marine plastics into the ocean while storms can remobilize plastic pollution sequestered in bottom sediment. Work on marine plastic pollution is achieved at the IAEA with the use of experimental aquaria with target marine animals, such as fish, coral, crustaceans and mollusks.



A subtle change in coral calcification rates resulting from systemic ocean change can be best quantified using radiotracer techniques. (F. Oberhaensli/Radioecology Laboratory, IAEA Monaco)

Linking land-based activities to degraded marine ecosystems

Nuclear and tracer techniques such as uranium-thorium (U/Th) series radionuclides, receptor binding assay (RBA) methods and compound specific isotope analyses are used to identify, source and track the spatial and temporal drivers of ocean health. Climate change impacts to the global ocean are manifested in ocean warming, acidification and deoxygenation, which collectively can degrade coastal and marine ecosystems and the vital services they provide.

Improving monitoring and assessment of contaminants and seafood authenticity

As finite marine resources (e.g., global fisheries, deep sea minerals) are threatened to be overexploited, large scale climate-change induced impacts to the global ocean will impose additional stressors to these valuable commodities. Nuclear techniques are developed and used to assess risks associated with diverse contaminants in seafood, as follows:

- Radiotracer techniques to assess movement and transformation of biologically relevant contaminants (e.g., polonium-210, methyl-Hg, flame retardants);
- Stable isotopes for seafood provenance and authentication (e.g. forensics);
- Precise isotope ratio measurements to source and better understand contaminant fate and provenance in marine biota;
- Novel use of complimentary nuclear techniques such as ion and X--ray fluorescence (XRF) beam methods for seafood safety applications.

Monitoring and assessing climate change impacts on coastal structures

Projected extreme weather events and rising water levels due to climate change can significantly impact sediment transport in seas and rivers. This is crucial for civil engineering structures and littoral protection and management. Nuclear techniques, namely tracer methods (radiotracers) and nucleonic gauges (sealed sources), are used to assess sediment dynamics and monitor sediment deposit density and circulating sediment concentration. In addition, natural and anthropogenic environmental radiotracers provide insight into short-term and long-term processes controlling sediment dynamics. The combined information is used to identify bordering land erosion and to plan dredging works to maintain transport waterways, allowing the proper water height for shipments to dock at the port and for better design, maintenance and optimization of protective civil engineering structures, such as dams and breakwaters. Radioactive tracers are the only method capable of providing direct, real time assessment of sediment transport pathways due to their inherent sensitivity. Their use to continuously monitor sediments associated with coastal erosion enables authorities and engineers to design engineering structures that minimize the impact of erosion. Nucleonic gauges provide information on the density of sediments deposited in a channel of navigation as well as on the concentration of sediments circulating in suspension, providing a detailed and broad overview of sediment processes.

This information is vital for optimising dredging activities and identifying sources of abnormal events in hydrographic basins, such as erosion arising from afforestation/deforestation, agricultural and mining activities in lake catchment basins.

IAEA's approach

The IAEA, in accordance with its Statute, seeks to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world. The IAEA is the world's main hub for the development and transfer of nuclear technologies and applications. Nuclear technologies, including all those described in this booklet, undergo rigorous validation through IAEA's research activities. Once relevant nuclear technologies are vetted, they can then be transferred to countries upon request, especially to developing Member States through the IAEA's technical cooperation programme.

Research to address climate adaptation

The IAEA maintains and operates twelve nuclear application research laboratories in Austria and Monaco. The laboratories implement activities that respond to the development and research needs of Member States in a range of subject areas. They have a well-established track record of conducting applied research, providing training and analytical services as well as transferring proven nuclear technologies and techniques to Member States.

Five laboratories focus on Agriculture and Biotechnology and are an integral part of the Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture, a unique model of cooperation and collaboration within the UN system. These laboratories support Member States in research on and development of techniques related to food and agriculture, animal and human health, environmental monitoring and assessment, as well as the use of nuclear analytical instrumentation.

Other facilities include the Terrestrial Environment Laboratory, which provides environmental assessments and ensures high quality analytical measurements for radioactive, industrial, and other pollution, and the Isotope Hydrology Laboratory, which focusses on sustainable management of freshwater and the impact of climate change on rivers, lakes and groundwater aquifers.

The FAO/IAEA Food and Environmental Protection Laboratory, in Seibersdorf, Austria assists Member States to improve laboratory and regulatory practices and methodologies in the areas of food traceability and authenticity, food safety and food quality in order to safeguard the health of consumers, help to facilitate international trade and enhance food security. (Photo: IAEA)

The IAEA also has three marine environmental laboratories in Monaco (Radiometrics, Marine Environmental Studies, and Radioecology) that provide technical support to Member States to address priority marine challenges. These topics may include emergency response, but are primarily aimed at developing, advancing, and transferring technical knowledge on a healthy and sustainable ocean. The marine labs, located in Monaco, provide information on global marine stressors, such as pollution, ocean acidification, deoxygenation, harmful algal blooms and warming, as well as marine radioactivity.

The IAEA Environment Laboratories in Monaco also house the Ocean Acidification International Coordination Centre (OA ICC), which serves as a hub to promote communication, capacity building and best practices in ocean acidification science.

The IAEA also undertakes research activities through its extended research networks, composed of research institutions, academia and reference laboratories, the IAEA's coordinated research projects and Collaborating Centres schemes [32]. Several Collaborating Centres are of direct relevance to the climate adaptation work of the IAEA. While some partner institutions have a particular expertise in isotopic techniques applied for marine and oceanographic studies, including ocean acidification, others focus on applications related

The IAEA Environment Laboratories in Monaco where scientific, technical and administrative staff work to tackle pressing environmental issues through nuclear and isotopic techniques. (Photo: D. Calma/ IAEA)

to soil erosion, freshwater availability assessments and again others on mutation breeding techniques.

The IAEA also brings together research institutions from its Member States to collaborate on research projects of common interest. Through these CRPs, the IAEA, as sponsoring and coordinating body, awards research, technical and doctoral contracts to institutes in Member States.

Technical cooperation for climate adaptation

Through its technical cooperation (TC) programme, the IAEA supports countries to build capacities and transfers technologies and knowledge. The TC programme is the Agency's primary mechanism for helping Member States to address key development priorities.

Work under each of these areas takes place through the implementation of national, regional and interregional projects designed to contribute to socioeconomic and environmental development. The TC programme provides support through capacity building, knowledge-sharing, partnership-building and procurement of equipment and services.

From 2012 until 2020, the IAEA supported 102 countries and territories in their efforts to adapt to climate change through 481 technical cooperation projects. Approximately €112 million of development assistance has been channelled through these projects, benefitting countries in their efforts to adapt to climate change.

The IAEA contributes to climate adaptation and climate science in six thematic areas as shown in figure 4. The distribution of these projects across regions is provided in figure 5.

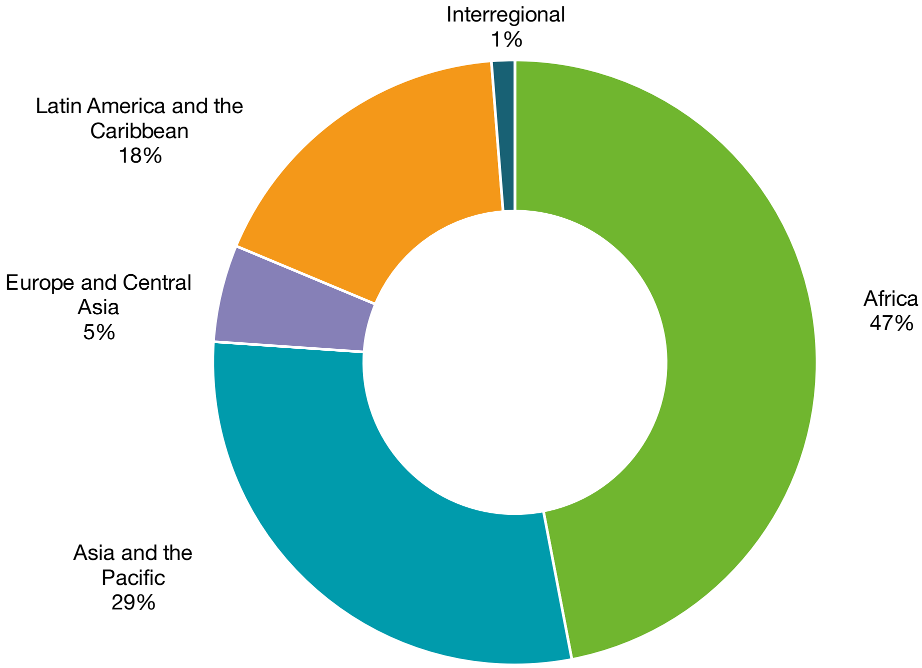


FIG. 3. Distribution of IAEA climate change adaptation projects by region.

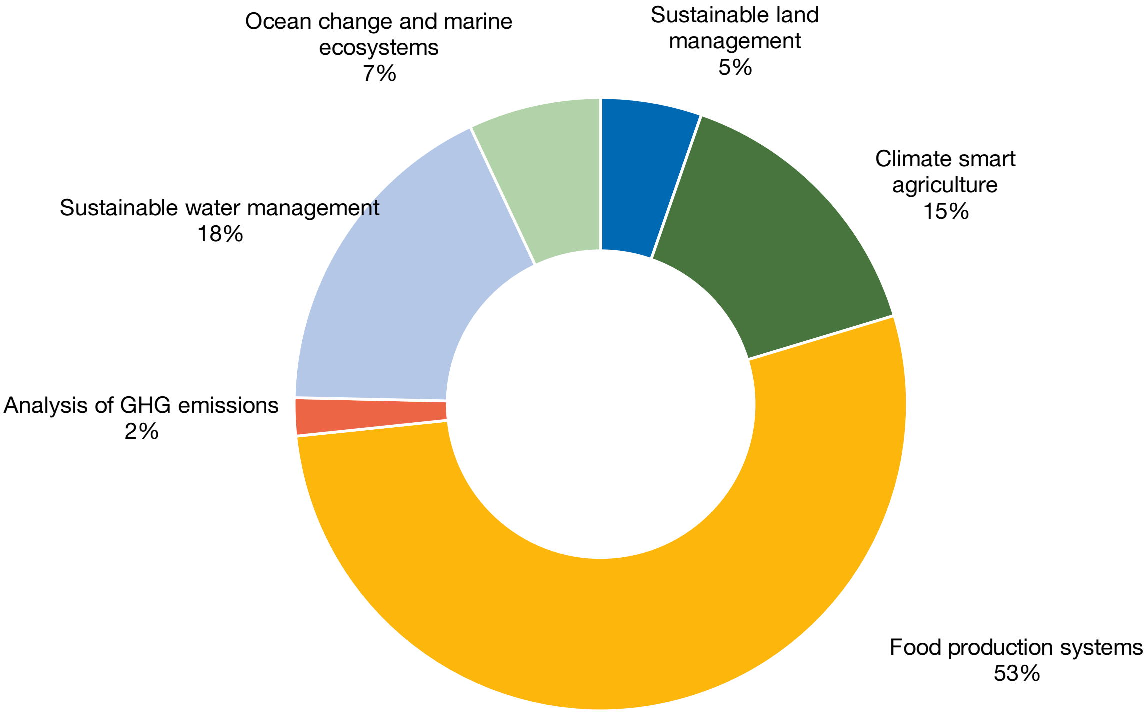


FIG. 4. Distribution of IAEA climate change adaptation projects by area.

IAEA support (2012-2020)

481 Climate Change Adaptation projects

102 countries and territories worldwide

112 million Euro invested in climate change adaptation projects

FIG. 5. Number and budget of active IAEA climate adaptation projects per region.

03

IAEA’S ADDED VALUE

3. IAEA's added value

How the IAEA makes a difference: the theory of change

The key elements of the Theory of Change[3] (ToC) for the IAEA's work for climate adaptation and resilience derive from the Agency's comparative advantages described in the preceding Chapter. Figure 6 summarizes the broad ToC[4], illustrating the key categories of results derived from the IAEA's work in the six thematic areas of nuclear science and technology for climate adaptation and resilience described in Chapter 2 and linking them to medium- to long-term objectives related to climate change adaptation and mitigation as envisioned through the SDGs and the Paris Agreement[5].

Objectives and outcomes

The overall objective of the IAEA's work on climate adaptation is ***to contribute to climate change adaptation efforts through research and technical cooperation in nuclear science and technology***.

Based on the ToC (figure 6), the key outcomes that are supported through the IAEA's activities can be grouped into the following five major categories:

- Strengthened Member State capacity in nuclear science and technology to support climate adaptation.
- Enhanced biodiversity and protection of the natural environment.
- Increased efficiencies and productivity in the use of natural and agricultural resources.
- Availability of tools and strategies for enhanced consumer protection.
- Reliable information to strengthen evidence-based decision making.

[3] A Theory of Change (ToC) describes what results a programme is aiming to achieve or contribute to, and how it works towards those results. A ToC illustrates the key elements of the results logic, moving progressively from the aspects that the programme can control, to those it is intended to influence towards the medium/long-term. As such, a ToC forms the basis for strategic planning, implementation and evaluation of a programme from a results-based perspective.

[4] The ToC is based on the ToC that was constructed for the OIOS Evaluation of the Agency's Contribution to Climate Change Adaptation and Mitigation Through the use of Nuclear Applications (PE2018002), providing more details on the Agency's generic outputs and contributions to outcomes.

[5] The outcome pathways at the level of long-term, high-level outcome is adapted from the Adaptation Fund's Theory of Change derived from the Agenda for Sustainable Development and Paris Agreement in its Medium Term Strategy 2018-2020; and Green Climate Fund's initial adaptation and mitigation logic models (document no. GCF/B.07/11).

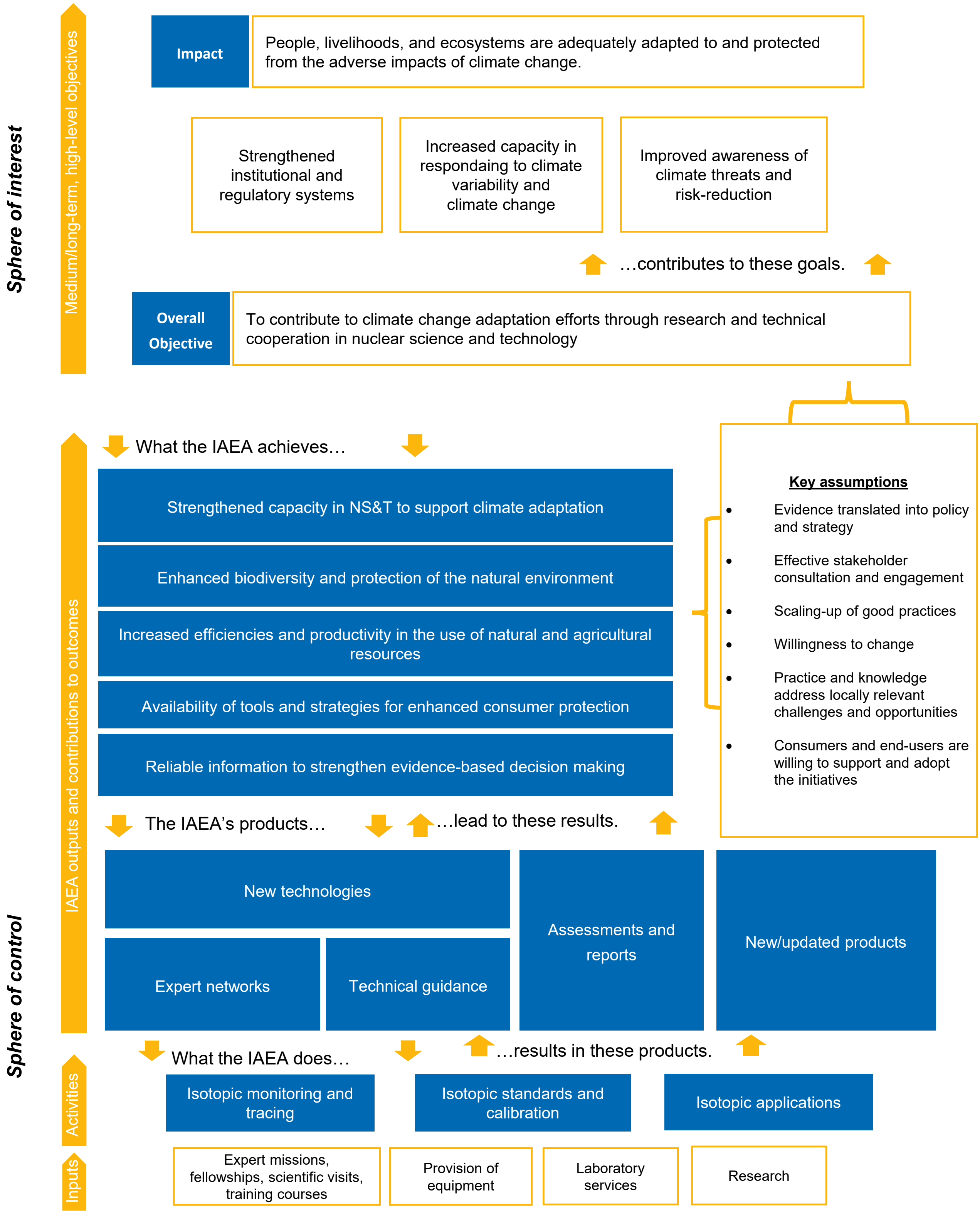


FIG. 6. Theory of Change

04

SCALING UP

4. Scaling up

While the scientific community is generally well aware of the potential of nuclear science and technology for climate adaptation, decision-makers, and the broader development and financing communities, are not. As a consequence, for instance, the contribution of nuclear technologies in support of climate adaptation solutions rarely features in NDCs or as part of multi-stakeholder initiatives.

To date, the efforts of the IAEA to promote and apply nuclear solutions for climate adaptation have focused primarily on the implementation of a large number of relatively small projects and pilot activities. The IAEA, however, stands ready to scale up its efforts to better assist its Member States in benefiting from the potential nuclear technologies offers as part of the solutions for climate adaptation.

To scale up, the IAEA needs to raise awareness about nuclear technology solutions related to climate adaptation and their complementarity with more conventional approaches to ensure optimisation and sustainability of results. To achieve this objective, the IAEA intends to capitalise on existing implementation mechanisms such as TC projects, CRPs, programme activities, as well as on the establishment of new partnerships.

Climate change is a key global challenge and as such needs to be addressed in a coherent and comprehensive manner. Partnerships are an important "enabler" to guarantee comprehensive and sustainable solutions and to bridge the gap between research and policy impact. Scaling up IAEA support in this area includes identifying and establishing meaningful partnerships to support Member States towards the achievement of the SDGs and the implementation of the Paris Agreement in areas such as sustainable land use, climate smart agriculture, food production systems, analysis of GHG emissions, water management, oceans and coastal protection.

Partners4Synergy

The existing FAO/IAEA partnership is a primary example of partnership that creates synergies. The Joint FAO/IAEA Centre advances and supports the safe and appropriate use by FAO and IAEA's Member States of nuclear and related technologies in food and agriculture, aimed at global food security and sustainable agricultural development worldwide. It does so through adaptive research and development at its own laboratories in Seibersdorf, Austria, as well as through annual support and coordination of more than 25 CRPs involving some 400 research institutions and experimental stations, capacity-building and technology transfer to over 200 national and regional technical cooperation projects, and technical and policy advice to policymakers.

Moving forward, other partnerships will be identified, which can support Member States in achieving climate change adaptation and resilience solutions using nuclear technologies.

Partners4Visibility

The establishment of partnerships with other key organisations/stakeholders active in climate adaptation will serve as a spin-off to reach out to decision makers, to ensure that nuclear applications are duly considered when defining suitable climate adaptation and resilience solutions for a country/region (for instance, becoming part of NDCs plans).

Partners4Financing

The IAEA is seeking to increase the amount of resources available to support IAEA-led initiatives in climate adaptation and resilience by reaching out to traditional partners, the private sector, and international financial institutions.

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